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ORIGINAL ARTICLE

Identifying the impact of generalization on maps of erosion dissection at different scales

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Abstract

The issue of building thematic maps of erosion dissection, despite its wide demand in various fields of human activity (construction of hydraulic structures, transport and housing construction, agriculture), still has no clear rules and instructions, which causes different perceptions of the obtained mapping results by specialists. The purpose of the study is to experimentally identify the change in the index of erosive dissection depending on the scale of the initial data, the size of the cell, the method of constructing the thematic map, etc. The methods used in this research are the method of mathematical statistics, GIS mapping and modelling, spatial analysis, and change detection. For each of the selected methods of thematic mapping, we compiled the cartograms that allow the visual tracking of changes in the elements of the erosion network depending on the geometric characteristics of the scale and cell size. The dimensions and characteristics with optimal results were substantiated. The main feature of erosional dissection mapping of any territory is to detect the negative relief or concave upward forms. The result is a visual perception accompanied by the addition of numerical values. Estimation of erosion dissection by these methods was used in the construction of a thematic map of the foothill territory with a relatively homogeneous relief pattern. It should be noted that the change in the morphometric index happens simultaneously with the change in orographic features. Therefore, for areas with different forms of relief, the combination or use of only one of the above methods allows identifying the optimal and most accurate one among them. The use of well-established methods will facilitate the study of foothill plains or mountainous areas and will allow expanding the scope of the use of thematic maps for applied purposes and forecasting.

Key words: generalization, GIS, mapping, morphometry, surface, relief

1 Introduction

A full-fledged morphological characterisation of a territory is necessarily accompanied by its precise morphometric indicators. The main task of the morphometric characteristics of the relief is to establish objective criteria for determining different types and subtypes of the relief and proposals for their use in geomorphological descriptions, creating geomorphological maps for various economic needs. There is a legally defined list of state programs, resolutions and regulatory documents during the implementation of which morphometric indicators are required; in particular, the third stage of the Ukrainian State Program for the Prevention and Combating of Land Flooding is currently underway (Government portal, 2004). Methodological recommendations for maintaining the state water cadastre under the section "Surface waters" (State Service of Ukraine for Emergency Situations, 2015) provide for quantitative assessment of morphometric characteristics and features of river basins. The critical level of provision of Ukrainian territory with up-to-date large-scale topographic maps has been repeatedly highlighted in scientific and technical publications. Today, their information content can be characterized as "outdated" and as one that does not correspond to the current state of the area and modern needs (Sossa, 2021). It can be applied to topographic, thematic and special mapping.

2 Aim of the study

The purpose of the study is to experimentally identify the change in the index of erosive dissection depending on the scale of the initial data, the size of the cell, the method of constructing the thematic map, etc.

3 Previous research on the subject

Bringing the basic cartographic materials into compliance with modern needs is a primary task in Ukrainian cartography. Thus, the resolution of the Cabinet of Ministers of Ukraine "On approval of the procedure for using the funds provided in the state budget for carrying out a land inventory and updating the cartographic basis of the State Land Cadastre" contains measures to create and update topographic plans at a scale of 1:10 000, as well as digital relief modelling (Cabinet of Ministers of Ukraine, 2023). Awareness of the priority of the movement of topographic, geodetic and cartographic activities to the formation of the national infrastructure of geospatial data led to the recent adoption by the Verkhovna Rada of the Law of Ukraine "On the National Infrastructure of Geospatial Data" (Verkhovna Rada of Ukraine, 2020). According to the provisions of the Law, the digital model of the terrain belongs to basic geospatial data, and any morphometric elements created independently or based on its analysis belong to thematic geospatial data.

During 2018-2021, the State Service of Ukraine for Geodesy, Cartography and Cadastre, as part of the implementation of a joint project with the Cartographic Service of the Kingdom of Norway "Maps to promote proper land management in Ukraine", created a digital topographic map on a scale of 1:50 000 and a topographic database on the territory of Ukraine, presented on January 27, 2022. (Government portal, 2022). The movement towards integration into the geo-information space of the European Union (INSPIRE program) continues, and international cooperation on international and global information infrastructures is expanding (Bespalko and Yarova, 2016). With the assistance of the UN, projects of Global Mapping and the Creation of Global Spatial Data Infrastructure (GSDI) are being implemented.

The lack of up-to-date topographic surveying materials determines the search for alternative sources of height data, in particular, materials from the space mission SRTM (Shuttle Radar Topography Mission) and ASTER GDEM (Hutsul and Smirnov, 2017). An attempt to build a map of the distribution of the index of the intensity of erosion dissection and to determine potentially dangerous erosion areas by analysing digital relief models built from SRTM data is considered in Lyalko et al. (2017). In addition, in the work Lyalko et al. (2018), the authors proposed a method for determining erosion-dangerous areas using Landsat 5/TM space images and introduced the concept of the intensity index of erosion fragmentation of the terrain. In the study Boiko and Koshliakov (2015) it is recommended to create digital relief models with a resolution of up to 30 m, as an informational and cartographic basis for regional landslide hazard forecasts and the creation of a series of terrain classification maps.

