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Spatial morphometric analysis of digital elevation model in landscape research

L. F. Bilous, P. Shyshchenco, V. Samoilenko, O. Havrylenko *(Taras Shevchenko National University of Kyiv)*

SUMMARY

Spatial analysis is considered as a complex scientific task of landscape science. Spatial structural and morphometric analysis of Digital Elevation Model (DEM) is defined as a methodology of information inventory of landscapes and their geoecological status. The effectiveness of this methodology is determined by the reliability of the DEM. It is suggested to use ArcGIS software for create DEM, in particular, the Topo to Raster data interpolation method. Specificity of construction of this the DEM and features of classification and interpretation of its data are considered.

Spatial structural and morphometric analysis of the DEM for landscape modeling is proposed. Its essence is determined by the application of mathematical actions with DEM and poly-vertex and poly-basic surfaces of the 1st order.

This technique enables the synthesis of information on the location of landscapes differing in the intensity of erosion-accumulation processes. Such information is crucial for the organization of balanced nature-management systems in the regions.

Introduction. Spatial analysis is the culmination of any GIS research. There are four traditional types of spatial analysis: surface analysis, spatial overlay and contiguity analysis, linear analysis and raster analysis.

Spatial analysis of Digital Elevation Model (DEM) is a complex scientific task. DEM is the digital representation of the land surface elevation with respect to any reference datum. DEM is frequently used to refer to any digital representation of a topographic surface. DEM is the simplest form of digital representation of topography.

DEMs are used to determine terrain attributes such as elevation at any point, slope, aspect. DEMs are widely used in hydrologic and geologic analyses. Hydrologic applications of the DEM include groundwater modeling, determining landslide probability, flood prone area mapping. DEMs are the basis of soil state, landscape and habitat modeling.

Spatial structural-morphometric analysis of DEM can be seen as a methodology of informational inventory of landscapes and theirs geoecology state. This technique enables the synthesis of information on the location of landscapes differing in the intensity of erosion-accumulation processes. Such information is crucial for the organization of balanced nature-management systems in the regions.

Methods of investigation. Many GIS software applications are available in both commercial and open sources. There are two popular applications: ArcGIS and QGIS.

This research was carried out using ArcGIS tools and Topo to Raster method to create a model of DEM in particular. The Topo to Raster is a specialized tool for creating hydrologically correct raster surfaces from vector data of terrain components such as elevation points, contour lines, stream lines, lake polygons, sink points, and study area boundary polygons. This tool should be used for local level research. TIN modeling was applied to generate additional data for areas of insufficient data for correct Topo to Raster interpolation.

The hydrological modeling tools in the ArcGIS Spatial Analyst Extension Toolkit have made it possible to describe the physical components of a surface. Hydrological tools allowed us to determine the direction of flow, calculate flow accumulations, delineate watersheds and create stream networks.

Spatial analysis of DEM for modeling of morphological landscape organization is made in connection with the method of morphometric research of relief proposed by Philosofov (1960). Its essence is determined by the application of mathematical actions to the delineate watersheds and flow accumulations surfaces created by DEM.

Results of investigations. Relief morphometry has been widely developed over the past decades, having achieved important results in the methodological and subject areas of research. A methodology of integrating GIS and statistics in morphometric analysis is presented for the most usual morphometric parameters - hypsometry, slope, aspect, swath profiles, lineaments and drainage density, surface roughness, isobase and hydraulic gradient.

Effective methods of geomorphological analysis are structural geomorphological and morphometric which were previously

based on the topographic map analysis and now are based on reliable DEM.

DEMs are a gridded digital representation of terrain, with each pixel value corresponding to a height above a datum. Since the pioneering work of Miller and Laflamme (1958), DEMs have grown to become an integral part of a number of scientific applications. DEMs can be created from ground surveys, digitizing existing hardcopy topographic maps or by remote sensing techniques. DEM’s are now predominantly created using remote sensing techniques. Remotely sensing techniques include photogrammetry (Uysal et al., 2015; Coveney and Roberts, 2017), airborne and spaceborne Interferometric Synthetic Aperture Radar (InSAR) and Light Detection And Ranging (LiDAR). Spaceborne InSAR is the most common technique to create global DEMs and is the technology behind the most widely used open-access global DEM; the Shuttle Radar Topography Mission (SRTM). SRTM is still the most popular global DEM because of its accessibility, feature resolution, vertical accuracy and a lower amount of artifacts and noise compared to alternative global DEMs (Rexer and Hirt, 2014; Jarihani et al., 2015; Sampson et al., 2016; Hu et al., 2017).

