Для прогнозу і управління процесами ерозії з метою захисту навколишнього середовища необхідна інформація про стан її компонентів і фактори впливу, а також результати цього впливу. Існуючі методи і способи оцінки водозбірної площі в основному носять описовий характер і не можуть бути використані в математичних задачах прогнозування. Найбільш коректна постановка задачі по кількісній оцінці водозбірної площі здійснюється при проведенні гідрологічних розрахунків. Це призводить до необхідності розроблення теоретичних передумов для агроекологічної оцінки схилових агроландшафтів по стійкості мережі тимчасових водотоків з використанням критерію Лохтіна.

Схилові агроландшафти є ерозійно небезпечними об'єктами. Існування на схилах системи, що безперервно видозмінюється, мікроручейків, які породжуються опадами, значно ускладнює ситуацію. Запропоновано критерії, що визначають основні тенденції розвитку русел річкових систем шляхом змиву або наносу грунту. Висновки про водозбірну площу в цілому можна отримати, дослідивши деяку область протікання мікроручейків протягом тривалого часу і зіставивши польові спостереження з лабораторними експериментами. Для визначення стійкості русла запропонована теоретично обгрунтована величина, яка дозволяє дати кількісну оцінку мережі тимчасових водотоків. При проведенні досліджень використовувалися дані про водозбірні площі річки Цивіль (Чуваська Республіка, Росія) з 1950 по 2010 рр.

Кількісна оцінка ерозійної стійкості системи мікроручейків проведена як для періодів сніготанення, так і для дощів, умовно розділених на літні та осінні. Розглянуті теоретичні передумови підтверджені даними багаторічних спостережень по річці Цивіль за шістдесят років. Отримані залежності дають можливість складання адекватного прогнозу напрямку еволюції водозбірної площі щодо процесів наносу грунту або його змиву. Розроблені критерії застосовні як для конкретної водозбірної площі мікроручейків, так і для водозбірної площі річкової системи в цілому

Ключові слова: схиловий агроландшафт, ерозійна стійкість, змив грунту, мікроручей, водозбір, стійкість мікрорусел

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DEVELOPMENT OF A CRITERIA-BASED APPROACH TO AGROECOLOGICAL ASSESSMENT OF SLOPE AGROLANDSCAPES

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1. Introduction

Since the decisive role in the metabolism of an agrolandscape belongs to its phytocenosis and pedocenosis, information is needed on the state of its components and impact factors as well as the results of this impact in order to predict and control erosion processes and to protect the environment. The existing methods for assessing the water catchment area are mainly descriptive and cannot be used in mathematical prediction problems. The available mathematical models do not take into account all the components of the "machine – soil – plant" system due to the lack of precise experimental methods for determining the initial parameters of the mathematical model. The most accurate formulation of the problem of quantitative assessment of the catchment area is established during hydrological calculations. Meanwhile, the hydrological process is characterized by multifactorial nature, insufficient development of experimental research methods and field observations, as well as uncertainty (insufficient initial data). It is impossible to create a mathematical model of "precipitation – catchment area – runoff" that is adequate to the actual process and necessary for the implementation and optimization of the "machine – soil – plant" system in the catchment area.

The melt water or rainwater flowing down a slope forms a temporary system of a large number of microstreams or watercourses. Such microstreams contribute to the deposition of sediments or, conversely, to the erosion of the watercourse along which they flow, and the altered course redefines the flow velocity field. This explains their mutual dependence. A distortion of the true slope was noticed long ago; it happens when the water flows not strictly down the slope but by a more tortuous path. However, studies aimed at researching and quantifying the winding currents on the slopes are few [1]. Meanwhile, it is a quantitative assessment of the sustainability of the network of watercourses, sediment deposition and soil erosion in the catchment area of sloping agrolandscapes that is the key for predicting erosion processes.

Water erosion is a major problem in all mountainous regions of the world. According to estimates [2], after carrying out activities at high altitudes in the alpine zone of Europe, it is necessary to restore 5,000 hectares of land annually, and more than 50,000 hectares of insufficiently restored areas need urgent improvement. Soil erosion is also an urgent problem for agriculture in the areas of ridge-valley relief [3].

