LANDFORM CLASSIFICATION AND ITS APPLICATION IN PREDICTIVE MAPPING OF SOIL AND FOREST UNITS

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Abstract

Georelief is one of the most important landscape components in conditions of Carpathian Mountains. The paper deals with an evaluation of georelief's influence on the other landscape and forest characteristics in selected model areas. Its aim is to evaluate the different algorithms of landform classification and their suitability for predictive mapping of soils and forests by analysis of spatial relationships between resulting landforms and selected maps of soil and forest characteristics.

Information on georelief is based on digital elevation models (DEM) and field research. The information on other landscape components was taken from existing resources (pedological map, forestry typological map) and also prepared by field research (detailed maps of forest stands).

Several algorithms of classification are tested: Hammond's (1964), Dikau's (1988 and 1991), MORAP's, estimation of topographic position index (Jenness 2006), classifications according to Iwahashi and Pike (2007) and Wood (1996), and delineation of genetically and dynamically well interpretable relief forms (Minár, Evans 2008). Algorithms were calibrated in areas with different types of terrain.

Preliminary results show that the evaluated methods can be helpful in the predictive mapping of soils and forest types. The correlations between classified landforms and soil types are lower than ones between georelief and forest types. The algorithms of landforms classification proposed by Wood and Jennes seem to be the most applicable methods from the pedological and forestry viewpoints. The Wood's approach uses a multi-scale approach by fitting a bivariate quadratic polynomial to a given window size using least squares. Jennes's classification is based on topographic position index values computed for the same location with two different scales. The future development of classification methods can bring new possibilities for predictive soil and forestry mapping.

Keywords: georelief, landform classification, predictive mapping, soil characteristics, forest stands

1. INTRODUCTION

Landform units have been used as basic georelief descriptors in soil and vegetation mapping [18, 4] for a relatively long time. Several papers document applicability of landform classification for predictive mapping of soil and vegetation properties, especially in steepland areas [24]. Utilization of automated landform classification started in 1990s [2, 6, 28]. There are new opportunities in this field, resulting from existence of relatively precise global and regional digital elevation models [16] and methods of their automated segmentation [17]. However, the terms and methods used in different fields of science vary in detail [1, 15, 23, 25].

The paper deals with an evaluation of georelief's influence on other landscape and forest characteristics in selected testing regions. Its aim is to evaluate the algorithms of landform classification and their suitability for predictive mapping of soils and forests by analysis of spatial relationships between classified landforms and maps of soil and forest units. The landforms are classified at three scales – macrolandforms using global elevation products, landforms with regional digital elevation model (DEM) and local scale with attempt to define elementary landforms (or landform elements) using detailed local DEM.

2. MATERIALS AND METHODS

2.1 Digital elevation models (DEMs)

Several digital elevation models were used during research. The global products include SRTM DEM and ASTER GDEM (90 and 30 m resolution); at regional scale a DEM with resolution 10 m and a local DEM with 5 m resolution, both based on topographic maps.

The NASA Shuttle Radar Topographic Mission (SRTM) produced DEM with spatial resolution of 90 m. The version 4 downloaded from http://srtm.csi.cgiar.org was used. For the macrolandform classification also DEM with resolution of 200 m was prepared from SRTM DEM.

ASTER Global DEM (ASTER GDEM) is a product of METI and NASA. Tiles, covering the whole Slovakia's territory, were downloaded using WIST web application of NASA. The missing values and values for pixels with apparently wrong elevation (e.g. pixels with elevation below sea level) were interpolated from surrounding pixels, using regularized spline with tension.

Regional digital elevation model was prepared by Topographic Institute of Armed Forces of Slovak Republic, using contours from topographic maps 1:25 000. The raster spatial resolution is 10 m.

Local DEM was interpolated from contours of topographic maps 1:10 000 using spline with tension. The spatial resolution is 5 m. It covers area of 70 ha.

2.2 Methods of classification

Three methods of macrolandform classification were tested with global elevation products. Dikau et al. [6] automated the manual identification of macrolandforms, originally proposed by Hammond [8, 9]. The method uses thresholds for slopes and flat plains determination (8% slope), 4 classes of slope, 6 classes of relative relief, 4 classes of profile type and a size of circular moving window. Original Hammond's subclasses of macrolandforms (96 possible) are grouped into 24 classes and 5 landform types. Similarly, the more simplified version of landform map, using a procedure suggested by Missouri Resource Assessment Partnership [20], was developed. All three methods (Hammonds's, Dikau's and MORAPS's) were applied to SRTM and ASTER GDEM with moving window sizes ranges between 1.6 and 10.2 km with 200 m step (radius range 0.8 – 5.1 km). The other parameters of the original methods were unchanged. All three methods were automated using bash scripts for GRASS GIS [21].

