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GEOMORPHOMETRIC ANALYSIS OF AGRICULTURAL AREAS BASED ON THE FABDEM DIGITAL ELEVATION MODEL

ABSTRACT

The application of geoinformation technologies and digital elevation models (DEMs) makes it possible to significantly automate the process of analyzing the terrain in the area under study. Modern DEMs are based on remote sensing data, and their accuracy is constantly improving. Based on new non-profit FABDEM DEM data and the SAGA GIS functionality, a geomorphometric analysis of the topography in the agricultural area of the experimental production farm (EPF) “Mikhailovskoye” was carried out at the Krasnoyarsk Science Center of the Russian Academy of Sciences. For the farm area, a series of large-scale thematic maps was constructed, including slope steepness and aspect, plan and profile curvatures, Terrain Ruggedness Index (TRI), Slope Length and Steepness Factor (LS-factor), Topographic Wetness Index (TWI), etc. A model of surface runoff was also built. The morphometric analysis of the area of EPF “Mikhailovskoye” shows that, despite its small size, the surface structure is heterogeneous. The analysis shows that 85 % of the farm area is flat land, while the remaining 15 % is located on more elevated local landforms. The steepness of most slopes is up to 3°, accounting for 92 % of the total area, with only 8 % of the land being steeper than 3°. The fields of the farm are dominated by western and eastern slopes, which account for 42 % of the total area, while 36 % of the area is represented by southern slopes, with 2 % represented by northern ones. The results of the analysis of the Topographic Wetness Index (TWI) for the entire farm indicate a low erosion risk: only 0.5 % of the farm land has drainage depressions, with 3 % located on hills. According to the Slope Length and Steepness Factor (LS-factor), the hilly areas are located on the slopes with the steepness higher than 4°.

KEYWORDS: digital terrain modeling, FABDEM, GIS, SAGA GIS, morphometric attributes

INTRODUCTION

The active application of digital technologies and remote sensing data in agriculture is currently a unique opportunity to obtain accurate and timely information regarding the condition of agricultural lands.

One of the most significant factors in the development of agricultural landscapes is the topography of the area, which greatly influences the local distribution of water and sunlight, as well as energy of slope processes. Topography is an essential part of soil formation. The study of structural and geomorphological characteristics of the terrain is taken into account in assessing agricultural lands and their monitoring [*Florinsky*, 2021].

Traditionally, quantitative information on geomorphology is obtained on the basis of morphometric analyses of topographic maps. However, with the development of aerial photography and information technologies, digital modeling has replaced the traditional methods. The morphometric analysis using DEMs is based on the analysis of this data used as an input to quantify the characteristics of the Earth’s surface [*Mitasova* et al., 1996].

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Modern DEMs are based on remote sensing data, and their accuracy is continuously improving. In the 1950s, there emerged a new approach to photogrammetry — digital terrain modeling [*Li* et al., 2005]. The widespread application of DEMs began about 20 years ago with the advent of an edited version of the satellite-derived Shuttle Radar Topography Mission (SRTM) model, which had a spatial resolution of 3 arc-seconds (~90 m at the equator). Its improved version, SRTM Plus, with a spatial resolution of 1 arc-second, became available in 2014. Over the past 15 years, a number of publicly available DEMs have been introduced, being created on the basis of satellite data and various processing algorithms: ASTER Global Digital Elevation Model (GDEM), Multiple Error Elimination Enhanced Terrain (MERIT), Copernicus DEM (GLO-30 & GLO-90), FABDEM (Forest and Buildings removed Copernicus DEM). These models are characterized by a spatial resolution of 3 or 1 arc-second, which corresponds to the grid spacing of approximately 90 × 90 m and 30 × 30 m, respectively. Data with the cell size of 1 arc-second are of particular interest to specialists in the agricultural sector, because they allow evaluating the morphometric characteristics of the land area even at the level of individual fields [*Kuznetsova* et al., 2023]. However, DEMs based on satellite data are not unique. At present, there is also a considerable interest in DEM data derived from unmanned aerial vehicles (UAV). It should be noted that the quality of DEM is a measure of how accurate the height of each pixel is (absolute accuracy) and how accurately the morphology is represented (relative accuracy) [*Uuemaa* et al., 2020]. Based on the combination of these factors, the most appropriate solution for this class of problems under consideration currently seems to be the application of non-commercial open data such as FABDEM DEM, which is a derivative product of Copernicus DEM.

Digital terrain modeling allows the analysis of the terrain in an area under study in order to derive morphometric attributes [*Shary*, 2006; *Wilson*, 2012]. These attributes have been applied in the research of agricultural lands in recent years [*Reuter* et al., 2009]. For example, the Topographic Wetness Index (TWI), which is an indicator of soil moisture [*Kopecký* et al., 2021], has been utilized. The relative exposure of the slopes to sunlight is a significant factor in predicting yield [*Sharaya* et al., 2018]. Additionally, the slope aspect index can be used to identify seasonal changes in Normalized Difference Vegetation Index (NDVI) values in cultivated areas [*Shinkarenko* et al., 2019].

