AUXILIARY DISCIPLINES

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GIS–BASED TERRAIN MORPHOMETRIC ANALYSIS FOR ENVIRONMENTAL MONITORING TASKS

Research article

Abstract

The article results the terrain morphometric analysis of the territory near the city of Novosibirsk, that is used to study the biodiversity of species and find the features of their spatial distribution, depending on the emerging conditions of agrocenoses and the features of the terrain. A detailed morphometric analysis of the area covered by the work sites was performed using Quantum GIS and Earth remote sensing. The terrain morphometric analysis was performed using digital modeling methods, which made it possible to characterize the study area by quantitative indicators for the purposes of environmental monitoring. The results of the analysis demonstrate that the study area is represented by flat with troughs, with low soil erosion and steepness of the slope from 0–3°. It is revealed that the study area is of the plateau and weakly sloping type, rugged with linear erosion forms. The working sites are mainly located on the prevailing 0–3° slopes. The soil covering is predominantly leached chernozem, which accounts for 87.1% of the total territory of the study area. Northern and eastern exposition slopes prevail, they account for 19.8 and 22.4% of the total area. The territory is attributed to the plain with poorly broken terrain, where the dissection by erosion forms is less than 0.2 km/km2, and the vertical terrain dissection varies from 0 to 8 m. Based on the terrain morphometric analysis, there is a high degree of similarity of the studied areas, with pronounced erosion processes caused by water runoff, flowing on the plots with spring wheat crops. As a result of the terrain analysis, ecological niches obtained informative, ecologically interpretable parameters that can be used in further studies of the spatial distribution of herpetobiont invertebrates, given their biotopic confinement and hygropreferendum.

Keywords: QGIS, terrain morphometric indicators, digital elevation model, vertical dissection, horizontal dissection, environmental monitoring.

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МОРФОМЕТРИЧЕСКИЙ АНАЛИЗ МЕСТНОСТИ НА ОСНОВЕ ГИС ДЛЯ ЗАДАЧ ЭКОЛОГИЧЕСКОГО МОНИТОРИНГА

Научная статья

Аннотация

В статье приведены результаты морфометрического анализа рельефа территории близ города Новосибирска, который используется для изучения биоразнообразия видов и выявления особенностей их пространственного распределения в зависимости от складывающихся условий агроценозов и особенностей рельефа. Детальный морфометрический анализ территории, охваченной рабочими площадками, был проведен с использованием программы Quantum GIS и дистанционного зондирования Земли. Морфометрический анализ рельефа был выполнен с использованием методов цифрового моделирования, что позволило охарактеризовать исследуемую территорию количественными показателями для целей экологического мониторинга. Результаты анализа показывают, что исследуемая территория представлена равниной с впадинами, с низкой эрозией почвы и крутизной склона от 0 до 3°. Также было выявлено, что исследуемая территория относится к плато и слабо наклонному типу, изрезанному линейными эрозионными формами. Рабочие площадки в основном расположены на преобладающих склонах 0–3°.

Почвенный покров представляет собой преимущественно выщелоченный чернозем, на долю которого приходится 87,1% от общей территории исследуемой территории. Преобладают склоны северной и восточной экспозиции, на их долю приходится 19,8 и 22,4% от общей площади. Территория относится к равнине со слабо нарушенным рельефом, где расчлененность эрозионными формами составляет менее 0,2 км/км2, а вертикальная расчлененность рельефа колеблется от 0 до 8 м. По данным морфометрического анализа рельефа, наблюдается высокая степень сходства изученных районов с выраженными эрозионными процессами, вызванными водным стоком, протекающим по участкам с посевами яровой пшеницы. В результате анализа рельефа экологические ниши получили информативные, экологически интерпретируемые параметры, которые могут быть использованы в дальнейших исследованиях пространственного распределения беспозвоночных герпетобионтов, учитывая их биотопическую ограниченность и гигропреферендум.

Ключевые слова: QGIS, морфометрические показатели местности, цифровая модель рельефа, вертикальное расчление, горизонтальное расчленение, мониторинг окружающей среды.

