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STUDY OF MORPHOMETRIC RELIEF INDICATORS FOR THE PROBLEMS OF ENGINEERING PREPARATION OF TERRITORIES

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Abstract

The article provides a review analysis of existing methods for determining the degree of complexity of the relief, which refers to morphometric characteristics. The determination of the coefficient of complexity of the earth's surface relief is one of the important indicators in the practice of engineering design in making decisions on the acceptability of a project. It is proposed to determine the relief complexity factor based on a rectangular network of initial data (DEM). The finite difference method determines the quantitative value of the complexity of the surface of a local area based on a 3×3 matrix. By moving the local window of the 3×3 matrix along the rows and columns of global regular network of initial data, visualization of complex relief sections in the form of a cartogram is provided.

Keywords: morphometric characteristics, relief, coefficient of complexity, local window, quartal of surface.

INTRODUCTION

In the practice of engineering preparation of territories for the construction or arrangement of industrial and civil structures, tracing of main lines of communication (auto and railway transport, power lines), a geoinformation model of the relief is required, which contributes to the choice of optimal design solutions. At the same time, various aspects of the engineering project can be the optimality condition. For example, the smallest amount of excavation of a construction site, the smallest average slope of the terrain for surface irrigation of agricultural land, the choice of the shortest trajectory with the least excavation costs in tracing main communications, etc.

Obtaining morphometric characteristics of the relief is of great practical importance. Without knowledge of these characteristics, the construction of buildings and the construction of structures, the laying of railway and highway routes, the implementation of various reclamation measures, etc., are inconceivable. Quantitative study of the relief [1; p-3, 2; p-26], it is important not only in geomorphology, but also in all related sciences, such as: topography, geodesy, engineering geology, construction, agriculture, military science, where relief is studied as a property of the earth's surface.

The morphometric characteristics of the relief include a quantitative study of the degree of complexity of the formation of the relief of the earth's surface. The initial data are points of the earth's surface, which are nodes of a rectangular network (Fig. 1) that form a global matrix of heights:

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$$(Z_{ij}) \equiv \begin{pmatrix} Z_{11} & Z_{12} & & \cdots & Z_{1n-1} & Z_{1n} \\ Z_{21} & Z_{22} & & \cdots & Z_{2n-1} & Z_{2n} \\ \cdots & \cdots & \cdots & & \cdots & \cdots \\ Z_{m-11} & Z_{m-12} & \cdots & & Z_{m-1n-1} & Z_{m-1n} \\ Z_{m1} & Z_{m2} & \cdots & & Z_{mn-1} & Z_{mn} \end{pmatrix}; \qquad \Delta X = \Delta Y = l. \qquad (1)$$

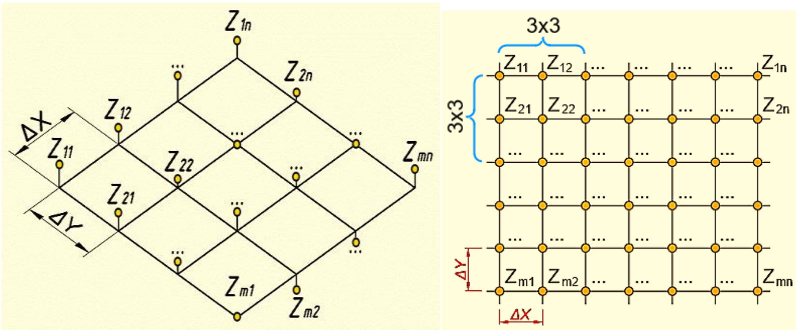

Figure 1: Rectangular Grid of Elevation Initial Data

The main morphometric characteristic of the relief is the degree (coefficient) of dissection or the complexity of the relief formation [3, 4]. Quantitative determination of the degree of relief complexity has different approaches in scientific circles. In the early works of Heifets B.S. and Khromchenko A.V. [5] had an approach to determining the degree of complexity of the relief by methods of probability theory and mathematical statistics based on data extracted from the topographic plan of the area. The work was based on the density ratio of isolines, the hydrographic network in km2, and took into account the signs of watershed lines, thalwegs, etc.

In his works I.V. Florinsky [6] proposes a computational method for calculating the local morphometric characteristics of a relief on a square grid. The method he developed is that the 3rd order polynomial approaches a 5×5 window using the least squares method. The local characteristics of the relief are functions of partial derivatives with five parameters - r, t, s, p, q. By moving a 5×5 sliding window along the rows and columns of the matrix, one can determine the morphometric indicators except for the two extreme rows and columns (see Fig. 1).