The best-known recommendations for maps of erosion dissection are found in the work of Spiridonov (1952), who recommends dividing the map, regardless of the scale, into squares with an area of 4 cm^2, which corresponds to a scale of 1:100 000 – 4 km^2, a scale of 1:1 000 000 – 400 km^2, changing these dimensions depending on specific geomorphological conditions and the required accuracy. Chernin (1966) proposed a small sample method for compiling small-scale morphometric maps. The essence of the method is to distinguish the territories similar in relief on geomorphological maps and to determine for them the mathematical (morphometric) characteristics of the relief. At the same time, the selected geomorphological regions are divided into squares (according to the topographic basis) and morphometric indicators are calculated. Narozhnyaya and Buryak (2016) found that during the morphometric analysis of digital relief models of various degrees of generalization (comparison between scales of 1:25 000 and 1:200 000) of a certain territory, the difference in the values of morphometric indicators can reach 13%. The morphometric indicators determined on the 1:200 000 scale map are diminished compared to the 1:25 000 scale map and do not reflect the specificity of the density of the erosional dissection of the territory. The generalization process involves generalizing spatial data based on more detailed topographic map scales. A scale of 1:200 000 is more detailed, so it can be used to generate 1:500 000 (Sorokina et al., 2017). Kuznetsova (2008) states that the use of morphometric analysis to determine erosion-dangerous areas is possible using topographic maps of various scales. However, one of the necessary conditions for conducting such works is the assessment of the degree of generalization, which affects the use of various morphometric indicators.

Nikolov (2009) calculated indicators of horizontal, vertical and complete dismemberment of the territory. Thematic maps constructed using the method of isolines were used to depict the erosive dismemberment of the relief.

A comprehensive approach to determine the risk of water erosion was used in Wawer and Nowocień (2007), where the information base was topographic maps 1:25 000, SRTM 90m DEM data, CORINE Land Cover data and a soil map 1:300 000. The data analysis carried out was based on the Józefaciuk method (Józefaciuk and Józefaciuk, 1996), which distinguishes five degrees of erosion intensity based on the operation of overlaying layers of spatial data: soil type, slope, average annual precipitation and land use type.

One of the methods of compiling such thematic maps has been known for a long time and consists in determining the erosion network per unit area $\frac{L}{P}$, where L – is the length of the erosion network in the area P. It is also widely used to determine the density of the hydrographic network (Spiridonov, 1952). In the traditional sense, on a topographic map with a detailed image of the erosion network, the study area is divided into squares of the same area by a system of mutually perpendicular lines. Subsequently, within each of the squares, the total length of the elements of the erosion network is measured. The obtained indicators are divided by the square area. Thus, an index of dissection intensity is calculated for each of them, i.e., a unit of erosion network length per 1 km^2. The larger it is, the more intense the dissection.

The detail of the map will depend on the size of the squares. Within large areas, there may be noticeable differences in the intensity of horizontal dissection, which will disappear according to the average values. The smaller the squares, the more detailed the relief elements are.

The construction of a series of consecutive images, geometrically shifted relative to each other by a certain side dimension of the square, allows to increase the resolution of one image by sub-pixel processing of another. Such processing is based on the acquisition of several consecutive images and their common processing in order to restore a single resulting image of higher resolution by the transition from the individual pixel grid of each individual image to a common subpixel grid combining all of them.

The map as a model of reality, which is considered from the standpoint of the theory of knowledge as a spatial mathematically defined and generalized figurative-symbolic model, has distinct properties. One of them, abstractness, is achieved by the generalization of the map, the transition from individual concepts by selecting the typical characteristics of objects and eliminating small and secondary details. And if there are some developed criteria for selecting features for topographic maps, which are regulated by normative documents (Head Department of Geodesy, Cartography and Cadastre of Ukraine, 1999), then thematic mapping relies more on the author's vision and certain recommendations.

On the one hand, to detail the content of such a map, you cannot excessively fraction the geometric grid, and on the other hand, if the squares are small, then they completely fall on the elements of watersheds and will intersect with the thalwegs of erosional forms.

