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Original article

DIGITAL MODELING IN THE STUDY OF AGRICULTURAL LAND DEGRADATION PROCESSES

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Abstract

Background. This article discusses the problem of soil degradation from flooding and waterlogging. The analysis of the influence of these factors on the quality of land resources and agricultural productivity is given. As a solution, it is proposed to use digital surface modeling and other methods aimed at preventing erosion and improving soil condition. The article may be useful for scientists and specialists in the field of land reclamation and agronomy

Purpose. Objective of the study to explore numerical modeling in the study of agricultural land degradation processes.

Materials and methods. The research was conducted in the Dinsky district of the Krasnodar Territory, which belongs to the steppe zone. This area is characterized by significant humidification (from moderate to severe), relatively warm winters, short spring, hot summers, and long warm autumn. The annual rainfall in recent decades has increased to 643 mm, including 370 mm for the warm period (April – October) and 273 mm for the cold period (November – March).

Results. A feature of the territory has been determined, which is weak slopes and depressions of the terrain, in which even small obstacles to surface and ground runoff in wet years can lead to waterlogging of soils. Closed relief depressions (saucers) were formed due to subsidence of soils under the influence of natural moisture. Due to the high porosity and significant carbonate content, loess-like rocks of the irrigation site are predisposed to subsidence phenomena that occur during irrigation or during waterlogging of rocks. The territory is in the initial stage of degradation caused by flooding and waterlogging of the land. Land degradation is caused by natural and anthropogenic factors, where anthropogenic factors are more strongly influenced.

Conclusion. For intensive use of the studied territory (which is represented by meadow-chernozem leached weakly developed soils) in agricultural production, it is necessary to: carry out reclamation work on drainage (reducing the level of high water) by installing tubular periodic drainage in irrigation fields with the withdrawal of excess water into drainage channels that are located parallel to the irrigation fields; construction of absorption wells in the centers of low-lying areas of fields with upstream and outlet through drainage pipes into drainage channels that are located parallel to irrigation fields; to improve water permeability and aeration, eliminate the plow sole and reduce the density of the humus horizon of meadow-chernozem leached weakly silted soils, use chisels or deep dredges once every 2-3 years; change the composition of crop rotation by increasing the proportion of legumes crops; application of organic matter to the fields in the amount of 8-10 t/ha for 5 years.

Keywords: land degradation; digital terrain models; flooding; waterlogging

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Научная статья

ЦИФРОВОЕ МОДЕЛИРОВАНИЕ В ИССЛЕДОВАНИИ ПРОЦЕССОВ ДЕГРАДАЦИИ СЕЛЬСКОХОЗЯЙСТВЕННЫХ ЗЕМЕЛЬ

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Аннотация

Обоснование. В статье рассматривается проблема деградации почв от наводнений и заболачивания. Приводится анализ влияния этих факторов на качество земельных ресурсов и продуктивность сельского хозяйства. В качестве решения предлагается использовать цифровое моделирование поверхности и другие методы, направленные на предотвращение эрозии и улучшение состояния почв. Статья может быть полезна для ученых и специалистов в области мелиорации и агрономии.

Цель. Цель исследования изучить цифровое моделирование в исследовании процессов деградации сельскохозяйственных земель

Материалы и методы. Исследования проводились в Динском районе Краснодарского края, который относится к степной зоне. Для этой территории характерно значительное увлажнение (от умеренного до сильного), относительно теплая зима, короткая весна, жаркое лето и продолжительная теплая осень. Годовое количество осадков за последние десятилетия увеличилось до 643 мм, из них 370 мм приходится на теплый период (апрель - октябрь) и 273 мм - на холодный (ноябрь - март).

Результаты. Определена особенность территории – слабые уклоны и понижения рельефа, при которых даже небольшие препятствия для поверхностного и подземного стока во влажные годы могут привести к заболачиванию почв. Замкнутые понижения рельефа (блюдца) образовались в результате проседания почв под воздействием естественного увлажнения. Из-за высокой пористости и значительного содержания карбонатов лессовидные породы участка орошения предрасположены к просадочным явлениям, возникающим при орошении или при подтоплении пород. Территория находится в начальной стадии деградации, вызванной затоплением и заболачиванием земель. Деградация земель происходит под воздействием природных и антропогенных факторов, причем антропогенные факторы оказывают более сильное влияние.