The steepness and exposure of slopes are used to improve techniques for determining the natural resource potential of lands intended for agricultural production by introducing correction coefficients for topography [*Shpedt* et al., 2023], etc. Morphometric data can be employed to predict a number of exogenous processes [*Stolbov* et al., 2022], and they allow estimating the probability and intensity of their occurrence. Stream modeling is used to assess the surface runoff and soil moisture level [*Permyakov*, 2014; *Entin* et al., 2017]. Digital terrain modeling allows the creation of thematic maps of the most significant morphometric terrain characteristics. Obtaining this information is an essential step in the development of intelligent agricultural land management using digital technologies. It allows one to identify patterns and trends, which can help in making decisions regarding the optimization of agricultural processes [*Ganieva*, 2019].

The aim of this research is to carry out a geomorphometric analysis of the terrain of the agricultural area of EPF "Mikhailovskoye" based on the FABDEM data as well as to assess the potential for applying this digital model to calculate morphological attributes for farmlands at the level of an individual field.

RESEARCH MATERIALS AND METHODS

The experimental production farm (EPF) "Mikhailovskoye" of the Federal Research Center "Krasnoyarsk Science Center of the Siberian Branch of the Russian Academy of Sciences" (FRC KSC SB RAS), located in the northwestern part of the Uzhursky District, 30 km from the town Uzhur (administrative center) and 250 km from Krasnoyarsk, was chosen as an object of research. EPF "Mikhailovskoye" occupies an area of 15 209 ha, with 11 294 ha being agricultural lands. It is located in the forest-steppe zone of the Chulym area, where the terrain is hilly and the climate is sharply continental with long cold winters and moderately cool summers. The soil cover of the agricultural lands includes gray forest soils, chernozems, and meadow soils. More than half of the area (69 %) is occupied by chernozem-type soils, which are distributed across the entire land. These are the most fertile soils, with an average amount of soil organic matter. Meadow soils take up the second position in the soil types (21 %), followed by meadow and chernozem soils (13 %).

Modern geoinformation systems (GIS) include a wide range of tools for collecting, analyzing, and organizing a large amount of diverse information into a single geospatial database for any given territory [*Shokin* et al., 2015]. The use of these technologies, including digital terrain models, allows a significant degree of automation in the process of geomorphometric analysis of the surface of the studied area.

A geospatial database was created for EPF “Mikhailovskoye”, containing relevant information for the operation of the digital agriculture system of the farm [*Erunova* et al., 2019]. The database includes a map of the fields, thematic maps of agrochemical properties of the soils, such as soil organic matter content, granulometric composition, pH, and presence of mobile compounds of nitrogen, phosphorus, sulfur, potassium, and trace elements. It also contains a digital map of the soils and information on the crops and their yields from different years.

The FABDEM model was used as the basis for determining morphological characteristics of an agricultural area [*Hawker* et al., 2022]. To ensure the accuracy of calculations, the original FABDEM data was reprojected from the geographical coordinate system into a metric projection (Universal Transverse Mercator) using the open-source GIS QGIS software.

The geomorphometric analysis of DEM was performed using the functionality of the ‘Basic Terrain Analysis’ toolset of the SAGA GIS software [*Conrad* et al., 2015]. The SAGA classification tool ‘TPI-based classification of Landforms’ was used to highlight the landforms. The hydrological analysis of the farm area (modeling of temporary watercourses and surface flow directions) was carried out in SAGA GIS using the ‘Hydrology’ module.

RESEARCH RESULTS AND DISCUSSION

A fragment of the DEM data was extracted from the FABDEM dataset for the area of EPF “Mikhailovskoye”. Preliminary data processing was performed using the SAGA GIS software. Smoothing and filtering techniques were applied to suppress high-frequency noise and artifacts in the digital terrain model.

To carry out the geomorphometric analysis, DEM was divided along the border of the farm and along the boundaries of individual fields. For the farm area under study, a series of large-scale maps were created for the key morphometric attributes: steepness, exposure, plan and profile curvatures. The Terrain Ruggedness Index (TRI) and Slope Length and Steepness Factor (LS-factor) were also calculated, as well as the Topographic Wetness Index (TWI). Analytical hill shading was also considered. Some examples of the resulting maps are shown in Figs. 1–6. The resulting maps were converted into GRID format raster files, which are regular grids with increments of 10 m. A statistical analysis of the data was made. The range of influence for each indicator was identified by extracting zonal statistics from cells in a regular network using the appropriate QGIS plugin.

