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Problems of spatially distributed quantitative evaluation of soil erosion losses

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ABSTRACT

Formulation of the problem. Water erosion of soils is the most widespread and dangerous soil degradation process in Ukraine. The development of an effective system of soil protection measures requires the use of spatially distributed mathematical models of soil erosion losses. This, in turn, highlights the problem of spatially distributed source data, which adequately reflect the spatial differentiation of factors of the erosion process, among which the main one is the relief.

The purpose of the article. Assessing the adequacy of available spatially distributed source data, including cartographic and freely distributed global digital elevation models (DEMs), for spatially distributed quantitative assessment of soil erosion losses at the local level of territorial coverage is the aim of the article. Assessing from this point of view the scale of the original cartographic data, different global DEMs and their spatial resolution, as well as the degree of spatial generalization of the original data.

Materials and methods. The solution of the set tasks was performed by the method of simulation modeling with the use of physical-statistical GIS-realized mathematical model of soil erosion-accumulation, developed at Odessa I. I. Mechnikov National University. Source data arrays were tested with DEMs SRTM90 and SRTM30 with a spatial resolution of 3 and 1 angular seconds, respectively, and AW3D30 with a spatial resolution of 1 angular second, as well as with cartographic DEMs based on topographic maps of scale 1:10000 and 1:25000. For testing the initial data, three test plots with an area of 2.67, 0.59 and 0.21 km^2 were selected. The plots are located in the Balta district of Odessa region on the southern spurs of the Podolska upland.

Results. It is established that freely distributed global digital elevation models SRTM and AW3D30 in the conditions of flat terrain do not always allow to adequately display the structure of slope runoff and, accordingly, to correctly perform calculations of soil erosion losses. The maximum deviation of the average soil erosion losses calculated for the test plots using global DEMs from the soil losses calculated using the reference DEM for SRTM30 and AW3D30 was 27%, for SRTM90 – almost 70%. The distribution of soil losses over the area of test plots obtained using different global DEMs differs even more.

When using DEM based on topographic maps, reducing the scale of the original maps from 1: 10000 to 1: 25000 leads to a decrease in the average value of soil erosion losses by about 20% due mainly to reducing the magnitude and area of distribution of maximum soil losses, and on slopes of complex shape also due to changes in the area of accumulation zones. The degree of spatial generalization of the initial data significantly affects the results of the assessment of soil erosion losses both in relation to the average values and their distribution over the area. For small areas, the use of raster cells larger than 50 m is impractical.

Scientific novelty and practical significance. It has been shown for the first time that in the conditions of flat terrain at the local level of spatial coverage, the freely distributed global DEM SRTM and AW3D30 are not always hydrologically correct. The reasons and conditions of violation of this correctness are specified. It has been established that the global DEM AW3D30 has local instrumental errors that may make it impossible to use it. The most realistic values of soil erosion losses are provided by DEM SRTM with a spatial resolution of 1 angular second.

***Keywords**: soil erosion, spatially-distributed assessment, global DEMs, cartographic DEMs.*

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Formulation of the problem. Water erosion is the most common soil degradation process in Ukraine, affecting almost all components of the landscapes and causing enormous economic and environmental damage. The end result of the development of erosional soil degradation is desertification [2]. According to the National Report [5], about 16 million hectares of agricultural land or 38.4% of their area, including 12.94 million hectares of arable land or 39.9% of their area, are eroded to varying degrees. Soil erosion is common in all over natural areas of Ukraine, but especially – in the north of the steppe and the south of forest-steppe zones, where the so-called zone of maximum erosion is located [14].

Given the prevalence of water erosion of soils in all over natural zones of Ukraine, it is important to develop a complex of anti-erosion measures to prevent erosion degradation of agricultural landscapes. In conditions of increasing erosion danger of agricultural lands, the protection of soils from water erosion can be provided only on the base of adaptive-landscape farming systems, which take into account the spatial differentiation of all major factors of water erosion. The leading role in the substantiation of soil protection complexes belongs to the mathematical model of soil erosion losses, which adequately takes into account the impact on the process of soil erosion of both natural and economic factors. Given that all these factors are characterized by complex spatial distributions, such a mathematical model must be, firstly, spatially distributed, and secondly, provided with the necessary spatial information.

Relief plays the greatest role in the spatial differentiation of soil erosion, providing a complex distribution on the surface of sloping lands of heat, moisture, surface runoff, the nature and intensity of the erosion and accumulation. At the same time, the informational support of the relief factor of soil erosion is the most difficult challenge.

Digital elevation models (DEM) are the basis of information support of modern mathematical models of soil erosion. Until recently, digital elevation models were typically built on the base of topographic maps of scale ranging from 1:10000 to 1:100000. Unfortunately, in our country only the last ones are publicly available. But for soil protective designing within an agricultural enterprise or farm the maps of scale 1:25000 or more detailed are required. If such maps can be used, the inevitable problem is the high laboriousness of creating DEMs based on them. The situation has changed dramatically in recent years with the advent of freely distributed global DEMs of high spatial resolution (3 and 1 arc seconds), built on the basis of remote sensing of the earth's surface. These are currently the SRTM digital elevation models developed by the National Aeronautics and Space Administration (NASA) and the Geological Survey of United States [21], the ASTER GDEM developed jointly by the Ministry of Economy, Trade and Industry of Japan (METI) and NASA [15], as well as the "digital surface model" or "digital elevation model" Alos World 3D-30 m (AW3D30), created by the Japan Aerospace Exploration Agency – JAXA) [25].

Analysis of previous research. To date, a large number of studies have been conducted in various countries to assess the accuracy of digital elevation models SRTM and ASTER, to a much lesser extent – AW3D30. The vast majority of studies have assessed the compliance of global DEMs with some referential DEMs. A digital elevation model built for the test site based on either instrumental surveying of the terrain, or geodetic reference marks or digitization of a topographic map ("cartographic DEM") was used as a reference DEM. The mean square error (RMSE), correlation coefficient (R) or Nash-Sutcliffe conformity criterion (NS) were most often used as evaluation criteria. A fairly detailed review of the results of these studies is presented in [11].

The assessment of the suitability of global DEMs for soil loss calculations has only just begun. However, in most studies on this issue, the accuracy of calculations on the basis of freely distributed global DEM only geomorphological indicators that to some extent determine soil erosion losses was evaluated. Only in works [4, 19, 23] the global DEMs SRTM and ASTER evaluated in terms of their direct application to quantify soil losses. In these works, the Universal Soil Loss Equation (USLE / RUSLE) [22, 27] was used, which has only a profile version and, strictly speaking, is not a spatially distributed model. In [4] an erosion model of the State Hydrological Institute [1] was used to calculate the spring soil erosion losses in which the terrain is taken into account very roughly. In [11] presents the results of a study of the application of global DEMs SRTM, ASTER and AW3D30 for calculations of soil erosion based on a spatially distributed mathematical model for a fairly large area (about 340 km^2) using as a reference DEM the cartographic digital elevation model which built on the base of a topographic map of 1: 25000 scale.