Заключение. Для интенсивного использования исследуемой территории (которая представлена лугово-черноземными выщелоченными слаборазвитыми почвами) в сельскохозяйственном производстве необходимо: провести мелиоративные работы по осушению (снижению уровня высоких вод) путем устройства трубчатого периодического дренажа на полях орошения с отводом избыточной воды в дренажные каналы, расположенные параллельно полям орошения; строительства поглотительных колодцев в центрах низменных участков полей с подъемом и отводом через дренажные трубы в дренажные каналы, расположенные параллельно полям орошения; для улучшения водопроницаемости и аэрации, ликвидации плужной подошвы и снижения плотности гумусового горизонта лугово-черноземных выщелоченных слабозаиленных почв использовать долота или глубокие землечерпалки 1 раз в 2-3 года; изменить состав севооборота за счет увеличения доли бобовых культур; внесение органического вещества на поля в количестве 8-10 т/га в течение 5 лет.

Ключевые слова: деградация земель; цифровые модели местности; наводнения; заболачивание

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Introduction

One of the main causes of degradation of agricultural lands in the south of the Russian Federation is the processes of flooding and waterlogging of lands. These phenomena are important factors that have a detrimental effect on cultivated crops, affecting the quality and quantity of the crop. The consequences of waterlogging and flooding are: soaking of crops, their diseases, oppression or complete death; the inability to carry out most types of agricultural work in optimal agronomic terms; the inability to cultivate certain types of crops (winter crops, perennial plantations and grasses); degradation of waterlogged soils (loss of structure, multiple decrease in water and air permeability, compaction, gluing, etc.), accompanied by a significant decrease in their potential and actual fertility [1; 2]. Waterlogging and flooding of lands is a phenomenon summing up the effects of natural and anthropogenic factors. Agro-landscapes are very sensitive to external influences, which leads to the exit of landscape systems from equilibrium after a certain time of man-made impact. An example of such a process development is the emergence of hydromorphic complexes among initially automorphic soils.

Due to the fact that engineering topographic surveys, which make it possible to assess the qualitative condition of agricultural lands, are financially costly, digital modeling comes to the rescue, which serves as the main tool, in particular, for studying the development of erosion, and also allows predicting its further development [3].

Topography is a soil-forming factor and, therefore, affects the characteristics of the soil that determine the use, management, conservation and degradation of this resource. In the case of erosion, the relief is a factor affecting the transfer and accumulation of soil by water, depending on the features of the relief. The influence of relief on erosion is associated with variables such as the length and steepness of the slope, the shape and uniformity of the slope.

Land degradation from the effects of flooding and waterlogging is a process of deterioration in the quality of land resources, which leads to a decrease in productivity and a general decline in the ecosystems of agricultural production. The *purpose* of this study is to study the effectiveness of digital modeling of the surface of agricultural fields to prevent soil degradation.

Materials and methods

The research was conducted in the Dinsky district of the Krasnodar Territory, which belongs to the steppe zone. This area is characterized by significant humidification (from moderate to severe), relatively warm winters, short spring, hot summers, and long warm autumn. The annual rainfall in recent decades has increased to 643 mm, including 370 mm for the warm period (April – October) and 273 mm for the cold period (November – March). The increase in precipitation is to some extent associated with the creation of the Krasnodar reservoir. Evaporation of water from the reservoir surface contributes to an increase in climate humidity and an increase in precipitation. The increase in precipitation during the cold season was 63 mm.

The soils of the study site are represented by leached low–humus heavy-duty light-clay chernozems on loess-like clays and meadow - chernozem leached weakly layered low-humus heavy-duty light-clay on modified loess-like clays. Meadow-chernozem leached weakly silted soils lie in the bottoms of shallow depressions. They were formed on modified loess-like clays. The morphological structure of the profile of these soils is similar to the structure of chernozems, but their periodic waterlogging contributed to the appearance of hydromorphic signs in the form of ochre spots, compaction and deterioration of the structural condition of the horizon to a depth of 1 m deep from the earth's surface. The water permeability of these soils decreases to 0.001-0.0001 m/day, they become practically waterproof, this factor is the main problem of flooding and waterlogging of the studied agricultural lands. Taking into account the anthropogenic impact, which is expressed in the planting of forest belts across the direction of prevailing winds, subsurface and surface runoff, as a result of deflationary processes, dust deposits accumulate, in which or next to which rises form, blocking the runoff, which contributes to the development of waterlogging along dry gullies and the formation of puddles. The formation of a closed depression is accelerated if a field road is laid along the forest belt. Since the direction of runoff and the direction of deflationary winds coincide (from east to west), flow blocking is observed everywhere in this area.