The most interesting approach is proposed by Huaxing Lu [7]. He introduced the term roughness coefficient - the ratio of surface area to flat area. He proposes a method for comparing the area of a surface compartment with the plane of a local window with a dimension of 3×3. That is, for each of the cells surrounding the central cell, triangular regions are created. The ratio of the total area of the 8 triangles to the total area of the 4 cells that were covered by the triangles in the local 3×3 moving window determines some factor of dissection or complexity. In the proposed Huaxing Lu method, it is required to determine the areas of triangles, which are an approximation of the surface in a 2×2 cell (Fig. 2). The sum of the areas of two triangles - S_1, S_2 is compared with the area of a rectangular compartment - S_3. Four

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adjacent 2x2 cells form a 3x3 local window.

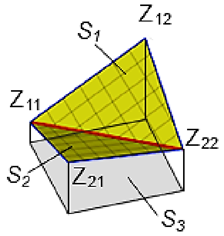

Figure 2: Rectangular Compartment (Quadrant)

At present, the study of the morphometric characteristics of the relief is mainly of a global nature. The morphometric characteristics of the relief of an applied nature for use in the field of engineering preparation of territories have been little studied and require a special approach. The task of determining the degree of complexity of the relief is important from the point of view of a quantitative comparison of relief sections, and it also contributes to making informed decisions and implementing various kinds of applied engineering problems. The complexity of shaping is an important characteristic of the relief in the digital analysis of the terrain, however, unlike the aspect, slope or curvature, the complexity of the relief is an ambiguous characteristic of the terrain, which has not yet had an optimal indicator for its quantitative assessment [7; p-159]. Traditional definitions of terrain complexity can be divided into statistical, geometric and semantic indicators.

The degree of dissection of the relief mainly has a semantic description as - a valley, a plateau, a mountainous region, a foothill region, high mountains, etc.

In the works of D.F. Kuchkarova defines the degree of complexity of the geometric model of a topographic surface. According to her definition, “the total absolute internal and external curvatures of the vertices determine the degree of complexity of the model” [8; p-69]. Also, “vertices with positive or negative curvature are called essential, vertices with zero curvature are called inessential” [8; p-27]. Consequently, “the simplest surface - a plane, regardless of the number of considered vertices, has a degree of complexity equal to zero [8; p-69].

In scientific publications there is no single definition or mathematical description of the degree of complexity, the degree of dissection or the complexity of the relief. Obviously, the degree of relief complexity depends on the quantitative and qualitative parameters of the initial data network. The same section of the relief with a different step of a rectangular network has different coefficients of complexity [9].

The complexity of the relief is the degree of its convexity or concavity. Since the total curvature will also generate a negative value, it needs to be changed to become a constant positive index [7; p-165], that is, the absolute values of the curvature of the structural lines of the surface are summed up.

If the surface is considered as “a set of successive positions of a line moving in space according to a certain law” [10], then the transverse and longitudinal sections of the relief, being flat curves on a rectangular network of initial data, have alternating discrete coordinates along the

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X and Y axes. By establishing some relationship between the known coordinates X, Y and unknown Z, it will be possible to have an approach to determining the complexity factor.

Two points of the line will uniquely define a straight line, for which we set the degree of curvature equal to "0". Three points on a plane can be located either on a straight line or outside. Therefore, the degree of curvature - the complexity of a flat curve can be determined by the location of three points on the plane.

The minimum condition for specifying a surface is the specification of four points that do not belong to the same plane. In a particular case, they can be located on the same plane, the complexity of which will be equal to "0". Therefore, the complexity of the surface seems to be determined by specifying four points that do not belong to the same plane. But, on a rectangular network of initial data, linear interpolation of four adjacent nodes in pairs will lead to a contradiction in the definition of the curvature of a flat curve, since a flat curve cannot be given by two points. From here we come to the conclusion that to determine the degree of complexity of the surface given by the rectangular network of initial data, it is fair to consider nine neighboring nodes based on a 3×3 matrix.

Let's call a local window of nine adjacent nodes of a 3×3 rectangular network of initial data a "quartal" – Z^K, which consists of four adjacent cells, called a "quadrant" – Z^K (Fig. 3):

$$Z_{ij}^{K} \equiv \begin{pmatrix} Z_{11} & Z_{12} & Z_{13} \\ Z_{21} & Z_{22} & Z_{23} \\ Z_{31} & Z_{32} & Z_{33} \end{pmatrix}; \qquad Z_{ij}^{k} \equiv \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix}. \tag{2}$$

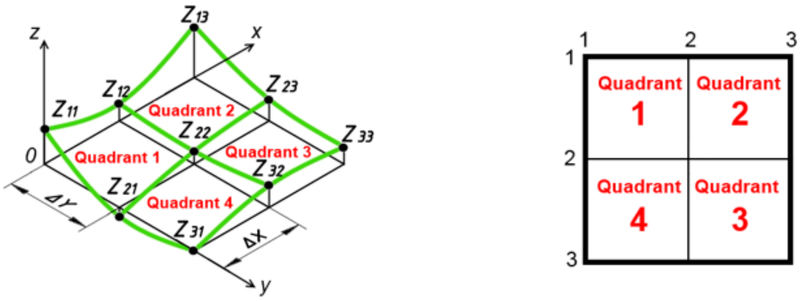

Figure 3: Terrain Surface Quartal

Let's establish some relationship between the nine members of the matrix – Z^K by the method of finite differences (2).