The morphometric analysis of the area of EPF “Mikhailovskoye” reveals that, despite its small size, the surface of the area is heterogeneous. The agricultural fields are located on a gently sloping plain, with predominant elevations of approximately 400 m (Fig. 1). Statistical data on the geomorphometric characteristics were collected for the entire farm area and individually for each field. Average, maximum, and minimum values for all the indicators were calculated for each field. For example, the steepness attribute of the slope was used to assess the potential for runoff and erosion. Figure 2 presents a thematic map showing the steepness of the slopes in the farm fields, created according to the classification of flat terrain.

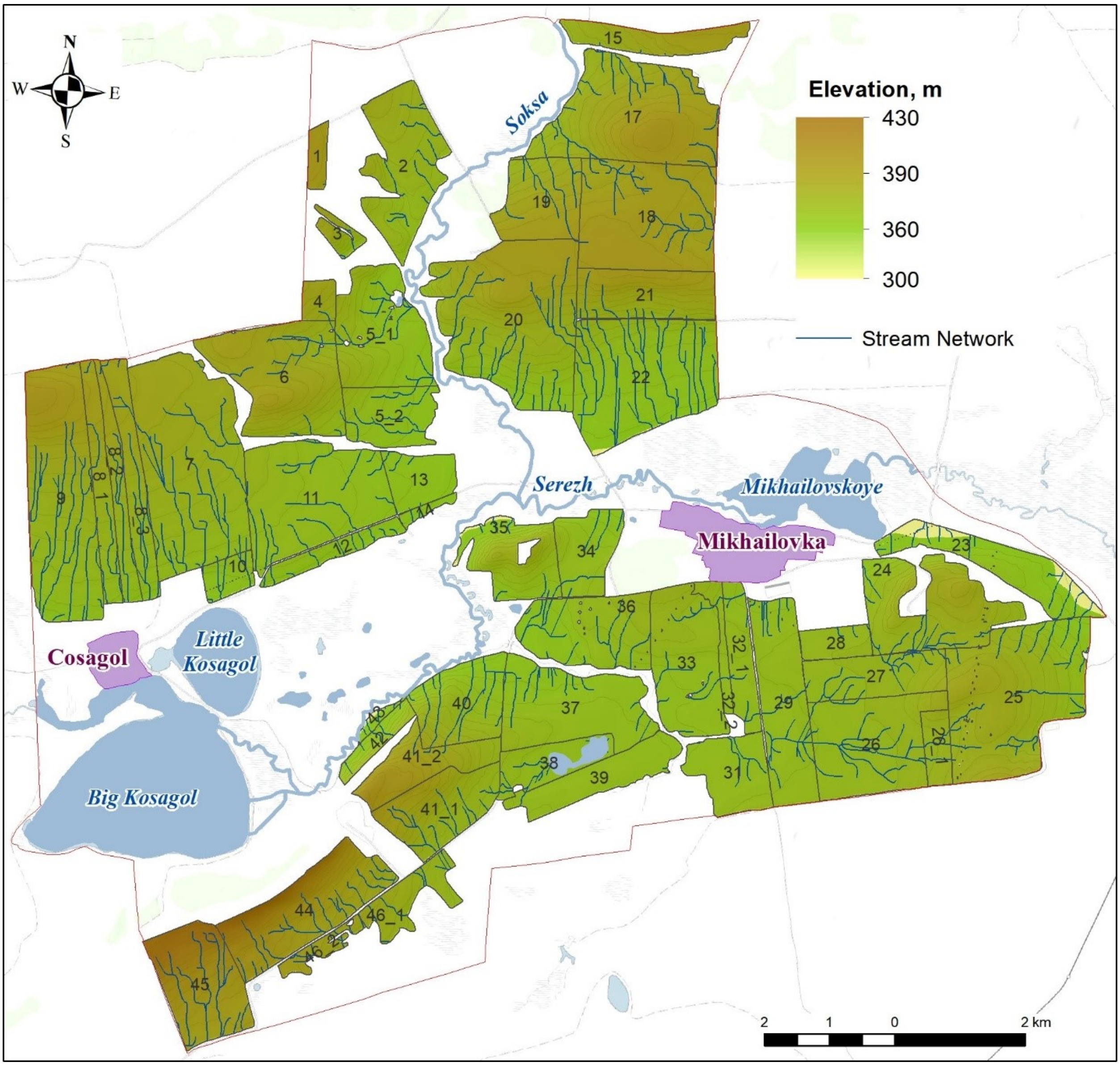

Fig. 1. Topography and water stream flow model

The fields located on the slopes with the steepness up to 3°, occupy 92 % of the area. Flat surfaces account for 51 % of the area, while gentle and very gentle slopes account for 30 % and 11 %, respectively. The areas with the slopes between 3 and 5 degrees account for 6 %, while those with the slopes above 5 degrees are located in the southwest part of the farm, making up 2 % of the overall area. The resulting slope map is a raster layer with a resolution of 10 m, allowing a more detailed analysis at the field level. In particular, field 22 which is to the north of the village Mikhailovka, is mostly located on the slopes of up to 1 degree (65 % of its total area), with 26 % accounting for the slopes between 1 and 2 degrees, 8 % between 2 and 3 degrees, and 1 % between 3 and 4 degrees. The statistics for this indicator, including minimum, maximum, and average values, is available for each field.