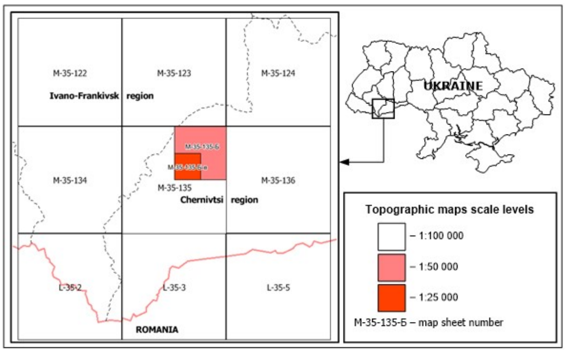

Figure 1. The scheme of the investigated territory within the nomenclature sheets of topographic maps of different scales

4 Methodology

Topographic maps of the scale 1:25 000 (M-35-135-B-v), 1:50 000 (M-35-135-B) and 1:100 000 (M-35-135) served as cartographic support for the study. The territory of the study was limited to the trapezoid of the nomenclature M-35-135-B-v (Figure 1), which made it possible to reveal the influence of the relief generalization factor on the thematic mapping of erosion dissection. There is virtually no economic activity (for example, open-pit mining) that could cause relief change in the designated area. To update the data, high-resolution remote sensing data was downloaded from open sources and deciphered in the laboratory based on direct signs of anthropogenic alteration of the specified territory.

Specific natural conditions of the territory of this study, namely the foothill areas of the Chernivtsi oblast (Bukovynian Subcarpathians), location at the contact of mountain and foothill landscapes, the lithological composition of rocks (predominance of clays and loams), different hypsometry of local bases of erosion, which determines the different intensity of erosion processes, as well as neotectonic processes, are an interesting object of research from both scientific and practical perspectives.

One of the specific phenomena on the territory of the Bukovynian foothills is stream capture. As a result, the so-called "dead valleys" or "abandoned valleys", "filled valleys", and "beheaded rivers" arise. A striking example of stream capture in the Bukovynian Subcarpathians is the Bahnenska Valley. Territorially, it covers the eastern part of Chernivtsi raion and the north-western part of Vyzhnytsia raion of Chernivtsi oblast. It stretches to the east of the town of Vyzhnytsia for 20 km, is 5-6 km wide, and its area varies between 160-170 km^2. The boundaries of its "dead valley" are clearly defined by natural boundaries. The western boundary is a precipice in the form of a high – 40-meter, steep, almost vertical slope to the valley of the Cheremosh River (near the town of Vyzhnytsia). The southern and southwestern borders of the valley are formed by the Bukovyna Carpathians, with absolute heights of 700-800 m, and the Siret-Mihydryn watershed. The northern border is defined by the watershed between the basins of the Prut and Siret rivers with absolute heights of 400-500 m.

At all stages of work with spatial data, the geographic information system MapInfo version 15.0 was used.

Any work with cartographic images with the GIS tools requires georeferencing. The Gauss-Kruger (Pulkovo 1942) coordinate system indicated on the topographic map should be chosen, and the elements of the kilometre (Cartesian) system of coordinates should be used. Since the raw data of raster images of topographic maps are devoid of visual deformations (absence of bends, stretches, folds), we use the method of affine transformations during image registration. Four equidistant points are enough for this method, and for these points, it is optimal to choose the extreme points of the border of the grid.

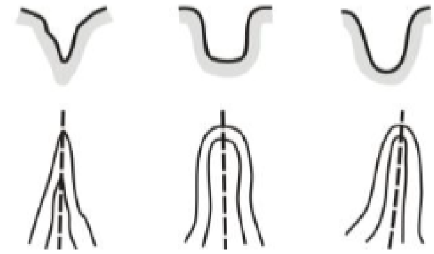

Figure 2. Shapes of the bottom a) and images of thalwegs b) on topographic plans

To create a grid of squares, we use the Grid Maker utility software, which is included in the MapInfo GIS Program Catalog by default. We highlight the territory around the working area of the map sheet, capturing approximately the elements of its frame design. The coordinates of the extreme values of the borders of the frame (north, south, east and west) will be determined and will appear in the dialogue box of the software automatically. Depending on the desired size of square elements (grid step), they should be rounded. Rounding is due to the need for accurate placement of the squares relative to the set multiplicity step. Some of the calculated squares may cover part of the territory outside the frame; to avoid disproportions in further calculations, we select the area of the nomenclature sheet and cut off all of the elements outside the trapezoid of the map. Thus, some of the figures take the form of quadrilaterals.

The calculation of the area of polygons is conducted using the Area function (Object, "sq km").

We build a network of thalwegs by creating a separate vector layer and semi-automatic vectorization of elements using a polyline. We vectorize thalwegs or watershed lines along the bottom of the washouts, ravines, streams or other relief depressions. On the map, the thalweg is represented by a straight or curved line that passes along the tops of the bends of the horizontals, connecting them. The direction of the flow lines is determined by the adjacent landforms, in particular elevations. To correctly depict the thalweg, it is necessary to identify the outer bend of the horizon relative to the positive form of the relief in the downward direction (rivers, streams, springs, ravines) and draw a line (Figure 2). The line of the thalweg must logically end, namely, be extended to the source of a river, stream, spring or cliff, or pass into a marked ravine, stream, etc.

