RECENT TREND OF EROSION RATES FOR THE SOUTHERN HALF OF THE RUSSIAN PLAIN

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ABSTRACT: The territory of the Russian Plain can be divided onto two parts in relation of agricultural activity. The northern half is taiga zone with extremely high proportion of forested area and very limited areas of arable fields. Southern half of the Russian Plain is located in broad-leaf forest, forest-steppe and steppe zones and it is characterized by high proportion of arable lands with period of intensive cultivation from 300-350 years in broad-leaf landscape zone up to about one century on the south-east of steppe zone. It is one of the main agricultural regions of Russia with relatively high rates of sheet, rill and gully erosion. The latest quantitative assessment of soil losses for the entire area of the Russian Plain was undertaken in the middle of 1980th, when maps of soil losses and gully density were constructed. Modified version of USLE model and State Hydrological Institute erosion model were used for evaluation of soil losses from arable lands during warm period of year and period of snow-melting respectively. Active gully headcuts were identified by using large scale maps combine with using aerial photographs. Land use transformation, climate changes and crop rotation modification during last 25-35 years lead to changes of soil erosion rates in different parts of studied area. Complex approach is applied for assessment of recent trends of sheet, rill and gully erosion in different landscape zones of study area. Investigations is undertaken in 6 selected sectors (area of each sector is about 6-10 thousand km^2), uniformly distributed over the area of the Southern half of the Russian Plain. Changes of the different factors, including some meteorological and hydrological parameters, land use, USLE C-factor, were determined for the period 1990-2014. Contribution of each from above mention factors on erosion rate trend changes is different in the different landscape zones of the study area. It was found, that decreasing of surface runoff from cultivated slope during snow-melting is the main driver of the reduction of the gully headcut retreat rate as well as sheet and rill erosion.

Key words: land use changes, erosion rate, climate change, Russian Plain.

Introduction

The Russian Plain is the largest agricultural region of Europe with high proportion of a fertile soil. The most part of croplands are located in the Southern part of Russian Plain within south part of forest, forest-steppe and steppe landscape zones. It is area with relatively short history of intensive agriculture with duration from 4-5 centuries in the center part around Moscow in forest zone up to about 120-150 years on the south and south-east within the steppe zones (Sidorchuk & Golosov, 2003). The highest area of cropland within the most productive soils of forest-steppe zone was reached in the second half of 19th century after land reform. Even very steep slopes were used for tillage, and maximum of gully erosion rates was reached immediately (Sidorchuk & Golosov, 2003). The cropland area was relatively stable in the different parts of the Russian Plain during 20th century with some reduction during World War II within the forest and forest-steppe zone while it was enlarged in the steppe zone because of virgin lands were cultivated in the end of 1950th.

Latest quantitative assessment of erosion rates for the entire European Russia was undertaken in the beginning of 1980th and it was based on application of modified version of USLE and State Hydrological Institute model for evaluation of erosion rate during rain-fall season and snow-melting respectively (Larionov,1993). Results of model calculations were verified based on the monitoring data of soil losses during snow-melting and using the evaluation of total soil losses, which were determined based on the evaluation of the total sedimentation in the small field ponds with well-known time of construction (Litvin, 2002; Golosov, 2006). It was shown that model calculations are in a good agreement with actual soil losses.

More than 35 years have passed since the last quantitative assessment of soil erosion losses from croplands of the Russian Plain. Considerable economic changes had occurred after USSR collapse in 1991 with following land use and crop-rotation changes in some landscape zones of European part of Russia. In addition, global warming is affecting on dynamic of meteorological characteristics in the different parts of the world since the middle of 1970th. It is very likely that land use changes and climate changes are both influenced on the soil erosion rates on the croplands of the Russian Plain. However currently, information about soil erosion rates during periods of spring snow-melt and rain-storms is absent because of lack of regular monitoring. So, it is only possible to evaluate the trend of erosion rates. It can be done based on application of erosion models, analysis of erosion factor changes and using quantitative data about deposition rates in different sediment sinks. Some results of such analysis are presented in given paper.

Material and Methods

The Russian Plain occupies area from the Caucasus mountain foothills and the Caspian Sea on the south, the Ural Mountains on the east, Arctic Ocean and White Sea on the north. Western boundary of the study area is corresponded to the western border of the Russian Federation (Fig.1). Quantitative assessment of soil losses was done for the entire Russian Plain, but the most attention was given to the southern half of studied territory to the south from the line Bryansk-Moscow – Nizhniy Novgorod – Kazan – Perm, because the most part of croplands are located within given territory. The Northern half of the Russian plain is located in tundra, taiga and mixed deciduous-coniferous forests landscape zones with poor soils with low content of organic matter. Therefore, proportion of croplands in this area is from 0% to 20% (from total area) and in addition the significant proportion perennial grasses are in crop rotations.