Evaluating the accuracy of the SRTM data (Farr, T. G., P. A. Rosen, et al. (2007), Rodriguez, E., C. S. Morris, et al. (2005) allows it to be used in regional studies. The SRTM data are defined as insufficient to generate reliable DEMs in a local research.

Since the purpose of this scientific research is synthesize information about the “drawing” of landscapes, which is determined, in particular, by the features of the manifestation of erosion processes, then the level of GIS analysis should be defined as local.
DEM for our local spatial structural-morphometric analysis was decided to create using the method of digitizing existing hardcopy topographic maps.
ArcGIS Topo to Raster interpolation data system was created as a result of the digitization of topographic maps of scales 1: 50000 and 1: 25000. The elements of this system are defined TopopointElevation (Point heights), TopoContour (Isolines), TopoStream (Watercourses), TopoSink (Local depressions), TopoBoundary (Boundary), TopoLake (Lakes), TopoCliff (Rocks), TopoExclusion (Exceptions) and TopoCoast (Coast).
Identifying and solving the problem of source data insufficiency is important in DEM modeling. Aligned areas of terrain (terraces, river valleys, lowlands, watershed, plateaus) are typically characterized by a lack of baseline data. Ignoring this problem is the reason for the existence of GRID cells in DEM, which do not have height values, and therefore do not participate in the following spatial analysis. To solve this problem, it is necessary to apply the Topo to Raster method, to build a preliminary DEM and to create a spatial model of biases for it, to convert it into a vector format and to select polygons characterized by a slope less than 0. These polygons are characterized by insufficient amount of data and, accordingly, need their revision.

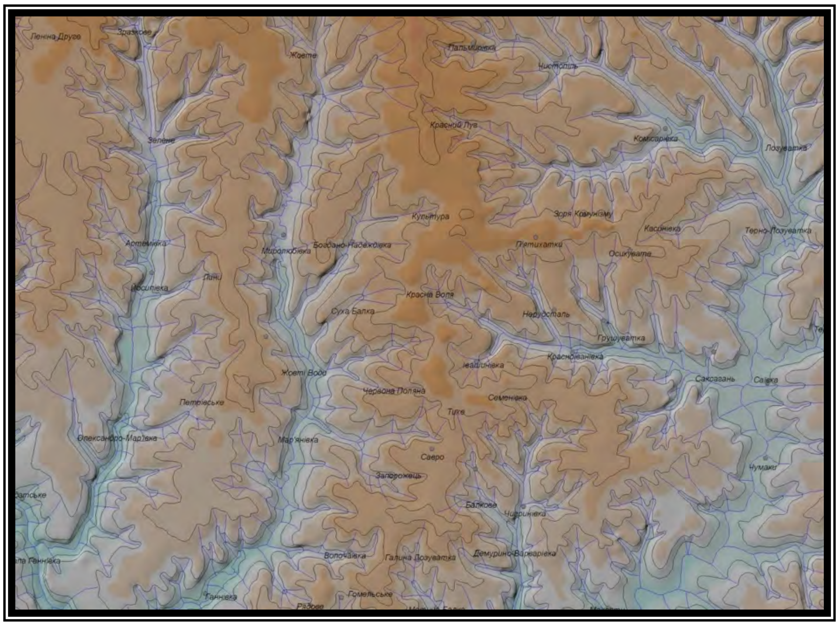

***Figure 1.** DEM fragment*

Thorough preparation of the ArcGIS Topo to Raster interpolation data system is a crucial prerequisite for creating a reliable DEM.
We made 3 iterations of supplementing their database in solving the data density problem.
The result is a highly accurate and representative DEM (Figure 1).
From the geomorphological point of view, the terrain of the study area unanimously belongs to the fluvial-erosional type of surface created in humid climates, which plays an important role in the territorial differentiation of erosion processes and, accordingly, landscapes.
The history of landscapes in any of such territory is characterized by phases of relatively rapid and slow changes, which are related to the change of relief, uneven morphogenesis in time and space. The epochs of youth and maturity of relief, denudation alignment, and formation of pediplanes and peneplenes are decisive in the formation of landscapes. Each cycle of morphogenesis forms new cuts and new surfaces of alignment, and, therefore, the layered terrain and the associated tier of the landscape organization of the plains.
Unlike the altitude, the landscape leveling of the plains is not associated with significant changes in the absolute height of the terrain. It is based primarily on the geomorphological conditions of the terrain, which determine the specifics of the complex of landscape-forming factors: climatic, soil, biotic, etc.
The study of the terrain morphology is based on the identification of the morphometric parameters of each terrain unit within the study area. Morphometry is the mathematical analysis of the configuration of the earth’s surface, shape, “drawing” and dimension of its landforms.
Within the framework of landscape science, the territorial differentiation of slopes by positional and process features was described by Haase (1961) and Milkov (1974). The first researcher extended the concept of catena; Milkov considered these microzones to be universal, that is, expressed on any slope,