Slope agrolandscapes belong to dangerous erosion objects. Erosion and washing away of soil negatively affect the general ecological situation and substantially depend on the shape of the slope [4]. The need for adequate methods for assessing the erodibility of soils on agricultural lands with complex relief makes it imperative to continue and deepen research into the physical and mechanical properties of the soil and erosion processes. Optimization of anti-erosion technologies can be implemented on the basis of assessing the state of slope landscapes, providing for a combined analysis of both measured and calculated values.

2. Literature review and problem statement

The number of controversial points in analysing hydrological information for sloping lands often includes the assessment and consideration of the spatial heterogeneity of precipitation entering the slope surface as well as water consumption for evaporation, absorption, and transpiration. The correct and adequate consideration of the topographic and hydraulic characteristics of the slope together with the arbitrary nature of precipitation can be attributed to the characteristics ambiguously estimated by researchers [5]. Such a formulation of the question is consistent with studies aimed at researching the effectiveness of implementing adaptive-landscape farming systems [6], designing agrolandscapes and formulating initial requirements for the means of mechanization of the new generation [7]. Proper and adequate consideration of the topographic and hydraulic characteristics of the slope is necessary when studying basin contamination with soluble and insoluble chemicals [8], analysing ecosystems for changing the parameters of the carbon cycle [9], and modelling erosion processes [10].

Most studies on assessing the state and modelling the agrolandscape are descriptive in nature and therefore cannot be used in the mathematical problems of predicting the permissible external load, obtaining the optimum agricultural harvest, and managing the ecosystem. The hydrological model proposed in [11] requires the removal and processing of a large amount of statistical data from the studied area of the physiographic zone, which reduces the possibility of its practical application. The fractal approach implemented in [12] makes it possible to reveal the characteristic features and dynamics of the structure of the river and erosion-channel networks. However, the analysis within the framework of the fractal approach can be carried out only if there is detailed topographic information, and therefore the use of this method is currently limited to the analysis of individual sections of river networks. The results of water erosion prediction on slopes in the framework of the GeoWEPP (Water Erosion Prediction Project) model have insufficient spatial resolution, as a result of which it does not take into account local features of the relief of the studied area. The results of [13] obtained within the framework of this model do not allow determining the localization of the most eroded areas. In [14], for different climatic conditions, the nonlinearity of the dependence of the erosion rate on the slope was revealed, which complicates the analytical solution of the problem.

Thus, the existing mathematical problems do not allow for adequate prediction of erosion processes in areas with complex relief, since they do not take into account all the components of the system "relief – soil – plant" due to the following facts:

– incorrect formulation of the problem and a weak choice of the mathematical method of solution;

– there are no exact experimental methods for determining the initial parameters of the model.

It seems that a more correct formulation of the problem of quantitative assessment of the catchment area as an object of human impact can be carried out on the basis of the criteria approach. A criterion for predicting landslide processes on a slope was obtained in [15], which relates the conditions of soil saturation and shear stress. However, it does not analyse the possibility of implementing this approach for the analysis of surface water erosion processes. In [16], criteria for ranking the river bed based on parametrization of channel processes, such as the Lokhtin number (the watercourse stability criterion), the watercourse stability coefficient, the morphometric indicator, and others, were substantiated and tested. The question of the possibility and features of applying the criterion approach to analyse erosion-channel networks on sloping agrolandscapes is not raised in [16].

In [17], the theoretical background for applying the Lokhtin criterion for agroecological assessment of slope agrolandscapes on the stability of a network of temporary watercourses is considered and practically tested. As a quantity characterizing the erosion resistance of the soil, the potential of erosion resistance equal to the energy required for destruction and removal of a unit of soil mass under conditions of natural occurrence is proposed in [17]. However, a more informative characteristic of soil erosion processes is the power required to destroy a unit mass of the soil. The erosion washout does not occur at all values of the intensity of the water stream flowing through the soil. With a low intensity of water flow, erosion washout may not happen; however, the flow energy is not zero, and its contribution can be taken into account when determining the potential of erosion resistance. In this regard, the estimated values are distorted, and during statistical processing the estimates are biased. The use of power as a characteristic of erosion properties can eliminate this problem, since power is directly related to the intensity of the water flow destroying the soil. Statistical estimates based on power measurements will be unbiased.