The southern half of the Russian Plain is mostly located in forest-steppe and steppe landscape zones where soils formed on the loess with high organic content dominate. The proportion of cropland change in the range 35-85%, and row crops (corn, sunflower, sugar beet, buckwheat etc.) are the significant component of the crop-rotation.

A temperate continental climate with relatively cold winter and warm summer is typical for the most part of the Russian Plain. Total (snow + rain) annual precipitation is decreasing from the north-west to the south-east territory from 650 to 350 mm with increasing of evaporation in the same direction. Droughts are observed very often in the south-eastern part of the steppe zone. Soil erosion during snow-melting is observed on the most part of the Russian Plain during the most part of the 20th century with maximum on the north of the forest-steppe zone while soil erosion during rain storms was widespread mostly in steppe and south part of forest-steppe zone. Sometimes extremely heavy rains promoted to severe erosion even in the forest zone (Golosov, 2006).

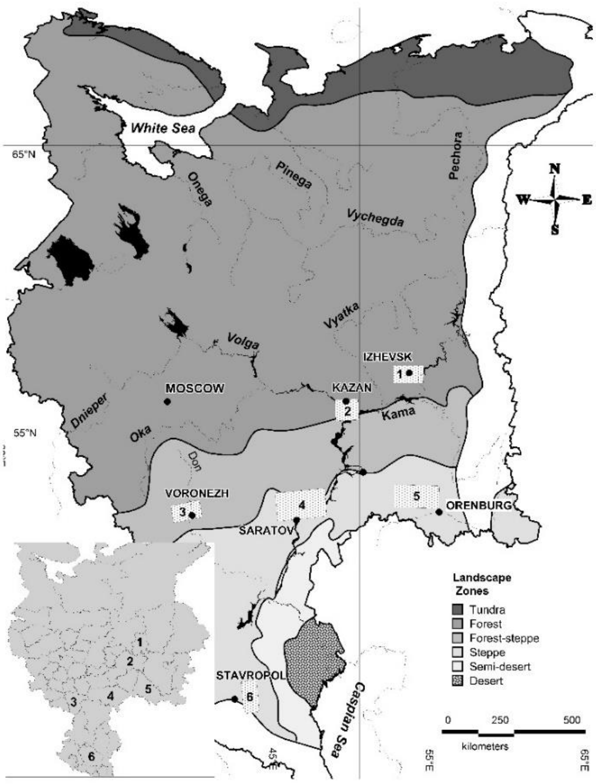

Figure 1. Map of the European part of Russia with location of studied transects.
Legend: sector; **3** - number of sector

The soil temperature (for the period of snow-melting) and number of rains with layer over 10 mm (for rain-fall period) are the key meteorological parameters which determine the erosion rate. Information about soil temperature dynamic for the European Russia for the period since 1960 was analyzed by Park et al (2014). Daily measurements of the rainfall amount at the weather stations were collected in the Russian Research Institute for Hydro-meteorological Information (RIHMI) network and were provided by the RIHMI World Data Center (http://aisori.meteo.ru/ClimateE; Veselov, 2002; Razuvaev et al., 1993). Data from 176 weather stations were selected for the analysis. The selection of weather stations was done on the basis of the time-series length.: They should fall into the period 1960-2015 (several exceptions were made; shift to 1966-2014 was accepted) and no more than 10% of years of time series may be missing. Following (Zolina, 2012), the years having more than 20% of data absent were excluded from the time series.

Rainfalls of warm season were split onto groups: >10 mm, 10-20 mm, 20-30 mm, 30-40 mm, 40-50 mm and >50 mm. The bounds of warm season at each meteorological station were defined using a single formal rule from the beginning of May and till the end of September. Two features of each rainfall group were constructed and analyzed: total amount and frequency. The tendencies at each time series were quantified by generalized linear model linked a studied feature with a calendar year. Data processing, model building and evaluation, visualization were performed in R environment (R Core Team, 2016).

