

Using GIS technology for identification of agricultural land with an increased risk of erosion

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Abstract. The article discusses the results of spatial analysis of agricultural land in geographic information systems for automated identification of arable land with high risk of soil water erosion. For the Belgorod Region, which has a high soil and climatic potential and is one of the leading agrarian regions of Russia, a spatial model for potential clean fallow-based rainfall erosion has been constructed. For calculations, the RUSLE equation was used, and the input data were obtained from a digital elevation model with 30 m resolution, 1:200,000 soil map and interpolated data on rainfall. As a result, we have identified the areas with very strong potential erosion (more than 20 t/ha per year) and generated a regional geodatabase. The obtained results can be used to plan measures to change the structure of crop rotation on the slopes and environmental renaturation of degraded arable land.

1 Introduction

One of the strategic goals of the Russian agro-industrial complex development until 2030 is to ensure its digital transformation. It is aimed, inter alia, at creating a common information system to collect data on the entire area of the agricultural land in Russia. The digital platform of the agro-industrial complex is designed to become a management tool aimed at improving agricultural production efficiency, maintaining and increasing the production potential of the country's soil resources.

In crop production, where soil and land resources are used as durable means of production, the geographic information systems (GIS) can make the basis for digitalization. GIS began to be actively introduced in domestic agricultural production since the 2000s and they are currently used in almost any area of the industry. The most common uses of GIS in crop production include mapping and geodatabases in special software and analytical services, satellite monitoring of crops, GPS navigation and precision farming [1]. Spatial analysis and geo-modelling are a promising yet not widely used line of activities. An analysis of the combination of various special factors makes it possible to simulate multiple scenarios of agricultural production management. For example, an analysis of agro-climatic conditions [2], the impact of negative factors [3], and an assessment of soil cover degradation rate [4] and others.

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This work describes the experience in the use of geomodelling for potential development of water soil erosion for the rational planning of agricultural land use.

Soil erosion by water causes severe damage to any national agricultural production. The arable lands of Russia annually lose over 500 million tons of the most fertile part of the soil due to active manifestation of water-erosion process, and for this reason, grain shortage is estimated by the country at 15.8 million tons per year [5]. The intensity of water erosion processes in agrolandscapes limits, on the one hand, the possibility of sustainable agricultural production in the region, and on the other hand, upsets the ecological balance of geoecosystems [6]. With intensive agricultural load under the conditions of slope landscape, the naturally occurring process of soil particles removal by water flows and their redistribution down the slope becomes one of the key types of soil degradation.

To deal with soil erosion rate control it is essential to transfer to an ecologically balanced spatial-temporal management of agrolandscapes in order to develop rehabilitation land use mechanisms for areas with low agro-soil anti-erosion resistance with due account for soil recovery standards [7]. To address this problem GIS technologies are required to ensure adequate identification of the most erosion threatening areas of arable land for further restoration of soil fertility.

2 Materials and Methods

The problem was dealt using the example of the Belgorod Region territory as an area, which is characterized by high soil erosion in agrolandscapes due to a number of erosion factors. Erosion processes have somehow affected 48% of the ploughed land of the region. To determine places with increased erosion hazard we used methods of mathematical modelling of erosion processes and the capabilities of geographic information systems, in particular, spatial analysis.

Geoinformation technologies for erosion processes distinguished by a pronounced spatial distribution can be used as an effective tool for research, evaluation, forecasting and justification of managerial decisions. Given the lack of empirical data on runoff and flush, mathematical modelling is the most common method to study mechanisms and consequences of water erosion processes.

To determine the erosion potential of arable land, the RUSLE modified universal equation for soil losses was used [8]. The RUSLE model allows predicting the potential of average annual soil erosion module for various scenarios of territory use and changes in climatic factors. The universal equation is a product of factors, which take into account the influence made by topography, soil cover, precipitation and agricultural background:

$$W = R \cdot K \cdot LS \cdot C \cdot P, \quad (1)$$

where W – average annual soil loss modulus, $t\ ha^{-1}$; R – rain erosion factor; K – soil erodibility factor; LS – relief factor, where L – length factor, S – slope factor; C – crop rotation factor (agricultural background); P – soil protection factor.

The ArcGIS 10.5 multifunctional geographic information system, in particular, the Spatial Analyst geoprocessing toolkits, was used in our studies to perform calculations.

Potential average annual soil losses due to storm erosion have been quantitatively assessed in GIS by producing derived rasters of erosion factors. Erosion hazard assessment by spatial washout mathematical model implemented in GIS is based on the continual account of the terrain features, soil cover and vegetation and makes it possible to obtain characteristics for any point (pixel) of the concerned territory in raster mode.

For each equation factor (1) a raster model was built on the territory of the Belgorod Region [9]. For this, we used a digital terrain model with a resolution of 30 m, a soil map

with a scale of 1:200,000, and interpolated data on rainfall. Using the Raster Calculator tool, we calculated the product of the resulting grids. At the same time, we estimated maximum erosion hazard - the soil fertility factor for complete fallow is one.

To identify areas of increased erosion hazard we used the potential fallow field washout model to select areas with potential erosion losses exceeding 20 t/ha (Fig. 1).