In general, it can be stated that the results obtained in research on this problem are of undoubted theoretical and practical interest. They provided an overall positive answer to the question of the possibility of using global DEMs for erosion calculations, made certain conclusions about possible limitations. However, in some respects the conclusions are contradictory. Many aspects of the use of global DEMs for spatially distributed assessment of soil erosion instead of or together with traditional sources of data about relief at different levels of territorial coverage, including local, have not been explored.

The purpose and objectives of the study. The purpose of the article is to assess the adequacy of various source data, including global DEMs based on remote sensing data, for spatially distributed quantitative assessment of soil erosion losses at the local level of territorial coverage. Assessment of the impact on the results of water erosion calculations of the scale of the original cartographic data, different global DEMs and the degree of their spatial resolution, as well as the degree of spatial generalization of the original data are the tasks that achieve the goal.

Materials and methods of research. Three plots K1, K2, K3 which are situated within the territory of the educational and scientific center of geology and geography faculty of Odesa I. I. Mechnikov National University "Krynychky" are chosen for the purpose of testing of initial data. The center is located in Balta district of Odesa region, on southern hillsides of Podolska upland (Fig. 1).

The test plot K1 is a part of the left slope of the dry valley Labushna. The area is 2.67 km^2. The slope is southwestern exposition. Average length from the watershed line to the valley bottom is 800 m. The transverse profile has a complex convex-concaveconvex form. Slope gradients change from 1-2° in the upper slope part to 11-15° closer to valley bottom. The soil cover is represented by typical chernozems on heavy loams of various degrees eroded, as well as accumulated (about 4% of the plot area).

Upper part of the plot is intensively used for pl-

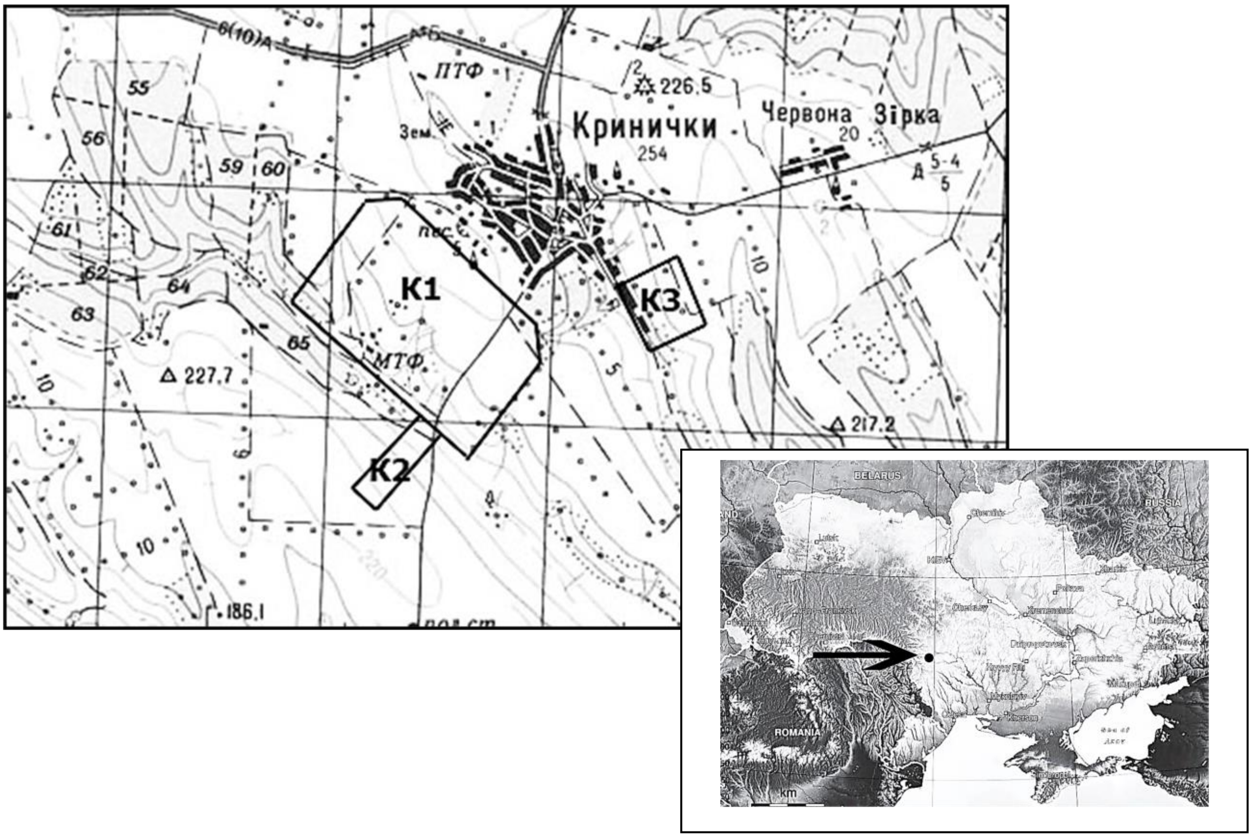

Fig. 1. Location of the test plots and a fragment of topographic map scale 1:100000 with plots boundaries

anting agricultural crops (cereals, sunflower, corn). The lower part of the plot is occupied by natural vegetation with species which are typical for dry grassland of the forest-steppe zone are predominant there. The projective covering of natural vegetation is 70-100%. The thickness of grass waste is about 1 cm, and root mat is about 2 cm. The valley bottom is also plowed up.

Plot K1 is divided by hollows and ravines in the middle and bottom part. One of the ravines (in the middle part of the plot) is covered by artificial forest which is 50 years old. The area of the forest is about 9 ha. There is a forest shelter-belt remainder along the road which is directed from Krynychky village to the southern west (Fig. 1). Somewhere alone trees and bushes also occur within the lower part of the plot.

The test plot K2 is situated on the opposite slope of the dry valley Labushna. The slope is northeastern exposition. The plot area is 0.21 km^2. The length is 750 m, the average slope gradient is 5.5°, and maximum one is 8.5°. The transverse slope profile is convex. On the bottom part of the plot the heavy diluvial sediments are observed. In the lower part of the plot there is a powerful diluvial plume, in the middle part a hollow up to 1 m deep was formed, which is weakly reflected on the existing topographic maps. Soils are regraded chernozems on heavy loam which are eroded especially in the middle and bottom parts. The plot is completely plowed. In spite of the big slope gradients and eroded soils the plot is annually used for cultivation agricultural crops (sunflower, soybean, barley, rape etc.).