Information about land-use changes and land area under different crops for different region of Russia for period since USSR collapse was collected from Russian Federal State Statistics Service. Particular attention was given to evaluation of changes of arable land area in the different landscape for the period since 1991. Additional independent sources of information were used for correction of possible mistake in official statistics (Lyuri et al., 2010). The plant cover factors were calculated separately for the rainfall season (May - October) and for the period of snow-melting for each year for period 1991-2014 based on the data about area under different crops in each region of the European Russia.

Calculation of erosion rates and total soil losses on croplands for different landscape zones of Russian Plain was done using modified version of USLE (rainfall period) and of the State Hydrological Institute model (period of snow-melt). Rainfall erosivity factor was re-calculated for the 2012 based on linear relationship between layer and rainfall erosivity of individual rain (Kanatieva et al., 2010). Changes of arable lands area were taken into consideration. However possible changes of LS factor wasn't included in calculations. All other parameters were taken from data base prepared in period of erosion rate calculation for the Russian Plain on 1980.

Six sectors located in different landscape zones of the southern part of Russian Plain were selected for the more detail assessment of possible trend of erosion rates during last decades (Fig.1). Complex approach is applying for evaluation of contemporary trend of the sheet, rill and gully erosion within each sector. Field methods and techniques are using for determination of gully headcut retreat rate, transformation of different erosion zones (sheet, rill, ephemeral gully) and sediment redistribution rates within small first-order catchments, including large-scale geomorphological mapping, 3-D scanning, topographical survey, ^{137}Cs technique, soil-morphological method and others. Set of high-resolution space images including IKONOS, GeoEye-1, Spot are using for evaluation land-use transformations, length of active gully within the key river basins selected within the each sector. In addition, long-term monitoring data about water discharges in the key river basins were collected. Particular attention was given to analysis of water discharge changes during spring floods, as a good indicator of the surface runoff trends from cultivated slopes in this period of year.

Results and Discussion

Significant reduction of the cultivated lands area for period 1980-2012 was found for the all landscape zones of the Russian Plain with maximum reduction in the forest zone (Table 1). Serious reduction of cultivated land in the forest-steppe zones are observed in the eastern part of the Russian Plain. Clear trend of increasing cultivated lands in the forest-steppe zone is observed since 2010. Reduction of cultivated land in the steppe zone is mostly associated with reduction of irrigation in dry steppe. The most part of such lands is located within area nearby with Caspian depression and they are characterized by very flat relief.

Table 1. Changes of cultivated lands (CL) in different landscape zones of the European Russia between 1980 and 2012

Landscape zone	Area of CL in 1980 10^3 ha	Area of CL in 2012 10^3 ha	% change in area of CL, in 2012, (+/-)%
Forest zone, total	20789.9	9222.1	-55.6
Forest-steppe zone	33286.4	23978.1	-28.0
Steppe zone	38544.8	27894.3	-27.6

It was found that despite of the serious changes in crop rotations, very small reduction of the USLE cropping factor was found for the forest-steppe and steppe zones (Table 2). However, increasing proportion of cultivated lands under annual and perennial grasses in the forest landscape zone leads to considerable reduction of the USLE cropping factor.

Table 2. Changes of the USLE cropping factors for the different landscape zones of the Russian Plain between 1980 and 2006

Region, landscape zone	C_r[1]			C_{sn}[2]		
	In 1980	In 2006	+/-, %	In 1980	In 2006	+/-, %
Total European Russia	0,37	0,35	-5,4	0,74	0,73	-1,4
Forest	0,26	0,21	**-19,2**	0,66	0,49	**-25,7**
Forest-steppe	0,37	0,34	-8,1	0,77	0,76	-1,3
Steppe	0,43	0,41	-4,6	0,75	0,71	-5,3

[1]C_r - plant cover factor for period of rain-storms

[2]C_{sn} - plant cover factor for period of snow-melting

Global climate warming is also affected on meteorological characteristics for both cold and warm seasons and in its turn on erosion rates during snow-melting and rain-storm seasons. It is found, that total number of rains with layers >10 mm had increased since 1960 on the most part of the meteorological stations and in particular in the southern half and in the western part of European part of Russia (Fig.2A). Obviously, that such increase should influence the intensity of soil losses during warm season. The more essentially, that number of heavy rains with layer 40-50 mm had increased considerably mostly along the line Bryansk – Izhevsk and near Caucasus mountains in the south-west parts of the steppe zone (Fig.2B). Taking into consideration that heavy rains are responsible for about 80% from total soil losses during warm season (Edwards & Owens, 1991), it is possible to conclude that proportion of rain-storm erosion became larger for the part of the Southern part of the Russian Plain.

