Relationships of attributes of gullies with morphometric variables

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Abstract— **Investigations were conducted on a sample of 439 gullies at Hronská pahorkatina Hill Land in the Slovak Republic. The size of gullies was described by their area and perimeter. Morphometric variables such as altitude, slope steepness, maximal catchment area as well as maximal, minimal, mean, horizontal and vertical curvatures were determined at the start and end points of gullies. The analysis of correlation between area and perimeter of gullies has revealed the linear trend between these variables, which is the result of the definition of a shape of a gully. The frequency distribution of morphometric variables in a specific points of land surface has discovered the different behavior of morphometric variables in these points from those on land surface in general.**

I. INTRODUCTION

The issue of gully erosion stands on the border between soil science and geomorphology. The main reason of this status is that gully is a form of the land surface formed by the process of soil erosion. The process is dangerous for man and society. Therefore the cognition of the gully erosion process is crucial for restricting negative influences.

Formation and behavior of gully erosion processes and consequently formation of gullies are influenced by a group of five factors (topography, precipitation, land cover, physical characteristics of material, and linear predispositions). Topography is a limiting factor, so in case of inappropriate configuration of land surface, gully erosion does not occur. Topography is described by morphometric variables. The system of morphometric variables consists of a relatively limited group of commonly used morphometric variables (*e.g.* slope, aspect, horizontal curvature, *etc.*) and of a larger group of not so commonly used morphometric variables.

A wide range of studies is focused on the analysis of correlation between ephemeral gullies on one side and morphometric variables of slope and maximal catchment area on the other, *e.g.* [1], [2]. Numbers of studies are aimed on the use of a wide range of morphometric variables as inputs into regression modeling, *e.g.* [3], [4]. Another group of studies is aimed on the analysis of thresholds of initial conditions for gully formation. The most advanced approach is the use of morphometric variables as inputs into analytical models of gully erosion [5], [6].
Morphometric variables are usually represented in the format of raster. One of the most important attributes of this format is grid spacing. Increase of size of a smallest element means decrease in a volume of information on land surface and change in values of altitude derivatives. The latter is defined as a change of scale [7], [8]. Dependence between morphometric variables and a grid spacing is analyzed in a number of studies, *e.g.* [9], [10]. The majority of the works takes into account only morphometric variables derived from the first and second directional derivatives or the catchment area with almost identical results [11]. The dependence between grid spacing and results of analytical models is analyzed only in a limited number of works, *e.g.* [12]. The majority of works considered only the change of grid spacing in several resolutions, not in a continuous scale. This paper aims on analysis of change of values of morphometric variables in dependence on different grid spacing, which is examined in start and end points of gullies as a specific points of land surface.

The main objective of the work is to study dependence between attributes of gullies and the wide range of morphometric variables. Partial objectives are:

* Analysis of correlation between area and perimeter of gullies on larger datasets.

** Analysis of morphometric variables in start and end points of gullies and differences between attributes of land surface in these positions.

*** Analysis of dependence between morphometric variables and grid spacing in start and end points of gullies.

**** Analysis of dependence between slope and maximal catchment area in incision (start) point of gully.

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II. METHODS

The area of investigations, the Hronská pahorkatina Hill Land, is located in the southern part of the Slovak Republic (fig. 1). It is on the contact between a neogene quaternary river basin and a chain of hills in the north-eastern part. On the shallow base fluvial and colluvial material with different thickness can be found. The mean annual temperature of the region is 8 – 10°C, average year precipitation is 500 – 600 mm. According to Stehlík [13] the present gully formation in this region is inactive.

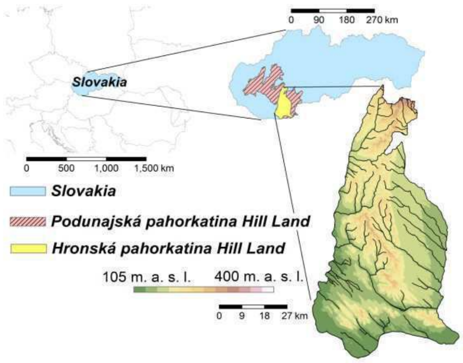

Fig. 1. Location of Hronská pahorkatina Hill Land

For the investigations the modern topographic map of the Slovak Republic 1:10 000 was used. Contour lines of this map were digitized using ArcGIS 10.0 and in the next step interpolated into a digital elevation model (DEM) with a grid spacing of 10 m. Interpolation was carried out using the algorithm *v.surf.rst* in GRASS GIS. DEMs with lower resolution were generated by eliminating rows and columns from the grid using GIS ECO [14]. For example, if grid spacing w = 10 m was to be changed to grid with spacing w = 20 m, every other row and column was removed. Totally, DEMs with a resolution from 10 m up to 100 m in a 10-meter interval were computed. Morphometric variables were computed from the generated DEMs using GIS ECO [14].