The test plot K3 is situated on the left slope of the middle part of the dry valley Krynychanska. The slope is southwestern exposition. The area is 0.59 km^2. The average hill length is 350 m, and the length from watershed line to bottom is 700 m. The transverse slope profile is convex in the most part. The slope is 1-3° in the upper part, 6-7° in the middle part and within the lower part it exceeds 7°, sometimes reaching 15-18°. The soil cover is represented by typical chernozems on heavy clays, eroded to varying degrees.

The upper part of the plot is plowed. The lower part is covered by natural vegetation with the predominance of typical gramineous species of forest-steppe herbs. Its projective covering ranges from 60 to 90%. Characteristic of this part of the plot are the remains of vines, as well as groups of trees and shrubs, located sporadically. The valley bottom is sheeted by herbs and weeds and is used like livestock pasture.

Topographic maps of scales 1: 10000 and M 1:25000, fragments of global digital elevation models SRTM with spatial resolution 3" (about 90 m), which hereinafter will be called SRTM90, SRTM with spatial resolution 1" (about 30 m), hereinafter - SRTM30, and AW3D30 with a spatial resolution of 1" were used as source data on the relief. The initial raster cell size of DEM created on the basis 1:10000 scale map is 10 m (in the article this DEM called "topo10") and on the basis of 1:25000 scale map is 30 m (“topo30”). The global DEM ASTER is not used in the research because of instrumental errors, which were not put away in postprocessing [4, 11].

The creation of a digital soil map and a map of land use of the test plots was performed on the basis of the relevant paper maps, a space image from the Internet service Google Earth and materials from the authors' field research.

The spatially distributed physical-statistical model of rainstorm erosion-sedimentation of soil is used like a working model implemented using the language and analytic abilities of package for environmental modelling PCRaster [20] and program language Visual Basic. The model was developed and programmatically implemented at the Department of Physical Geography, Nature Management and Geoinformation Technologies of I. I. Mechnikov Odessa National University [6, 7, 9, 10, 12] on the basis of logical-mathematical model of soil erosion losses by H. I. Shvebs [13, 14]. The advantage of the model is taking into account the non-stationarity of stormwater erosion-accumulation process, spatial variability of all factors of water erosion, complex spatial structure of surface runoff and independent verification for the conditions of the Forest-Steppe and Steppe zones of Ukraine.

Results. ***Assessing the adequacy of global DEMs***. The results of calculations of soil erosion losses using cartographic DEM topo30, which was considered at this stage of the study as a reference DEM, and global DEMs AW3D30, SRTM30 and SRTM90 for test plots K1-K3 are presented in Table 1 and in Fig. 2-4. In order to identify the impact of the features of the DEMs on the results, calculations of soil erosion losses were carried out under the assumption that the territory of the test plots is completely plowed, anti-erosion measures are not carried out. That is, the so-called “potential” soil losses were calculated. At the same time, for the K2 plot, soil erosion losses calculations using the AW3D30 DEM were not performed due to the presence in the middle part of the plot of an explicit “artifact” – a practically horizontal diamond-shaped “terrace” with a maximum width of about 150 m.

The calculated area average soil erosion losses obtained using global DEM, less than calculated using the reference DEM by 8.4-27.0%. In this case, for digital elevation models with a spatial resolution 1" (AW3D30 and SRTM30) values of the average soil losses differ the most from those obtained using reference-DEM for the plot K3 (21.6-27.0%), and for DEM SRTM90 with a spatial resolution of 3" – for the plot K2 (by 21.9%).

The spatial distributions of soil erosion losses over the area of test plots, obtained using different digital elevation models, differs even more (Fig. 6-8). Firstly, these distributions are characterized by different values of the coefficient of variation, which varies from 1.14 (for DEM SRTM90) to 2.21 (for DEM AW3D30). Secondly, the ratio between the parts of the area of the test plots with different values of soil erosion losses and, accordingly, with different erosion hazards differ significantly. It should be emphasized that these differences are manifested in different ways in different test plots (Fig. 2-4).

Thus, for test plots K1 and K2 the spatial distribution of soil losses, calculated using the global DEM SRTM90, is characterized by significantly smaller compared to the reference DEM and other DEMs areas of accumulation zone (<0 t/ha/year) and

Table 1

Soil erosion losses averaged over the area of the test plots, calculated using various DEMs

Test plot	Characteristic	Digital elevation model			
		topo25	AW3D30	SRTM30	SRTM90
K1	Average soil losses, t/ha/yr	10.7	8.80	9.05	8.44
	Part relative to losses obtained using reference DEM, %	100	82.2	84.5	78.9
K2	Average soil losses, t/ha/yr	26.9	-*	23.8	21.0
	Part relative to losses obtained using reference DEM, %	100	-*	88.5	78.1
K3	Average soil losses, t/ha/yr	16.7	13.1	12.2	15.3
	Part relative to losses obtained using reference DEM, %	100	78.4	73.0	91.6

* digital elevation model AW3D30 of the plot was rejected

catastrophic soil erosion losses zone (>50 t/ha/year). Within the plot K3, the area of the accumulation zone for all global DEMs is approximately the same, and the area of the catastrophic soil loss zone is significantly different. A similar situation is typical for other ranges of soil erosion losses. For test plot K1, the best correspondence of the spatial distribution of the calculated soil losses of the reference distribution was obtained using the DEM AW3D30, for which only the areas of the accumulation zone differ significantly (7.7 and 12.5%, respectively). For the plot K2, the DEM AW3D30 could not be used due to existing errors in this relief model. For the plot K3 the situation is opposite to K1 - only the areas of the accumulation zone are close to each other, the areas of all other gradations of soil erosion losses differ significantly from each other.

The analysis of digital elevation models used in the study showed that the difference between the global DEMs and cartographic DEM is, firstly, due to the fact that global DEMs are, strictly speaking, digital surface models that take into account the altitude of artificial and natural objects located within the territory. In the test plots, these objects are represented by soil-protective forest plantations in the form of separate massifs of trees (including an area of approximately 9 ha in plot K1) and sporadically located individual groups of silver sucker, hawthorn, wild

