

Changes of cropland area in the river basins of the European part of Russia for the period 1985-2015 years, as a factor of soil erosion dynamics

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Abstract. The work is devoted to the effect of the change of cropland area on the rate of soil erosion in sites of the European part of Russia located in different climatic, landscape and geomorphological conditions. Mapping of the croplands on the territory of 9 river basins for the two time slices (the middle of the 1980s, and the present-day period 2013-2015) was carried out by visual interpretation of multi-seasonal images Landsat 5 and Landsat 8. Using vector layers obtained as a result of digitization, the areas of croplands in the analyzed periods have been calculated, and changes which occurred in 30 years were estimated. The decrease of croplands area was revealed in all studied river basins. An assessment of the effect of cropland reduction on the soil loss rate was carried out. Using the SRMM DEM with a 30 m spatial resolution, the following morphometric characteristics of relief for cultivated and abandoned croplands were calculated: steepness of slopes, flowpath length, factor LS. Based on the results of calculations, the average values of the factor LS reduced from 1985 to 2015 on the croplands in all considered basins. The obtained data confirm that the reduction of the croplands area is one of the factors responsible for the decrease of modern soil loss rates observed in field studies.

1. Introduction

In numerous works devoted to the dynamics of land use and the estimation of the areas of abandoned croplands on the territory of the former USSR, the possible causes of these changes are discussed in detail [1, 2, 3, 4]. However, information about changes in the structure of agricultural lands for assessing the ecological condition of the territories isn't less important, especially for a territory with a significant share of cropland. The features of land use change largely determine the rate of erosion-accumulative and a number of other exogenous processes. Within the plain territories the reduction of croplands leads to a decrease of erosion processes rates, since the main loss is formed on the cultivated land. In the mountainous areas where the cultivated land is mainly located on terraced slopes, erosion-denudation processes on the abandoned cropland are activated [5].

Changes of cropland area on territories with a high percentage of cultivated land determine the volume of material moved by erosion processes and, to a certain extent, affect the change in loss intensity which depends on the relief parameters [6, 7]. Water soil erosion is one of the most important agents of soil mantle degradation and, at the same time, the main mechanism of the transport of pollutants sorbed by soil particles [8, 9] as well as carbon into permanent watercourses and reservoirs [10, 11]. Thus, the intensity of erosion processes and the spatial coverage of the territory on which they occur, largely determines the ecological pressure in the regions with a high share of cropland [12, 13] and is an



important part in the global carbon cycle [14, 15, 16]. The river basin is the most convenient territorial unit for assessment of erosion processes rate trends and revealing their impact on the quality of surface waters [17, 18]. Equally, the optimization of land use in order to reduce the rate of erosion processes and their negative impact on the ecological state of surface waters and reservoirs, is advisable to be carried out using river basins as spatial units. In this case the interests of various land and water users can be taken into account, and ecological risks will be minimized [19].

The structure of agriculture lands is the most dynamic factor in comparison with such conservative conditions as lithology, relief, soil cover and climate, the changes of which are more gradual. Unfortunately, official statistics, for example, data about sown areas do not allow to estimate spatial changes in land use due to its representing using administrative region boundaries. Also, quantitative indicators of land use change vary widely in different sources. For example, in state ecological and agricultural reports land areas are given on the basis of their legal belonging to a particular category rather than real land use. Therefore, a large number of croplands which have not been used for several years, can still formally belong to this category. Thus, the reduction of croplands area according to official data is often greatly underestimated when compared with the actual value [20].

Satellite monitoring plays an important role in assessing the land use dynamics and vegetation cover condition [21]. Remote sensing data can be used as a source for the detailed agricultural land use change mapping [22, 23]. Multi-temporal multispectral medium resolution (10-30m) imagery (for example free Landsat data) is suitable for creation and updating of spatial databases of land use at the regional level [24, 25].

The main objectives of this study is to assess the change of cultivated croplands area in the river basins of the European territory of Russia located in different climatic, landscape and geomorphological conditions from 1985 to 2015, and to estimate affect of these changes on the soil erosion rate.

Main goals of the research: 1. Mapping of the croplands on the territory of 9 river basins for the two time slices (the middle of the 1980s, and the present-day period 2013-2015) by visual interpretation of multi-seasonal images Landsat 5 TM and Landsat 8 OLI. 2. Accuracy assessment. 3. Quantitative analysis of the croplands area change based on the resulting vector layers. 4. Calculation of a number of morphometric parameters of relief on cultivated and abandoned croplands using SRTM DEM with a spatial resolution of 1 arcsecond. 5. Analysis of changes of the given above parameters aimed to determine their effect on the soil erosion rate.

2. Material and methods

2.1. Study area

The studied territory is the southern half of the East European Plain which is the main agricultural region of Russia. Research was carried out within the 9 river basins located in different agroclimatic zones (figure1).