Thus, for the development of a promising criterion approach to predicting erosion processes on sloping agrolandscapes, it is necessary to analyse and refine the parameters included in the criterion relationships.

3. The aim and objectives of the study

The aim of the study is to modify the Lokhtin criterion to increase the objectivity of predicting erosion processes on sloping agrolandscapes on the stability of the network of temporary watercourses.

To achieve this aim, it is necessary to solve the following objectives:

– to offer a characteristic of the erodibility of the soil, which is more informative in comparison with the potential of erosion resistance, and obtain an analytical dependence on the definition of a modified Lokhtin criterion;

– to obtain the results of applying the modified Lokhtin criterion for the agroecological assessment of the sloppy agrolandscape.

4. Obtaining the modified Lokhtin criterion for evaluating erosion processes

Lokhtin's formula for describing the stability of the watercourse is derived from the relationship of the force of resistance to erosion to the force of the dynamic pressure of a stream:

$$k = \frac{G}{F_{\text{H}}} = \frac{d}{v^2}, \quad (1)$$

where G is the weight of the soil microaggregate, F_{H} is the force of the dynamic pressure of the fluid (frontal pressure), d is the effective size of the average soil aggregate, and v is the velocity of the fluid flow.

If in expression (1) we replace the square of the velocity with the stepping drop of the water level H, we obtain the Lokhtin criterion $\Lambda^* = d / H$, which helps compare the beds of various rivers according to their stability.

For an integral assessment of the stack-forming slope surface, let us consider the similarity of the total river system and the microstream system. Such an assumption makes it possible to use the Lokhtin criterion.

To study the stack-forming surface, let us consider the water flow in the microstream system per unit of time Q. Let the flow rate be equal to Q_x at some time point at some distance from the dividing line. Naturally, the flow will vary from zero to its maximum value $Q_{x\,\max}$. This change will be both in space along the length of the microstream and in time. Moreover, microstreams can merge and be divided into components. If n streams merge, then the corresponding expense is

$$Q_x = \sum_{k=1}^{n} Q_{xk},$$

when microstreams are separated, then

$$Q_{xk} = Q_x - \sum_{\substack{j=1 \\ j \neq k}}^{n} Q_{xj},$$

where Q_{xk} is the consumption of the k-th stream of the system.

The roughness and microrelief of the underlying surface cause the meandering of the microstream. The microrelief is mainly formed by anthropogenic impact: when ploughing, sowing or harvesting agricultural plants. At the same time, irregularities are formed on the soil surface, with characteristic dimensions ranging from five centimetres to half a meter. Soil lumps, formed as a result of anthropogenic influences, break up into constituent elements when raindrops fall or as a result of repeatedly occurring freezing-thawing phenomena in the spring-autumn period. As a result, a surface is formed, characterized by a more or less uniform roughness. If the depth of a microstream, on average, depends on the size of the roughness, then the meandering (its tortuosity) is associated with the spatial variability of the roughness. The deviation of the direction of the runoff from the slope can be caused by the microstream crossing the border between the underlying surfaces, which differ in the value of the potential of erosion resistance. This is especially characteristic of the initial stage of the formation of the microwatercourse, when the flow rate in the microwatercourse is quite small and the deformation of the underlying surface is almost at a right angle to the equivalent surface [18]. As for the mesorelief (irregularities, whose width is in the range from 0.5 to 30...50 m), the direction of the flow coincides with sufficient accuracy with the slope of the surface, determined both by cartographic materials and according to land surveys. This is due to the fact that the surface of the slope is already adapted to the discharge of melt and rainwater and bears the "imprint of their runoff" as a result of the development of runoff-forming surfaces for many millennia.

It has been found that the most significant contribution to the process of changing the microwatercourse is made by the angle of inclination of the surface of the microrelief, since it determines the rate of the runoff of rain and melt waters, due to gravity. If we denote the slope by i and the value of the angle of inclination by α at the same distance l from the watershed line at a certain point in time t, we obtain $g \sin\alpha = gi$, where g is the acceleration of free fall.