The method of classification, using a multi-scale approach by taking fitting quadratic parameters to mowing window, was proposed by Wood [28]. It is scale-dependent and it identifies 6 morphometric features (peaks, ridges, passes, channels, pits and planes). The method is implemented within GRASS GISS module r.param.scale. It was applied with slope tolerance between 1° to 7° (defines flat surface), curvature tolerance ranging from 0.001 to 0.007 (defines planar surface) and mowing window-sizes from 30 to 500 m.

The landform classification following Iwahashi and Pike [11] is based on an unsupervised nested-means algorithms and a three part geometric signature. The slope gradient, surface texture and local convexity are calculated within a given window size and classified according to the inherent data set properties. It can be characterized (in terms of thresholds) as a dynamic landform classification method. Original AML scripts for ArcINFO, published by J. Iwahashi, were rewritten for GRASS GIS. All the threshold values of parameters for classification are derived during computation from the properties of DEM raster (range of values, distribution) therefore selection of different computational region extents can lead to slightly different results.

Estimation of topographic position index (TPI) [7] at different scales (plus slope) can classify the landscape into both slope position (i.e. ridge top, valley bottom, mid-slope, etc.) and a landform category (i.e. steep narrow valleys, gentle valleys, plains, open slopes, etc.). This method was further developed by Weiss [27] and Jenness [12]. The classification of slope position to 6 classes requires setting the radius of neighbourhood (mowing window) and its geometric shape. Classification of landforms is based on analyses of TPI index and slope at two different scales; therefore it requires 2 values of radius size. A computer version of this method is available as an extension for ArcView 3.x [12]. Topographic position index maps with radius size between 50 and 1000 m with 50 m step were computed and used for landform classifications.

The classification of landform elements [5] is probably the simplest of mentioned methods. It was applied using curvature threshold values ranging from 0,001 to 0,005 to regional and local DEM. Resulting maps were simplified by majority filter with 7x7 pixel neighbourhood. The curvature threshold sets the boundary between curved and plane forms. The method was applied within SAGA GIS (module *Curvature Classification*).

The last used method is the determination of genetically and dynamically well interpretable relief forms [17]. An attempt to create automated procedure for delineation of forms is still solved only partially [22]; therefore this method was applied only at local level using manual expert delineation of landforms. The results of field research were also applied for classification.

2.3 Evaluation of landform classifications

To assess the accuracy of classification results, an error matrix and a kappa index [14] were computed for each classification map (map of classified landforms), with respect to reference maps (maps of soil and forest types). Kappa index of agreement equals 1 when agreement between reference and classification maps is perfect and kappa equals 0 when agreement is as expected by chance. The classification map with the best value of kappa index was chosen as the more appropriate combination of algorithm's input parameters (according to georelief of testing region and quality of DEM). Only those soil and forest types (e.g. scree and ravine forests - *Fraxineto-Aceretum* forest types according to Zlatník [30]), which are typically found at certain landforms, were used for assessment.

Classifications of macrolandforms led to a division of state area into similar categories that can be found in the map of morphological-morphometrical landform types [26]. A direct comparison of macrolandforms and soil and forest type's maps is impossible. Therefore, the accuracy of macrolandforms classification maps was assessed by comparison with mentioned map and not with the maps of soil and forest types.

2.4 Testing regions

Three types of testing regions were selected (Fig. 1). The classification of macrolandforms, based on global elevation products, was done for the whole state territory of Slovakia. Mesolandforms were classified in the south-western part of Nízke Tatry Mts. and adjacent part of Horehronské podolie basin. This region has highly diversified georelief, with almost the all expected landform classes. It covers 290 km^2. At a local level, the elementary landforms were classified on the slopes called *Medvedia úboč (Bear's slope)* in the eastern part of testing region for landforms.