From the other hand, different indicators allow suggesting that soil losses during snow-melting decreased considerably in the southern half of the Russian Plain because of decreasing of the surface runoff from the arable lands. First indicator of this processes is serious growth of the soil temperature since 1960 up to 2006 from +8° in the south-western part of the Russian Plain in the steppe zone up to 4°C in the southern part of the forest zone near the Ural mountains (Park et al., 2014). Secondly, clear trend of spring flood reduction is observed on the small rivers of the Southern half of the different landscape zones of the Russian Plain since the beginning of the global warming (Fig.3). Also, results of direct monitoring of surface runoff from cultivated lands received on the Novosil experimental station, located in the middle part of the Zhusha River basin (Orel region), is also confirmed, that coefficient of surface runoff had decreased from 0.5 for period 1955-1980 up to <0.1 for the last decades (Petelko et al., 2007). In the result, it is more likely that soil losses on the cultivated lands during period of snow-melt become insignificant.

Changes of the climate and land-use lead to different changes of erosion rates and the total soil losses in the different landscape zones of the Russian Plain. The most considerable reduction of both erosion rate and the total soil losses was found for the different parts of the forest zone (Table 3-4). There are several reasons determined the given trend, including reduction of arable land area, changes in crop rotations and serious decreasing of surface runoff during snow-melting. Also, some reduction of erosion rates was found for the forest-steppe zone with more serious decreasing of the total soil losses mainly because of reduction of arable land area. It is more likely that possible increasing of soil losses during rain-storm season don't compensate the decreasing of soil losses during snow-melt. However, soil erosion rate increase in the steppe zone according results of the model calculation because of increasing of frequency of the rain-storms with layer 40-50 mm. But the total soil losses in steppe zone also decrease because of reduction of arable land area (Table 4). It is necessary to emphasize that area of cultivated lands partially restored since 2012 due to the plowing of previously abandoned land.

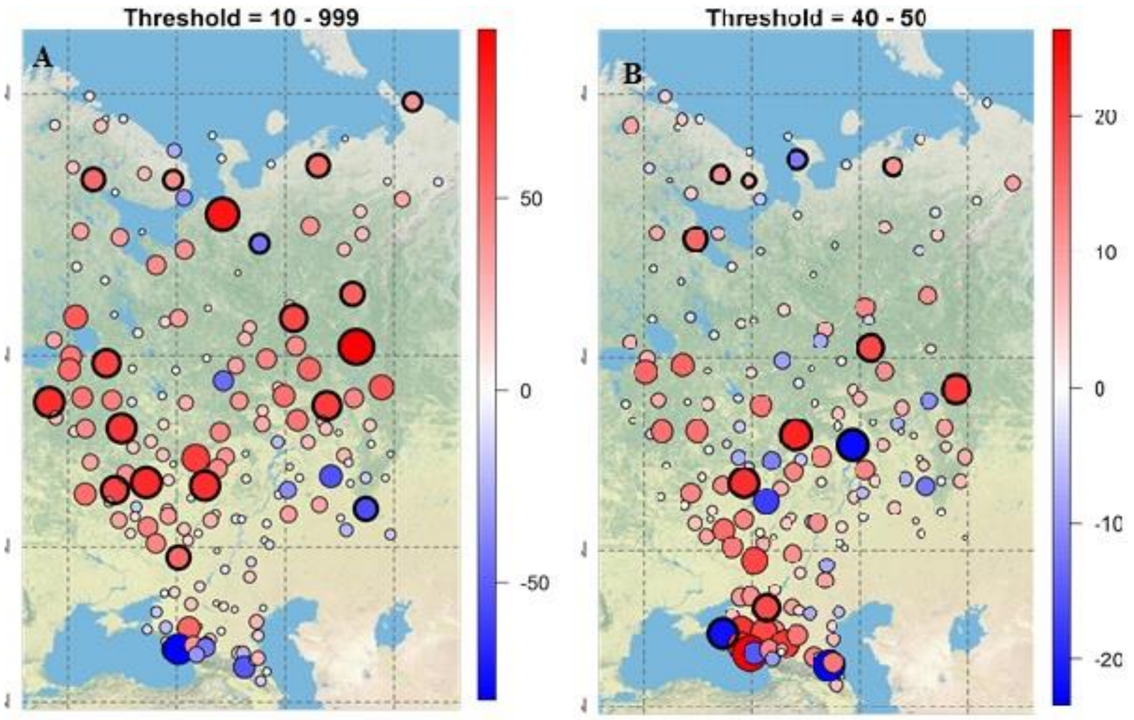

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Figure 2. Annual frequency of precipitation events (A – all rain > 10mm, B – rain 40-50 mm for period May- September) predicted by a linear model in 2015 and 1960. The change in frequency shown in the size and color of the icon. Positive values (red) correspond to an increase of warm season precipitation over the study period, the negative (blue) - a decrease in frequency. Black stroke shows the station, where there is a statistically significant pattern (at least 0.05 level of significance).

