GeoTerrace-2020-053

Application of GIS for morphotectonic analysis (on the example of Kremenets Mountains)

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SUMMARY

This study aims to show the possibility of using GIS for morphotectonic analysis of the territory that by the use of geomorphic indices helps us in reconstruction the stages of the development of the landforms during a certain period. On the example of Kremenets Mountains, the created maps of differences of isobase surfaces within the limits of the second, third and fourth orders are analysed. This is one of the methods of morphotectonic analysis. A map of the differences of the isobase surfaces of the second and third orders as well as a map of the differences of the isobase surfaces of the third and fourth orders are a part of created cartographic material. Based on them, two stages of influence of recent tectonic (mainly vertical) movements on this territory have been identified, which together with the processes of denudation and accumulation have formed a general appearance of the Kremenets Mountains. Within both stages, areas that have been significantly affected by modern tectonic uplifts and lowerings have been identified. The publication also presents several methodological aspects for constructing cartographic material for morphometric analysis.

Introduction

Kremenets Mountains is a unique area of the Podillia Upland, which occupies the northeastern edge of the Podillia region to the east of the Ikva River valley and the west of the Viliya River. The intensively dissected landforms, wide growth of deep gullies and ravines, phenomena of slope recession are widespread here as well as karst and karst-suffosion processes, etc. The relief of the mountains clearly shows some residual mountains such as Zamkova (Bona), Stizhok, Maslyatyn, Buzha and others. Kremenets Mountains have some features of structural relief, which is also reflected in the structure of its erosion network. Cretaceous deposits, Neogene deposits of limestone and sandstone, as well as Quaternary deposits of loess-like loams are observed in the geological structure of the territory (Laskarev 2014).

The use of modern research methods, in particular GIS, allows a clearer understanding of the geological structure of the Kremenets Mountains, especially the influence of morphotectonics on the formation of their modern appearance.

Method and Theory

Morphotectonics is a field in geomorphology intended to identify the role of tectonic structures and processes in the formation of modern relief. Classical methods of morphotectonic and morphostructural analyses can be used in the GIS environment, using the functions of modelling different theoretical aspects and conditions. The ArcGIS software, which is characterized by a large number of tools for technical application and modelling of spatial objects, is the most suitable for GIS analysis.

In this software environment, you can link cartographic material to a particular cartographic or mathematical coordinate system. Furthermore, you can digitize point, linear, planar objects, create a series of 2D and 3D structures (rasters), changing them in time and space, as well as conduct various scales investigation and other. We outline four stages of GIS-building:

1) Preparation of the cartographic basis, a division into toposheets, binding of the basis in the ArcGIS environment and creation of several layers for the needs of certain analysis.

2) Vectorization of isolinear, point and planar objects, analysis of cartographic vectors and creation of raster models (digital elevation model). This stage is the most time-consuming.

3) Work with tools in the software environment, production the final cartographic material for the needs of morphostructural and morphotectonic analysis.

4) Analysis of neotectonic and modern movements, defining the connection of tectonic and geological structure with modern relief based on the cartographic interpretations and constructions.

To create high-quality cartographic material, the following data set is required: isohypses, vertex points and their altitudes, water edge points and their altitudes, thalweg lines of streams, study area boundaries. The Topo to Raster tool is designed to obtain a raster by interpolating the altitude values when applying constraints that provide a linked drainage structure, the correct display of ridges and streams from the input vector data (Klapchuk 2015). For morphotectonic analysis such morphometric maps as hypsometric, slope degree and slope aspect, vertical (interfluvial dimension) and horizontal (amplitude altimetry) dissection are required. They are obtained as a result of DEM processing and special tools of the Spatial Analyst module (tool group Surface: Slope, Aspect, Line Density, Neighborhood). More complex constructions, in particular isobase and vertex surfaces need a clear methodological approach. Isobase surfaces are built using isobasites – lines that run along the points of intersection of horizontals with thalwegs of erosive streams.

On the example of the study area (Kremenets Mountains), different geomorphological analyses, as well as the creation of cartographic models, were carried out (Bermes 2015, 2016, 2018, 2019; Novak, Bermes 2014; Bermes et al. 2018). This paper presents an analysis of the construction of the differences of the isobase surfaces between the third and fourth order and the second and third order.