1. Introduction

Scientific and technological breakthroughs in the field of remote sensing of the Earth's surface and information technology, currently enable to obtain high–resolution digital images of the territory. Given this, approaches that are based on image data processing and the application of intelligent data analysis offer a tremendous potential for us to introduce geographic information systems (GIS) into the process of environmental monitoring of objects and territories [1], [2]. Digital elevation models (DEMs) are now widely used in land management [3], monitoring water level changes [4], crop yield forecasting [5], sustainable ecosystem management [6], etc. Although, there are not many works related to the study of environmental conditions and their influence on the dynamics of soil mesofauna communities and their spatial distribution [7], [8], [9], [10]. Understanding the natural processes of community formation can be obtained using a detailed characterization of the study area, which becomes possible with the use of GIS technologies. The species composition and structure of the beetle community of agro–ecosystems, which are often used as bioindicators, are determined by a characteristic (defining) set of factors at different hierarchical levels of organization. At the landscape level, these include: moisture of the area and mesorelief features. Terrain and moisture features create prerequisites for species with different biotopic preferences and contribute to the formation of species–rich communities that use the space in different ways. Mechanisms of spatial separation of species are activated at this level, facilitating a more efficient use of the territory's resources [11], [13]. One of the important factors in the distribution of imago ground beetles in habitat, in addition to their structure and way of life, is their high mobility associated with the capability of unimpeded movement across the territory. Yet, the analysis of published materials evidenced minor research on the spatial distribution of model groups of ground beetles and the consideration (search for correlations) with terrain features when studying and comparing different biotopes [12], [16], [17], [18]. Many factors, such as the degree of dissection, erosion processes, slope steepness, and altitude, are simply not considered in multifactorial studies [17], [18], [19].

A promising approach to understanding the peculiarities of the formation of species communities' structures can be the study of terrain on the basis of GIS–technologies. In particular, to obtain information about the terrain, it is advisable to use global digital models that produce slope angles and exposure of slopes, the degree of horizontal and vertical dissection [20–23].In order to identify the particularities of the spatial distribution of species on the territory of agrocenoses and search for the factors that make the greatest contribution, it becomes relevant to perform the characterization of the territory based on the morphometric analysis of the relief performed using GIS–technology and Earth remote sensing methods. The data obtained will be used in the correlation analysis (search for the factors of influence and their degree of contribution). This work is the result of research carried out at the Department of Digital Technologies in Agriculture of Siberian Federal Scientific Centre of Agro–BioTechnologies of the Russian Academy of Sciences jointly with the Department of Ecology of Federal State Budgetary Educational Institution of Higher Education Novosibirsk State Agrarian University.

2. Material and methods

Investigations on terrain morphometric analysis were made on the territories of the farm "Elitnaya" and JSC Plemzavod "Uchkhoz Tulinskoye" (54°54'05.86 "N, 82°54'54.21 "E) of Novosibirsk district, Novosibirsk region, located on the third terrace of Priobsky plateau, which has a slight slope towards the Ob. Earth remote sensing data, Landsat–8 space images with spatial resolution of 30 m in one pixel and digital elevation model (SRTM) data were used for this study. The satellite images and SRTM were taken from the U.S. Geological Survey website (https://earthexplorer.usgs.gov). Remote sensing data was used to map working land use areas, calculate vegetation indices, exposure and slope steepness, and horizontal and vertical landform partitioning. All electronic layers were created in a single 3857 WGS–84/Pseudo–Mercator coordinate system using Quantum GIS (QGIS) open access software (https://qgis.org/ru/site/). To edit the space image, an atmospheric correction was performed using the SAC module in QGIS. The slope steepness and exposure were calculated using an algorithm: "Morphometric Analysis" → "Exposure" and "Morphometric Analysis" → "Steepness". To assess the horizontal dissection of the terrain, the area was divided into squares of 1 km^2. Main indices were calculated within the obtained squares using GRASS GIS in the QGIS interface. To assess erosion processes, the morphometric analysis of the watershed provides a quantitative description of the system, which is of great importance in the evaluation of the study area. GIS technologies with embedded modules provide a powerful tool for integration, assessment and analysis of spatial information [20]. Horizontal dissection of the terrain was calculated in several stages, using the algorithm "Fillsinks" → "catchmentarea" → "channelnetwork", and calculating in each grid a square of watercourses. The vertical dissection of the terrain was calculated on the basis of the elementary watershed map, using the algorithm → "r.watershed". Using the zone statistics option, the maximums and minimums of the absolute heights were calculated, and subsequently the magnitude of their difference. Seven working areas with crops (spring wheat, corn) are considered in detail in the work. Given a certain heterogeneity of the terrain, the territory of the first working area was divided into parts: 1.1, 1.2 and 1.3 to determine its morphometric characteristics in detail. Corn crops were located in plots No. 4, 5–7 (in different years). Spring wheat crops were located in areas No. 1 (1.1, 1.2, 1.3), 2, and 3.