The Military topographic map 1:10 000 constructed between years 1957 – 1971 was used for construction of a database of gullies. Based on this map, gullies were digitalized using ArcGIS 10.0 into a polygon layer. Topographic information contained in this map is not as precise as topographic information contained in the topographic map of the Slovak Republic 1:10 000. Thus, the integration of all spatial datasets into one GIS system showed a positional error between the Military topographic map and the constructed digital elevation model from the topographic map of the Slovak Republic. Therefore, position of each gully was checked and corrected on the base of the DEM constructed from the topographic map. Gully positions were verified on the basis of isolines of altitude and thalwegs derived from the Military map and the digital elevation model.

The gully database was coupled into two datasets. Firstly, to the merged dataset, where complex gullies were merged into a single shape. Characteristics such as area (m^2), perimeter (m) and ratio between them were the same for the whole complex gully. Secondly, to the split dataset, where complex gullies were split and recorded as a set of simple gullies. Characteristics such as area (m^2), perimeter (m) and ratio between them were not the same for the whole complex gully. In the final datasets gullies were represented by their start and end points, see fig. 2.

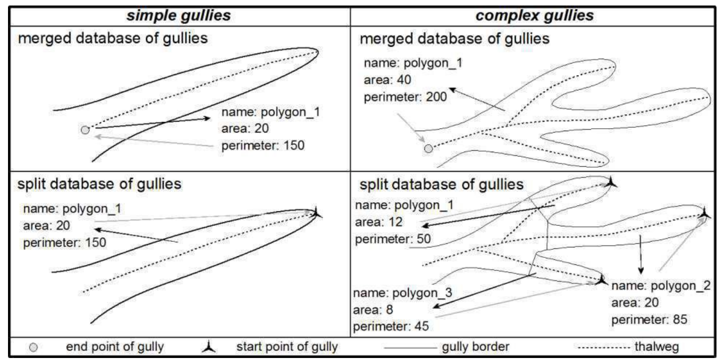

Figure 2. Differences between merged datasets and split datasets in case of simple and complex gullies.

Correlation between them was taken into account as statistically significant at $p \leq 0.05$.

Dependence between slope and maximal catchment area was analyzed using the methodology of Poesen [15]. Start (incision) points of gullies were set on a logarithmic scatter plot of slope and maximal catchment area. Cloud of points is represented by exponential function approximated on the basis of the lowest values located in the upper left part of the scatter plot.

III. RESULTS AND DISCUSSION

The ratio between perimeter and area of gullies is described by a linear trend with relatively high value of R^2 (fig. 3). Dependence between area and perimeter of gully is only mediated dependence between wide and length of gully. In the lower right part of the cloud narrow and long gullies can be found. In the upper left part wide and short gullies are located.

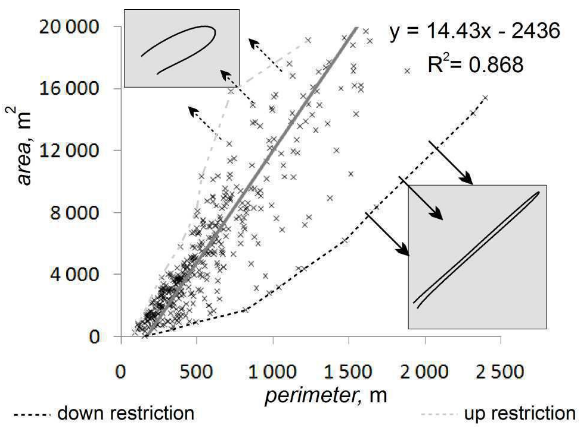

Figure 3. Ratio between perimeter and area of gullies on example of end points of gullies with additional potential shapes for extreme values. Down / up restriction is defined by the lowest / highest values of the area.

In fig. 3. is pointed out on example of dependence between area and perimeter of gully on dataset of end point of gullies. Linear trend in this figure represents the average ratio between area and perimeter, which represents the shape of a gully. Consequently, the linear trend in fig. 3 represents the potential ideal shape of a gully in the Hronská pahorkatina Hill Land. Coefficient of determination in case of trend line constructed from the database of (incision) start points of gullies is 0.80 and in case of end points 0.87. It can be assumed that this trend is dependent on the location of sampling points and the location of the database itself. There exist two possibilities of explanation.

*The common approach with another characteristic was used for many landforms as landslides [16], underwater landslides [17] or glacial cirques [18]. In this studies it was proven that correlation between some different quantitative characteristics of landforms exists. These correlations are close to a linear, logarithmic or exponential trend.

**A gully is the only form of land surface which stands between ephemeral gully and valley. Ephemeral gully is transformed to gully, which changes into valley. Both transitions are caused by erosion. Is it possible that trend will disappear in case that ephemeral gullies and valleys will be incorporated into the scatter plot. Therefore the trend is only result of a definition of shape and size of gully.

