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Degradation of landscapes in the south of the Privolzhsky Upland

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Abstract: Landscapes in the southern part of the Privolzhsky Upland represent a complex ecological system, functioning in severe geomorphological and climatic conditions. The study of erosion degradation and zoning of the southern part of the Privolzhsky Upland, limited by the interfluve of the Volga and Ilovlya rivers, with a total area of 1,156 thousand hectares, where the dissection of the gully and ravine network is 0.4–1.0 km·km^{-2}, reaching in some places 3.5 km·km^{-2} was carried out by the methods of the joint analysis of digital elevation model, large-scale topographic cartographic basis and satellite images of the studied territory, using specialized programs and geographic information systems "Surfer" and "QGIS", using the developed equation (S = 240exp(–(H–98.6)^2/(–2,798.4)) + 2.16), which provides a simulation in landscape analogues. Studies provide an opportunity to identify the quantitative parameters of the landscape for each of the selected contours, to determine the most vulnerable areas to erosion, which will allow us to develop a plan of work to prevent the washing away of the fertile soil layer using the example of our modelling.

Keywords: mapping; soil erosion; modelling; forest plantations

Landscapes of the southern part of the Privolzhsky Upland represent a complex ecological system, functioning in severe subarid conditions, in connection with which it is in a state of unstable equilibrium. Any external influence on this system exceeding the stability threshold removes it from equilibrium and, like any self-regulating system, it tends to return to its original state.

Water and wind erosion of soils, salinity, desertification and other processes leading to the degradation of agricultural lands are among the dangerous processes occurring in the landscapes under consideration. Erosion is one of the most dangerous forms of degradation, causing the destruction of soils and the loss of their fertility.

The territories in the south of Russia are vulnerable to erosion, where 24.3% of the lands are exposed to this type of degradation.

The intensity and spatial distribution of erosion processes determine the decline in the fertility

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of agricultural lands in agro-forestry landscapes, which makes it necessary to identify the indicators that characterize them.

Aerospace researches of landscapes, geo-information technologies and computer modelling open new opportunities for complex estimation of agro-landscapes taking into account the time factor. The works of Rulev and Yuferev (2007), Kulik et al. (2010), Kulik and Yuferev (2010) showed the effectiveness of these methods in studying the changes in landscapes associated with the impact of natural and anthropogenic factors.

The agro-landscapes in the south of the Privolzhsky Upland are confined to the area of medium and severe erosion (Armand 1956). The erosional state of the area under study is distinguished by a high gully and ravine dissection, sometimes exceeding 2 km·km^{-2}, which, combined with the presence of sloping lands, reduces the arable land area, worsens its quality, lowers the groundwater table, etc. Eroded land is characterized by a variety of soil and geomorphological conditions that affect the nature of their economic use.

The relief dissection is determined by the hydrological regime of the territory: by flushing and erosion of the soil, especially on the sloping sides of the eastern and southern exposures (Shvebs 1974). Significant areas of beam slopes with angles of inclination greater than 5° are occupied by washed-out soils, bedrock outcrops. Such a state of landscapes stipulates the need for continuous afforestation of the slopes of beams that are not suitable for agriculture.

The various parts of ravines and gullies differ in soil-geomorphological and vegetative conditions, in the manifestation of soil erosion, in the possibilities for their economic use (Bettis 1983; Dicky, Jasa 1984; Lee 1984; De Roo et al. 1996; Morgan et al. 1998).

In connection with the foregoing, we can conclude that water erosion is the most dangerous of the degradation processes occurring in the Privolzhsky Upland, due to the peculiarities of both geomorphological and climatic conditions.

Based on the analysis of data characterizing the landscape features in the south of the Privolzhsky Upland, it can be concluded that there is a complexly formed landscape with a pronounced dissected relief due to the diversity and high saturation of the erosion forms. The dissection of the gully and beam network is 0.4–1.0 km·km^{-2}, in some places reaching 3.0–3.5 km·km^{-2} or more. The depth of the erosion network incision varies from 40 to 120 m. The features of the landscapes in the southern part of the Privolzhsky Upland with the presence of relatively easy erodible layers do not ensure the stability of the lithological base, creating the prerequisites for erosion. All this together with the basis of erosion, reaching 11 m, determines the predisposition to the manifestation of soil erosion.