3. Results and discussion

Many species of terrestrial invertebrates are represented in the study area. Considering that ground beetles were the most numerous groups represented in the records (up to 83% of the species composition), this makes them very convenient for zoogeographic studies. In the agrocenoses and virgin plots we investigated, the complex of ground beetles dominated, confined to open landscapes. The formation of carabid complexes is mainly due to the participation of meadow, meadow–field and meadow–steppe species. The occurrence of forest species is associated with the location of small forest areas near the study areas, which, in turn, are the habitat of forest species. Analysis of the structure of ground beetle complexes in terms of hygrorepresentation indicated the presence of mesophiles, mesoxerophiles, and mesohygrophiles. The dynamics of ground beetle abundance had differences for the period of 2019–2021. The ecological diversity of the species composition of ground beetles, that reflects the differentiation of the formed conditions, makes it relevant to use the parameters of the studied areas to find the features of formation and spatial distribution of model species of herpetobionts (Coleoptera: Carabidae).

The terrain has a special ecological role, which affects the formation of dangerous and adverse geomorphological processes, namely: erosion processes, landslides and others. The digital elevation model (DEM) for the terrain parameters calculations was formed on the basis of SRTM data. The terrain of the territory (working areas) covered by the research is represented by a flat area with small depressions (Fig.1).