Differentiation of the absolute values of the sum of the difference between the elements of the matrix rows (2) will determine the complexity of the relief in the longitudinal sections:

$$m_t = \sum_{j=1}^{2} \left| \frac{Z_{t,j} - Z_{t,j+1}}{s} \right|; \qquad t = 1, 2, 3 \tag{3}$$

Differentiation of the absolute values of the sum of the difference between the elements of the matrix column (2) will determine the complexity of the relief in cross sections:

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$$n_t = \sum_{i=1}^{2} \left| \frac{Z_{i,t} - Z_{i+1,t}}{s} \right|; \qquad t = 1, 2, 3 \tag{4}$$

In equations (3-4) t is the iteration counter; s is the step of the rectangular network of the initial data in meters.

Differentiation of the absolute values of the sum of the difference between the elements of the matrix diagonal (2) helps to determine the differences between the longitudinal and transverse sections of the relief:

$$d = \frac{|Z_{11} - 2Z_{22} + Z_{33}| + |Z_{13} - Z_{22} - Z_{31}|}{\sqrt{2}\,s}. \tag{5}$$

Equations (3-5) each separately act as a definition of the complexity factor of a flat curve. Equations (3-5) are summarized and we get a certain value ξ - the coefficient of complexity of the surface of the quartal:

$$\xi = m_t + n_t + d \tag{6}$$

If, in equation (6) ξ=0, the considered surface will be a plane.

The local window of quartal (3×3) moves along the rows and columns of the global matrix (1) and determines the morphometric indicators for all network nodes except for the boundary rows and columns (Fig. 4).

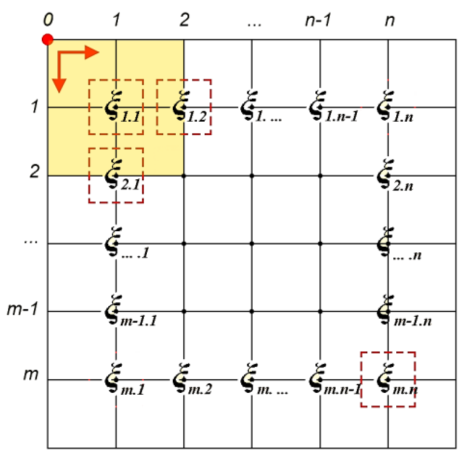

Figure 4: Scheme of moving the local window of the quarter on the surface of the relief

Determining the coefficient of relief complexity by quartals contributes to their visualization as a gradient fill by quadrants in the spectrum of RGB color palettes (R-red, G-green, B-blue). The saturation coefficients of each color are equated to each other R=G=B=k (k=0…255). The minimum coefficient of complexity is equated to white (k=255), the maximum to black (k=0). Each quadrant of the surface, except for the four corner ones, is overlapped by neighboring quartals, and for each quadrant, the average complexity coefficient of the overlapping quartals

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is selected, thus providing visualization of the complexity of the sections (Fig. 5).

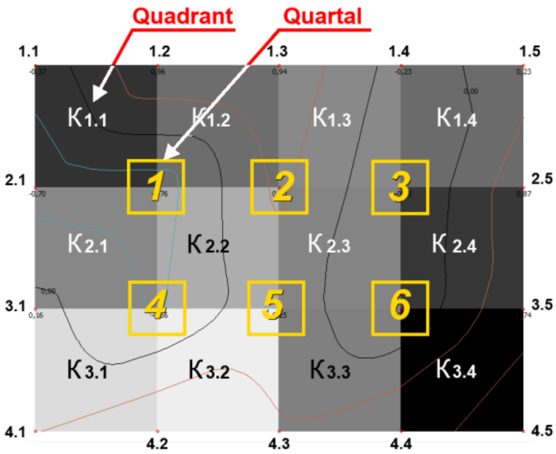

Figure 5: Relief Complexity Cartogram

A geoinformation model of the relief in the form of visualization of the coefficients of complexity of the relief based on quarters contributes to the adoption of sound decisions in the practice of engineering design. On the basis of the method of determining the coefficient of complexity of the surface quartal, the morphometric characteristics of the relief of the city of Bukhara were derived [11].

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