The restriction line in the lower part of the plot is conditioned by a minimal width of the gully. This minimal width depends on the gully area. But this is the only an indirect dependence between minimal width and length of the gully. It can be assumed that the lower restriction is represented by a strict border. On the other hand, the upper restriction is just a diffuse area.

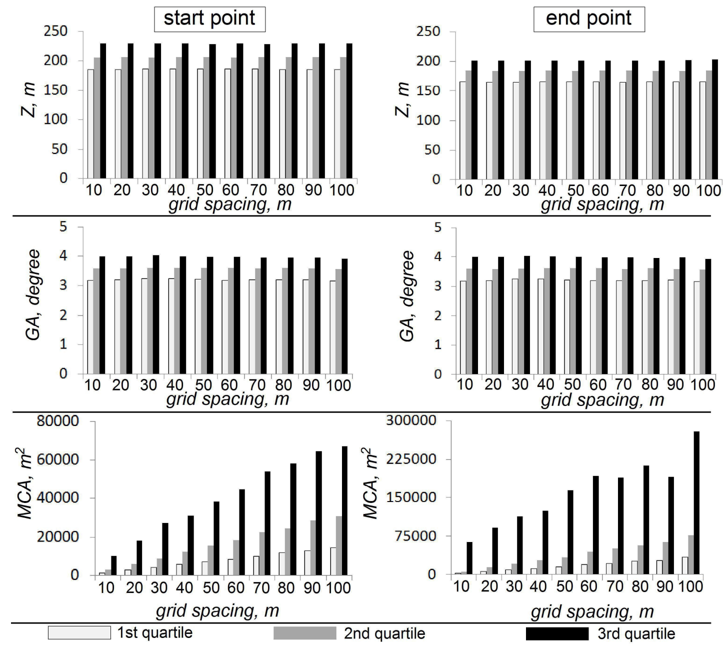

Figure 4. Quartiles for sets of morphometric variables on DEMs with different grid spacing for the dataset of start points and end points on Hronská pahorkatina Hill Land. Left – values for start point of gullies, right – values for end points of gullies, Z - altitude, GA – slope, MCA – maximal catchment area.

Only specific points of the land surface are represented by the datasets of start and end points of gullies, thus some statistical attributes of morphometric variables are different in comparison with a common land surface. On the basis of work by Shary [19] altitude and slope are scale-dependent morphometric variable and maximal catchment area is scale-free morphometric variable, which is not in an accordance with our results. It can be assumed that this is caused by the specific position of gullies on land surface in this area when gully is situated on smooth slopes with constant values of slope or in flat part of land surface, thus value of slope and altitude is almost constant for different grid spacing. Reason for increase of maximal catchment area depending of grid spacing is still unclear, however it can be assumed that this fact is caused by change of position of divide line due to change of grid spacing.

An example of the analysis of dependence between a maximal catchment area and a slope in start and end points of gullies using scatter plot is in fig. 5. The approximated line in the scatter plot provides information about resistivity of the study area against gully formation.

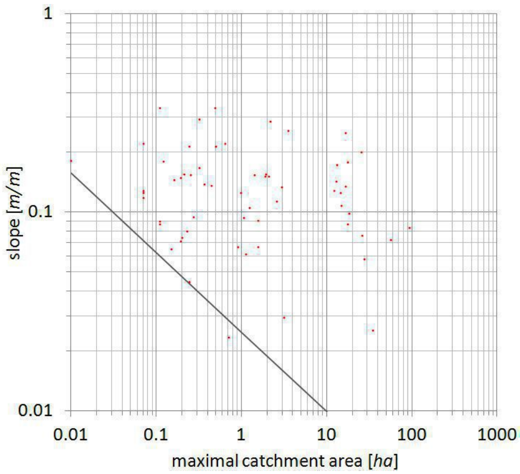

Figure 5. Example of the scatter plot of dependence between maximal catchment area [*ha*] and slope [*m/m*] for catchments forested less than 50 % for start (incision) points located in Hronská pahorkatina Hill Land. Each point represents one start point of gully. Gully located below the line is an outlier of the dataset.

During this analysis it is crucial to take into account differences between land use classes in catchments, thus resistivity of the area against gully formation varies in dependence on land use of the catchment area. This approach can be directly used for prediction position of start (incision) point of gully under different land use classes.

IV. CONCLUSION

According to the results, correlation between perimeter and area of gullies was discovered, but it can be assumed that this correlation is just a result of your definition of gully. Frequency distribution of morphometric variables in specific points of land surface is influenced by different rules than statistical distribution of morphometric variables on whole land surface. We have proven this fact only for a change of values of morphometric variables in dependence from grid spacing, however it can be assumed that there exists a higher number of similar phenomena. It was proven that the potential position of the start point of gully can be predicted using dependence between maximal catchment area and slope.

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