Selected sites are covering the territories with various landscape and climatic conditions and the farming features are specified by these conditions. According to the landscape map of the USSR, edited by I.S. Gudilin, scale of 1: 2500000 [26], studied basins within three landscape zones are located in: forest, forest-steppe and steppe. Izh river basin and north-eastern half of the Mesha basin are lying in the sub-taiga landscapes. Basins of the Ulema, Sviyaga, Veduga and the northern part of the Medveditsa basin are located in the forest-steppe landscapes. All other sites are corresponding to typical steppe landscapes.

2.2. Input data

As the input data for mapping, Level-1 standard data products Landsat 5 TM and Landsat 8 OLI were used. For each studied basin multi-seasonal images in a snowless period in two time slices: middle of 1980s and 2013-2016 years period were selected. For visual interpretation the 5, 4, 3 bands RGB combination for Landsat 5 and 6, 5, 4 bands for Landsat 8 were used. This combination provides the user with a great amount of information and color contrast. Healthy vegetation is bright green and soils are mauve. This combination is widely used for agricultural land dynamics analysis [27]. As the reference data

we used high resolution images presented in Google Earth. Calculation of the relief morphometric characteristics was carried out using SRTM DEM with 1 arcsecond (~ 30 m) spatial resolution.



Figure 1. Studied basins: 1 - Izh (Udmurtian Republic), 2 - Mesha (Republic of Tatarstan), 3 - Sviyaga (Ulyanovsk Region), 4 - Ulema (Republic of Tatarstan), 5- Medveditsa (Saratov Region), 6 - Samara (Orenburg Region), 7 - Veduga (Voronezh Region), 8 - Kalaus, 9 - Kuma (Stavropol Territory)

2.3. Mapping technique

We were using mapping technique realized in the CORINE Land Cover 2000 project (CLC2000) [28, 29], adjusted to the regional features and purposes of our study. The main method is visual interpretation and further manual digitization.

Croplands, in general, are easy to be separated from land use classes such as water bodies, urban areas and woodlands (except for undergrowth, young plantations). Separation of cultivated croplands from abandoned cropland and grassland is problematic but usage of multi-seasonal images allows to divide used and unused agricultural lands more accurately. In addition to the standard interpretation keys of cropland, such as orthogonality of borders, fragmented pattern and color, it is possible to distinguish a number of classification characteristics that will depend on the territory such as: kind of use of particular field and season of survey, including tone and texture [30].

At the first stage, croplands boundaries were manually digitized according to the images of 1980s. Not only particular fields were digitized, but the common boundaries of the cultivated croplands as well. Previously abandoned fields were not assigned as a separate class. Resulting polygons were overlaid on the images of the second time slice. Using keys described above, abandoned croplands were determined and the boundaries were corrected accordingly. Such approach allows to preserve topology of unchanged objects on the layers of different periods. However, the position of boundaries of the same field on images for different years in some cases was shifted. This could be explained by accuracy of the Landsat spatial reference and actual differences in the boundaries of plowing in different years. Deviation of no more than 3 pixels of Landsat TM (less than 100 m) in width was acceptable, which corresponds to the geometry accuracy specified in the CORINE CLC project. In addition, 100 m is the minimum boundary displacement which is mapping as a land use change [31]. Result of digitization are 2 vector layers of cultivated croplands. Overlaying these layers, the areas of cropland reduction and increase over the period under review were obtained. Area of used and abandoned croplands was calculated in hectares.

2.4. Accuracy assessment

Validation was carried out according to the methodology used to assess the accuracy of the CLC in Portugal [32]. Reference information was used to compare results of the interpretation with reality and should have a higher level of accuracy than the information used for production of maps. Sources of such information are: aerial imagery; satellite images with better resolution than those used in the maps production; field research [33]. Congalton and Biging think that only field observations could be used to assess the accuracy and reliability of interpretation, but there is a number of limitations: territory inaccessibility, human and material resources, cost and time. The reference information should be close to date of the data used in maps production to avoid the impact of landscape changes [34] and should be independent [35, 36].

Since there are no high-resolution imagery for the 1980s, we estimated the accuracy of the croplands mapping for 2015. For this aim, high-resolution images, partially covering the territory of three sites (Mesha, Medveditsa and Kalaus), located in different landscape zones were used. Each selected image covers more than 15% of the basin area to provide representativeness (table 1).

Table 1. High-resolution images used for validation.