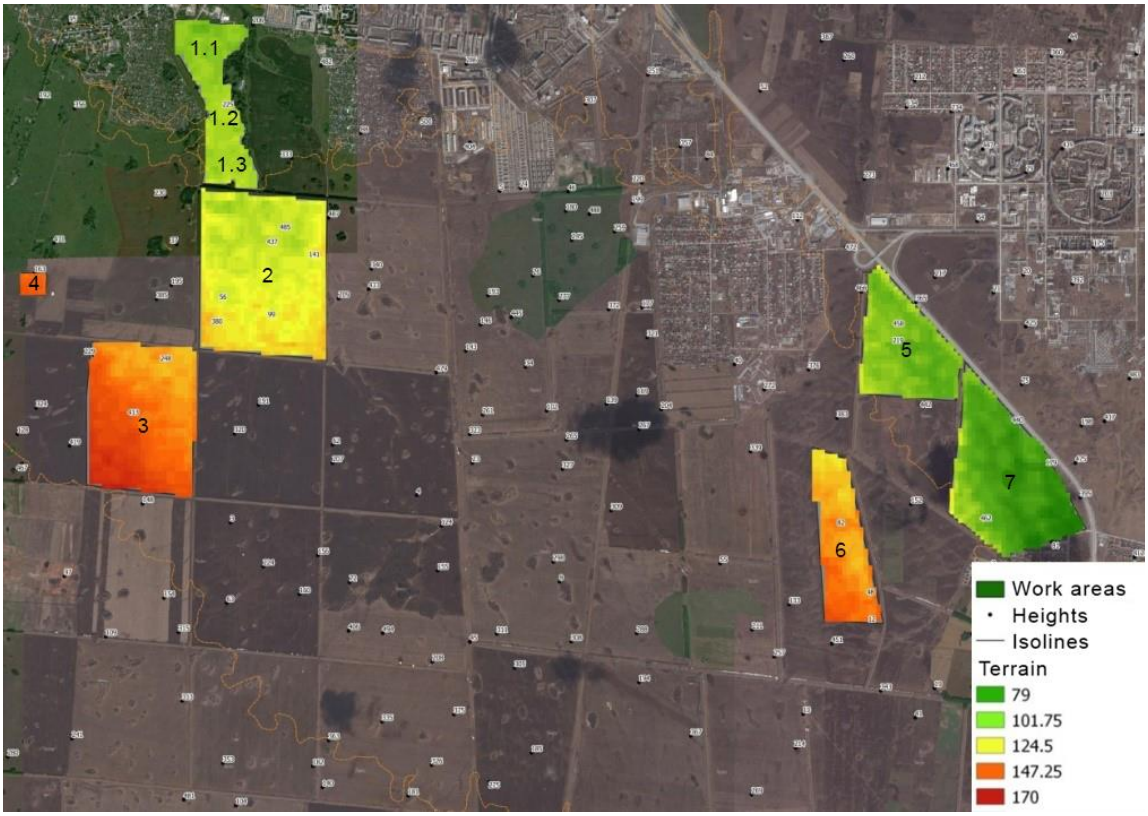

Fig. 1 – Digital elevation model

The maps of morphometric indicators: steepness and exposition of slopes (Fig. 2 A, B), as well as horizontal (Fig. 3) and vertical dissection (Fig. 4) were obtained on the base of the generated DEM. One of the leading characteristics of the terrain is the steepness of the slope and its shape, which determine the rate of surface water runoff. The slope steepness determines the heating and temperature of topsoil, thickness and rate of snow cover melting, thickness of soil profile, erosion processes, as well as species composition, structure of phytocenosis, type of vegetation. Considering that the main abiotic factors such as temperature, humidity and precipitation, light, wind, along with soil conditions, sharply influence the activity of herpetobionts, temperature also has a great influence on their activity. For instance, ground beetles are poikilothermic organisms, the influence of the environmental temperature factor in the life of ground beetles is important for their lifestyle and distribution over biotopes [24].

