Generalization of DEM looking for hierarchic levels of landforms in the land surface segmentation process.

Anton Popov, Jozef Minár
Department of Physical Geography and Geoecology,
Comenius University in Bratislava, Slovakia
popov3@uniba.sk
Michal Gallay
Institute of Geography
Pavol Jozef Šafárik University in Košice, Slovakia

Abstract— **High-resolution digital elevation models (DEMs) need to be generalized before a land surface segmentation is applied. A measure of the quality of segmentation can reflect the usefulness of the generalization. We developed a method to evaluate a quality of results of multiresolution segmentation (MRS). The method was implemented in geographic object-based image analysis (GEOBIA). We tested a dependence of local variance (LV) on a number of resultant objects, generalization level and coincidence of segmentation with real landforms. The last was tested using a hypothesis, that an index of concentration of values of curvature change around zero (K_0) reflects an optimal DEM generalization. Estimation of scale parameter by ESP 2 tool and DEM generalization using polynomial approximation in increasing window, was used. Altitude, slope, aspect, profile and plan curvatures were used as the input variables. Results from the two areas with a different type of land surface show a clear dependence of local variance on generalization level, and partially confirm the suitability of the K_0 index for determination of optimal generalization.**

I. INTRODUCTION

High-Resolution DEMs enabled detection of landforms of different orders: From the simplest forms (elementary forms) to complex forms (landforms, land systems) [1]. However, such DEMs contain noise and elevation uncertainty leading to incorrectness in landform delineation. A task of looking for an appropriate measure of generalization that follows a method of landform mapping is crucial in this aspect. The concept of elementary forms, developed for detailed geomorphological mapping [1], is used in our study.

II. THEORETICAL BACKGROUND

Generalization

In general, elementary forms can be defined as "landform elements with a constant value of altitude or two or more readily interpretable morphometric variables, bounded by lines of discontinuity" [1]. Later, in ref. [2] was proposed a quantile – based index of concentration of derivatives of altitude around zero (K_0) as a measure of the affinity of real land surface to set of elementary forms:

$$K_0 = \frac{\tilde{x}_{95} - \tilde{x}_5}{\tilde{x}_{0+5} - \tilde{x}_{0-5}}$$

where $\tilde{x}_{95}$ and $\tilde{x}_5$ are percentiles representing the spread of the set without extreme values and $\tilde{x}_{0+5}$ and $\tilde{x}_{0-5}$ represent the fifth percentiles on the right and on the left from the zero value [2].

If the affinity to constant value of various geomorphometric variables exists, K_0 index should rise with variable (derivative) order. For the first, second and third derivative of altitude in the direction of slope line, the K_0 index increases up to the third-order much more for real surface than for various mathematical models. Thus it confirms the affinity of altitude, slope and profile curvature to constant values [2].

The computation of change of curvature is the first step to K_0 determination. Upgrading the least squares method applied on a polynomial function [3], dynamic last squares method (DLS) was suggested by [4] for the third-order geomorphometic variables computation. To achieve an optimal relation between method and data error, flexible window size and polynomial order were used. Generalization of the land surface is a side effect of such computation [4]. The method allows generalize a DEM in two ways: extending either number of computational points (window size), or by increment of polynomial order. In both cases it is supposed to detect a nested hierarchy of elementary forms by peak values of concentration around zero (K_0) index.

Segmentation

One of the most popular approaches of a land surface segmentation is Object-Based Image Analysis (OBIA). OBIA targets on the maximization of internal homogeneity within an image object and external contrast, which are fundamental properties of elementary forms. Average heterogeneity of segments within a scene defines the local variance (LV). LV is calculated as the average standard deviation of all input variables for all objects. LV depends on (fig. 2): i) Number of objects (1),

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consequently, LV increase with the number of delimitated objects; ii) Window size (WS) (2), a measure of generalization, that increases with WS; iii) Coincidence of segmentation with real landforms (3), that is investigated in this work.