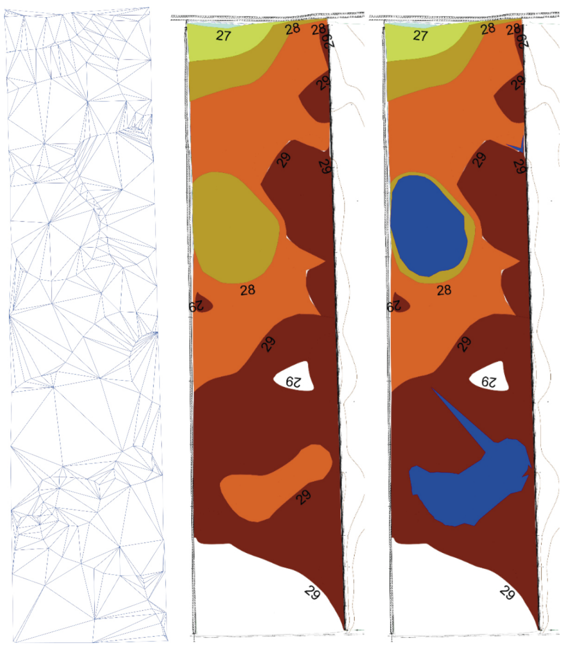
Also, the development of land degradation is influenced by methods of tillage with agricultural implements leading to the formation of foci of local waterlogging – plowing across the direction of natural runoff, plowing of beams, passages of heavy agricultural machinery, etc.

All this confirms the need to pay special attention to measures to regulate the nutrient and water regime of irrigated soils in the reclamation system. It is necessary to note two important circumstances that determine the special importance of the nutrient regime of irrigated soils:

– firstly, high crop yields on irrigation leads to accelerated removal of food elements from products;

– secondly, increased soil moisture causes higher mobility of mineral nutrition elements and their leaching into the underlying layers, and microbiological activity under optimal humidity conditions leads to accelerated mineralization of humus. The reaction of the soil medium is neutral (pH 6.6 – 7.2).

Crop rotation, cover culture and resource-saving tillage are traditional farming methods aimed at improving soil conditions. These methods reduce soil erosion and promote nutrient cycling. Their effectiveness depends on factors such as crop selection, application of cover crops and optimal tillage methods. In addition, the implementation of these methods by farmers may be difficult due to lack of awareness and potential resistance to change. The development of technologies, in particular digital surface modeling (DSM), has made it possible to create reliable tools and methods to solve this problem, such as geographic information systems (GIS) [4; 5]. The analysis of surface changes over time allows for detailed and comprehensive mapping and monitoring of land degradation processes. The overlap of various spatial data, such as topography, vegetation cover and human activity, makes it possible to identify areas subject to degradation in GIS [6].



a) b) c)

Fig. 1. a – triangulation of the surface, b – digital model digital model of the relief of the studied area, c – hydrodynamic model of flooding of the area of the studied area

Digital surface modeling is the most important tool for modern analysis and visualization, allowing you to create detailed representations of real surfaces in digital format. While traditional modeling methods required the creation of physical prototypes, computer algorithms are also used to capture and manipulate geometric surface data. By integrating climate data, it is possible to predict future changes in the land surface according to various scenarios, which allows us to obtain valuable information about the potential consequences of climate change and develop adaptation strategies [7; 8]. Modeling the effects of precipitation or temperature changes in various climatic scenarios can exacerbate soil degradation processes, and in the future it becomes possible to develop strategies to mitigate such consequences, for example, to introduce methods of sustainable land use or identify zones to prevent soil erosion through reclamation [9].

To analyze the spatial variability of the relief, which is the main parameter for evaluating geomorphometric variables, the profile characteristic of the landscape unit was determined. One field of the studied crop rotation was selected as a landscape unit.

The process of modeling a digital surface model was performed using the IndoorCAD program. Before starting the modeling process, it is necessary to collect the necessary data. IndoorCAD relies on accurate measurements, these data can be obtained using laser scanning or total station survey. IndoorCAD supports various file formats, including DXF and DWG, which are widely used in engineering applications.

The import of the collected data into the IndoorCAD program should be carried out with the condition that the coordinate system and units of measurement correspond to the collected data. Accurate geographic reference is necessary to align the model with any external data sources or geospatial information. The workflow in the project is organized by creating the necessary layers. Specific model elements, relief points, triangulation lines (Fig. 1, a), isolines, and isocontures are assigned. This arrangement of layers helps simplify the modeling process and makes it easier to make changes later.

It is necessary to make sure that all dimensions, heights and details accurately reflect the real space. All inconsistencies and errors that may have occurred in the process are eliminated, and edges are shifted during triangulation if necessary to display the slopes more correctly. The study was conducted in two stages:

– Creation of a digital terrain model. Using a 1:1000 scale topographic survey and a specialized IndorCAD Topo/Road 2023 software package to create a digital terrain model (which includes processing and analyzing terrain data to create a three-dimensional terrain model).