Fig. 2A – Geoinformation layer of distribution of values of steepness

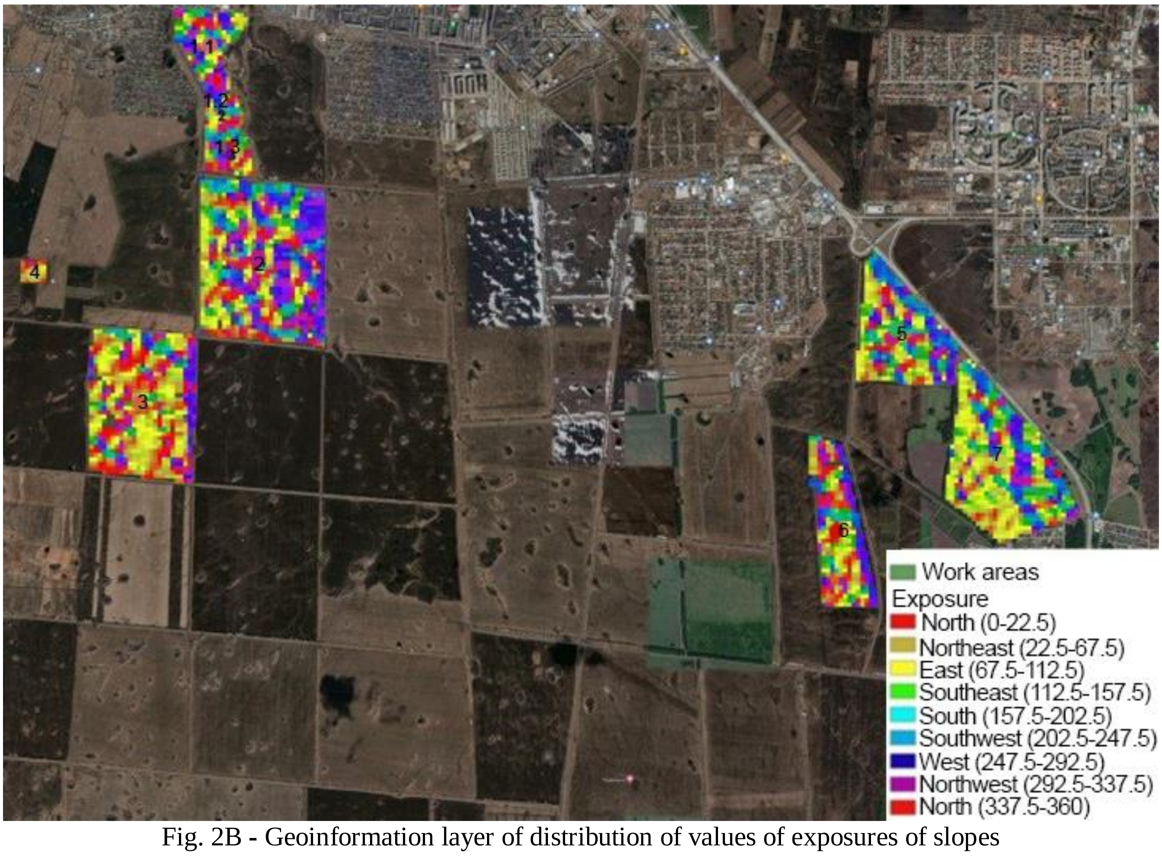

Fig. 2B - Geoinformation layer of distribution of values of exposures of slopes

The working areas of the investigated territory are mainly located on slopes (flat surfaces) from 0–1^0 which is 72.1%, but the most part of the investigated territory is occupied by slopes 0–3^0 which make up 97 % of the total area. Surfaces are very sloping in 24.2 % of the area, 3.2 % are gently sloping, and 0.5 % are slightly sloping. According to the data obtained, the steepness of the territory varies from flat surfaces to slightly sloping ones (Fig. 2A). The territory of plots No. 1.1, 1.2 and 4 is mainly represented by slope steepness from 0–2^0, the territory of plots No. 1.3, 2, 3, 5 and No. 6 is 0–3, and No. 7 is 0–4^0.

Slope exposure is the orientation of the territory relatively to the cardinal directions, which determines the degree of warming and moisture content of the soil. Therefore, for the characteristic of the investigated areas, a division into eight slopes was assumed. Thus, the general characteristic in the study area is represented by the fact that the slopes of the northern exposure account for 19.8%, the north–eastern is 13.6, the eastern is 22.4, the south–eastern is 9.5, the western is 9.2 and the north–western is 10.7%. The slopes of the southern is 7.5% and the southwestern exposition are represented by the smallest share with 7.2% of the total area. Working area No. 1.1 has 15.5% eastern slope exposure and 16.5% western slope exposure, working area No. 1.2 has equally prevailing northeastern and southern 18.7, in area No. 1.3 the northern 35.8, in area No. 2 equally prevailing northern and western 16.27, in area No. 3 prevailing northeastern (23.7) and eastern (32.8) slopes. On the analyzed area No. 4, half of the area is occupied by the northeastern exposition (50%). At area No. 5, the eastern exposure prevails at 17.3, and equally the northeastern and southwestern exposures of the slope at 15.1. At area No. 6 the northern exposure is 20.5, and northeastern 20, at area No. 7 northeastern is 18 and eastern is 29.2% of the total area of slope exposures. Based on the results obtained, it is worth noting that slopes of eastern and northeastern exposures are most common in the study area (Fig. 2B).

Erosion processes also depend on the exposure of the slope, the calculations of which are presented in Figures 3 and 4.