The development of erosion degradation, even in conditions of the existing agroforestry-ameliorative complexes, indicates the need for further study of this problem, identification of contributing factors and development of refined agroforestry techniques to prevent this dangerous phenomenon.

MATERIAL AND METHODS

The definition level of the degradation is the main element of their management. At that, it is necessary to establish not only the level of erosion degradation, but also the situation of degraded sites in the landscape. In this regard, the study of erosion degradation and zoning of the territory according to its levels is carried out by the methods of the joint analysis of digital terrain model, large-scale topographic cartographic base and space images of the study area, as well as additional information obtained as a result of field research, using specialized programs and geographic information systems (GIS) "Surfer" (Version 13, Golden Software, USA) and "QGIS" (Version 3.4.8 "Madeira", Free Software Foundation, USA).

Geo-information support of landscape management is now becoming a priority, included in the organization of anti-erosion measures (Gerasimov et al. 2002). Among the most important sources of information about landscapes and their condition are the results of remote sensing – optical and radar images of the surface (Yuferev 2007).

The study of agro-landscapes is carried out using aerial and space surveys and is based on the results of their geomorphological, geo-botanical, soil-ameliorative, erosion and other surveys.

Landscape mapping is based on drawing up a series of maps characterizing the natural potential of the studied area, its environmental conditions, as well as the current state of the natural and territorial complexes. Mapping of agro-landscapes includes: (1) preliminary interpretation of images; (2) field calibration; (3) extrapolation of decryption features; (4) field inspection; (5) final interpretation and mapping (Yuferev et al. 2010).

https://doi.org/10.17221/141/2018-JFS

It is noted here that the interpretation of images for mapping is different from the usual estimation of the structure and texture of the image to identify contours and boundaries of objects and their spatial analysis.

Input spatially distributed data of the model of agro-landscapes are specified in the form of raster electronic maps characterizing the relief, soils, the nature of land use, vegetation in the catchment area, as well as morphometry and hydraulic resistance of the bed and floodplain (Van der Perk et al. 2000). As a result of the simulation, digital flow, flush and accumulation maps are created, as well as tabular data characterizing the course of runoff, flushing, turbidity and final values using large-scale topographic and soil maps and high resolution satellite imagery from GeoEye (Version 1, DigitalGlobe, General Dynamics, USA), WorldView (Version 3, DigitalGlobe, Ball Aerospace & Technologies, USA), and others.

Computer mapping allows solving a wide range of problems in the modelling and study of landscapes:
– determination of coordinates of terrain points;
– determination of land areas;
– construction of three-dimensional models of terrain, etc.

This approach is most consistent with the direction developed for mapping and modelling of erosion degradation in agro-landscapes in the south of the Privolzhsky Upland.

To date, space-based digital scanner imagery in terms of coverage, repeatability and regularity has no other alternative, and by resolution it approaches analogue aerial photographs. The existing databases of archival and actual space images have created a new information environment, with the possibility of constant monitoring of selected research objects. The task that must be solved in this case is the development of methods for analysing information and methodology for developing the required map layers and, on their basis, GIS technologies for mapping agro-forest landscapes (Rulev et al. 2013, 2014).

Thus, the simulation of agro-landscapes in the GIS environment makes it possible to characterize with some certainty their parameters, to reveal the dynamics and to estimate the level of erosion degradation.

RESULTS AND DISCUSSION

The study of the relief features by the developed local digital model based on the global model Aster GDEM makes it possible to develop analytical dependences for the description of stably repeating patterns, calculate the slopes and angles of the slopes for their extent in any direction, which is the basis for creating landscape plans. When processing data of digital models of heights, presented in the form of spreadsheets with regular and irregular steps, algorithms for determining slopes and exposures of slopes were previously developed. They are based on the sliding window method with elevations at the nodes of the regular grid. Examples of data processing and methods are given in the work edited by Yuferev et al. (2010).