River basin	Satellite	Date of survey	Coverage, ha	% of basin area	Digital Globe Catalog ID
Mesha	GeoEye-1	12.07.14	67485	15.5	1050410010D5FD00
Medveditsa	WorldView-2	16.09.15	83153	23.03	1030010047C35A00
	WorldView-2	16.09.15			1030010049158C00
Kalaus	GeoEye-1	09.03.15	52806	29.85	1050410012519C00
	WorldView-2	16.12.14	17413	9.84	103001003B1BA200

Polygons, which are the results of croplands mapping, were overlaid on the above images. If the polygon boundaries were shifted by 100 m or more from the boundaries, recognized on high resolution images, they were corrected. Polygons adjusted using high resolution images were overlaid on the croplands 2015 layer obtained from Landsat images, and agreement and disagreement regions were extracted.

The areas of these regions were calculated; the error matrix was created and the producer's accuracy and user's accuracy were obtained. Results demonstrate that accuracy of interpretation in the examined areas is more than 98% (tables 2 and 3).

Table 2. Error matrix for accuracy assessment of mapping of the croplands 2015.

		Cropland area (ha) calculated using high-resolution satellite images			
		Mesha		Total	
Cropland area (ha) calculated using Landsat images	Cropland	Cropland	32596	33022	
	Other land use	Other land use	426	34463	
	Total	Total	308	34580	
			32905	67485	
			Medveditsa		
		Cropland	Cropland	49291	49715
		Other land use	Other land use	425	33438
		Total	Total	467	33395
			49758	83153	
			Kalaus		
		Cropland	Cropland	25815	26012
		Other land use	Other land use	208	44206
	Total	Total	2022	44196	
			70219		

Table 3. Errors and accuracy.

	Mesha	Medveditsa	Kalaus
User's accuracy, %	98.7	99.2	99.2
Producer's accuracy, %	99.1	99.1	99.2
Commission error, %	1.3	0.8	0.8
Omission error, %	0.9	0.9	0.8

2.5. Calculation of morphometric parameters of relief of the used and abandoned croplands

Using DEM, rasters of slopes steepness and flow path lengths (determining relief factors for erosion processes rate estimation) were calculated for territory of the studied basins. As an integral factor, the LS-factor was calculated using the "Sediment Transport Index" tool in WhiteBox GAT using the following equation:

$$LS = (m + 1) \times \left(\frac{A_s}{22.13} \right)^m \times \sin \left(\frac{B}{0.0896} \right)^n, \quad (1)$$

where A_s – is the specific catchment area, B - is the local slope gradient in degrees, m - the contributing area exponent usually set to 0.4, n - the slope exponent usually set to 1.3 [37]. Using the vector layers of cultivated and abandoned croplands as masks the average values of the above morphometric parameters for each basin were calculated.

3. Results and discussion

Based on the mapping results, the croplands areas in the studied time periods were calculated (table 4) and the changes that occurred over 30 years were estimated (table 5). Croplands is the dominant category of land use in almost all regions. The minimum percentage of croplands (25.6%) in the Izh river basin has been observed, which is located in the forest landscape zone, in the northernmost and therefore the coldest agroclimatic zone.

Table 4. Croplands areas.

River basin	Basin area, ha	Cropland area		Cropland area	
		1985 year, ha	1985 year, %	2015 year, ha	2015 year, %
Izh	250819	64228	25.6	40229	16
Mesha	435421	271257	62.3	243918	56
Sviyaga	343250	195150	56.9	141598	41.3
Ulema	88145	60753	68.9	56782	64.4
Medveditsa	361064	247290	68.5	223538	61.9
Samara	287416	167817	58.4	144412	50.3
Veduga	119347	84068	70.4	76610	64.2
Kalaus	176887	81544	46.1	70763	40
Kuma	246675	153988	62.4	127281	51.6

Table 5. Changes of croplands over the considered interval.

River basin	Decrease of cropland		Increase of cropland		Total change	
	Decrease of cropland, ha	Decrease of cropland, %	Increase of cropland, ha	Increase of cropland, %	Total change, ha	Total change, %
Izh	24205	37.7	206	0.3	-23999	-37.4
Mesha	30106	11.1	2767	1	-27340	-10.1
Sviyaga	54468	27.9	916	0.5	-53552	-27.4
Ulema	4328	7.1	356	0.6	-3971	-6.5
Medveditsa	25748	10.4	1995	0.8	-23753	-9.6
Samara	26078	15.5	2673	1.6	-23405	-14
Veduga	8073	9.6	615	0.7	-7457	-8.9
Kalaus	15907	19.5	5125	6.3	-10781	-13.2
Kuma	28602	18.6	1894	1.2	-26707	-17.3

Due the different basins area, for an objective assessment of the croplands dynamics the changes were calculated as a percentage of the croplands area in the 1980s. The areas of abandoned croplands, newly plowed land plots, as well as the total change were calculated (table 5).