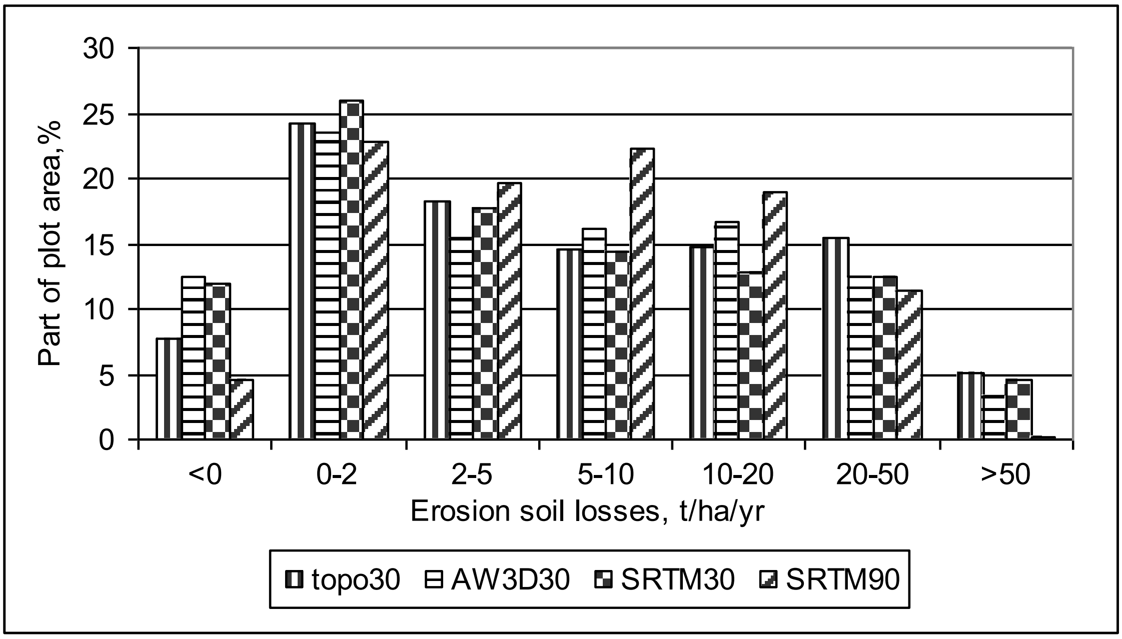

Fig. 2. Distribution of soil erosion losses, calculated using different DEMs, over the area of plot K1

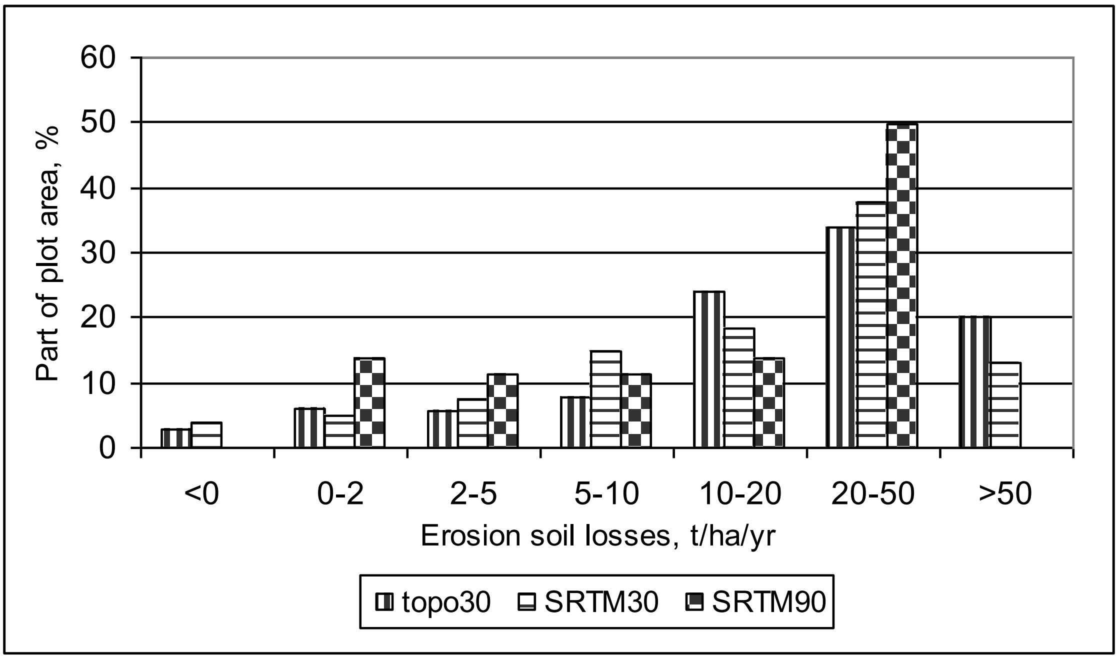

Fig. 3. Distribution of soil erosion losses, calculated using different DEMs, over the area of plot K2

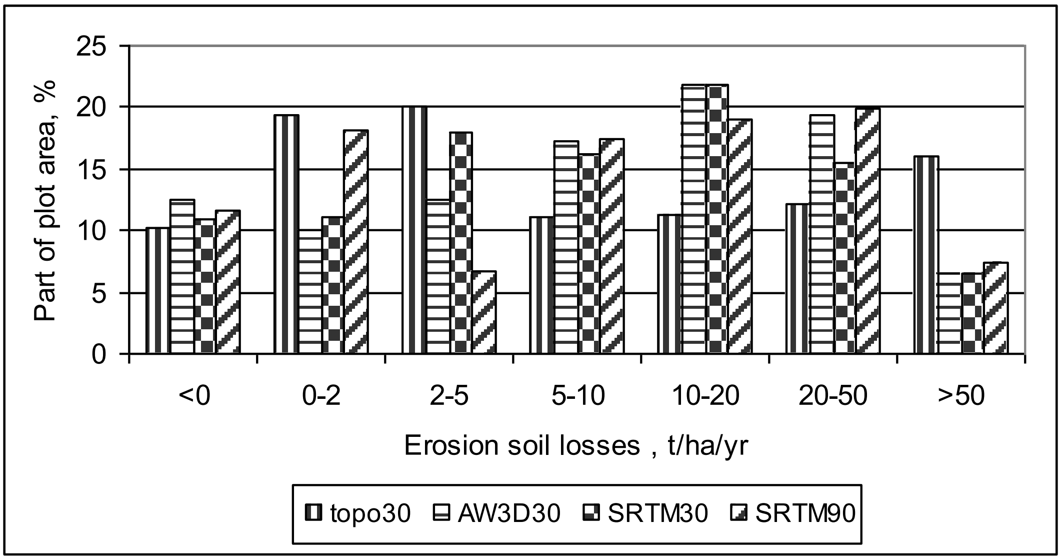

Fig. 4. Distribution of soil erosion losses, calculated using different DEMs, over the area of plot K3

pear and apple on beam slopes, and soil-protective forest belts, and their remains 3-5 m wide on agricultural lands.