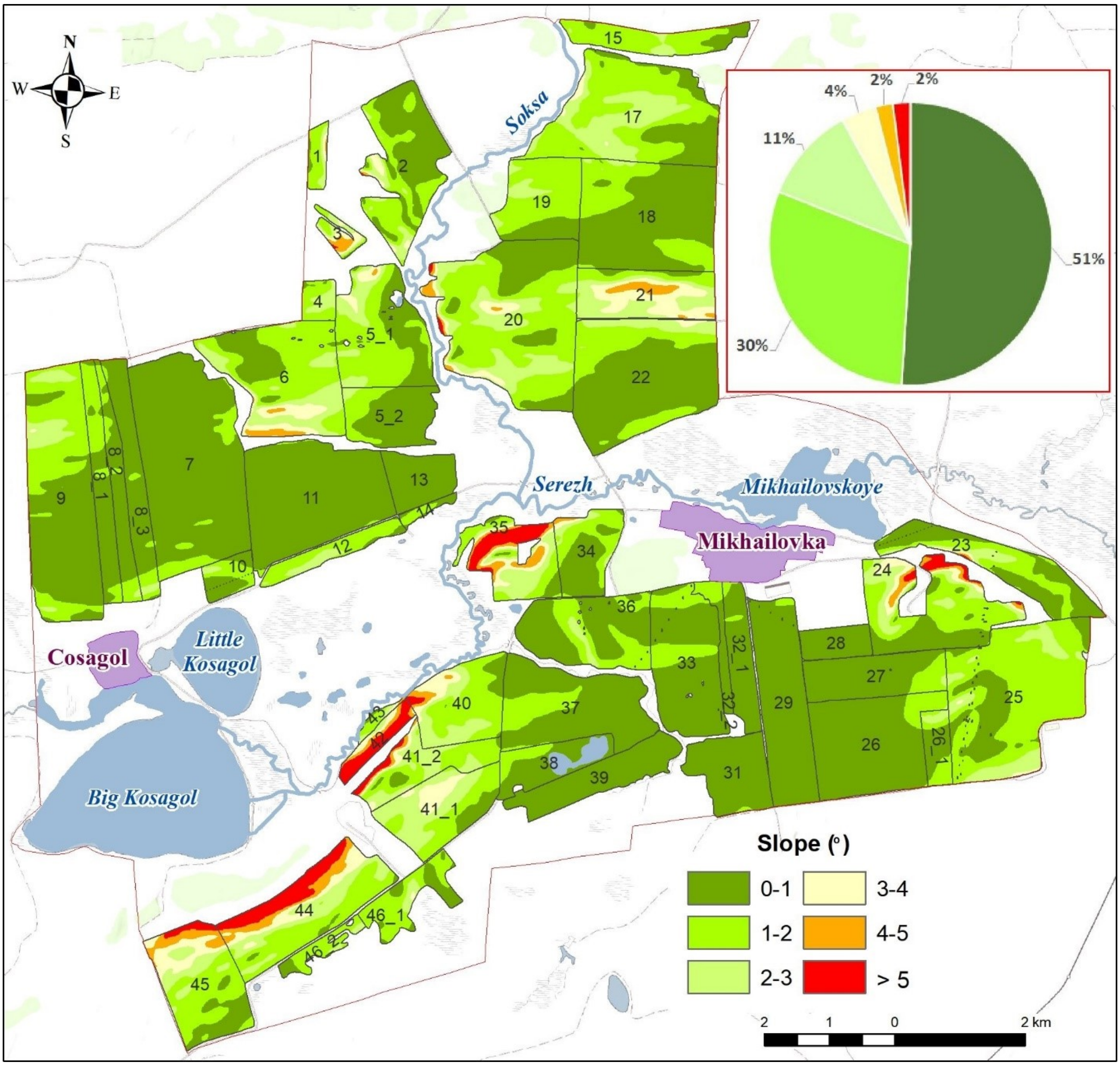

Fig. 2. Slope steepness, with a diagram showing the percentage of the occupied areas

Other geomorphological indicators were also analyzed in a similar manner. Figure 3 shows a map of topography elements generated using the ‘TPI-Based Landform Classification’ SAGA GIS algorithm [*Weiss,* 2001]. The Topographic Position Index (TPI) compares the elevation of each cell in DEM with the mean elevation of a specified neighborhood around that cell. The analysis of the map reveals that 85 % of the fields of EPF “Mikhailovskoye” are flat areas with a flat surface. The remaining 15 % of the terrain is characterized by localized, predominantly elevated landforms.