Any surface, including a sloping one, possesses a certain erosion resistance in relation to a microstream that penetrates into it. In the framework of the energy approach to the description of a wet soil implemented in this work, it is proposed to use the potentials as the ratio of a certain intense value to an extensive value [19]. To describe the resistance of the soil surface to erosion destruction by a microstream cutting into it, ψ is used for erosion resistance. The value of ψ represents the energy required for the destruction and removal of a unit of mass of soil in specific conditions of its occurrence per unit of time,

$$\psi = \frac{\Delta A}{\Delta t\, \Delta m}, \quad (2)$$

where ΔA is the energy spent on destruction and removal, Δm is the mass of the soil, and Δt is the time.

Phenomenological consideration of the erosion process suggests that the average depth h and width b of the microstream depend on three quantities: water consumption per unit time Q_x, m^3/s, gravitational force gi, m/s^2, and erosion resistance ψ, J/(kg·s)≡m^2/s^3.

Having taken a general view of the proposed unknown dependences for the width and depth beyond the power, we have

$$h = A_1 Q_x^{x_1} (gi)^{y_1} \psi^{z_1}, \quad (3)$$

$$b = A_2 Q_x^{x_2} (gi)^{y_2} \psi^{z_2}, \quad (4)$$

where x_1, y_1, z_1, y_2, x_2, and z_2 are sets of numbers that equalize the dimensions in the left and right sides.

Since all the quantities included in relations (3) and (4) are dimensional, it is possible to use the dimension method. In the left parts of relations (3) and (4), there are quantities that are expressed in units of length (m). In the right-hand parts, the flow rate of water is expressed in m^3/s, the gravitational force in m/s^2, and the erosion resistance in m^2/s^3, that is, there are units of length and time. According to relation (3), in turn we equate the exponents in the left and right parts, corresponding to the length and then time. We combine the obtained identities for units of length and time into the system of equations (5). Similarly, for expression (4), we obtain system (6):

$$\begin{cases} 1 = 3x_1 + y_1 + 2z_1, \\ 0 = x_1 + 2y_1 + 3z_1; \end{cases} \quad (5)$$

$$\begin{cases} 1 = 3x_2 + y_2 + 2z_2, \\ 0 = x_2 + 2y_2 + 3z_2. \end{cases} \quad (6)$$

Both systems of equations (5) and (6) contain three unknowns each and only two equations each, which means there are infinite sets of numbers that are their solutions. Therefore, expressing y_1 and z_1 through x_1, and y_2 and z_2 through x_2, we obtain the same sets of solutions, but depending on x_1 and x_2. Now by elementary transformations in relations (3) and (4), we leave the values x_1 and x_2 free from the degree on one side of the equality and the content of x_1 and x_2 on the other side. Such a transformation helps, on the one hand, single out a new criterion, and on the other, give certainty to the expression, substituting the values measured in the experiment for x_1 and x_2:

$$\frac{h(gi)^3}{\psi^2} = A_1 \left\{ Q_x \frac{(gi)^7}{\psi^5} \right\}^{x_1}, \quad (7)$$

$$\frac{b(gi)^3}{\psi^2} = A_2 \left\{ Q_x \frac{(gi)^7}{\psi^5} \right\}^{x_2}. \quad (8)$$

The value in brackets in expressions (7) and (8) can play the role of the Lokhtin criterion in the energy interpretation:

$$\lambda = Q_x \frac{(gi)^7}{\psi^5}. \quad (9)$$

As a quantitative characteristic of Er, defined, on the one hand, as an erosion washout and, on the other hand, as a deposition on the underlying surface, caused by the water flow; the dimensionless quantity $\frac{h(gi)^3}{\psi^2}$, is presented in the left side of equation (7):

$$Er = \frac{h(gi)^3}{\psi^2}. \quad (10)$$

When dividing the microwatercourse's width by its depth $\varepsilon = b/h$, we get the relative width; in this case, expressions (7) and (8) take the forms of