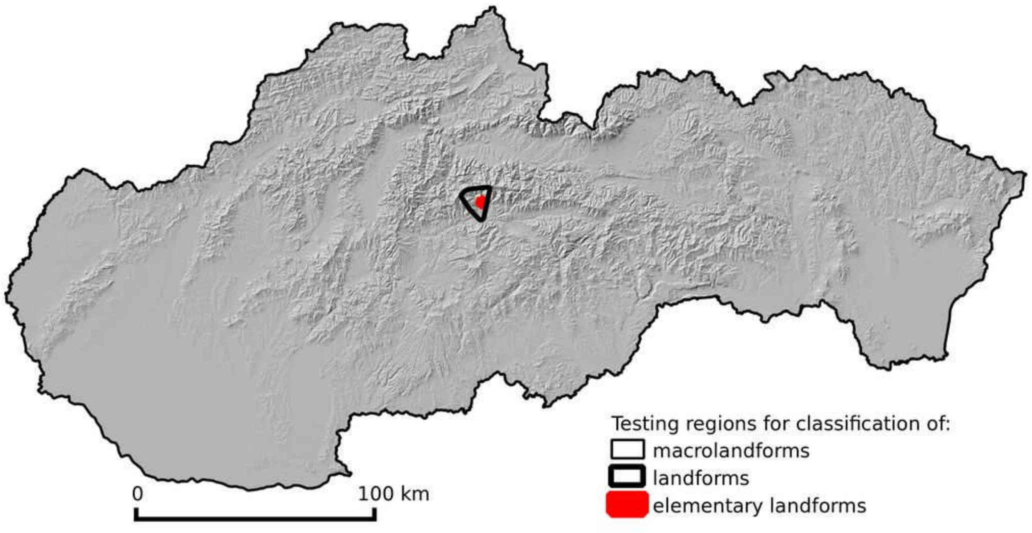

Fig. 1. Location of testing regions within Slovakia

2.5 Soil and forest type maps

The maps of soil and forest types were prepared by National Forest Centre (NFC), Zvolen, Slovakia. Their accuracy was evaluated by their cross combination and expert method considering the probability of occurrence of each combination (Fig. 2) (see [10]). The combinations were conforming for 87,44% of testing region's area, disputable for 5,5% and nonconforming for 7,06%. The evaluation showed that the main disproportions results mainly from different generalization levels of both maps, e.g. pedological map missed fluvisols in the narrow valleys where vegetation units of alluvial forests with *Alnus* sp. were mapped by forestry typologists.

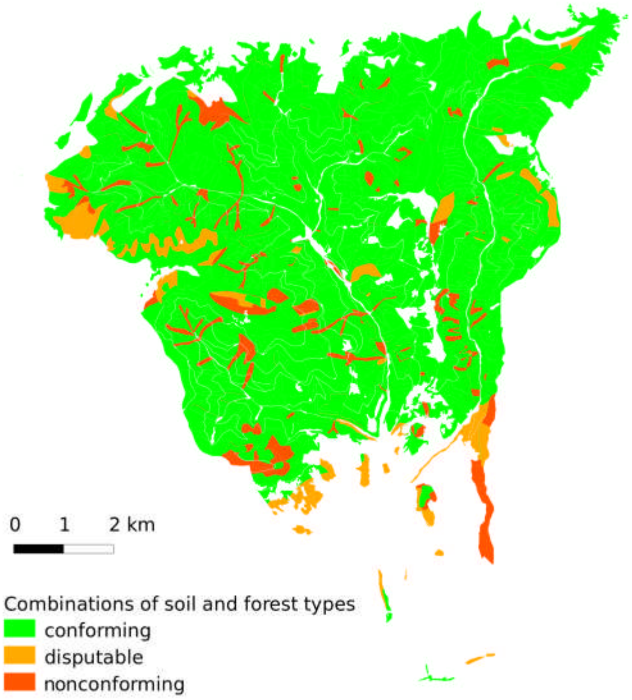

Fig. 2. Accuracy assessment of maps of soil and forest types, prepared by NFC (testing region for classification of landforms)

3. RESULTS

3.1 Classifications of macrolandforms

The best results were achieved using classification according to Dikau et al. [6] with radius 3.7 km (Fig. 3, Tab. 1). This is similar to the results of further development of Dikau's algorithm presented by Brabyn [3]. Original size of the moving window (~ 10 km) used by Hammond, Dikau and MORAP team seems to be too large for Central European conditions. The lower values of radius lead to cutting of single slopes into several landform classes. The MORAP's team algorithm is too much simplified and low number of classes is not appropriate for classification of Western Carpathian's diversified georelief. Direct comparison of classification according to Hammond and MORAP was impossible due to the different meaning of categories in classification and reference maps.