As a result of geoinformational studies of the relief of the southern part of the Privolzhsky Upland, limited by the interfluve of the Volga and the Ilovlya rivers, with a total area of 1,156 thousand ha, it has been established that territories with the absolute height of 50–150 m are predominant (Figs 1 and 2),

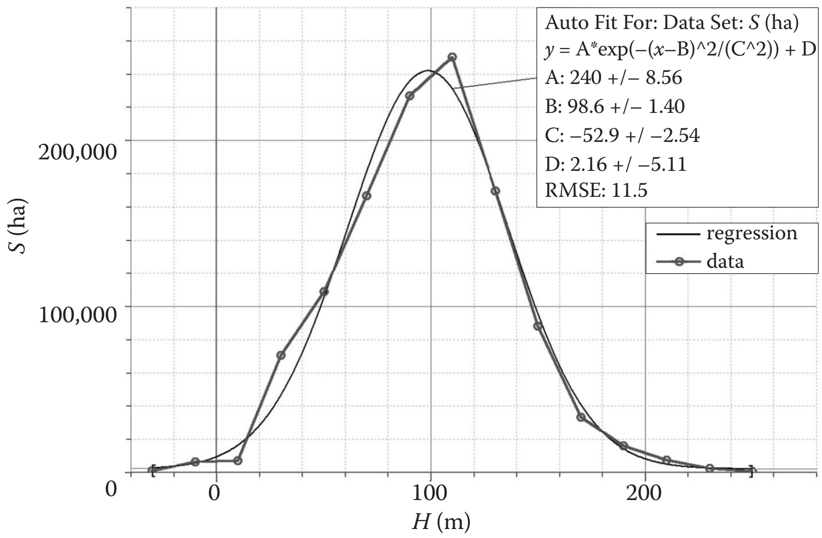
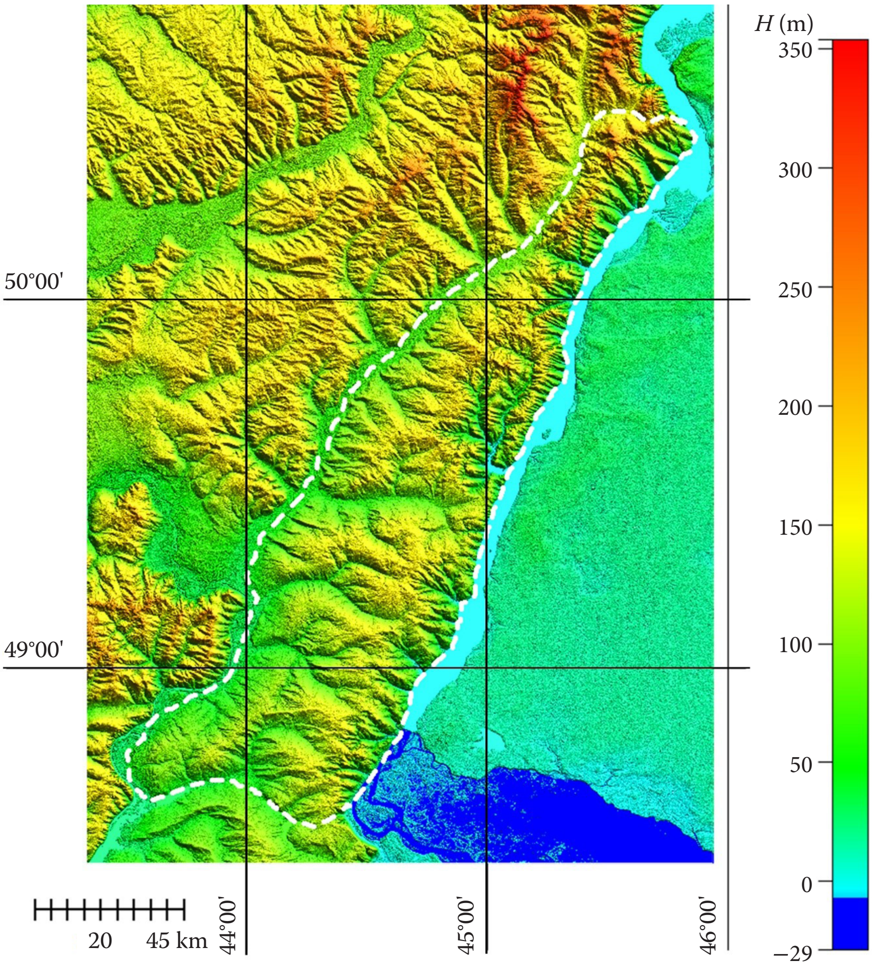


Fig. 1. Distribution of the study area (S) over the absolute altitude ranges (H)

https://doi.org/10.17221/141/2018-JFS



white dashed line – research area boundary

Fig. 2. Digital model of the elevation of the southern part of the Privolzhsky Upland with shaded areas

occupying about 80% of this area. For example, the area of the territory having a height of 120 m is 250,000 ha or about 22% of the total research area. The minimum height is –31 m, the maximum height is 270 m, the average height is 104.9 m, the standard deviation is 41.1 m.