The differences between the isobase surfaces of adjacent orders is a reflection of the algebraic sum of vertical movements of the Earth's surface, erosion-denudation washout over a certain period (Palienko et al. 2013; Filosofov 1975). These data allow estimating the amplitudes of vertical movements and identifying potential active tectonic structures. The differences may be both positive and negative. Positive differences between the isobase surfaces indicate upliftment of the Earth's surface, and negative ones mean its lowering. Thus, the differences between the isobase surfaces of the second order register the upliftment and lowering of the Earth's surface at a time closer to the present, and the fourth order – the older movements. Maps of differences of isobase surfaces are constructed by subtraction of a surface of the higher (third, fourth) order from a surface of the lower (second, third) one (Tustanovska 2011).

Examples

In the result of the analysis of the created map of differences of isobase surfaces (Fig. 1), it is necessary to note the dominance of positive elevations over the negative ones. This fact indicates the domination of the uplifting of the territory over the lowering during the older stage of relief formation within the chronological framework selected for our study. The highest uplift amplitudes unite in a ring-shaped structure characterising the elevation along the escarpment of the Kremenets Mountains. Furthermore, high rates of elevation in the ring-shaped structure are inherent in the plateau-like part of the mountains; the relative elevations over the adjacent territories are insignificant. These facts indicate a slight uplift of the territory with the impact of planation.

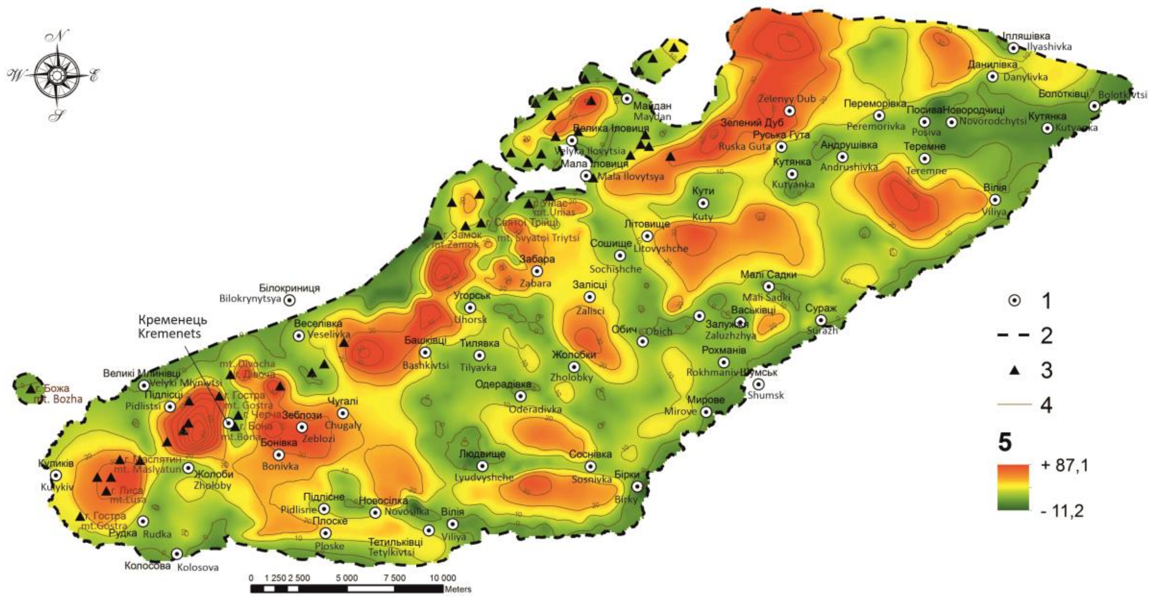

__Figure 1__ Map of the differences of the isobase surfaces between the third and fourth order: 1 – settlements; 2 – boundaries of the study area; 3 – main peaks; 4 – isolines of the differences between the isobase surfaces of the third and fourth orders; 5 – height scale of the differences of the isobase surfaces of the third and fourth orders.

The lowest parameters of uplifting are inherent in the areas of the present foothills along the escarpment of the Kremenets Mountains, the valley of the river Kutyanka, as well as on the southern edge of the territory. A high level of vertical dissection is inherent in the area along the escarpment.

Simultaneously, low uplifting rates indicate a considerable impact of downward vertical movements on this territory, which caused its lowering. The terrain of the Kutyanka River basin is characterised by negative rates due to both the lowering of the territory and the predominance of substantial accumulation processes in this area. As can be seen in Figure 1, the parameter of the differences of the isobase surfaces reflects the erosion activity in this area quite well and almost does not reveal the residual forms of the Kremenets Mountains. Hence, we can suppose the residual hills obtained their present appearance during the younger stage of development of the territory.