regardless of its length and shape. Shvebs (1985) proposed to distinguish landscape strips (LS) - territorial units specific in terms of dynamic processes and position in the relief.
Subsequently, it was established that the territorial relationships of the same type are at the basis of landscape layering and stripes, which gave reason to justify the taxonomic series and the principles of allocation of units of the position-dynamic landscape territorial structure (LTS) (Shvebs et al, 1996).
We propose the method of standard deviation classification of DEM in ArcGIS for automatic modeling of the LS "draw". It is organic to apply this method to integral territorial entities, such as basin territorial structures.
The standard deviation classification method shows how much a feature's attribute value varies from the mean.
The mean and standard deviation are calculated automatically. Class breaks are created with equal value ranges that are a proportion of the standard deviation (Bilous, 2005, 2008).
The result of DEM classification by the method of standard deviation is presented on Figure 1. The selected object classes correspond to certain LTS landscape tiers (LT). These are the Eluvial (watershed-altitude), Trans-Eluvial (slopes), Eluvial-Accumulative (terrace, floodplain), Alluvial-Deluvial (ravines, beams, river valleys).
The territorial differentiation of the selected LT on the LS is determined by the intensity of the landscape processes within their boundaries.
The morphometric analysis of DEM is the resultant method of studying the intensity of the intensity of landscape processes.
Hypsometry, slope, aspect, swath profiles, lineament and drainage density, surface roughness, isobase, hydraulic gradient are morphometric indices.
Isobase lines draw erosional surfaces, hence isobase surfaces are related to erosional cycles, mainly the most recent ones (Filosofov, 1960; Golts and Rosenthal, 1993).
The concept of "isobase map" is similar to the "Thalweg" of Annaheim (1946), the "Reliefsockel" of Louis (1957), the "streamline surface map" of Dury (1952) and Pannekoek (1967), the "subenvelope map" of Hack (1960), or the "Sloping Local Base Level" of Jaboyedoff et al. (2004, 2009).
These isobase methods were developed enough by Filosofov who applied them successfully in research works for different kinds of minerals.
The morphometric maps are created namely in the process of analysis: maps of basin surfaces, erosion depths, river valley depths etc., being a derivative for analytical calculations in order to outline prospective areas for certain kinds of minerals.
Isobase methods are based on the identification and study of the relief structural lines that collectively form its frame.
Spatial morphometric analysis of DEM by the isobase approach involves the study of structural relief surfaces, determined by the points characterizing the spatial arrangement of structural lines of some (certain) order (I. Chervaniov, 1979).
For example, to construct a mono-basic or mono-vertex surface of a certain order, the points array of DEM is used to characterize the spatial position of structural lines (thalweges or watersheds) of the same order. And for constructing a poly-basic or poly-vertex surface of a certain order, the spatial analysis includes an array of DEM data that characterize the corresponding structural lines of the same order as the created surface, and higher orders.
Mathematical actions with poly-vertex and poly-basic surfaces of the 1st order (PVS1 and PBS1) and DEM are the basis of this structural morphometric analysis of the relief and synthesis of the models of LSs. The LSs are differ in the intensity of erosion and accumulation of matter in their lithological and soil components.
The vector data for the construction of PVS1 and PBS1 surfaces were obtained by DEM and using the ArcGIS Hydrology Modeling module, in particular, using Flow direction, Watershed and Flow accumulation functions.
The following was the conversion of constructed vector models of vertex and basic linear elements into raster format, into the surfaces (PVS1 and PBS1).
Several effective mathematical actions with these surfaces and DEM were proposed. These mathematical actions have been identified as effective after GIS experimentation in ArcGis and geo-environmental testing.

These are the next mathematical actions: PVS1- DEM = the denuded landscape components (Figure 2); DEM - PBS1 = the residual landscape components (Figure 3).
The standard deviation classification method of these surfaces was applied to represent the results of mathematical actions. The use of this method of surface classification made it possible to outline the difference of all data from the average value of the data and, accordingly, to reveal the peculiarities of the territorial manifestation of modern landscape processes.