Secondly, for agricultural lands, perhaps the main reason for the differences is the publication of matrixes of heights of most global DEMs with rounding of surface heights to whole meters. This rounding at small slope's gradients of the surface, characteristic within the study area for the upper parts of slopes near watersheds, has a significant impact on the magnitude of the length of flow lines, the distances from a certain location on the slope to the local watershed along the path of water movement. As a result, the artificial "hilly" surface with short multidirectional slopes and closed drainless depressions form because of such rounding on DEMs with high resolution [11]. In this regard, firstly, the influence of the upper part of the slopes is actually excluded from the calculation of such an important parameter of the soil erosion model as the length of the flow line, and secondly, a large number of short slopes appear. From the Table. 2 it clearly shows that for digital elevation models of 30-meter spatial resolution (AW3D30 and SRTM30) the estimated average length of flow lines in the test plot K1 and K3 is almost 2 times less than obtained using a cartographic DEM. At the same time, the average slope gradients calculated using these global DEMs differ from the average slope gradients of the reference DEM slightly, but in different ways – from -6 to + 17%.

Table 2

Average lengths of flow lines and slope gradients for different digital elevation models

Test plot	Parameter	Digital elevation model			
		topo25	AW3D30	SRTM30	SRTM90
K1	Average lengths of flow lines, m	376	180	250	369
	Average slope gradients, ‰	49.8	53.4	46.6	39.6
K3	Average lengths of flow lines, m	306	164	142	270
	Average slope gradients, ‰	67.2	78.8	74.1	62.1

The situation is different for the DEM SRTM90. Due to the three times lower spatial resolution and correspondingly larger raster cell size, the effect of rounding the surface heights to whole meters on the construction of the map of flow lines and, accordingly, their estimated length is much smaller. Their average length differs from the average length of flow lines calculated using the reference DEM by only 2-12%. In addition, the DEM SRTM90 is characterized by 8-20% smaller compared to the DEM topo30 slope gradients, but here, obviously, is affectted by a 9-fold increase.

Considering the reasons for the differences between the global DEMs, it is impossible not to mention the technical features of the survey, in particular, its original spatial resolution. Thus, the spatial resolution of shooting of digital elevation models SRTM is 10x20 m, digital elevation model AW3D30 - 5x5 m. Subsequently, when constructing a DEM with a spatial resolution of 1" (about 30 m) and 3" (about 90 m), the initial information was generalized. However, analysis of the global DEM SRTM30 and, especially, DEM AW3D30 shows that the effect of the original spatial resolution on them can be traced.

An attempt to eliminate the irregularity of the digital terrain models AW3D30 and SRTM30 at low slope gradients using the procedure of their sliding averaging in the window 3x3 of the raster cell size did not give a positive result. Although the values of the average soil losses, flow lengths and slope gradients obtained using smoothed DEMs became closer to the corresponding values obtained using the reference DEM, the correspondence of the spatial distributions of erosion dangerous within the test plots as a whole did not significantly improve.

The area average soil erosion losses are of interest from the point of view of the general assessment of the intensity of the erosion situation within the considered territory. The difference between the calculated average values of the soil erosion losses of 20-25% can even be considered acceptable. But for the design of soil protection systems of agriculture is important namely the spatial distribution of soil erosion losses and, accordingly, erosion hazard within the design area. Studies have shown that none of the tested global DEMs provides a sufficiently complete correspondence of the spatial distribution of the calculated soil erosion losses of the distribution obtained using the reference DEM for all test plots.

The digital relief model, designed for spatially distributed calculations of soil erosion losses, must be hydrologically correct, providing the generation of an adequate map of water flow lines for the study or design area. Unfortunately, today's freely distributed global DEMs do not fully comply with this requirement. In this regard, their use for the design of soil protection systems against erosion, including on the basis of adaptive-landscape farming systems, requires careful preliminary analysis.

Assessment of the impact of the scale of cartographic basis, which is usually used for the territory of agricultural enterprise, is based on comparing the results of calculations of soil erosion losses using an array of digital maps based on digitization of paper maps at a scale of 1: 10000 (topo10) and 1: 25000 (topo25). As a result, it was obtained that when reducing the scale of the cartographic basis from 1: 10000 to 1: 25000, the average over area soil losses decreases by about 20%. This is mainly due to changes in the share of the area with a catastrophic soil erosion loss (>50 t/ha/year), which usually decreases (Fig. 5) and possibly due to changes in the

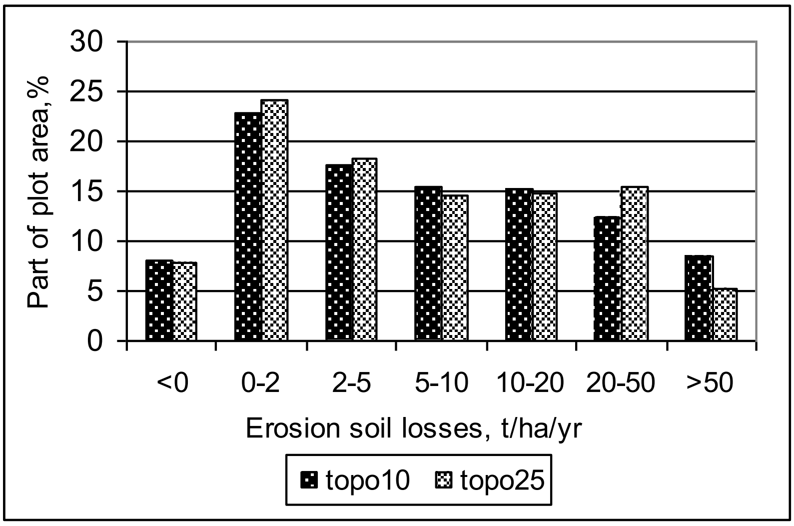

Fig. 5. Distribution of soil erosion losses calculated using cartographic DEMs topo10 and topo25 over the area of plot K1

area of accumulation zones (<0 t/ha/year).

Assessment of impact of the initial data spatial generalization on calculated soil erosion losses is made by application of raster cells sizes 10, 20, 30, 50, 70 and 90 meters. In this case the DEM by raster cell size 10 meters constructed on the basis of the 1:10000 scale paper map is considered like a reference one.

The implemented calculations of soil losses in current land use conditions and soil cover structure make it clear that the results are extremely susceptible to the range of initial data spatial generalization (Table 3). The difference in the area average soil losses can equal almost 70%. In most cases, the increase of raster cell size demonstrates the decreasing area average soil losses on 1.1 – 67.9 %. But the decrease is not monotonous. For the plots K1 and K3 there are defined local maximum values of average soil losses for raster cell size 30 m, and for the plot K2 – for raster cell size 70 m. Thus, on all three plots the greatest decrease in soil erosion losses takes place at the size of a cell of a raster of 90 m.

The general tendency of decrease in calculated erosion losses of soil with increase in spatial generalization of initial data received in research is quite expected and confirms the results received earlier [8, 23]. But the absence of monotony of those changes is not exactly expected. The used mathematical model of soil erosion allows to take into account not only the average values of one or another erosion factor, but also their spatial distributions, which can be quite complex. The result is a complex spatial structure of the calculated soil erosion losses. In particular, the map of soil losses shows the alternation of zones of washout and accumulation, showing "waves" in the distribution of soil erosion losses along the slopes. (Fig. 6).