$$Er = A_1 \lambda^{x_1}, \quad (11)$$

$$\varepsilon Er = A_2 \lambda^{x_2}. \quad (12)$$

The numerator in expression (10) is the squared specific work done by gravity on the flow of water per unit of time. When multiplying the denominator by the square of the mass of the underlying surface Δm_s and also by the square of the coefficient k_r, taking into account the resistance to friction, we get the square of the power required for estimating the erosion damage. The coefficient k_r is the ratio of the change in the energy of the flow of a microstream flowing on a rough surface to the change in the energy of the flow of a microstream flowing along a smooth surface [20].

The obtained expressions for Er allow the substitution of real numerical values and are interpreted for specific cases as follows:

1. $Er_1 = \frac{h_1(gi)^3}{\psi^2} = 1$, erosional removal of soil by the microstream under these conditions does not occur, and thawed water or rainwater does not destroy the channel and does not leave sediment (the equilibrium of the system is a microwatercourse – water flow).

The non-negativeness of the values ψ, h, and i allows, using (11), to write

$$\lambda = \left(\frac{Er_1}{A_1} \right)^{\frac{1}{x_1}} = \left(\frac{1}{A_1} \right)^{\frac{1}{x_1}}. \quad (13)$$

2. $Er_2 = \frac{h_2(gi)^3}{\psi^2} > 1$, under this condition, the water flowing down its course removes the soil and deforms the watercourse:

$$\lambda = \left(\frac{Er_2}{A_1} \right)^{\frac{1}{x_1}}. \quad (14)$$

3. $Er_3 = \frac{h_3(gi)^3}{\psi^2} < 1$, under this condition, the water flowing along its channel produces a sediment of the soil and deforms the watercourse:

$$\lambda = \left(\frac{Er_3}{A_1} \right)^{\frac{1}{x_1}}. \quad (15)$$

4. $Er_{\max} = \frac{h_{\max}(gi)^3}{\psi^2} >> 1$, a critical case in which soil flushing occurs in fairly high values:

$$\lambda = \left(\frac{Er_{\max}}{A_1} \right)^{\frac{1}{x_1}}. \quad (16)$$

Studies of the development of a network of microstreams on converging slopes have shown that the flow wave that occurs in the section between the upper and lower parts of the stream has the greatest destructive ability [17]:

$$h_t = \left[\frac{l_\tau J_r (L - 0{,}5 l_\tau)}{C_k (L - l_\tau)} \right]^{\frac{1}{n_1+1}}, \quad (17)$$

$$h_b = h_{\max} = \left[\frac{J_r (L - l_\tau)}{2C_k} \left(\frac{1}{u^2} - 1 \right) \right]^{\frac{1}{n_1+1}}, \quad (18)$$

where J_r is the rain intensity determining the surface runoff; l_τ is the distance from the watershed in the direction of the flow τ; L is the length of the converging slope; is the constant depending on the slope angle, the microrelief and the vegetation on the surface of the slope; m is the coefficient taking into account the roughness of the slope and sinuosity of the microstreams; α is the slope angle at the considered point of the catchment area; h_t, h_b=h_{max} is the depth of the flow layer in the section, respectively, between the upper and lower parts of the flow; n_1 and n_2 are power coefficients; u is a parameter depending on the distance l_τ.

During the runoff of melted snow and rainwater on a slope, the appearance of periodically recurring strongly reduced "stretches" and "shallows" is often observed. This fact is explained by the Lokhtin criterion, since it reflects the nonstationarity of the process of interaction of the channel of the microstream with the water flow [21]. In this case, the numerical values of the criterion, as follows from the theory, fluctuate around the equilibrium value.