The analysis of changes in the erosion rates and total soil losses are based on the use of the results of erosion models and changes in the factors included in the models, as well as the trends of individual hydrometeorological parameters changes associated with the formation of surface runoff on the cultivated slopes. In the absence of direct observation of the soil losses from the arable lands, it is possible to use the quantitative information about trend of deposition rates in the different sediment sinks, located along sediment pathways from cultivated slope to the river channel and further downstream to the river mouths. In addition, available information about gully headcut retreat rates may be used for understanding of recent trend of the erosion rates. Given information was collected for the some sectors and adjacent areas. Also, detail monitoring of gully headcut retreat rate was organized within the each sector and comparison of gully head positions for the different years determined on the high resolution space images allows identifying the recent gully headcut rates.

Published data about deposition rates in the bottoms of the first order dry valleys for two time intervals (1963-1986 and after 1986 until the sampling data) are available for several locations in the different regions of the Southern half of the Russian Plain (Belyaev et al., 2008;

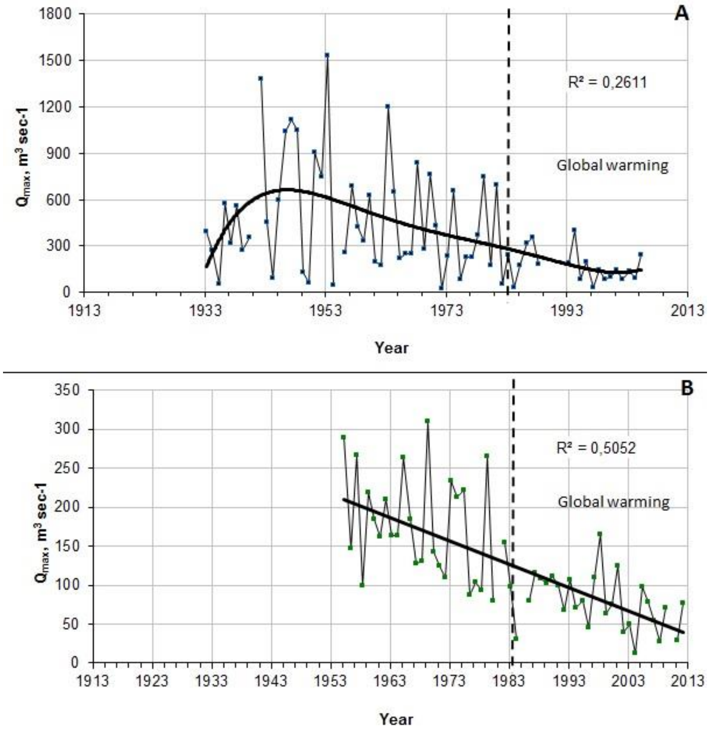

Fig.3. Trends of maximum water discharge changes during period of spring snow-melt for the typical small rivers of the southern part of forest zone and forest-steppe zone. A- Bityug River (sector 3); B – Kazanka River (sector 2).

Table 3. Changes of mean annual soil erosion rate in 1980 and in 2012, calculated using modified version of USLE (rain-storm erosion) and State Hydrological Institute (erosion during snow-melt) models

Landscape zone of European part of Russia (without mountain area)	Mean annual soil erosion rate in 1980, t ha^{-1} $year^{-1}$	Mean annual soil erosion rate in 2012, t ha^{-1} $year^{-1}$	Change of mean annual soil erosion rate*, (+/-)%
Northern and middle taiga zone	6.5	4,0	-38.4
Southern taiga zone	7.3	4,1	-44.0
Forest zone, total	7.3	4,1	-43.8
Forest-steppe zone	4.1	3,3	-19.4
Steppe zone	3.9	4,63	18.7
Total European Russia	4.7	4,0	-15.0