Statistical analysis of the obtained data using the STATISTICS software (Version 6, StatSoft, USA) on the distribution of areas *S* over the altitude ranges of 20 m with the lower boundary of the –30 m ranges showed good agreement with the Gaussian curve (R^2 = 0.986, RMSE = 11.5), the equation of which was found as (Eq. 1):

$$S = 240e^{\frac{(H-68.6)^2}{2,798.4}} + 2.16 \quad (1)$$

where:
S – area (ha);
H – lower limit of the absolute height range (m).

Since cellular-node digital elevation models are inherently discrete, interpolation methods are used to restore the height field at any point, the most commonly used method is universal kriging (Yuferev et al. 2010). Available in modern mapping and geoinformation software packages (Surfer, QGIS) mathematical functions provide both a digital description of the calculated characteristics of the relief and visualization of these calculations. This makes it possible to build maps of the angles of slopes.

The need to determine the slope angles is determined by the task of assessing the risk of water erosion, which involves the calculation of morphometric and soil characteristics, and the level of anthropogenic impact is determined by the equation of soil erosion USLE (Universal Soil Loss Equation), proposed by Wischmeier and Smith (1978).

Statistical analysis of the distribution of slope angles showed that the main background is made up

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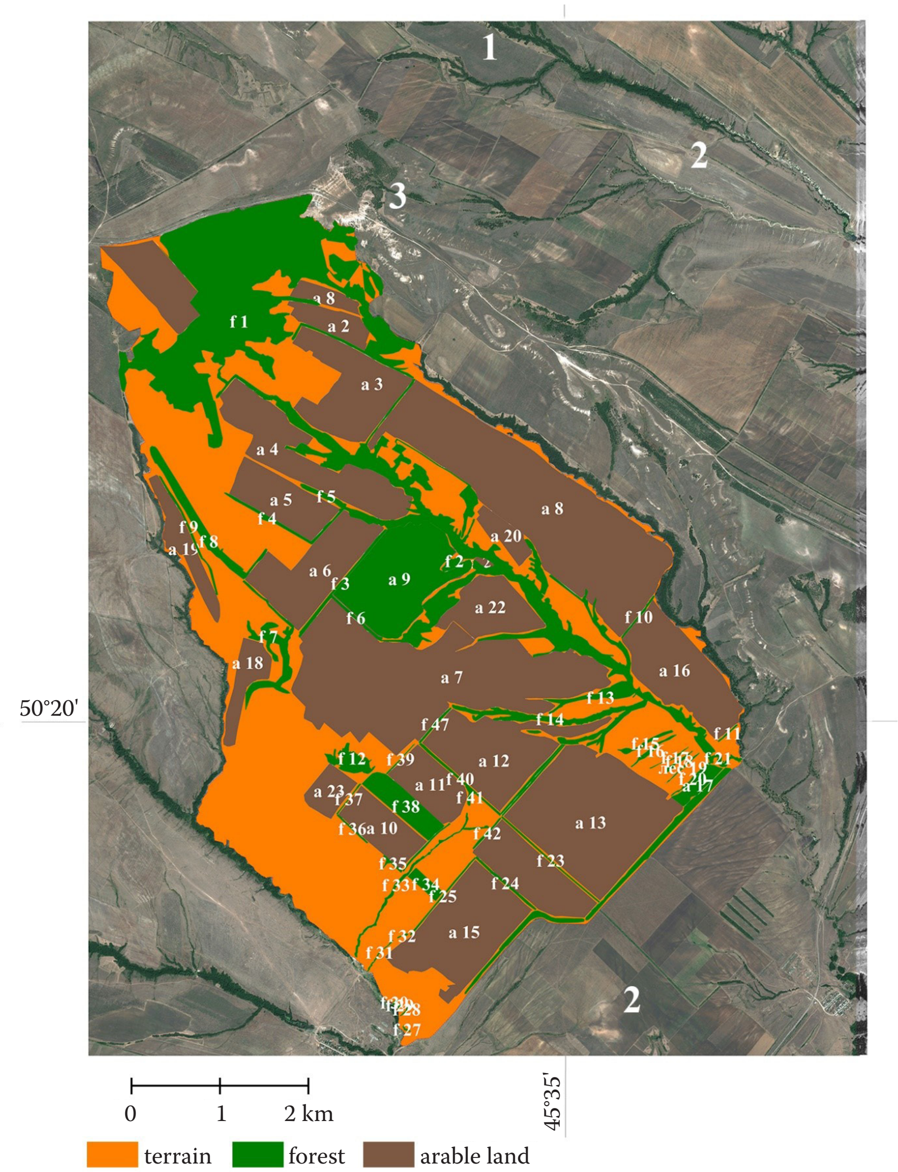