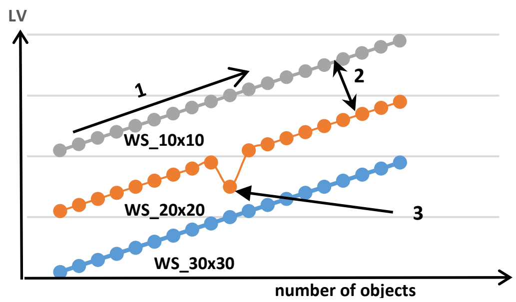

Figure 2. Schematic interpretation of Local Variance. From Upper line to the bottom 10x10, 20x20,30x30 cells window sizes (WS)

Estimation of Scale parameter (ESP) tool was proposed in [7] to substitute the frequently used method of trial and error for determination of optimal SP.

III. Material and methods

The first test area with hilly topography, Slovinec (9.36 ha), is located on the boundary of the Carpathians and the Vienna basin (fig. 3A). The DEM of Slovinec was derived by digital aerial photogrammetry with pixel size 2x2 meters. The second area, Silica (222.7 ha), comprises karst plateaus with sinkholes and uvala (fig. 3B). The DEM of the area was generated from airborne laser scanning (ALS) data with original 1x1 m cell size, resampled to 2x2 m cell size [10].

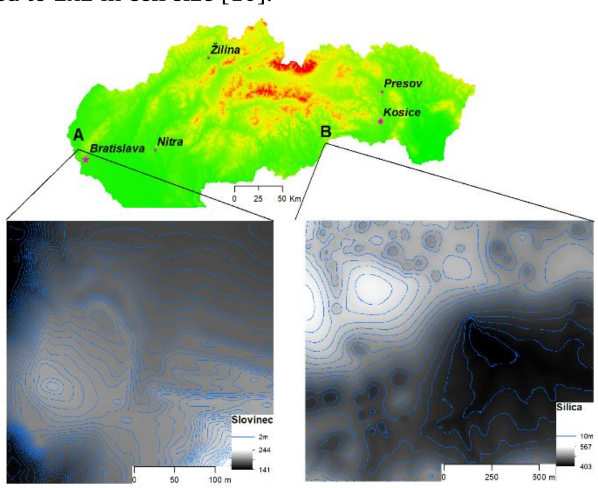

Figure 3. Locations of the test areas in the Slovakia. A– Slovinec, B – Silica

We tested whether generalizations with maximal K_0 values of change of profile curvature (G_{nn}), generally lead to optimal land surface segmentation in areas of interest. It was decided to use fix polynomial function of 4th order with changing window size to find optimal generalization levels for elementary forms mapping.

We suppose that LV can be used as a measure of the quality of segmentation processes over various generalization levels of DEM and so confirm or refuse K_0 index utility for DEM generalization. To achieve this goal, the influence of DEM generalization and number of land surface segments on LV was investigated first.

IV. Results

Graphs of dependence K_0 on window size (Fig. 4) show distinct local maxima (green) that should identify generalization levels the most suitable for the segmentation.

Beside local maximums of K_0 values we also tested local minimums values to compare results and to test a hypothesis of K_0 as the generalization criterion. For Silica was chosen one absolute maximum (window size 43) and two minimums (window size 5 and 145). For the Slovinec area we chose most distinct local maximums (window size 5, 61, 91) and local minimum values according to their affiliation to the maximums, i.e. (window size 27 most distinct to WS 5 max, 43 to 61, 107 to 91 and127 as the absolute minimum).

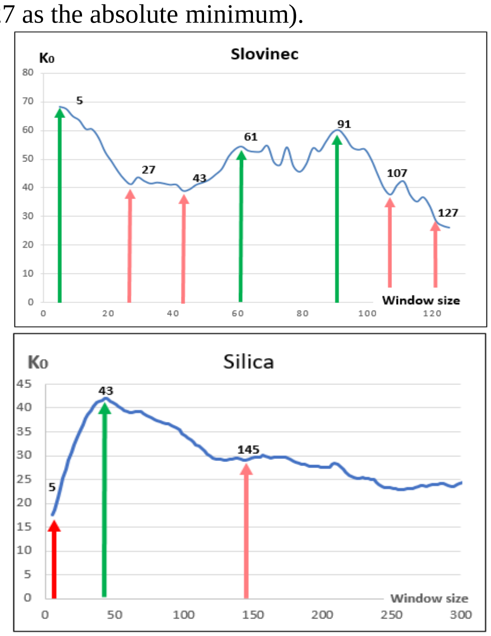

Figure 4. Dependence of K_0 of G_{nn} on the window size for areas of interest. Green arrows pointed to local maximums, red ones – local minimums of K_0 values.