As the raster cell is enlarged, the longitudinal

Table 3

Soil erosion losses averaged over the area of the test plots, calculated using different raster cell sizes

Test plot	Characteristics	Raster cell size, m					
		10	20	30	50	70	90
K1	Average soil losses, t/ha/year	5.8	4.3	5.8	5.7	4.8	2.7
	Fraction of soil losses in comparison with cell size 10 m, %	100	74.1	100.0	98.3	82.8	46.6
K2	Average soil losses, t/ha/year	27.3	27.0	26.9	26.9	28.1	25.2
	Fraction of soil losses in comparison with cell size 10 m, %	100	98.9	98.5	98.5	102.9	92.3
K3	Average soil losses, t/ha/year	5.3	4.1	4.8	4.2	4.5	1.7
	Fraction of soil losses in comparison with cell size 10 m, %	100	77.4	90.6	79.2	84.9	32.1

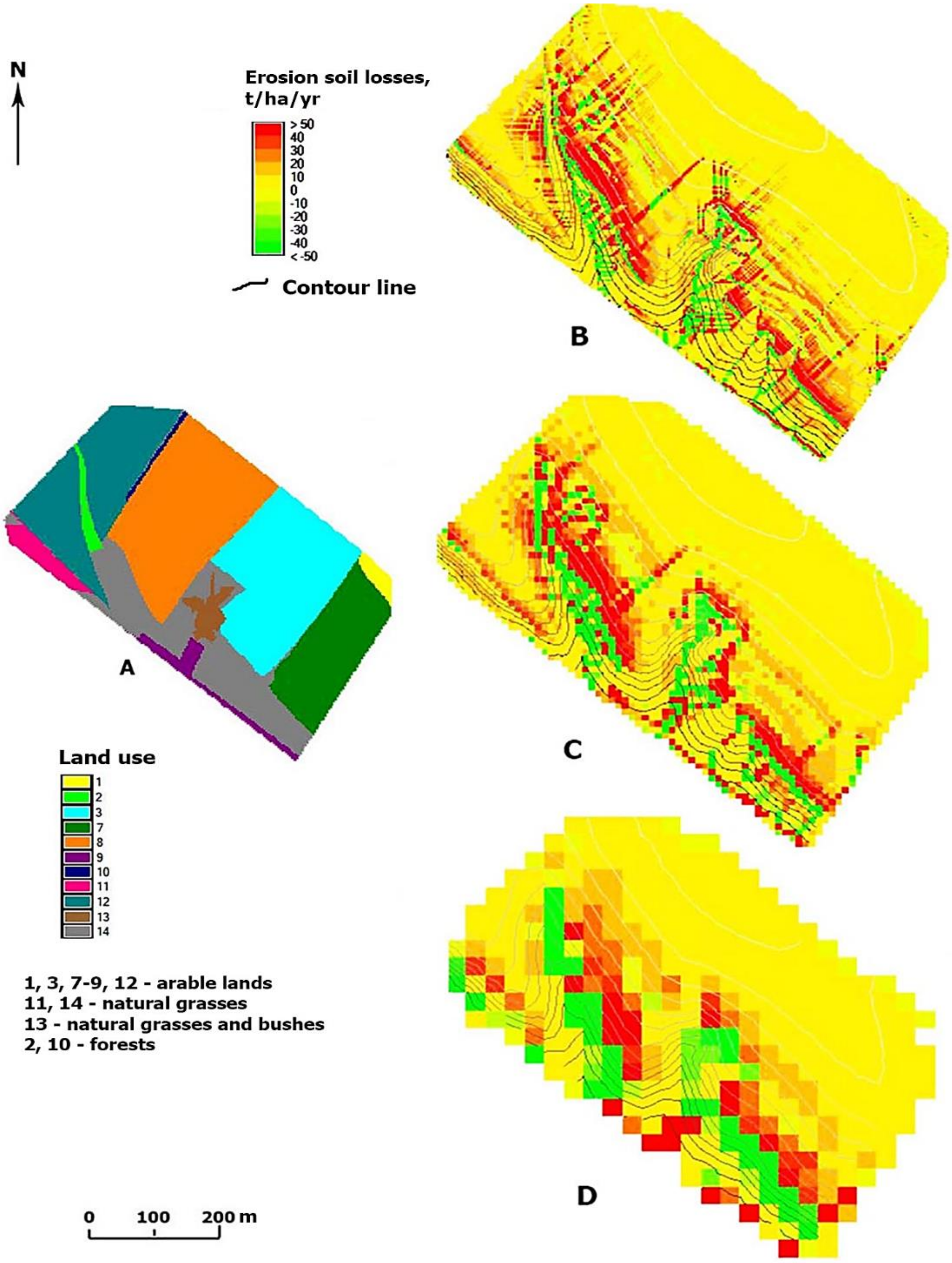

Fig. 6. Land use map (A) and maps of soil erosion losses calculated using raster cell size of 10 m (B), 30 m (C) and 90 m (D) for test plot K1