Elements of vectorized thalwegs are cut along a grid of squares. In the layer table for the values of the length of the thalwegs, it is necessary to provide real (INTEGER) data type or short type, since rounding the lengths of the lines to integers will cause a significant error. The value of the length of the thalwegs is returned using the ObjectLen function (Object, "km").

To read the length values from the table of the layer with vectorized elements of thalwegs into the table with constructed quadrilaterals (mostly square-shaped), we will use the possibility of updating the column and the "Inserted in" command.

To calculate the coefficient of erosion dissection, we use the Equation (1):

$$k_{ep} = \frac{L}{P} \tag{1}$$

To calculate the geostatistics of the values given, we use the Column Statistics function.

Producing a thematic map in the MapInfo GIS environment involved three steps:

- selecting the way to display the thematic map (according to the given templates);
- selection of a data table and data field/fields for building a thematic map;

- selection of the method of distribution of data ranges and editorial settings of styles of thematic objects and map legend.

The collation maps method is the most appropriate for thematic mapping of erosion dissection. It allows the depiction of certain quantitative phenomena of the average intensity within the boundaries of the objects (squares) depicted on the map with the help of graphic means of area display (for example, background colouring and hatching). At the same time, the intensity of graphic markings will correspond to the intensity of erosion dissection.

The data table will be presented as a layer with a grid of squares, into which the values of the lengths of the thalwegs per unit area have been previously read.

The choice of the data distribution method ranges was based on the options available in the MapInfo – equal distribution of values; natural distribution of values; variance, and quantiles. In all cases, 5 ranges of values were selected, which were automatically rounded to 0.01.

The scale of the density of erosion dissection of the territory is different and is marked depending on the scale and detail of the map having an average interval of 0.05 – 0.1 km per 1 km^2. Map symbols can be depicted using a colour scale, a quantitative background method, or hatching. However, in any case, it is necessary to adhere to a single rule — the greater the rate of erosion dissection of the territory, the darker the colour or the more intense the colouring or hatching of the squares.

A variant of point assessment and ranges of the density scale of erosion dissection is proposed (Bezdukhov and Filonenko, 2017) in the methodology of ecological and geomorphological assessment of the territory.

If the colour scale is used, it should range from light yellow to its darker shades, moving, if necessary, to brown, red, and orange colours. The hatching should differ in the frequency of location and thickness of the lines drawn in the square, which can be replaced by a filled cell. Each square of the map is coloured or shaded following the accepted map symbology and based on the length of the erosion grid per 1 km^2. Thus, the areas with different intensities of erosion dissection of the territory will be drawn mutually perpendicular to straight lines.

As a result, we get not a map, but a cartogram of the erosional dissection of the territory. For a more geographical appearance of the image, the boundaries between areas with different intensities of erosion dissection of the territory can be slightly bent in different directions, depending on the features of the topographic base and visualization of the image. This method of determining the intensity of erosion dissection of the territory can be used for maps with a scale of 1:200 000 and more. At a smaller scale, the generalization of the relief, which does not reflect certain erosional forms, should be considered (Spiridonov, 1952).

5 Results

The first question that arises during the analysis of spatial data is what is the distribution of objects in space? In our case this is in the form of a regular network of squares. Their simple cartographic visualization cannot give a precise answer using only visual analysis. The perception of the image by different researchers may be different therefore the conclusions will be different.

5.1 Spatial statistics of results

Each vector layer of the surface of a regular network of squares of different sizes with data from different scales of topographic maps was compared for the value of the average density of erosion dissection density, variance and standard deviation (Table 1). Variance is given as:

$$\sigma^2 = \frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{N} \tag{2}$$

where x – each value in the data set; $\bar{x}$ – mean of all values in the data set; N – number of values in the data set. The standard deviation is described as:

$$\sigma = +\sqrt{\sigma^2} \tag{3}$$

where σ^2 – variance.

There is a high level of correlation $r < 0.9$ and a linear relationship between the change in the scale of the original data and the index of the average density of the density of erosion dissection. Such changes are due to the generalization of relief elements or, conversely, their excessive detailing, depending on the value of the map scale denominator.

Larger variance values indicate larger deviations of random variable values from the centre of the distribution.

One of the most common indicators of the dispersion of the values of a random variable relative to its mathematical expectation, i.e. the centre of the distribution, is the root mean square deviation. Practically this is the value of the square root of the dispersion of the random sample value, which in turn is the random value for the squared deviations from the mean sample.

5.2 Thematic mapping of erosion dissection based on equal distribution of values

The main point of the equal distribution of values is that each range has an approximately equal difference between the upper and lower values (Figure 3). The equal distribution of values practically does not highlight the elements of erosional dissection of the relief, and with the increase in scale and the increase in the size of the cell, the characteristic features of the mapped phenomenon are lost.