Table 1.. Kappa index values for the classifications according to Dikau's [6] algorithm. Comparison based on the high mountain categories of both classification and reference maps.

Neighborhood radius [km]	0.8	1.2	1.6	2.0	2.4	2.8	3.0	3.4	3.7	3.8	4.2	4.6	5.0	5.1
Kappa index	0.01	0.09	0.27	0.48	0.59	0.64	0.65	0.66	0.68	0.67	0.54	0.52	0.48	0.45

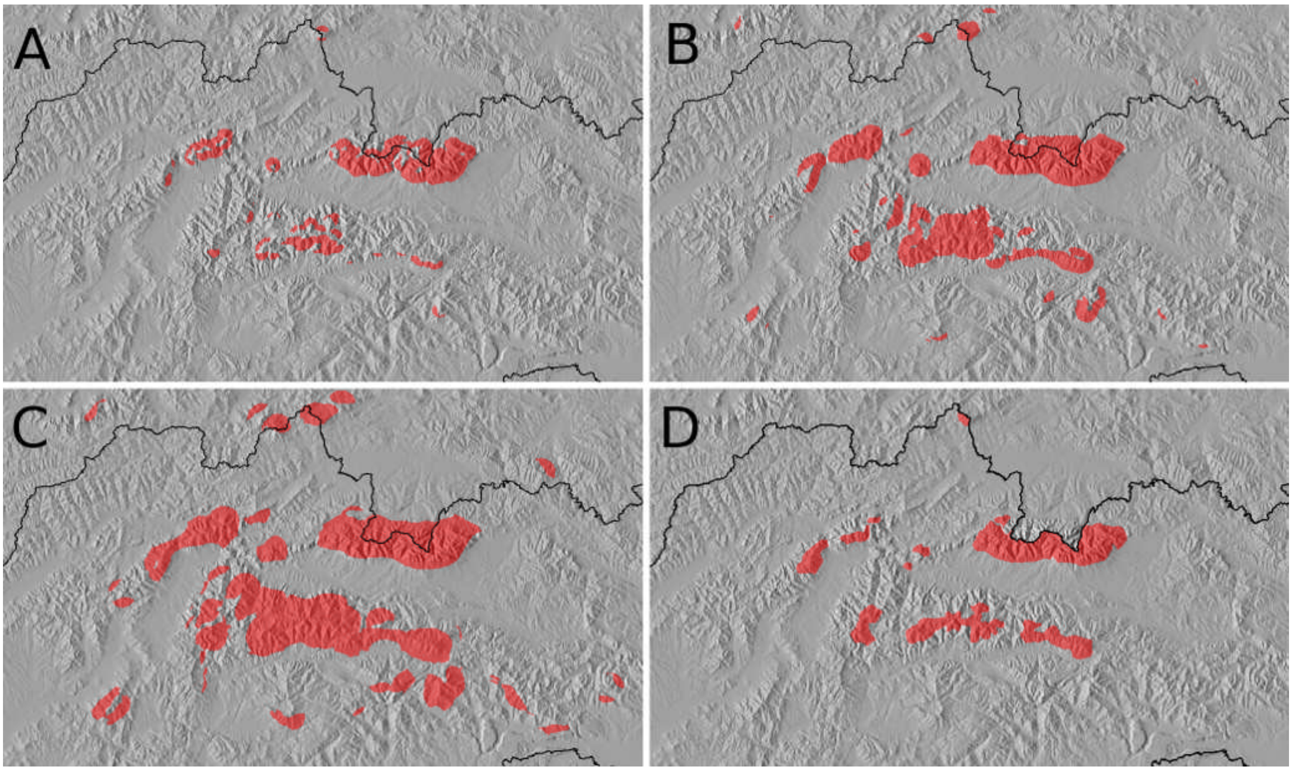

Fig. 3. Class of high mountains according to Dikau's algorithm and traditional classification. A- 2.5 km radius, B – 3.7 km radius, C – 10.2 km radius, D – high mountains according to Tremboš, Minár (2001). Central part of Slovakia. Red – high mountains.