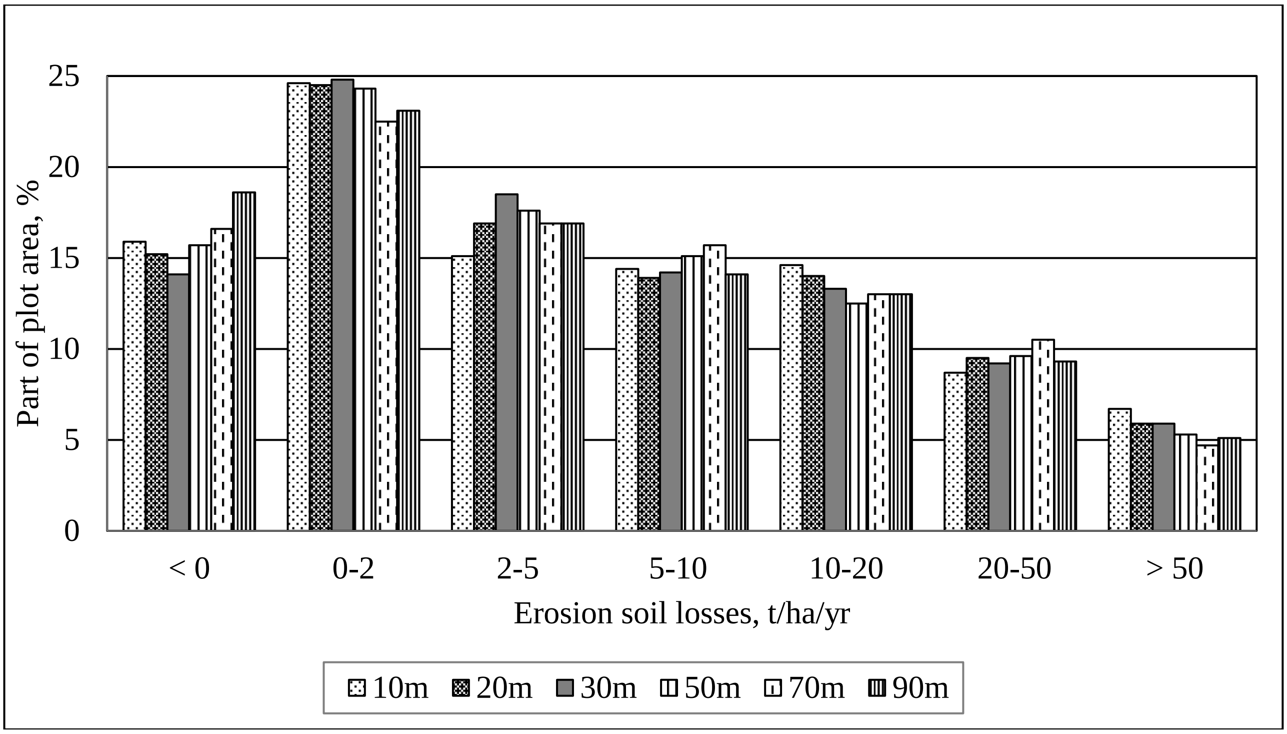

Fig. 7. Spatial distribution of erosion soil losses for the test plot K1

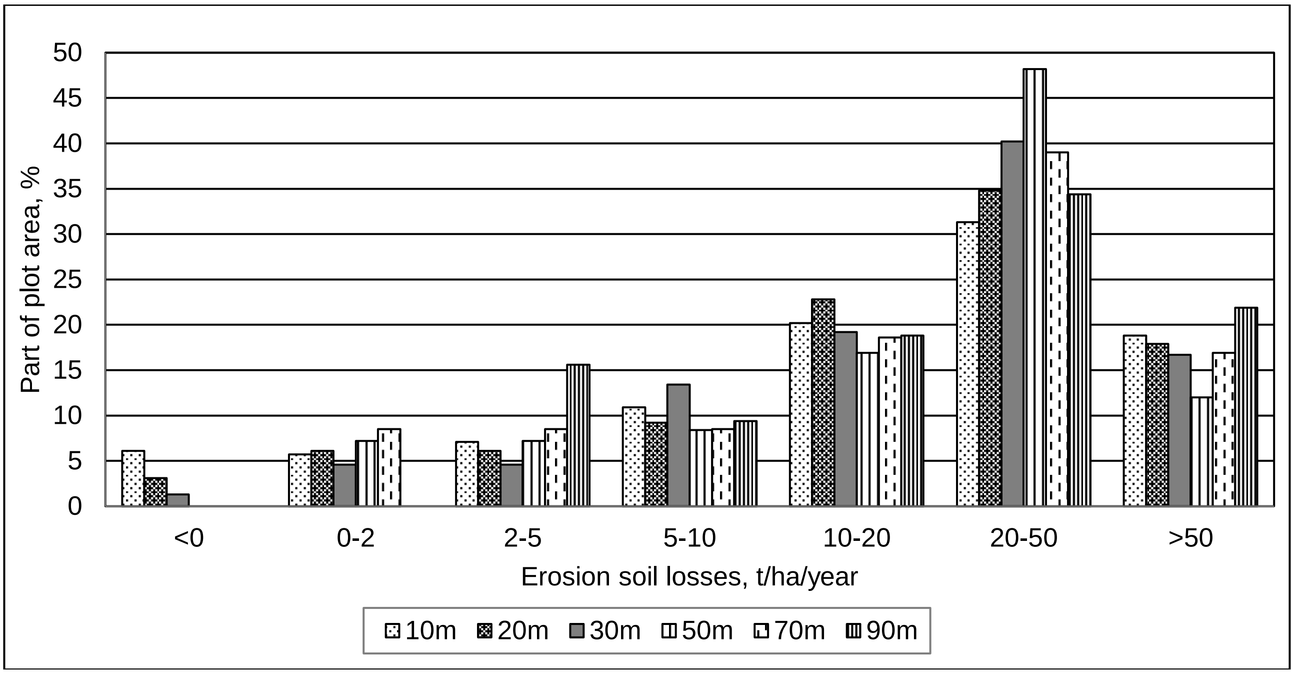

Fig. 8. Spatial distribution of erosion soil losses for the test plot K2

and transverse shape of the slope and the spatial structure of the surface runoff are simplified accordingly. All small relief forms within the slope “disappear”. The "wave-likeness" of changes in soil losses along the slope also disappears. The contribution of the spatial distribution of erosion factors to the amount of soil erosion losses is leveled. As a result, when the raster cell increases, contrary to the general trend average soil losses can suddenly increase locally.

In general, for the test plot K1 the average soil losses which is the nearest to the reference value obtained using raster cell size 30 m. For the test plot K3 such result obtained for the raster cell sizes 30 m and 70 m. For the plot K2, the values of average soil losses are close to each other for all raster cell sizes except 90 m. That is, here, as in other plots, the largest difference in the average soil losses was obtained by using raster cells with a size of 90 m.

It should be noted that using different raster cell sizes there is also a difference in the distribution of areas with different ranges of soil erosion losses (Fig. 7-9). Interestingly, this distribution is different for different plots. For example, for the plot K1 the most common soil losses from the range of 0-2 t/ha/year – 23-25% of the plot area. A significant area is occupied by accumulation zones – 14-17%. For other ranges of soil losses, the distribution area is reduced from an average of 15% for the range of 2-5 t/ha/year to 5% for the range of >50 t/ha/year.

For the plot K2, the estimated soil losses from the range of 20-50 t/ha/year occupy the largest areas (from 32% using 10 m cell size and to 48% using 50 m cell size). On a significant area soil loss 10-20 and >50 t/ha/year are from 15 to 20% of the plot area. Accumulation zones on the plot using 50 m cell size and more are absent at all.

Another distribution of areas occupied by different ranges of calculated soil erosion losses is observed for the test plot K3. Here, accumulation zones occupy significant area (from 12.2 to 22.5%) when using raster cells of any size. Moreover, this area increases with increasing cell size. The minimum soil losses (0-2 t/ha/year) are spread over 18-23% of the plot area, and the size of the area decreases with increasing cell size. For the remaining ranges of soil erosion losses, the areas of their distribution change in different directions with an increase in the cell size.