5.3 Thematic mapping of erosion dissection based on the natural distribution of groups

Natural distribution ranges are created based on the assumption that the values distribute into several distinct groups. At the same time, errors are reduced, and the quality of data presentation is improved (Figure 4). The results of the method demonstrate the clarity of the image of erosion network elements at a cell size of 250 m at all scales. However, as the cell size increases to 1000 m, the situation becomes practically unreadable.

5.4 Thematic mapping of erosion dissection using the quantile method

Quantiles determine the distribution of data by segments specified by another variable (Figure 5). We should note that when dividing by quantile, objects with close values can be distributed into different classes, specifically if the values are densely situated. It can lead to their causeless distribution, and conversely, several distant adjacent values can appear in the same class, hiding the differences between objects.

Classification using the quantiles method can also change the real patterns of the distribution if the regions have a significant difference in size.

In general, the clarity can be followed uniformly with the increase of the scaling exponent and the increase of the cell size.

Table 1. Statistical parameters of different thematic maps of erosion dissection

The width of the square on the grid [m]	Scale source data	The number of grid cells, units	The average density of erosion dissection, [km/km^2]	Variance σ^2	Standard deviation σ
250	1:25 000	1454	5.25	26.06	5.10
	1:50 000		2.93	9.60	3.09
	1:100 000		1.52	3.26	1.80
500	1:25 000	380	5.23	13.43	3.66
	1:50 000		2.94	4.73	2.17
	1:100 000		1.97	2.43	1.56
1000	1:25 000	110	5.05	6.77	2.60
	1:50 000		2.88	2.87	1.69
	1:100 000		1.87	1.29	1.13
2000	1:25 000	36	5.16	3.99	2.00
	1:50 000		2.85	1.67	1.29
	1:100 000		1.77	0.82	0.90