3.2 Landform classifications (mesolandforms)

Different values of input parameters (7 for slope tolerance, 7 for curvature tolerance and 24 window sizes) led to 1176 unique classifications according to Wood [28]. The best combination of input parameters (the highest kappa index values) determined by comparison with the soil and forest type maps (0.76 for forest types, 0.68 for soil types) is as follows: slope tolerance 1° (defines flat surface), curvature tolerance of 0.002 (defines planar surface) and window-size of 170 m. The results are shown at Fig. 4.

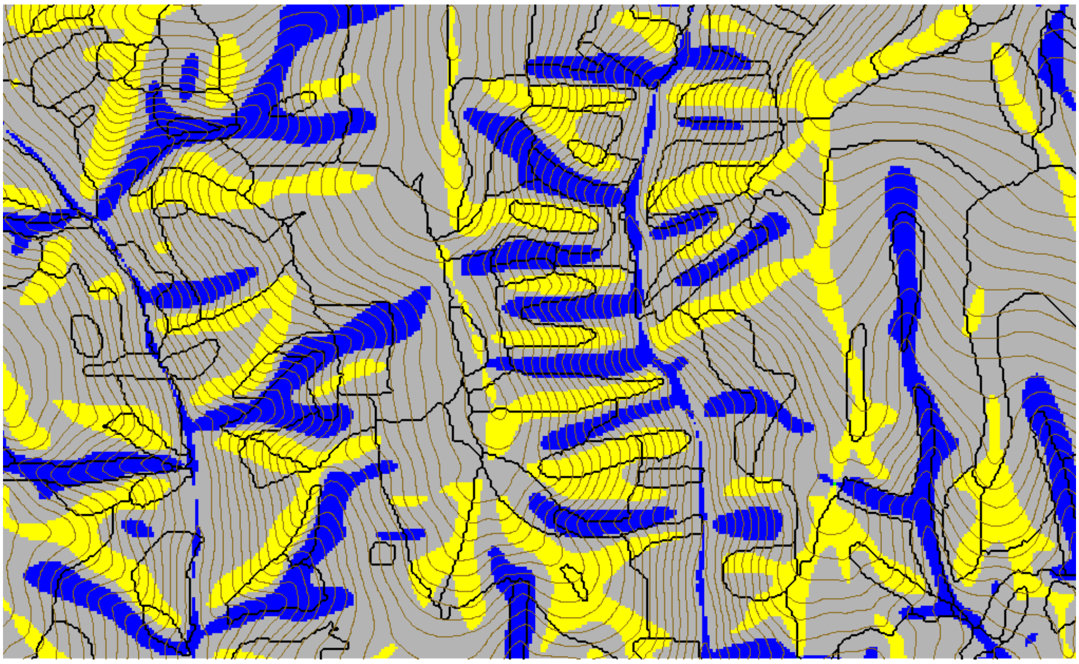

Fig. 4. Comparison of landforms according to Wood (1996) and boundaries of forest types. Central part of testing region. Blue – valleys, yellow – ridges, grey – slopes, black lines – boundaries of forest types

The method proposed by Iwahashi and Pike [11] classifies relief into 8, 12 or 16 classes without possibility to change other input parameters. Therefore only 3 classifications were prepared with almost the same kappa index values. The Fig. 5 shows results with 8 landform classes. More detailed classifications are achieved by more precise segmentation of relatively flat areas (Fig. 6), which were not the subject of comparison. Kappa index values were the same for all 3 classifications (0.58 for forest types, 0.51 for soil types), because only steep forested parts of testing region were evaluated.