Figure 4 shows the slope aspect, which was used to assess the availability of heat and moisture. The farm land is divided into the following fields: the southern slopes account for 36 % of the total area, while the northern slopes make up 22 % of the land, the western slopes represent 15 % of the area, and the eastern ones account for 27 % of the entire farm. Using this map, it is possible to determine the characteristics of light and warmth of the surface, distribution of light and heat in each individual field, and to identify areas with more favorable lighting and thermal conditions.

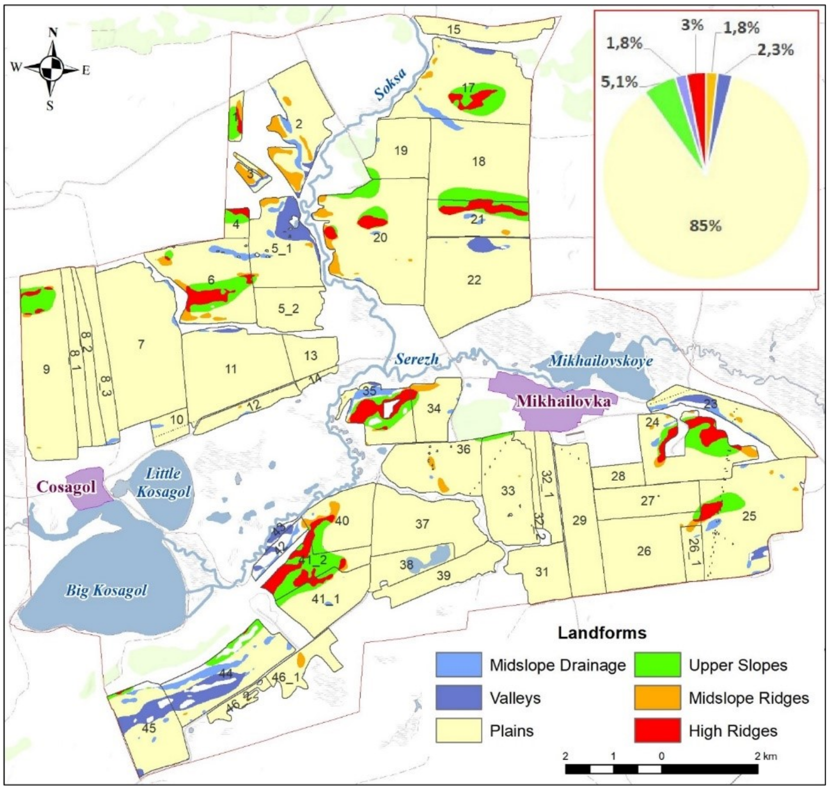

Fig. 3. Landforms, with a diagram showing the percentage of the occupied areas

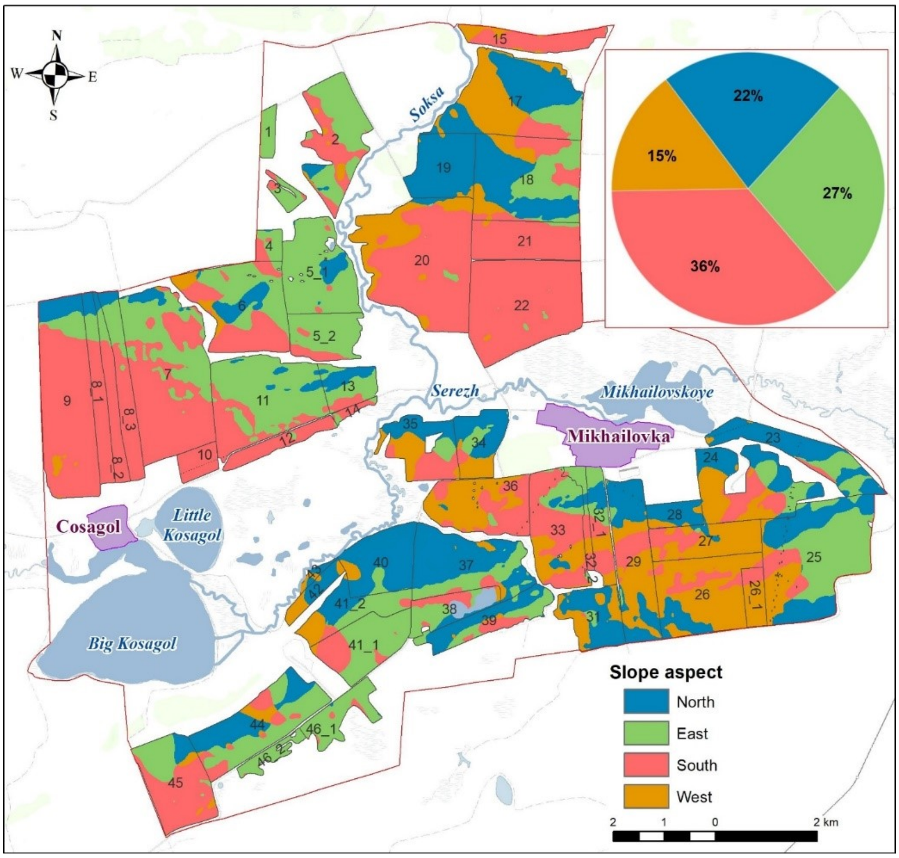

Fig. 4. Slope aspect, with a diagram showing the percentage of the occupied areas

Based on the FABDEM model, a thematic map of the Topographic Wetness Index was created (Fig. 5). With regard to digital elevation models, the Topographic Wetness Index (TWI) is an attribute that describes the tendency of a particular grid cell to collect water, i.e., the tendency to collect precipitation [*Meles* et al., 2020]. The Topographic Wetness Index is an indicator of the hydromorphicity of the soil surface, which is largely influenced by the topographic characteristics of the area. It allows one to assess the conditions for the development of wetlands and the occurrence of waterlogging, as well as to take this factor into consideration in planning optimization measures (reclamation). Therefore, the topographic index serves as an indicator of the soil moisture content. The analysis of the map reveals that the areas with the highest TWI values (greater than 17) are drainage depressions. These areas have increased content of moisture in their soils. The plots with the highest TWI values are located in the southeastern part of the farm. The low values of the TWI index in fields 2, 3, 44, 42, and 43 amount up to 7, and these sections correspond to those with the steepest slopes. The results of the analysis of the Topographic Wetness Index (TWI) for the entire farm indicate a low erosion risk: only 0.5 % of the farm land has drainage depressions, and 3 % is located on the hills.