The decrease of croplands was established for the all studied river basins. Analyzing the obtained results, some regularities connected with the natural conditions of the basins location could be revealed, which in turn can cause some socio-economic reasons for the croplands reduction. The largest decrease of croplands (37.7%) is observed in the Izh river basin located in the forest landscape zone, namely in sub-taiga landscapes. The value is comparable to the percentage of abandoned land in the period 1990-2000 obtained for the number of regions of the Russian Federation using the automated classification method: 46% in Smolensk region, 30% in Kaluga region, 26% in Tula region, 28% in Ryazan region and 27% in Vladimir region [38]. It is worth to note, that these regions also belong to subtaiga and southern taiga landscapes, and the southern parts of Ryazan and Tula regions - to the forest-steppe.

Significantly smaller reduction of croplands (10%) observed in the basins belonging to the forest-steppe landscape zone: Mesha, Ulema, Veduga, Medveditsa. Here, the greatest plowing of the territory is observed - from 62 to 70%. The exception is the territory of Sviyaga basin where the croplands area decreased by 27.4%. If we consider natural conditions, this can be related with the location of the basin in the cold-moderate agroclimatic zone with the sum of active temperatures up to 2200 °C, and also with low-quality soils common to the basin.

In the basins located in the steppe zone (Kalaus, Kuma, Samara) the reduction of croplands is in the range 10-20%. There are territories with maximum values of the absolute heights range. Basins of Kalaus and Kuma rivers are characterized by wide slope complexes. In addition, solonetzic soils are widespread here. In contrast to all the sites, in Kalaus basin, with a general cropland reduction, a relatively large percentage of newly cultivated land is observed when compared with 1985.

Abandoned sites are mainly located on the edges of cropland massifs and border with river valleys, gullies and settlements. Colonization of abandoned croplands by grass, by bushes and forest vegetation is observed. It should be noted that croplands reduction is also associated with the transfer of land to another category, most often in woodlands and settlement. Such sites can not be interpreted as abandoned croplands.

Based on the results of calculations of the morphometric characteristics of the relief (Table 6), the mean values of LS factor reduced from 1985 to 2015 on cultivated croplands in all studied basins. At the same time for the abandoned croplands the maximum values of this factor were obtained, which indicate that areas vulnerable to erosion were abandoned.

Table 6. Morphometric parameters of relief of cultivated and abandoned croplands

River basin	Landscape zone	S ₁₉₈₅	S ₂₀₁₅	S _{Ab}	L ₁₉₈₅	L ₂₀₁₅	L _{Ab}	LS ₁₉₈₅	LS ₂₀₁₅	LS _{Ab}
Izh	South of the forest	2.59	2.60	2.59	120.24	116.78	126.29	1.50	1.47	1.56
Mesha	North of the forest-steppe	1.79	1.77	2.07	115.67	115.02	120.76	1.04	1.01	1.53
Sviyaga	North of the forest-steppe	1.52	1.48	1.62	115.98	119.02	109.82	0.87	0.84	0.98
Ulema	North of the forest-steppe	1.89	1.88	2.07	129.36	128.76	144.34	1.03	1.02	1.34
Medveditsa	North of the steppe	1.53	1.49	1.80	98.55	96.74	116.24	0.80	0.77	1.06
Samara	East of the steppe	2.01	1.92	2.54	129.48	129.44	129.71	1.19	1.12	1.63
Veduga	West of the forest-steppe	2.30	2.23	3.42	91.42	90.14	120.33	1.34	1.27	2.52
Kalaus	South of the steppe	2.57	2.43	3.23	121.44	118.53	144.39	1.48	1.38	2.04
Kuma	South of the steppe	2.84	2.79	3.22	113.05	110.25	132.79	1.75	1.67	2.26

S – mean slope, degrees; L – mean flow path length, meters; LS – mean LS-factor

Indices: 1985, 2015 – on the croplands of the corresponding year; Ab – on the abandoned croplands

The decrease of the LS-factor in different basins depends on changes of various morphometric parameters. In the basins of the rivers Medveditsa, Veduga, Kalaus, Kuma, there is a decrease of mean values of both slope steepness and the flowpath lengths. In the Izh and Ulema river basins at constant values of slopes, the decrease of the LS-factor was due to the reduction of flow path lengths. For the Mesha, Samara and Sviyaga rivers, the reverse picture is observed where the slope steepness was the

primary factor in reducing the LS-factor at equal mean flow path lengths (and in the case of the Sviyaga River at an increased value).

Previously, for a number of regions of the European Russia, the croplands reduction in studied period was largely explained by socio-economic drivers [3]. The obtained results suggest that within the studied river basins, the most inconvenient land, susceptible to erosion and located at the lower parts of the convex slopes was abandoned. This trend is more pronounced in the river basins of the steppe and western part of the forest-steppe zone and in a less degree in the south of the forest and northern forest-steppe zones. Thus, it can be concluded that a reduction of croplands area provided decrease of the average annual erosion rate on the remaining croplands.

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