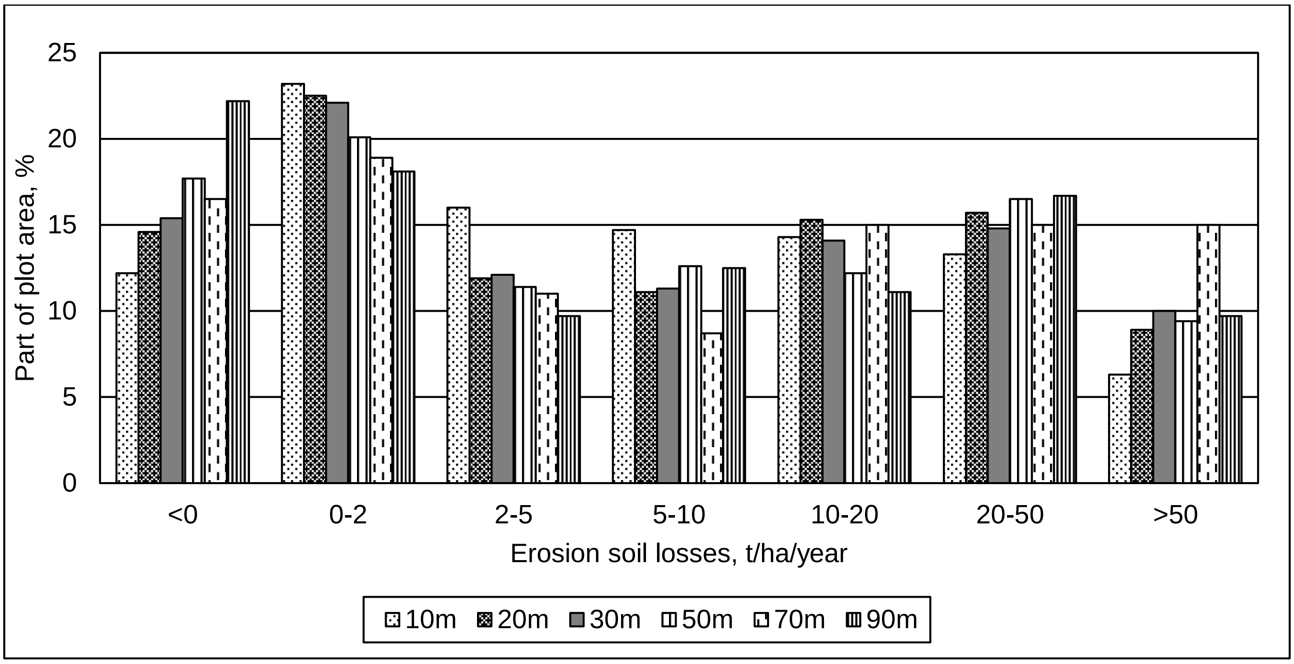

Fig. 9. Spatial distribution of erosion soil losses for the test plot K3

Conclusions. First of all, it is necessary to define that at the moment the global DEM ASTER cannot be recommended to use because of the great number of instrumental errors that have not been removed during post-processing.

Freely distributed global digital elevation models with high spatial resolution SRTM and AW3D30 in the conditions of flat terrain and local level of spatial coverage are not always hydrologically correct, that do not allow to adequately reflect the structure of the surface runoff and soil erosion. The maximum deviation of the average soil erosion losses calculated for three test plots with the area from 0.21 to 2.67 km^2 from the soil losses calculated using the reference DEM for SRTM30 and AW3D30 was 27%, for SRTM90 – almost 70%. The distribution of soil losses over the area of test plots obtained using these DEMs differs even more. The closest to the reference values of soil losses obtained using the DEM SRTM30.

Using DEM based on large-scale topographic maps, reducing the scale of the original cartographic basis from 1:10000 to 1:25000 reduces the average value of erosion losses of soil by about 20% mainly due to the reduction of the area with maximum soil losses, and on slopes of complex shape also due to changes in the area of accumulation zones.

The degree of spatial generalization of the initial data significantly affects the results of the assessment of soil erosion losses both in relation to the average values and their distribution over the area. For small areas, the use of raster cell larger than 50 m is impractical. Decreasing the raster cells makes it possible to take into account the complex structure of surface runoff more accurately, but the decreasing cannot be infinite. As a compromise, a raster cell size of 30 m can be recommended, which practically coincides with the spatial resolution of the freely distributable global DEMs with a spatial resolution of 1 arc second.

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Проблеми просторово-розподіленої кількісної оцінки ерозійних втрат ґрунту

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Розглянуто проблеми просторово-розподіленої оцінки ерозійних втрат ґрунту з використанням сучасних математичних моделей як основи оптимізації раціонального використання ерозійно-небезпечних земель. Метою статті є оцінка адекватності наявних просторово-розподілених вихідних даних, включаючи картографічні і вільно поширювані глобальні цифрові моделі рельєфу (ЦМР), для просторово-розподіленої кількісної оцінки ерозійних втрат ґрунту на локальному рівні територіального охоплення. Досягнення поставленої мети виконано методом імітаційного моделювання з використанням фізико-статистичної ГІС-реалізованої математичної моделі змиву-акумуляції ґрунту, розробленої в Одеському національному університеті імені І. І. Мечникова. Тестувалися масиви просторово-розподілених вихідних даних з ЦМР SRTM90 з просторовою роздільною здатністю 3 кутові секунди і з ЦМР SRTM30 і AW3D30 з просторовою роздільною здатністю 1 кутова секунда, а також з «картографічними» ЦМР, отриманими на основі топографічних карт масштабів 1:10000 і 1:25000. Для тестування вихідних даних обрано три ділянки площею 2,67, 0,59 і 0,21 км^2. Ділянки розташовані в Балтському районі Одеської області на південних відрогах Подільської височини. Встановлено, що вільно поширювані глобальні цифрові моделі рельєфу SRTM і AW3D30 в умовах рівнинного рельєфу далеко не завжди дають можливість адекватно відобразити структуру схилового стоку і, відповідно, коректно виконати розрахунки ерозійних втрат ґрунту. При використанні

ЦМР, побудованих на основі топографічних карт, зменшення масштабу карт з 1:10000 до 1:25000 призводить до зменшення середньої величини ерозійних втрат ґрунту приблизно на 20% за рахунок, головним чином, зменшення площі з максимальними втратами ґрунту, а на схилах складної форми – також за рахунок змін площі зон акумуляції. Вказано причини і умови порушення коректності глобальних ЦМР. Встановлено, що на глобальної ЦМР AW3D30 зустрічаються локальні інструментальні похибки, які можуть зробити неможливим її використання. Показано, що найбільш наближені розрахункові значення ерозійних втрат ґрунту до референційних продукує ЦМР SRTM30.

Ключові слова: *ерозія ґрунту, просторово розподілена оцінка, глобальні цифрові моделі рельєфу, оцінка адекватності.*

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