1 – erosion relief, 2 – erosion of the soil, 3 – output of underlying rocks

Fig. 3. Scheme of land location in the research area (f 1–47 – number of forest plantations, a 1–23 – area of arable land)

of areas with angles from 0 to 3°, an average value of 1.6°, a standard deviation of 1.7°. Maps provide the identification of the most dissection territories and the selection of objects for further development of plans for their landscape arrangement.

The area of the catena of the Ilovlinsky catchment area is 776,570 ha, with the length of the tributaries of the first, second and large third order of 1,937.8 km, the total dissection is 0.25 km·km^{-2}. The area of the Volga catchment area is 420,230 ha, the length of the thalweg is 1,634.1 km, the total dissection is 0.39 km·km^{-2}.

Thematic mapping of erosion degradation was carried out in the study of agro-landscapes in the south of the Privolzhsky Upland. The geomorphological research area is represented by structural and denudation terraced areas of the southeastern end of the Privolzhsky Upland. The relief and structure of the territory determined the genesis of the soil-geomorphological catena of the southeastern end of the Privolzhsky Upland with high dissection of the gully and ravine network (up to 1.5 to 2.0 km·km^{-2}). The main relief-forming rocks here are Paleogene-Syzran siliceous marl and siliceous marl-form sandstones, as well as sands and sandstones of the Tsaritsynsky Stage.

As a result of the research carried out by Karandeeva (1957), the general geomorphological char-

https://doi.org/10.17221/141/2018-JFS

acteristics of the territory under consideration were obtained. In contrast, our studies were carried out using a digital elevation model and actual satellite images, comprehensively, taking into account both natural and anthropogenic changes in agricultural landscapes, causing their degradation, while the relief characteristics were revealed and their spatial distribution was established. Methods for assessing the shape of the slopes proposed by Bondarev (1996) assume that when calculating the structural elements of the relief that form its framework (lines of thalwegs and watersheds, keel and ridge, base and top), modelling of surface runoff lines is carried out. In the same way, the boundary of the catchment is established (the watershed line), and the drain lines determine the erosion pattern approximately corresponding to thalwegs.

Fig. 3 presents a generalizing geo-information layer on which the forest resources, arable land and the research area as a whole are highlighted by contours, which is a typical agro-forest landscape with the presence of beam forests, protective forest plantations and agricultural lands typical of the Lower Volga region. In this case, the current satellite imagery was used as a basis for the spatial map and the subsequent allocation of land contours using it makes it possible to determine the degree of erosion degradation taking into account their purpose and location in the landscape. As a result, it was found that the area of arable land is 1,984.75 ha, forest plantations 698.77 ha, pastures 1,135.3 ha in the research area of 3,818.80 ha.

Studies have made it possible to identify the features of the terrain as a research area as a whole, and individual sites. For example, for the plot of "arable land 5" (Fig. 4), it can be noted that the basis of erosion in the considered landscape is 50 m, the height difference is 207 m, and the maximum slope angle is 13.55°.

The maximum slope of the plot used for arable land is observed in the contour "arable land 5", an area of 55 ha, and is equal to 6.48°. The length of the slope is 487 m.