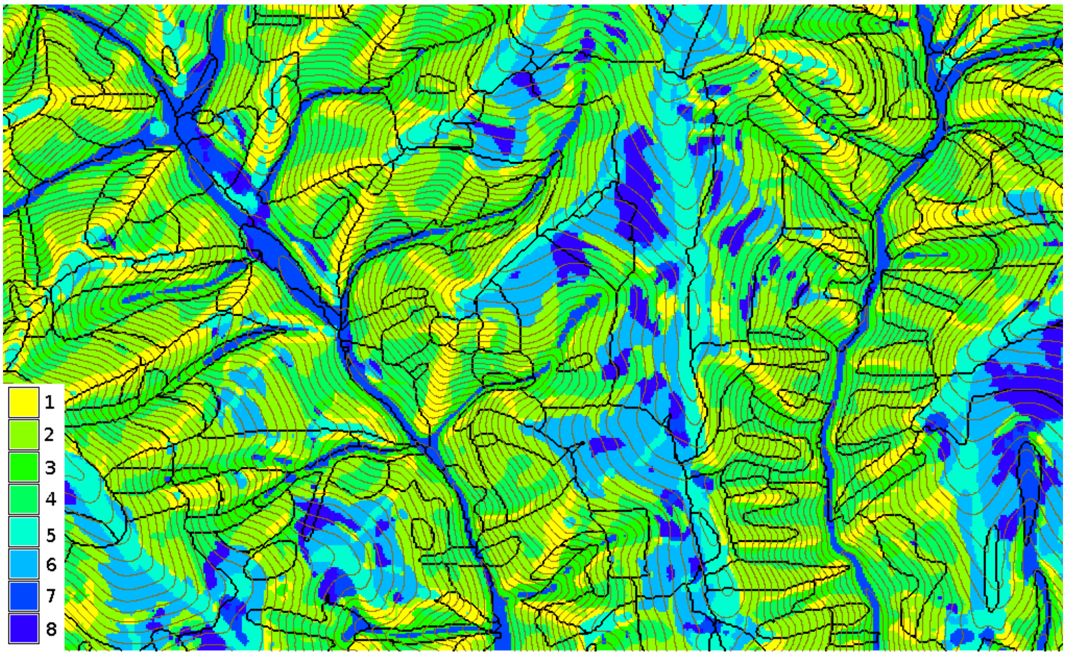

Fig. 5. Comparison of landforms according to Iwahashi and Pike (2007) and boundaries of forest types. Central part of testing region. 1 – steep, high convexity, fine texture; 2 – steep, high convexity, coarse texture; 3 – steep, low convexity, fine texture; 4 – steep, low convexity, coarse texture; 5 – gentle, high

convexity, fine texture; 6 – gentle, high convexity, coarse texture; 7 – gentle, low convexity, fine texture; 8 – gentle, low convexity, coarse texture

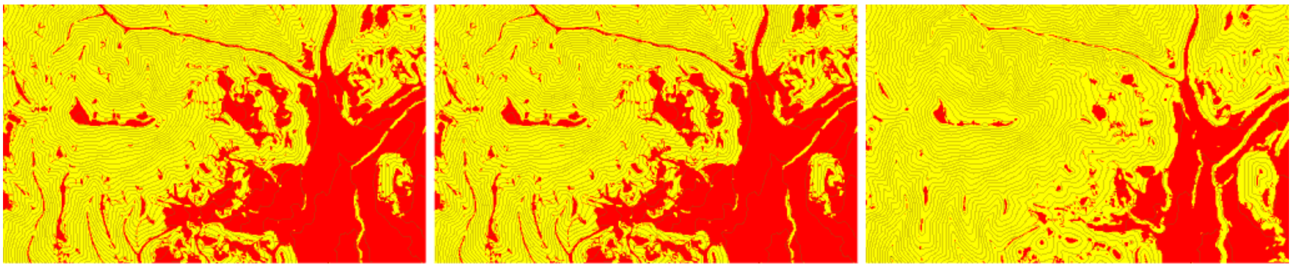

Fig. 6 . Differences between three types of landform classification according to Iwahashi and Pike (2007). Southern part of testing region. From left to right: differences between maps with 8 and 12 classes, between 8 and 16 and between 12 and 16 classes. Red – difference, yellow – agreement

The best results for algorithm according to Jennes [12] were achieved using 2 circular neighbourhoods 100 and 900 m in diameter with kappa index 0.73 (Fig. 7). With these settings, the algorithm was able to distinguish between shallow valleys on side slopes and main valleys of mountain ranges. However, it was not possible to set one setting appropriate for both mountainous and hilly land georelief.