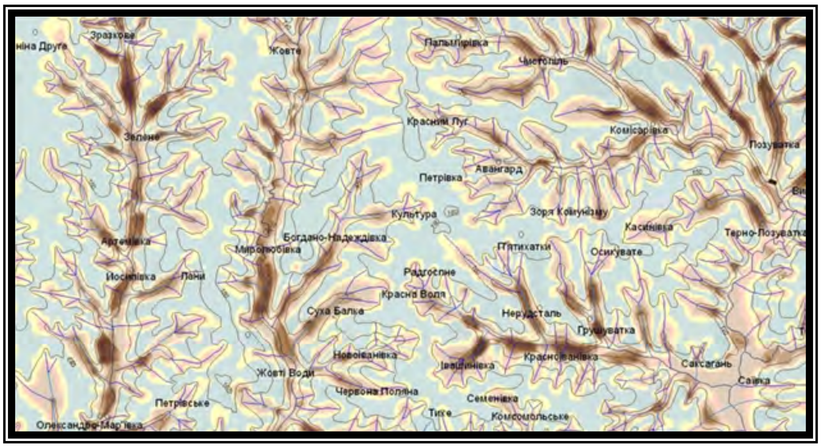

Figure 2 The denuded landscape components

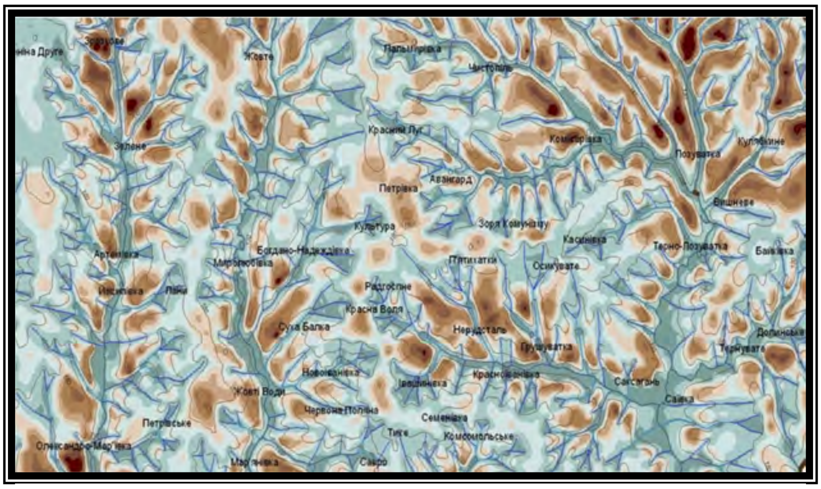

Figure 3 The residual landscape components

As a result of the ordering of the residual landscape components surface the classes of objects (Figure 3), corresponding to the transit-hydromorphic and hydromorphic landscapes, were selected and for which the thickness of the residual landscape components was less than or equal to zero. Accumulating landscapes are also well differentiated on this surface. They belong to the data class of maximal values of the residual landscape components surface (more than 26.082 m). These accumulative landscapes are limited, in particular, by concave morphological landforms, and are characterized by a topologically determined high probability of pollution accumulation.
Concerning the results of classification of the denuded landscape components surface (Figure 2), it is necessary to note the close correlation of its structure with the intensity of manifestation of modern erosion processes. The selected object classes correspond to landscapes with soil complexes of different degree of manifestation of erosion processes.
The verification of the results of the surface analysis was carried out using the methods of profiling, analytical comparison and expedition research.

Recommendations and conclusions. Morphometric features of the terrain determine the features of the organization of landscapes of the regions. Spatial structural-morphometric analysis of DEM can be seen as a methodology of informational inventory of landscapes and theirs geoecology state.
One of the methods for studying morphometry is to extract morphometric variables from the DTM, construct and interpret the corresponding surfaces, such as watersheds, erosion bases, thalwegs of various orders, and average heights.
The proposed method of mathematical actions with surfaces (PVS1-DEM; DEM - PBS1) is effective for modeling the surfaces of denuded landscape components and residual landscape components and, accordingly, inventory of landscape territorial structures.
This technique enables the synthesis of information on the location of landscapes differing in the intensity of erosion-accumulation processes. Such information is crucial for the organization of balanced nature-management systems in the regions.

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