The map of the differences of the isobase surfaces between the second and third order (Fig. 2) also has a clear ring-shaped structure (spotted pattern) of the elevations, although smaller than in the previous stage. The elevations along the escarpment of the Kremenets Mountains are traced clearly. It is evidence of the beginning of the formation of the present appearance of residual hills. Uplifting, as well as lowering, have local spatial distribution. The highest elevations are recorded along the escarpment, namely at the confluence of the rivers Zbytynka and Viliya. Furthermore, high rates of differences are characteristic of the southern edge of the Kremenets Mountains, which led to the formation of an unclear orographic limit. Minor depressions are characteristic of the plateau-like area of the mountains, resulting in the formation of a slightly undulating relief.

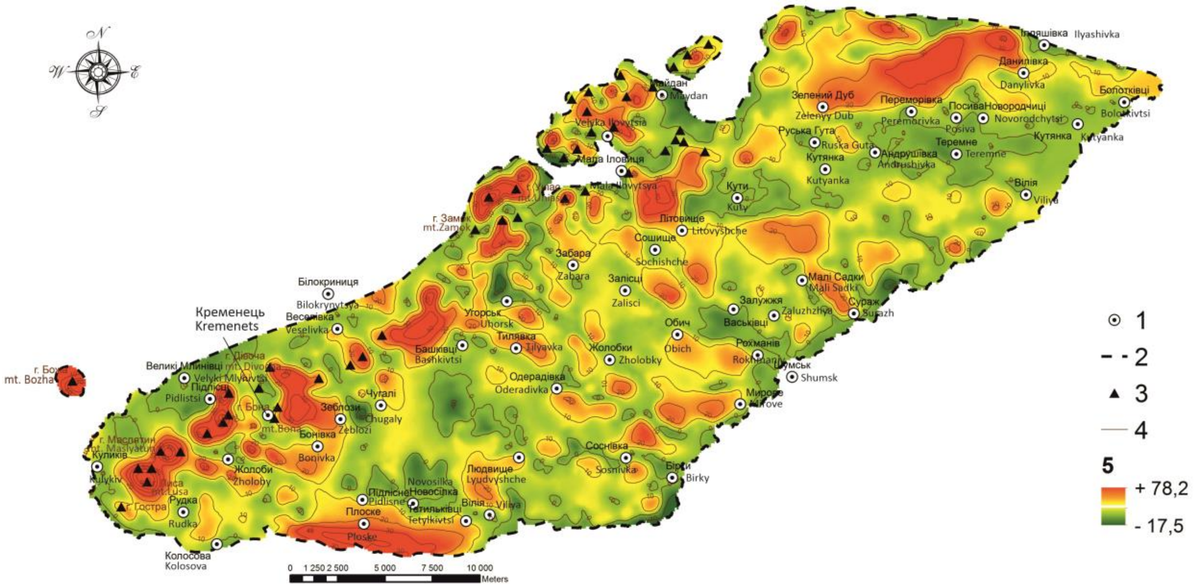

Figure 2 *Map of the differences of the isobase surfaces between the second and third order: 1 – settlements; 2 – boundaries of the study area; 3 – main peaks; 4 – isolines of the differences between the isobase surfaces of the second and third orders; 5 – height scale of the differences of the isobase surfaces of the second and third orders.*

Conclusions

Analysing the obtained results, we should note that modern tectonic (mainly vertical) movements have a significant influence on the homogeneous geomorphological structure of the Kremenets Mountains. In addition to the processes of denudation and accumulation, they have determined the present features of the territory. High rates of tectonic influence in both studied cases are inherent in the territory along the escarpment, moderate values - in the plateau-like part of the mountains, and the lowest ones - in the basin of the river Kutyanka and the foot of the escarpment. For a more complete representation of the amplitudes of neotectonic movements, we need to create a map of the differences of vertex surfaces and the differences of single-order vertex-isobase surfaces.

Acknowledgements

This study partially was supported by the project of National Research Foundation of Ukraine "Development of palaeocryogenic processes in the Pleistocene loess-palaeosol sequences of Ukraine: engineering-geological, soil, climatic, and environmental protection aspects" (project number 2020.02/0165).

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