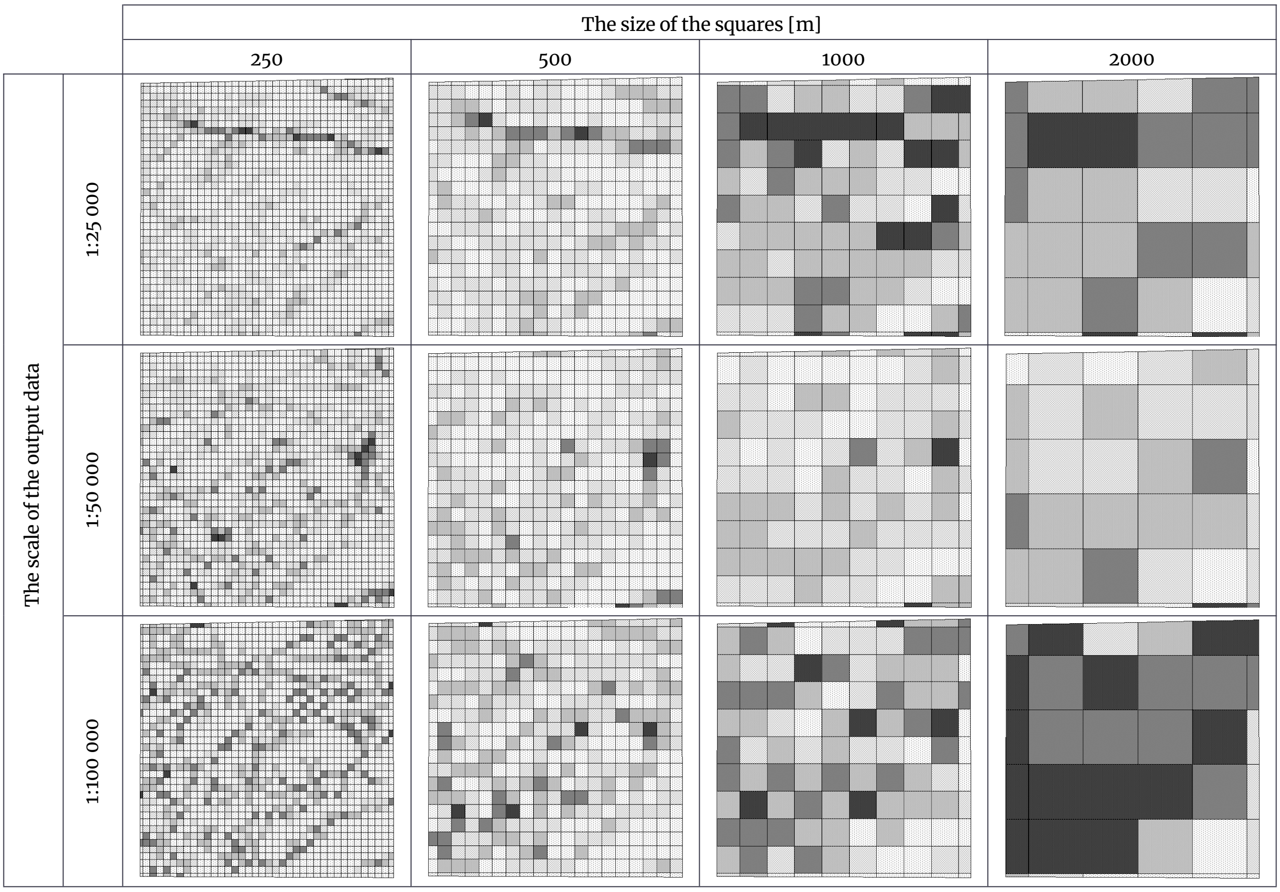

Figure 3. The density of erosion dissection (built on the basis of equal distribution of values)

5.5 Thematic mapping of erosion dissection based on dispersion

In this case, every class is defined by the deviation from the sample mean. GIS first finds the average value in the sample by dividing the sum of all values by the total number of objects. The root-mean-square deviation is then calculated by subtracting the mean from each value and squaring the resulting difference (to ensure a positive value). The obtained values are summed up and divided by the number of objects. In the end, the root is calculated from the obtained result (Figure 6).

This approach makes it possible to visualise the direction of deviation of the object parameter from the average value in a larger or smaller direction, as well as to pay attention to data that has a minor deviation from the average (log-normal or normal distribution). At the same time, we should note that the map obtained as a result of classification by root-mean-square deviation will never reveal the real characteristics of objects. Its purpose is to detect only deviations from the average.

6 Discussions

Applying any one accepted method of entering data ranges manually is not possible. First, any area will have a different terrain. Secondly, the factor of generalization at different scales (the regulatory document "Basic provisions for creating and updating topographic maps...") does not contain clear criteria for the selection of features when depicting the relief at different scales, and therefore much is left to the subjective opinion of the author's original of the map of a certain scale. Thirdly, on any of the distribution of values, there are extrema (their number can be traced by the dispersion index) which are represented by some random values that differ or are as far away from the average as possible.