The slope is concave, clearly divided into 2 parts: the average steepness with an average inclination angle of more than 6°, a length of 290 m and a very

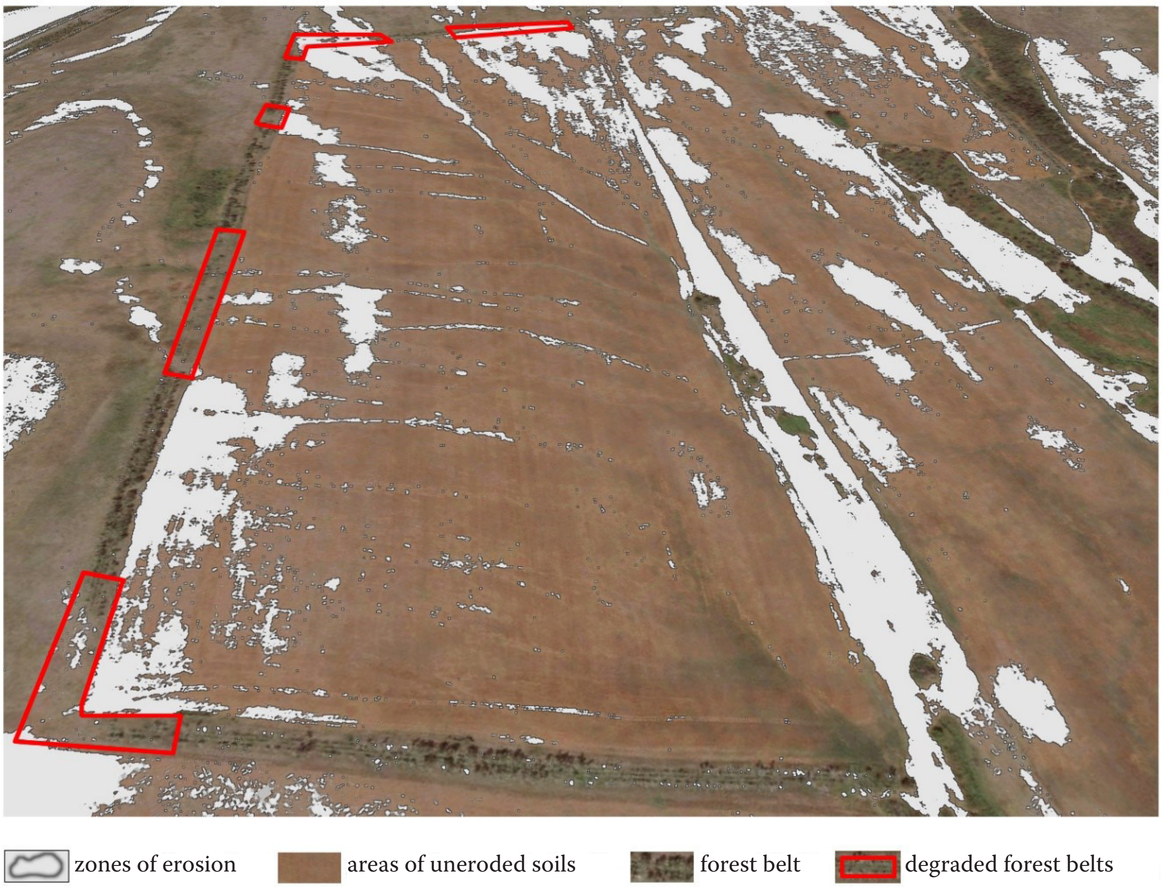

Fig. 4. Visualization of the 3D model of the area of arable land "a 5"

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flat one, with an average angle of 1.6°, a length of 197 m. The height difference in this section is 38 m.

The slope is of medium length. The contour under consideration is now strongly eroded, traces of linear (tautness) and flat (eroded) erosion are clearly visible on the spatial map.

On the perimeter of the contour there are 3 effluent-regulating forest belts. At present, only 2.18 ha, or 42%, remain of 5.16 ha of plantations. The strips, instead of regulating the runoff, concentrate it in this form, so that an increased level of erosion degradation is observed in the places where the plantations die.

CONCLUSIONS

Thus, in the joint geomorphological analysis of the digital elevation model and the spatial map, the quantitative parameters of the relief for each selected contour were identified.

An analysis of the distribution of areas (S, hectare) over the altitude ranges of 20 m (R^2 = 0.986, RMSE = 11.5) allowed to develop an equation in the form $S = 240\exp(-(H-98.6)^2/(-2{,}798.4)) + 2.16$, the use of which provides for the simulation of such a distribution in landscapes analogues.

It is established that the area belonging to the catchment area of the Ilovlya river is 776,570 hectares, with the length of the tributaries of the first, second and third order of 1,937 km, and the total dissection is 0.25 km·km^{-2}. The size of the catchment area of the Volga river is 420,230 hectares, the length of tributaries is 1,634 km, the total dissection is 0.39 km·km^{-2}. Such characteristics indicate vulnerability of landscapes to soil erosion.