– Creation of a hydrodynamic model: Software tools for modeling phenomena are used to create a hydrodynamic model of flooding of the area. Take into account the terrain and other parameters that may affect the spread of water and flooding.

The digital model (Fig. 1, b) reflects the peculiarity of the relief with the predominance of closed contours of surfaces, the isocontures are highlighted in different colors with a step of 0.5 m marks. Thus, altitude information about the relief, data on the drainage system are reflected, which will help to build hydrographic maps and other parameters that may affect.

The modeling process takes into account various factors that can affect the spread of water and flooding, such as the speed and direction of flow, surface and underground runoff, soil properties, etc. The blue contours represent the most negative flooding scenario (Fig. 1, c).

The actual flood data used, hydrological markers, as well as other parameters, confirm the accuracy and reliability of the model, since the calculated flood contours coincide with the locations of confirmed flood sites at the moment.

Results and conclusions

The modeling process takes into account various factors that can affect the spread of water and flooding, such as the speed and direction of flow, surface and underground runoff, soil properties, etc. The blue contours shown in Figure 2 represent the most negative flooding scenario. The results of hydrodynamic modeling of the surface during flooding of the studied field revealed 2 flooding locations with depths of 0.1 – 0.4 m, the corresponding flooding areas are 546.0 m2 and 127879.2 m2. The actual data on flooding used, hydrological markers, as well as other parameters, confirm the accuracy and reliability of the model, since the calculated contours of flooding coincide with the locations of confirmed flood sites at the moment, confirmed by a route survey.

A feature of the territory has been determined, which is weak slopes and depressions of the terrain, in which even small obstacles to surface and ground runoff in wet years can lead to waterlogging of soils. Closed relief depressions (saucers) were formed due to subsidence of soils under the influence of natural moisture. The shape of the saucers is very diverse (rounded, elongated, dumbbell-shaped, amoeboid, etc.). The number of saucers will increase over time, and the area of existing ones will noticeably increase. The soil–forming rocks are represented by loess–like clays, which contain 60.9 – 66.4% physical clay, 35.7 - 40.1% silt, 48.0 - 69.0% dust and sand 3.4 – 17.4%. Due to the high porosity and significant carbonate content, loess-like rocks of the irrigation site are predisposed to subsidence phenomena that occur during irrigation or during waterlogging of rocks. The territory is in the initial stage of degradation caused by flooding and waterlogging of the land. Land degradation is caused by natural and anthropogenic factors, where anthropogenic factors are more strongly influenced.

For intensive use of the studied territory (which is represented by meadow-chernozem leached weakly developed soils) in agricultural production, it is necessary to: carry out reclamation work on drainage (reducing the level of high water) by installing tubular periodic drainage in irrigation fields with the withdrawal of excess water into drainage channels that are located parallel to the irrigation fields; construction of absorption wells in the centers of low-lying areas of fields with upstream and outlet through drainage pipes into drainage channels that are located parallel to irrigation fields; to improve water permeability and aeration, eliminate the plow sole and reduce the density of the humus horizon of meadow-chernozem leached weakly silted soils, use chisels or deep dredges once every 2-3 years; change the composition of crop rotation by increasing the proportion of legumes crops; application of organic matter to the fields in the amount of 8-10 t/ha for 5 years. One of the main measures is the drainage of surface and soil water in relief depressions. To do this, you need a drainage device at a depth of 1.0-1.1 m in the form of a perforated pipe with a slope towards the main drainage channel. The pipe into the trench is filled with coarse-grained to a depth of 0.6 m. The thickness of the layer is due to the filtering ability of the soil (table), which has a high filtration coefficient in the upper vegetation layer and will allow excess water to be removed from this layer. An additional mandatory measure is capital planning on the areas of waterlogged lands where drainage is arranged. Capital planning must be carried out with a bias towards drainage channels, which are collectors for all excess water in the area of the reclamation system

Conflict of interest information. The authors declare that they have no conflict of interest.

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Lyudmila V. Kravchenko: data analysis, digital modeling, editing the article.

Anna E. Khadzhidi: general management of the research, assistance in conducting the research, editing the article.

Arsen N. Kurtnezirov: conceptualization, data collection and analysis, conducting research, preparing the text of the article, compiling a list of literature on the research topic.

Kharlampiy I. Kilidi: methodology, data collection and analysis, conducting research, preparing the text of the article, formatting the article according to the template.

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А.Е. Хаджиди: общее руководство исследованием, помощь в проведении исследования, редактирование статьи.

А.Н. Куртнезиров: концептуализация, сбор и анализ данных, проведение исследования, подготовка текста статьи, составление списка литературы по теме исследования.

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