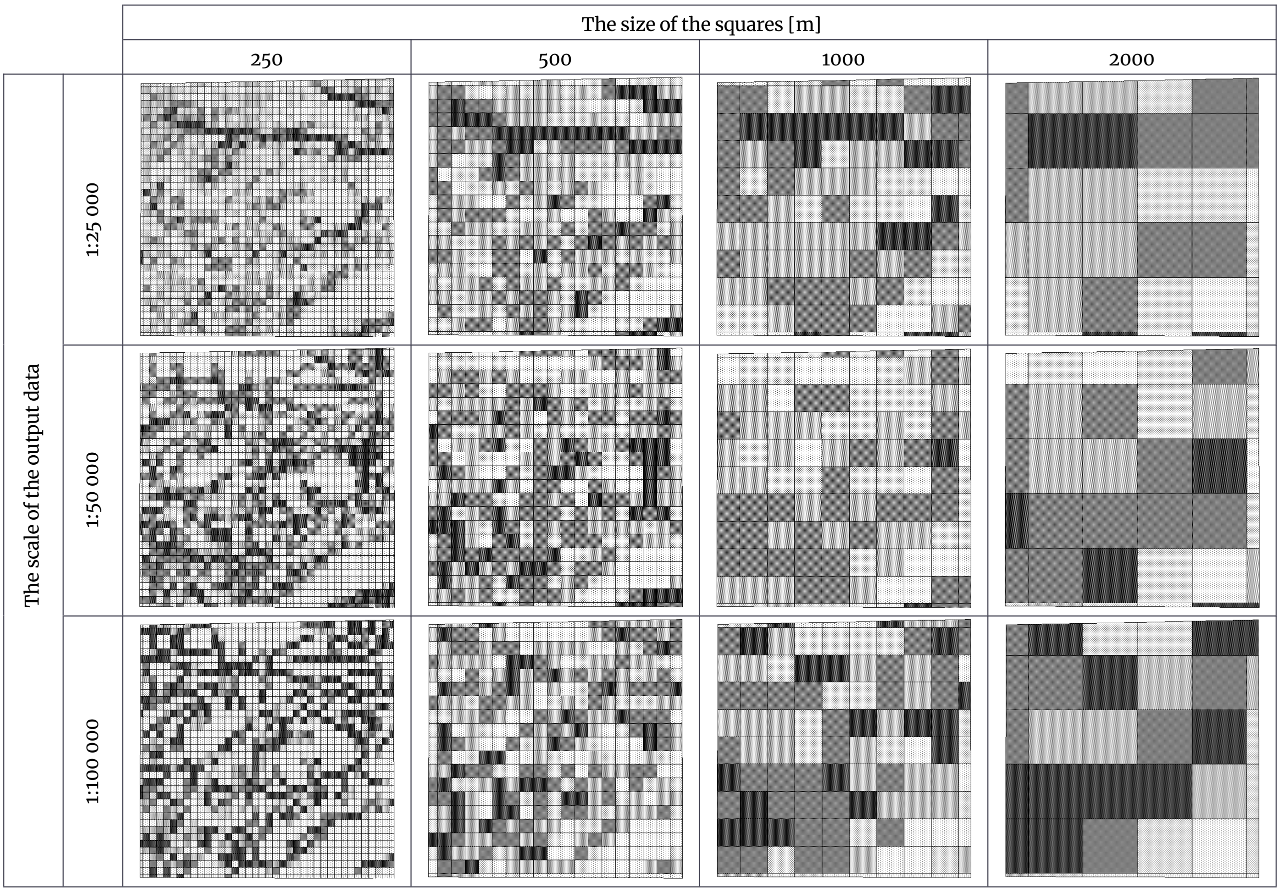

Figure 4. The density of erosion dissection (built based on the natural distribution of groups)

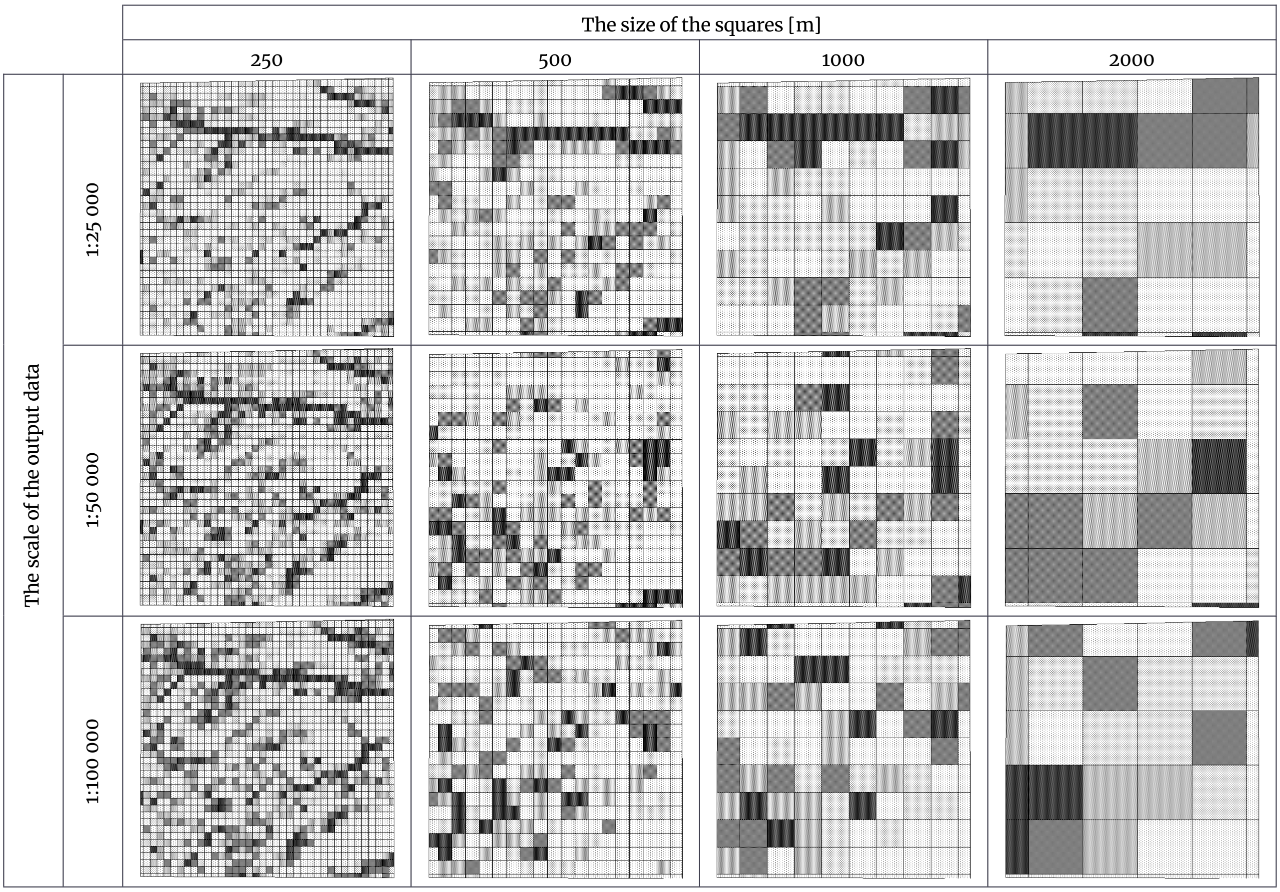

Figure 5. The density of erosion dissection (created using the quantile method)