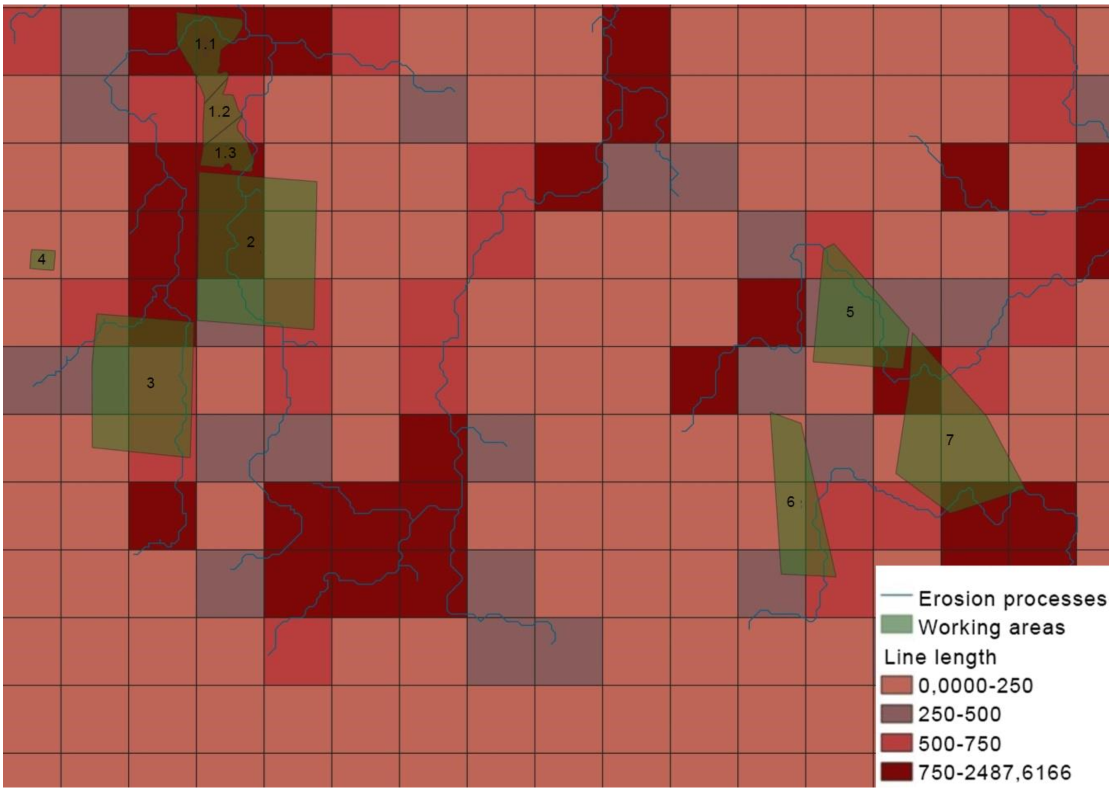

Fig. 3 – Geoinformation layer of horizontal terrain dissection

The data of horizontal terrain dissection calculations indicate that the study area is referred to a weakly dissected plain with insignificant manifestation of erosion processes (Fig. 3). The dissection by erosion forms is less than 0.2 km/km^2. The dissection by erosion forms of the terrain from the north to the northeast increases from 0.1 to 0.7 km/km^2. Weak dissection of the area is 26.5% of the total area, medium dissection is 20.6, strong dissection is 29.4, and very strong dissection is 23.5%. There is a very strong dissection of the territory of the working area No.1.1 in the northwestern and northeastern parts, which varies from 0.3 to 0.4 km/km^2; in the working area No.1. 3 very strong dissection also prevails in the southern part 0.1; on the working area No. 2 from north to south, dissection by erosion processes decreases, with very strong dissection from 0.1 to 0.7, strong at 0.1, medium at 0.4; on the working area No. 3 very strong dissection in the west and south–west varies from 0.1 to 0.2, in the north strong dissection from 0.4 to 0.6. Very strong dissection in the south at 0.2, strong dissection in the north at 0.4; and in the north, northeast and south of work area No. 5 dissection by erosion processes varies from 0.2 to 0.4. In working area No. 6, in the southeast and south, the dissection varies from 0.2 to 0.4; and No. 7 shows a very strong dissection in the north of 0.4, and in the south, it varies from 0.1 to 0.5 km/km^2.