* - relationship between 1980 and 2012

The similar trend of decreasing of gully headcut retreat rates was found in the result of long-term monitoring (about 150 gullies) in different parts of Vyatsko-Kamsckoe interfluve area for period 1978-2015 (Rysin et al., in press). Three main reasons of decreasing gully headcut retreat were selected including increasing of abandoned of arable lands, decreasing of surface runoff during snow-melting and permanent reduction in the catchment area as consequences a regressive retreat of gully head. However more detail monitoring data about rates of gully head retreat separately for the period of snow-melting and rainfall season, collected for the about 50 gully heads allows to confirm, that very sharp reduction of surface runoff during snow-melt are the most important reason of serious reduction of gully head retreat (Rysin et al., 2017).

Table 3. Changes of total soil losses in 1980 and in 2012, calculated using modified version of USLE (rain-storm erosion) and State Hydrological Institute (erosion during snow-melt) models

Landscape zone of European part of Russia (without mountain area)	Total soil losses in 1980, 10^3 t	Total soil losses in 2012, 10^3 t	Change of total soil losses* (+/-)%
Northern and middle taiga zone	6131.5	1808,8	-70.5
Southern taiga zone	145031.9	35965,9	-75.2
Forest zone, total	151163.4	37790,9	-75.0
Forest-steppe zone	136449.7	79277,3	-41.9
Steppe zone	148617.8	127662,7	-14.1
Total European Russia	436230.9	244830,9	-43.9

* - relationship between 1980 and 2012

Golosov et al., 2012, 2014). It was found that deposition rates in the valley bottoms had decreased in 2-4 times if it is compared time intervals 1963-1986 and 1986 – 2004(6). Floodplain deposition rates in the small river valley bottoms for the same time intervals had decreased even more seriously up to 5-7 times (Golosov et al., 2010,2012, Markelov et al., 2012), mostly because of reduction of spring flood levels.

Perspectives

Available data allow evaluating the recent trend of soil erosion within the Russian Plain during last decades, but some additional information should be collected for more detail understanding of the consequences of climate and land-use changes for the different landscape zones, their different parts and for territories with different types of relief (uplands, lowlands). Recently complex study is carried out within the six sectors relatively uniformly covered the Southern part of the Russian Plain. River basin approach are used for understanding dynamic of different erosion processes (sheet, rill and gully erosion), their influence on the land degradation and water quality and influence of land-use and climate changes. Initial results obtained in the first year of investigations in the most cases confirm already published data. However, it is some local features have been identified for the different river basins and key study catchments within studied river basins. For example, relatively high proportion abandoned lands was identified in the Kalaus River basin (sector 6) and the Izh River basin (sector 1). Mainly very steep slopes were abandoned in case of the Kalaus River basin. It is undoubtedly led to reduction of soil losses in the river basin scale. It is very likely, that in case of the Izh River basin much more serious reduction of soil losses is occur because of combined effect of reduction of arable land area, increasing of perennial grasses proportion and decreasing of surface runoff coefficient during snow-melting. The latter factor play important role for given area, because previously the contribution of erosion losses during snow-melting was very important in total annual soil losses from cultivated lands in given region. Further detail investigation will allow to understand the more precisely the influence of climate and land-use changes on the erosion rate trend for different regions of the Southern half of the Russian Plain.

Conclusion

Quantitative assessment of contemporary erosion rates on the arable lands of the Russia Plain was undertaken using erosion model calculations. Temporal changes of some key parameters of erosion model (erosion index of precipitation, the plant cover factor and surface runoff coefficient for period of snow-melting) were taken into consideration. It was found, that mean annual erosion rate decrease if it is compare 1980 and 2012 from 7,3 t yr^{-1} to 4,1 t yr^{-1} in forest zone, slightly decrease in forest-steppe and insignificantly increase in the steppe zone (Table 3). Total soil losses had decreased in all landscape zones because of decreasing of cropland area. Recently proportion of cultivated lands in the forest zone is very low (< 10% from the total area). So, the more attention should be given to the southern half of the Russian Plain (south of forest, forest-steppe and steppe landscape zones).

Comparison of deposition rates in different sediment sinks along the pathways from cultivated slopes to the river and floodplain sedimentation for two time intervals (1963-1986 and 1986-2006) based on application ^{137}Cs technique allows confirming the decrease of soil losses during last decades mainly because of reduction of erosion during period of snow-melting. However additional information should be collected for quantitative assessment of erosion rate trends for different regions of the southern half of the Russian Plain.

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