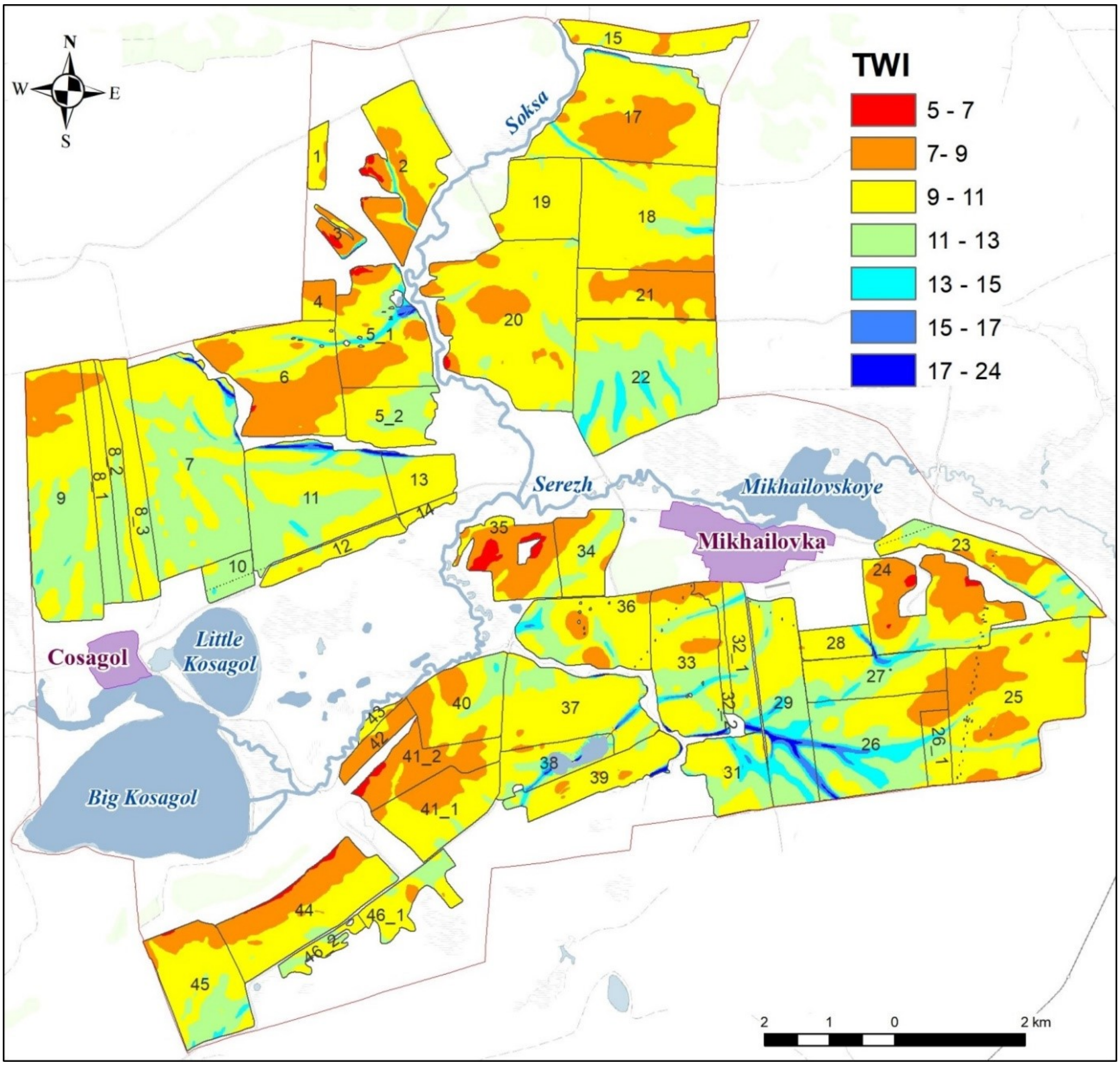

Fig. 5. Topographic Wetness Index (TWI)

One of the complex morphometric indicators used to assess the potential for erosion on the slopes is the index of the potential of planar erosion (Slope Length and Steepness factor, LS-factor). This indicator determines the effect of slope length and steepness on the erosion of soils and rocks caused by the surface runoff from temporary water flows, mainly resulting from melting snow or rain. The LS-factor is used in such models as the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE), which are among the most commonly used methods for assessing the risks of erosion and soil loss [*Gopp*, 2021].

A thematic map of the LS-factor for the planar erosion potential is shown in Fig. 6. The higher the value of the LS-factor, the larger the influence of the topography on the water erosion processes. This means that the processes of soil washing are more pronounced. The highest values (dark pink) of this attribute are typically found in the areas with the slopes larger than 4° and increased ruggedness of relief. These areas include fields 3, 21, 35, 42, 44 and 45. The areas with high values of the Topographic Wetness Index, or drainage basins also fall into this category. In general, EPF “Mikhailovskoye” is located on a flat area and only its small part is subject to erosion processes.