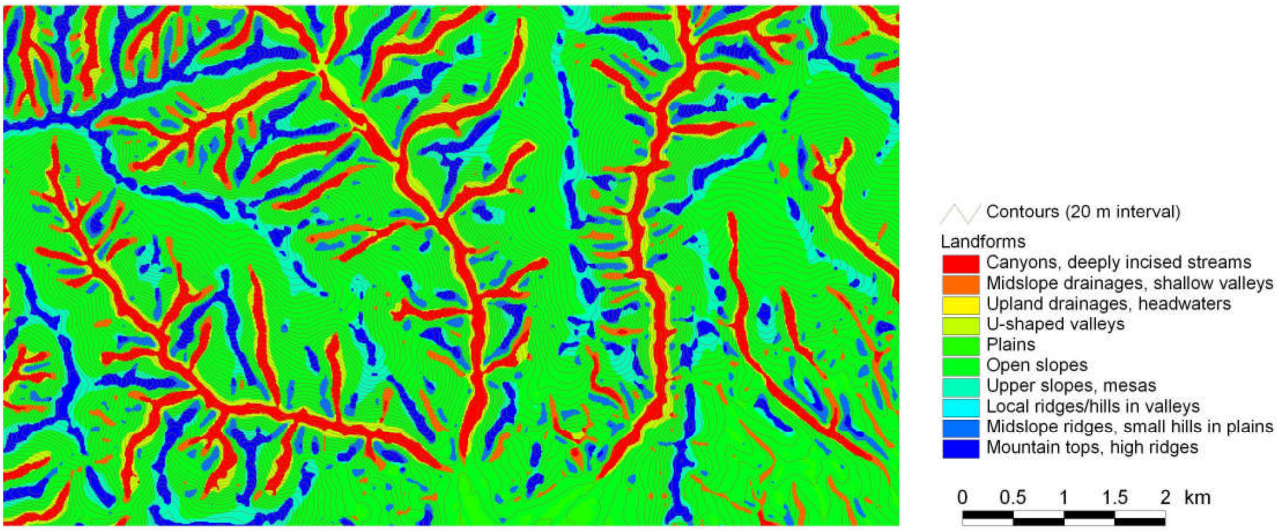

Fig. 7. Landform classification according to Jennes. Central part of testing region.

3.3 Landform elements, elementary landforms

The classification of landforms elements according to Dikau [5] was not able to identify bottoms of wider valleys (Fig. 8). The wider bottoms are classified as linear slopes or planes combined with concave slopes at valley sides. Classification of steeper shallow valleys is more successful. The best threshold value of curvature tolerance in testing regions and DEMs was 0.003, but the kappa index values were very low – only 0.42. The better results were achieved for 10 m resolution DEM with kappa index 0.51. Results for local DEM with 5 m resolution were partially influenced by artificial undulations caused by interpolation method.

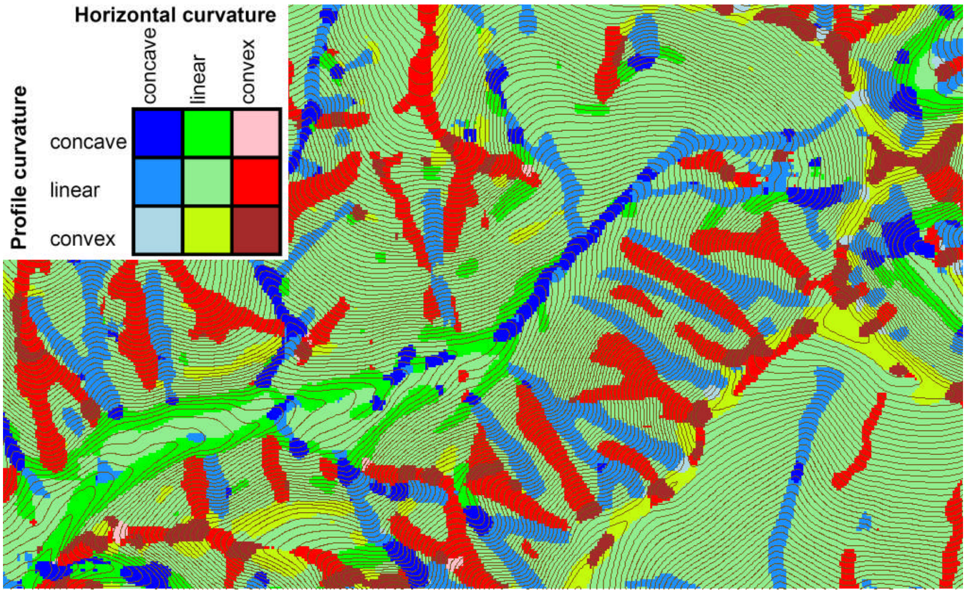

Fig. 8. Landform elements (Dikau 1988). Valley bottom (lower right part) classified as plains and concave slopes. Upper part of Lomnistá dolina valley.