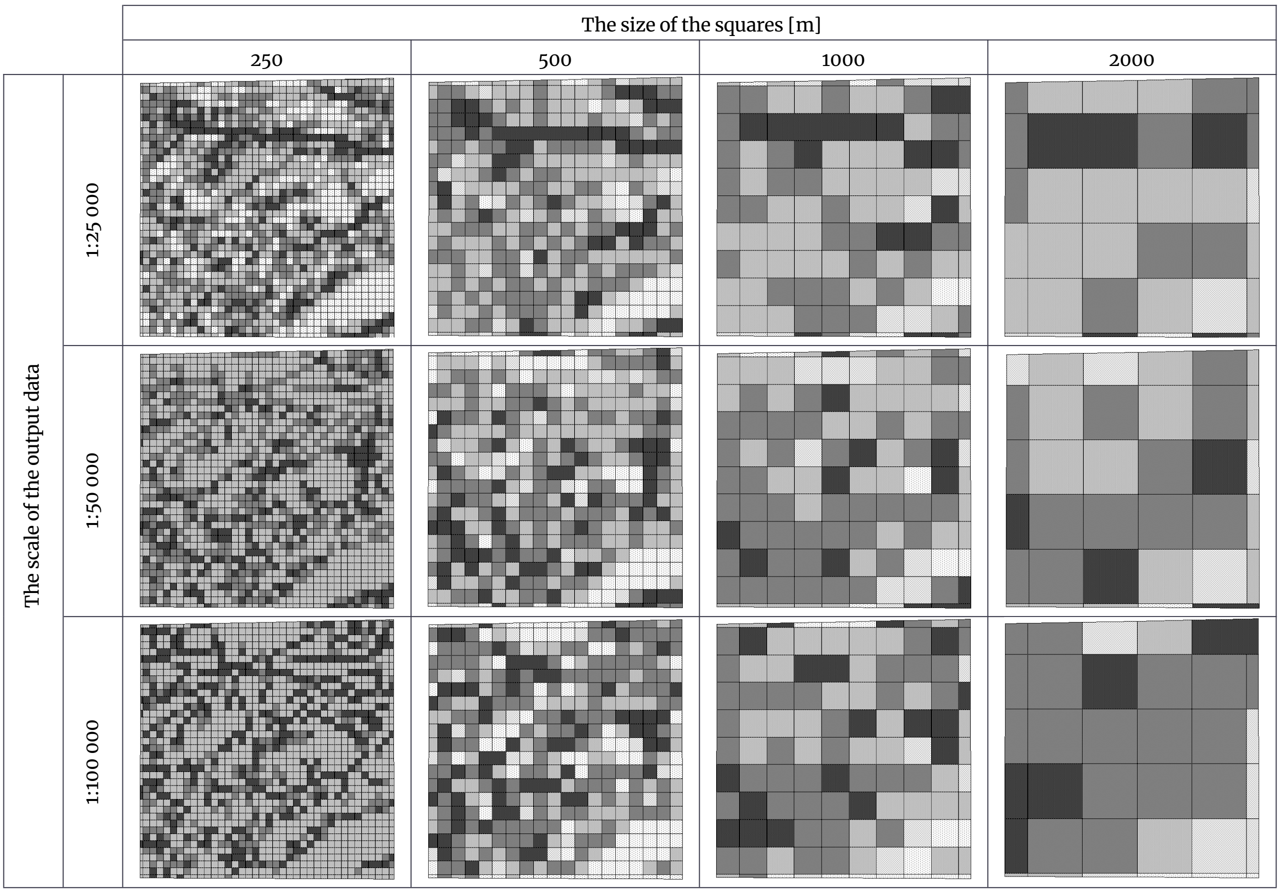

Figure 6. The density of erosion dissection (built based on dispersion)

7 Conclusions

Determining the effect of generalization on maps of erosional dissection of the territory of different scales was carried out using the methods of quantiles, dispersion, the natural distribution of groups and equal distribution of values. These methods made it possible to identify some features of relief depiction. The orographic heterogeneity of the area of our study determines the presence of clearly visible differences in geological and geomorphological processes over a small scale. Such features influenced the development of mesoforms within the specified territories and, accordingly, erosion dissection.

With the help of the selected methods, it was possible to establish that among topographic maps, for most economic needs (construction of hydraulic structures, transport and housing construction, agriculture), it is best to use maps of a scale of 1:25 000 with cell sizes of 250×250 m. It should be noted that the frequency of displaying the main features of the relief remains when using any of the specified methods. As the cell sizes on the 1:25 000 scale maps increase, the information remains readable (or is stored). Also, cartograms constructed using the quantile method at scales of 1:50 000 and 1:100 000 convey a detailed picture of erosive landforms. In all other cases with the decrease of map scale, small erosive landforms are generalized, and depiction accuracy is lost. Accordingly, such a cartographic basis is not suitable for conducting detailed applied research.

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