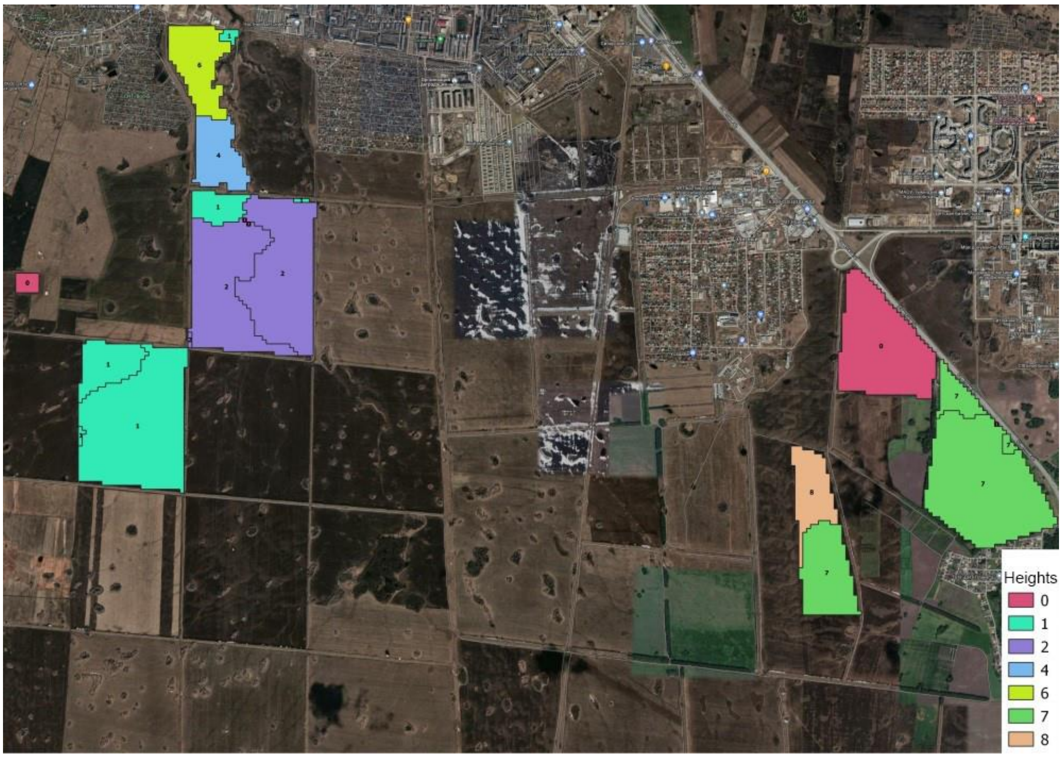

Fig. 4 – Geoinformation layer of vertical dissection of the terrain

The study area is characterized by a conditionally undivided plain according to the data of the vertical dissection of the terrain. The difference between heights varies from 0 to 8 m (Fig. 4). Height difference at the working area No. 1.1 varies from 1 to 6 m, at the working area No. 1.2 varies from 6 to 4 m, at the working area No. 1.3 it is 4 m, at the working area No. 2 the difference is from 0 to 2 m, at the working area No. 3 surface is smooth, where the difference is 1 m, at areas No. 4 and 5 surface is plain, the difference is 0 m, area No. 6 varies from 7 to 8 m and at the area No. 7 from 0 to 7 m. Proceeding from the result, the areas No. 1.1, 1.2, 1.3, 2, 6 and 7 are located on flat and weakly sloped areas, and areas No. 3 to 5 are located on the plateau. In general, the study area is characterized by a conditionally undivided plain, the share of which from the total area is 100% [23].

4. Conclusion

Within the study the terrain of the study area was assessed by morphometric indicators. As a result of the analysis, the ecological niches obtained data–intensive, environmentally interpretable parameters. It was determined that the study area has a plateau and weakly sloping type of terrain, rugged with linear erosion forms. Working sites are mainly located on the prevailing 0–3^{o} slopes. The soil covering is predominantly leached chernozem, which accounts for 87.1% of the total territory of the study area. Northern and eastern exposition slopes prevail, they account for 19.8 and 22.4% of the total area. The territory is attributed to the plain with poorly broken terrain, where the dissection by erosion forms is less than 0.2 km/km^2, and the vertical terrain dissection varies from 0 to 8 m. Based on the terrain morphometric analysis, there is a high degree of similarity of the studied areas, with pronounced erosion processes caused by water runoff, flowing on the plots with spring wheat crops. A geographic information layer of terrain was created in the context of the work, using digital modeling methods. The results of the work will be used for an in–depth study of the nature of factors influencing the spatial distribution of various herpetobiont species, including the most massively represented species of the family Carabidae.

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Conflict of Interest

None declared.

Конфликт интересов

Не указан.

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