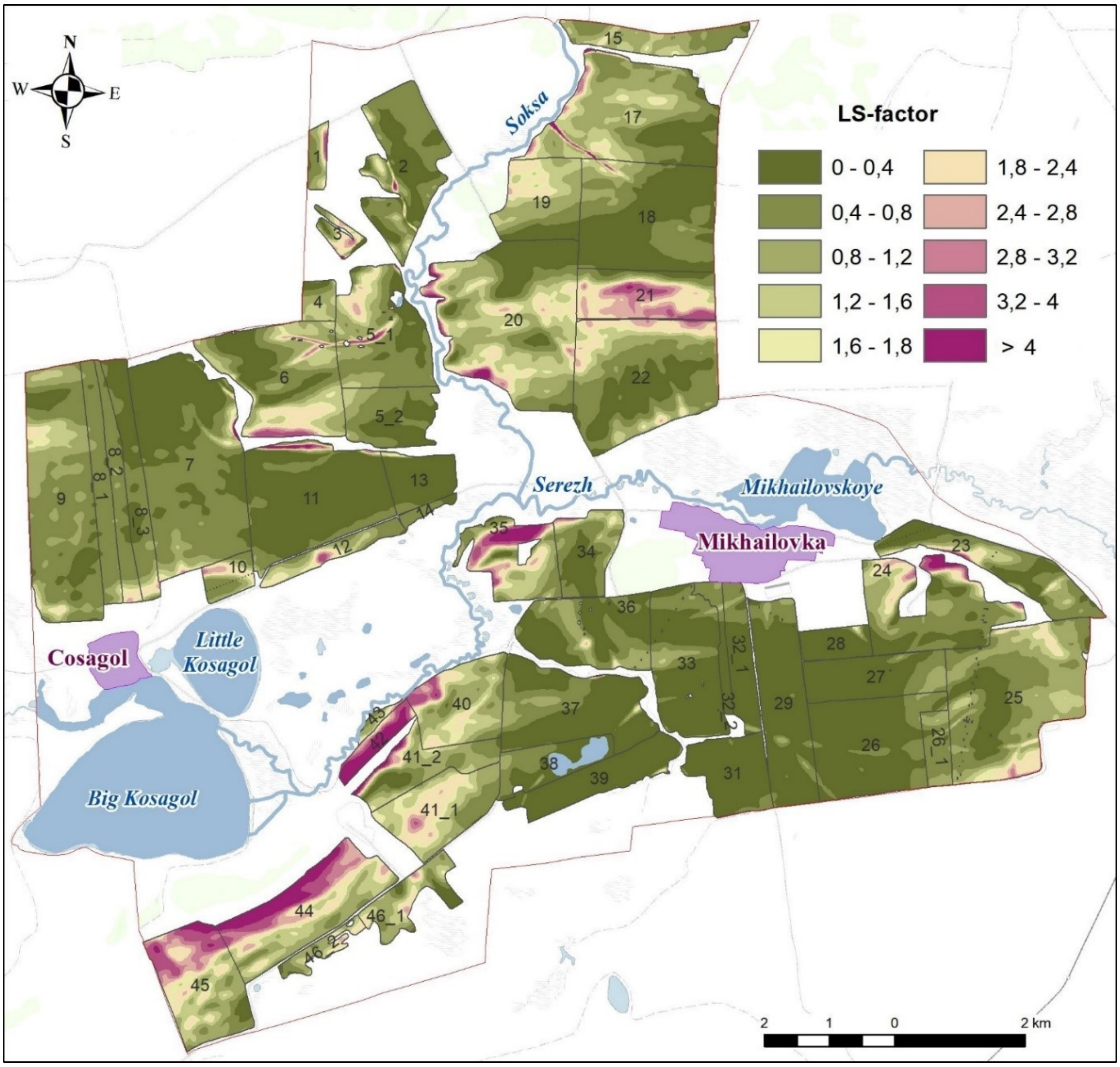

Fig. 6 Potential of planar erosion

An important stage in hydrological analysis is modeling water streamflows and direction of the surface runoff. The water streamflow model is a representation of the movement of water through a landscape under the influence of gravity. This model is determined by the direction of the steepest descent, or maximum descent, which allows assessing the potential and extent of exposure of agricultural fields to water erosion. A model of surface water streamflow was developed for the farm lands, allowing the identification of characteristic areas in water-logged fields during snow melt or prolonged rain. The thematic map (see Fig. 1) depicts the topography and the obtained water streamflow model for the farm fields. Here, the brown areas correspond to higher elevations, while the lighter ones indicate lower elevations. The network of water streams is shown as black lines, being connected to the existing rivers and swamps. The potential for planar erosion and water streamflow modeling provides the basis for planning hydro-reclamation measures aimed at mitigating soil washing and erosion [*Maltsev* et al., 2018].

The obtained model data confirm the low risk of water erosion at EPF "Mikhailovskoye". At the same time, this data forms the information basis for making management decisions for protecting soils from erosion and under unfavorable weather conditions, allows one to plan management and forest reclamation activities as well as economic, agrotechnical and hydraulic anti-erosion measures aimed at preventing soil washing and erosion.

CONCLUSIONS

For the area of EPF "Mikhailovskoye", digital elevation modeling was performed based on the FABDEM dataset and functionality of the SAGA GIS toolkit. A geomorphometric analysis was made, and key attributes were obtained, such as the steepness and slope aspect, plan and profile curvatures, Terrain Ruggedness Index (TRI), LS-factor, Topographic Wetness Index (TWI) etc. These attributes are stored in a geospatial database for this farm, as well as in the form of thematic maps for the key topographic features in the given territory. The results show that modern FABDEM data can be used