For each area and generalization level (represented by the window size) was undertaken a multiresolution segmentation using ESP2 tool with step sizes 1 to 20, and calculated average segment area (ASA, hectares) for each segmentation. To avoid distortions of results, repeating values were eliminated. 54 of such segmentations was done for the Slovinec territory (fig. 5, A).

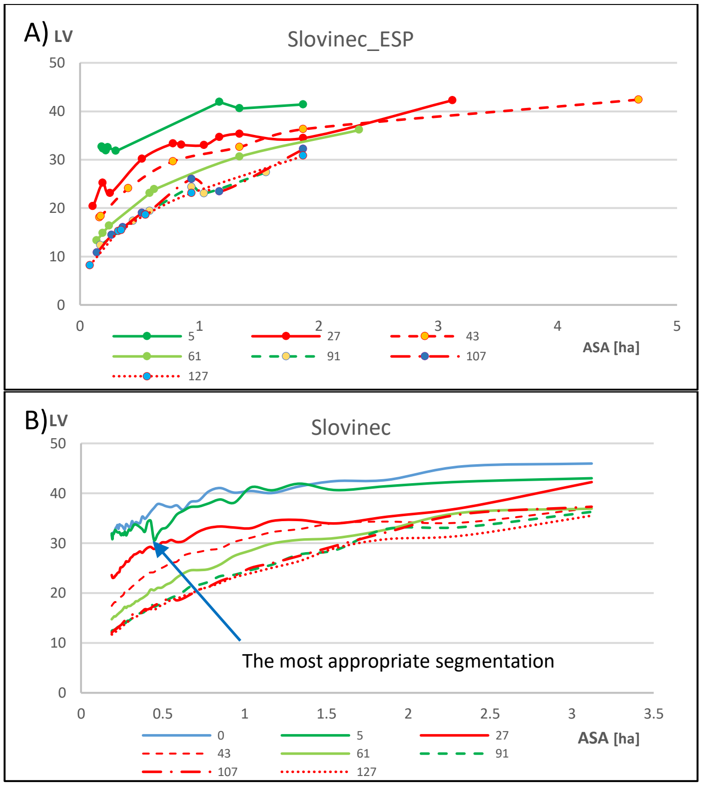

Figure 5. Dependence of local variance (LV) on average segment area (ASA, ha), for different window sizes; A) using ESP2 tool, B) with constant increment of object number. Green – local maximums, red – local minimums of $G_{nn} – K_0$ values. Slovinec territory.

The graph shows clear decrease of LV with increment of the generalization level. However, dependence of LV on ASA for high generalization levels (WS 91, 107,127) is (mainly for range 0.1 – 1 ha) practically same. It can be explained by an “overgeneralization” in these cases. Another multiresolution segmentation was done without ESP2 tool to trace a behavior of LV with constant increment of object number (fig. 5, B). At WS 5 it is clearly seen an abrupt decline of LV that after the hypothesis points to the best segmentation.

In the Silica area the same procedure was done. Graph of dependence LV on ASA (fig. 6) do not shows general decrease of LV with generalization levels. LV values for WS 43 sharply increase from ASA 0.41 to 1.51, then stabilize at the values of LV 30 – 36 and last two levels (WS 5 and 145) are parallel. It can be an evidence of absence of a hierarchic levels of elementary forms in this size diapason.