The above formulae (7) and (8) connect the flow of water Q_x, the gravity component gi, and the erosion resistance ψ. This connection is valid for microstream, stream and river systems on the slopes. However, before using the revealed dependence, it is necessary to get rid of the uncertainty associated with the fact that in each of the systems of two equations (5) and (6) there are three unknown values. In this case, the system of equations can have an infinite number of solutions. Therefore, to get out of this situation, one of the unknowns can be given a specific meaning. In this case, the preference is given to statistically reliably determined experimental values of x_1 and x_2. For specific values, we write:

$$D_1 \equiv x_1 = \frac{\lg Er - \lg A_1}{\lg \lambda}, \quad (19)$$

$$D_2 \equiv x_2 = \frac{\lg Er + \lg \varepsilon - \lg A_2}{\lg \lambda}. \quad (20)$$

The above estimates contain erosion resistance ψ as one of the main characteristics and describe sediment movement and erosion destruction of the underlying surface by a slope flow.

5. Application of the modified Lokhtin criterion to assessing erosion processes in catchment areas

To determine the numerical values of x according to the method described in [17], statistical data were processed on the catchment area of the Tsivil river (Chuvash Republic, Russia), which is about four thousand square kilometres, for a rather large time interval (1950–2010).

The statistically reliable obtained results are the following:

– summer precipitation: x=1.047±0.060;

– autumn precipitation: x=1.185±0.072;

– total catchment area (including rain, groundwater, etc.): x=4.438±0.742.

The closest integer value to the numbers 1.047 and 1.185 is 1, so the choice for the values of x_1 and x_2 to be equal to one becomes obvious. Then the modified Lokhtin criterion can be defined as $\lambda=Qg^7i^7\psi^{-5}$. For a quantitative assessment of the flushing of the surface by a slope flow or run, the ratio $h(gi)^3/(\psi k_r)^2$ is used, where $h(gi)^3$ is the square of the work of gravity on the water transfer through the selected section per unit of time while $(\psi k_r)^2$ is the square of work required for erosion destruction and transportation of a unit of mass of soil per unit of time. The use of the squares of quantities instead of the quantities themselves in this case is preferable due to the nonlinearity of the evaluation scale near the critical value, which is equal to one.

The obtained numerical values made it possible to implement an unambiguous solution of the system of equations (5) and (6) and make the analysis of the processes of runoff and sediment accumulation statistically reliable and theoretically justified. The developed values allow establishing trends in degradation or restoration of the catchment area. Moreover, not only the specific catchment area of a microstream system but also a river system as a whole can be described.

On the territory of the reconstructed irrigation system Druzhba, there are dangerous areas with slopes up to 0.08 (Fig. 1, 2), in which the erosion resistance varies from 3 to 12 J/(s·kg). Let us determine the critical value of the depth of the microstream that flows without destruction and removal by the condition that λ=1 with i=0.08 and ψ=3÷12 J/(s·kg). For grey forest soil, we have an interval from 3.6 to 14.4 mm. This result is of practical importance when using the system of circular irrigation, providing for the supply of the required amount of water to a specific sector (VRI Speed Control) or controlled zone (VRI Zone Control).

It should be noted that the compacted subsoil layer of soil has a strong influence on the rate of water absorption and, consequently, on the formation of the surface runoff. Using the magnitude of the filtration coefficient, rather than the generally accepted value of the density of the soil, as an indicator of the presence of compaction makes it possible to investigate compaction profiles and, having greater information, more accurately localize compactions for decompaction measures. To determine the infiltration and the rate of absorption, experiments were conducted on the main soil types of the Chuvash Republic (Russia). The discrepancy between the experimental data and the results of numerical simulation using any particular model of the pore space averages 15–17 %. However, if we consider the function of moisture conductivity and soil moisture characteristic in the context of pedotransfer functions and "flexibly" select the parameters of the model, the discrepancy decreases to 4–7 %.

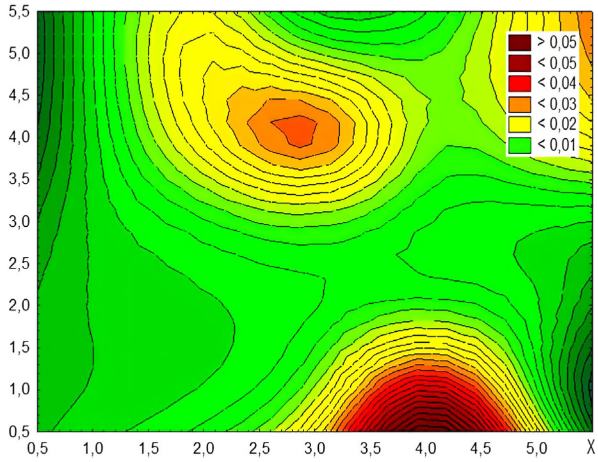

Fig. 1. Spatial distribution of the modified Lokhtin criterion in the territory of the Druzhba irrigation system, Kanashsky District, Chuvash Republic, Russia