to obtain information on general topographic characteristics of an area, both at the level of a farm and individual fields. The application of DEM and publicly available remote sensing data allows complete collection and analysis of topographic features in any agricultural area. The obtained geomorphometric data of the landscape can serve as a basis for predicting the range of exogenous processes such as erosion, destruction, and accumulation, and help us to assess the likelihood and intensity of their occurrence.

The morphometric analysis of EPF "Mikhailovskoye" shows that despite its small size, the surface structure is heterogeneous. The analysis shows that 85 % of the farm area is on flat land, while the remaining 15 % is represented by more elevated local landforms. The steepness of most slopes amounts up to 3°, accounting for 92 % of the total area, with only 8 % of the land being steeper than 3°. The farm fields are dominated by western and eastern slopes, which account for 42 % of the total area. Southern slopes are found in 36 % of the area, with northern slopes accounting for 2 %. The results of the analysis of the Topographic Wetness Index (TWI) for the entire farm indicate a low erosion risk: only 0.5 % of the farm land has drainage depressions, and 3 % is located on the hills. According to the Slope Length and Steepness Factor (LS-factor), the hilly areas are located on the slopes with the steepness higher than 4°. It seems advisable to remove these areas from arable land and convert them into hayfields or plant them with perennial grasses. In terms of the remaining flat area, it is necessary to conduct agrochemical research to determine the most efficient use of mineral fertilizers for agricultural crops.

The results obtained from FABDEM DEM show that it is suitable for collecting and analyzing information on the general topography of the area, both at the level of a farm and individual agricultural fields. These morphometric attributes can be used as initial data to predict various exogenous processes, such as erosion, destruction, and accumulation, as well as allow one to assess the likelihood and intensity of these processes.

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