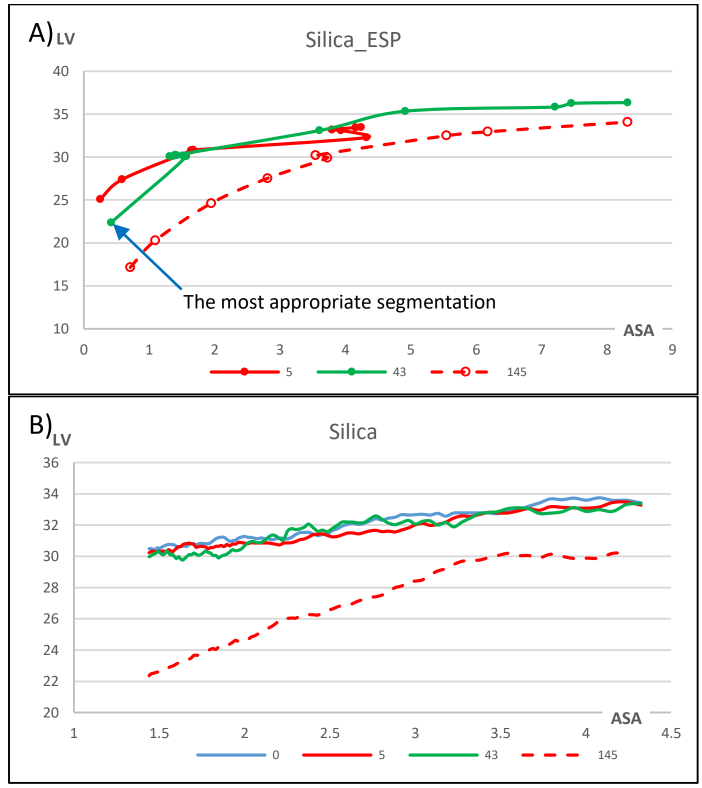

Figure 6. Dependence of local variance (LV) on average segment area (ASA, ha), for different window sizes; A) using ESP2 tool, B) with constant increment of object number. Green – local maximums, red – local minimums of $G_{nn} – K_0$ values. Silica territory.

The best results of segmentation on WS 43 are for ASA = 0.25 ha, that could be considered as a partial confirmation of $G_{nn} – K_0$ hypothesis. The rest of the data does not show any meaningful results. The LV dependence on the number of objects (fig. 6, B) also shows decreasing trend of LV with generalization levels. WS 43 has no clear decline of LV in comparison with the original data and WS 5, while WS 145 is distributed aside of the rest of the data, which could point to catch bigger landforms by this generalization level.

V. DISCUSSION AND CONCLUSIONS

The results partially confirm the suitability of K_0 index for the Slovinec area. However, the algorithm does not work perfectly for all of the generalization levels, as was shown at the area of Silica. It can probably point to overmuch simplification of theoretical assumption. Suitability of generalization level with a maximal value of K_0 index for elementary land surface segmentation results from the following assumption: Elementary forms with affinity to the constant value of normal change of gradient change (G_{nn}) and its parents' variable (normal gradient change - G_n and slope gradient G) make the significant part of the area. It is probably not true for the Silica territory. One of the most appropriate ways to find optimal generalization for land surface segmentation is to use a more complex criterion (criteria) for selecting a suitable window size or polynomial order in the framework of approximation by DLS method. The new index should include optimization of the generalization not only in the slope gradient (normal) direction, but also in the orthogonal (tangential) direction, as these are the directions used to define slope aspect, plan and tangential curvatures. A substitution of used DEM generalization by more sophisticated method, e.g. by the widely used wavelet transform [11] can also leads to a progress.

In conclusion, the hypothesis about suitability of the DEM generalization using minimization of concentration of change of gradient change (G_{nn}) around zero (K_0 coefficient minimization) [3] was partially confirmed. The method developed for evaluation of resultant quality of GEOBIA land surface segmentation shows potential to become widely applicable for finding appropriate level of DEM generalization in the task of detection hierarchy of real landforms. The method can be not only instrumental to distinguish the most suitable generalization of a DEM but it can also serve as a general tool for evaluation of effectiveness in using various input variables or variants of the segmentation procedure.

VI. ACKNOWLEDGMENTS

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