It can be noted that mapping and modelling of the geomorphological features of the agro-landscape based on regular satellite images made it possible to proceed to locating and selecting the contours of erosion degradation. At the same time, parts of the landscape were identified by separate contours. Such a selection made it possible to reveal changes in the shape and area of the contours in time.

Geo-information analysis of the territory in the south of the Privolzhsky Upland made it possible to determine the most vulnerable areas to erosion, which would allow choosing the optimal variant of landscape protection in the development of environmental rehabilitation plans and to identify measures to prevent the washing away of fertile soil layer.

References

Armand D.L. (1956): Anthropogenic erosion processes. Agricultural erosion and struggle with it. Moscow, USSR Academy of Sciences: 737. (in Russian)

Bettis E.A. (1983): Gully erosion. Iowa Geology, 8: 12–15.

Bondarev V.P. (1996): Morphometric analysis of gully and ravine systems of the Central Black Soil Region for their classification. Geomorphology, 1: 53–57.

De Roo A.P.J., Wesseling C.G., Ritserma C.J. (1996): LISEM: A single event physically–based hydrologic and soil erosion model for drainage basins. Hydrological Processes, 10: 1107–1117.

Dicky E., Jasa P. (1984): Soil erosion: mechanisms and control. Mitchell Farm, Ranch and Home Quarterly, 30: 6–8.

Gerasimov Yu.Yu., Khlyustov V.K., Kilpelyaynen S.A. (2002): Aerospace Methods in Forestry. Petrozavodsk, Petrozavodsk State University: 248. (in Russian)

Karandeeva, M.V. (1957): Geomorphology of the European Part of the USSR. Moscow, Moscow State University: 10–25. (in Russian)

Kulik K.N., Rulev A.S., Yuferev V.G. (2010): Aerospace monitoring of pastures in conditions of dry steppe and semi-desert. In: Abstracts of reports International Scientific Conference Science, technique and innovation technologies in an epoch of great revival, Ashgabat, June 12–14, 2010: 406–407.

Kulik K.N., Yuferev V.G. (2010): Computer-aided mathematical cartographic modeling of agroforestry landscapes on the basis of aerospace information. Russian Agricultural Sciences, 36: 63–66.

Lee L.K. (1984): Land use and soil loss. Journal of Soil and Water Conservation, 39: 226–228.

Morgan R.P.C., Quinton J.N., Smith R.E. (1998): The European soil erosion model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms, 23: 527–544.

Rulev A.S., Yuferev V.G. (2007): The catena-logistical approach to the estimation and mapping of erosion processes on water catchment areas with the use of spaceaerophotos. In: Proceedings of the tenth international symposium on river sedimentation “Effects of river sediments and channel processes on social, economic and environmental safety”, Moscow, August 1–4, 2007: 348–355. (in Russian)

Rulev A.S., Yuferev V.G., Yuferev M.V. (2013): Geoinformational studies of erosion degradation in agricultural landscapes. Proceedings of Nizhnevolzhsky Agrouniversity Complex: Science and Higher Professional Education, 2: 84–88. (in Russian)

Rulev A.S., Yuferev V.G., Yuferev M.V. (2014): Simulation of agrolandscapes. Proceedings of Nizhnevolzhsky agrouni-

https://doi.org/10.17221/141/2018-JFS

versity complex: science and higher professional education, 2: 14–18. (in Russian)

Shvebs G.I. (1974): Formation of water erosion of runoff, sediments and their assessment. Moscow, Gidrometeoizdat: 182. (in Russian)

Van der Perk M., Svetlichny A.A., Den Besten J.W., Wielinga A. (2000): Spatial redistribution of radionuclides within catchments: development of GIS-based models for decision support systems (SPARTACUS). Utrecht, Utrecht University: 165.

Wischmeier W.H., Smith D.D. (1978): Predicting rainfall Erosion losses. A guide to conservation planning. Maryland. The USDA Agricultural Handbook, 537: 65.

Yuferev V.G. (2007): Remote monitoring of the condition and dynamics of agrolandscapes. Agriculture, 3: 8–9. (in Russian)

Yuferev V.G., Kulik K.N., Rulev A.S. (2010): Geoinformation technologies in agroforestry. Volgograd, All-Russia Scientific Research Institute of Agroforestry: 102. (in Russian)

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