Elementary landforms defined by manual expert method following Minár, Evans [17] were compared with forest types mapped by detailed field research of the smallest testing region. This comparison gave the highest kappa index value (0.87) comparing with all other methods at all three scales. However, this is probably influenced by the methodology of field research, when forestry typologists for mapping of forest types used the geomorphological maps prepared specifically for testing region.

4. DISCUSSION

The main reason why the classification of macrolandforms was tested is the possibility the define regions (using classes of macrolandforms) for which the different values of another algorithm's input parameters can be set when classifying landforms and elementary landforms (at regional or local level). However, the evaluation of this possibility will require the modification of used computer programmes and algorithms and therefore it will be a task of the future research. The most promising classification method from this viewpoint seems to be the one of Dikau et al. [6]. Its main problem – a progressive zonation when landform changes from plains to mountains could be solved according to Brabyn [3]

The computed correlations between classified landforms and soil properties at regional and local level were lower than ones between georelief and forest cover properties. This is probably due to the more simplified soil map comparing with map of forest types.

Method of J. Wood is the most promising algorithm for classification of landforms for forestry and pedological predictive mapping. It is highly configurable and this increases its applicability in different types of relief. The number of resulting landform classes (6) is usually adequate; however incorporation of other relief characteristics (e.g. aspect) can significantly help to predict spreading of specific units.

Estimation of topographic position index according to Jennes [12] is also of high interest, because of variability of input parameters and simple user interface.

From the viewpoint of forestry and pedological predictive mapping, Iwahashi's algorithm is less usable, because it can not be parameterized by modifications of input values.

The parameter for method of Dikau [5] is highly dependent on the type of relief and DEM quality, especially if it is computed from vectorised contours. In the mountainous relief of Nízke Tatry Mts. the best results with regional DEM were achieved with curvature threshold set to 0.004, which is significantly more than standard value of 0.001 set as default. This high threshold filtered out the influence of microrelief (either natural or artificial resulting from the DEM interpolation method) and allowed clear identification of small valleys and steep ridges (spurs) on large valley slopes (Fig. 8). Even higher values of threshold led to discontinuous classification of forms. The lower thresholds resulted in extremely dissected map affected by microrelief. However, the lower values (0.002 or 0.001) were usable in Horehronské podolie basin with gentle slopes and wide valleys. This simple method is also unable to define terrain context and uses hard classifiers. The bottoms of major valleys are classified only as concave forms at the bottom of side slopes, bottoms of wider valleys are classified as plains. The main purpose for which it could be used is the delineation of soil and forest types typically occupying bottoms of small side valleys (Fig. 8) or steep ridges (spurs) on valley sides within a small region with relatively simple relief.

The best results were achieved by expert manual delineation of elementary landforms using detailed topographic maps and field research. However, its application is time consuming which makes it unsuitable for mapping of larger areas.

Setting the best values of input parameters for each classification method is dependent on spatial resolution, quality of DEM, characteristics of georelief in study area and spreading of pedological or forestry units, which are to be predicted. Moreover, specifically in this study the correctness of reference maps is a little bit questionable. At this stage of research the question is how the low values of kappa index should be understood: (i) the values of input parameters are not optimal, (ii) the selected method is not appropriate or (iii) the accuracy of reference maps is low. An answer should be based on results of detailed field research and mapping of geomorphological, pedological and forestry units.

5. CONCLUSIONS

It is supposed that maps of soil and forest types can be improved using more detailed information on abiotic environment. A terrain classification is one of the methods which can significantly help in boundary delineation of pedological and forestry units. It is clear that the landforms themselves, without information on other landscape components, can not successfully predict distribution of specific soil and forest types. It is necessary to incorporate other characteristics of abiotic environment (e.g. geology) and other characteristics of georelief itself (elevation, slope and aspect with respect to solar radiation, wetness index and other). However, the map of landforms, based on DEM, can significantly help in predictive mapping of soil and forest types.

The presented paper is the introductory study of future research and application of relief classification in predictive pedological and forestry mapping in Slovakia. The future research will concern on detailed specification of input parameters of selected methods suitable for predictive mapping of specific soil and forest types (groups of forest types resp.).

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