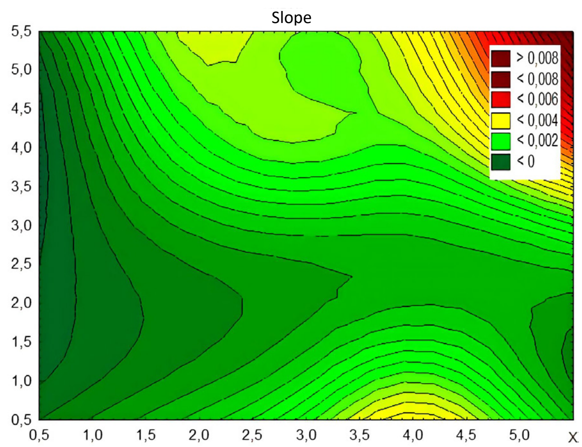

Fig. 2. Spatial distribution of the slope in the territory of the Druzhba irrigation system (Kanashsky District, Chuvash Republic, Russia)

Water that has not been absorbed into the soil flows down the microchannel. The question "Does this occur when soil is washed away or deposited?" can be answered by using the values of the modified Lokhtin criterion calculated for a given point of the field. The modified Lokhtin criterion links the slope, the erosion resistance of the soil, as well as the depth and width of the microstream formed during excessive irrigation.

6. Discussion of the results of applying the modified Lokhtin criterion

The results of applying the modified Lokhtin criterion on the catchment area of the Tsivil river (Chuvash Republic, Russia) show a more adequate prediction of erosion processes in comparison with [17] when analysing a microstream or stream network with characteristic depths from 0.5 cm (smaller sizes were not studied) to 1.5 meters. With a further increase in the depth values, a gradual increase in the deviation of the exponent from unity is observed, which leads to a deterioration in the agreement between theory and practice.

The disadvantages of the study include the fact that for the total catchment area, taking into account rain and groundwater at the same time, the values of x=4.438±0.742 were not considered.

The research development can consist in obtaining and taking into account the theoretical dependences of erosion resistance on the specific surface of the soil of various types and porosity.

At the initial stage of development and verification of model concepts with regard to erosion resistance, it is necessary to have collection and timely processing of large arrays of representative statistical material, which should be obtained from the entire catchment area.

7. Conclusion

1. As a quantity characterizing the erosion resistance of soil, the power used is the energy required for the destruction and removal of a unit of soil mass per unit of time. This value is more informative than just energy, since there is an obvious connection between the erosion losses of the soil and the intensity of the water flow. A quantitative assessment of the erosion resistance of a microstream system was carried out both for periods of snowmelt and for rains, conditionally broken into summer and autumn. Setting specific values eliminates uncertainty and makes the analysis of complex processes of washing away and deposition of soil in a given catchment area fully justified. The role of the modified Lokhtin criterion for the energy interpretation is played by the value of $\lambda=Qg^7i^7\psi^{-5}$, which is determined by the water flow per unit time Q, the gravitational force gi, and the erosion resistance ψ.

2. Modification of the Lokhtin criterion by replacing energy with power ensures objective evaluation of erosion properties. The use of the square of power in the modified Lokhtin criterion makes the comparative scale non-linear, which is especially important near critical values reflecting the presence or absence of soil erosion. The nonlinear, "stretched," scale helps detail the analysis of critical values located near the unit. Developed on the basis of the energy approach, the criteria and the obtained dependencies make it possible to compile an adequate prediction of the direction of evolution of the catchment area in relation to the processes of soil deposition or flushing. The obtained criteria are applicable to both a specific catchment area of microstreams and the catchment area of a river system as a whole.

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