Fig. 1. Steps for identifying areas of high erosion hazard: A – view of arable land in a satellite image; B – simulation results of the soil losses caused by erosion with water fallow field; C – identification of areas of high erosion risk (more than 20 t/ha per year).

For vector format data, we developed a regional geodatabase for arable land areas with high erosion hazard and estimated the total area of such territories. The raster model of erosion losses was converted into a vector format and then generalized. Separate small areas were removed by aggregation using a distance criterion of less than 100 m; also, we rejected areas of less than two ha.

3 Results and Discussion

For the arable land of the Belgorod Region we calculated maximum potential soil losses caused by fallow-based storm erosion (Table 1).

Table 1. Distribution of potential soil erosion losses from the arable land of the Belgorod region (for complete fallow).

Average annual soil loss modulus	Area, km ²	Share of arable land, %
Insignificant (up to 2.5 t ha ⁻¹)	4133.4	33.2
Weak (2.6-5.0 t ha ⁻¹)	2941.2	23.6
Moderate (5.1-10.0 t ha ⁻¹)	2354.5	18.9
Average (10.1-15.0 t ha ⁻¹)	1017.3	8.2
Strong (15.1-20.0 t ha ⁻¹)	567.1	4.6
Very strong (более 20.0 t ha ⁻¹)	1433.5	11.5

In total, 67% of arable land is subject to annual washout exceeding the permissible level (2-2.5 t/ha). Moreover, 11.5% account for the areas with potential soil losses of more than

20 t/ha per year. This ratio is quite high but we should keep in mind that the simulation results show erosion potential - the “worst deal” with other things being equal. The soil fertility factor conditionally accepted by us as a unit for fallow field conditions can be significantly lower depending on the erosion resistance of the crops grown. Therefore, to prevent soil erosion by water it is most efficient to plan soil protection structure of cultivated areas depending on steepness and other factors.

Having analysed the resulting erosion risk model for the Belgorod Region we identified 14,000 areas with increased erosion hazard within the arable lands ranging from 2 to 700 hectares. As a result, using these areas we established a geodatabase, which contains exact localization of each site. According to the data obtained, we constructed a distribution density map for the high erosion hazard areas (including weight coefficient by areal size) (Fig. 2).

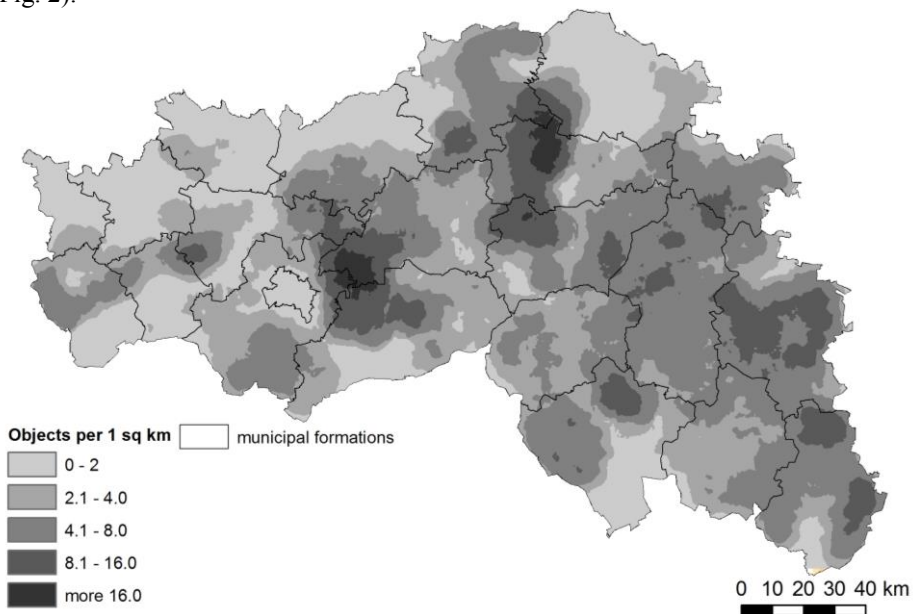


Fig. 2. Territorial distribution of the density of habitats with increased erosion hazard in the Belgorod region according to the results of GIS modeling.

The results presented in Fig. 2 show the uneven distribution of erosion risk: it grows from west to east, and in the central part of the region, it appears in the form of two vast areas. When you place a grid of municipalities on the results shown in Fig. 2, you can see a preliminary picture of municipalities, which should focus on measures for abandonment, and recovery of degraded arable land. To determine the specifics of further use of the identified territories it is necessary to conduct ground-based monitoring of actual erosion.

4 Conclusion

Advanced methods of geographic information analysis can be introduced into the practice of digital management of agricultural processes. A scientifically based assessment of agricultural land condition supported by the capabilities of geoinformation modelling should form the basis for territorial planning strategy for the national agricultural sector, particularly, as regards the efficient use of soil resources.

Using the example of the Belgorod Region, we could show the GIS capabilities for quantitative assessment of land degradation caused by water erosion of soils. Regional

authorities and land users can use the database of increased erosion hazard areas formed by geomodelling as a basis for structural rearrangement of cultivated areas in order to recover soil fertility.

Acknowledgments

This work was funded by the Russian Science Foundation, project no. 20-67-46017.

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