Erosion Losses of Soils on Arable Land in the European part of Russia

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Abstract. The quantitative assessment of potential soil losses in arable lands of the European part of Russia is carried out in the article. The assessment was carried out using a mathematical model based on the mathematical dependencies of the universal soil loss equation and the mathematical dependencies of the State Hydrological Institute of Russia. Assessment of potential soil losses was performed using calculations in a geographic information system. To perform the calculations the database was created containing information on: the relief; properties of soils; climate and land use. The raster model of data organization was used to create the database and subsequent calculations. The assessment shows that the average amount of soil loss in the plowed land of the European territory of Russia is 11 t/ha per year. At the same time, about half of the territories are located in conditions where the soil loss value does not exceed 0.5 t/ha per year. The potential loss of soil taking into account the soil protection role of vegetation is 3.3 tons/ha per year. In addition, a spatial analysis of the distribution of soil loss by landscape zones shows that there is a consistent reduction in the potential loss of soil from the forest zone (20.92 t/ha per year) to the forest-steppe (10.84 t/ha per year), steppe (8.13 t/ha per year) and semi-desert (4.7 tons/ha per year) zone.

1. Introduction

Water erosion is the leading process of denudation within the land and simultaneously carrying out migration of pollutants transported together with sediments [1, 2, 3]. The issues of quantitative assessment of the intensity of erosion and spatial distribution within objects of different scale from small catchment to the continent, on the basis of erosion modeling, are given great attention [4]. The European territory of Russia has more than once become the object of a quantitative assessment of erosion processes and soil erosion mapping. For example, S.S. Sobolev and I.F. Sadovnikov published "Soil-erosion map of the USSR" with scale of 1: 5,000,000 [3]. A small-scale map of agricultural lands erosion of a scale of 1: 2,500,000 was compiled for the same territory in the 1990s, by soil Institute named after V.V. Dokuchaev. The map data were obtained using cartographic generalization of large-scale soil-erosion survey data obtained by soil-morphological method.

In addition, in the late 80's and early 90's of the twentieth century on the basis of the modernized Universal Soil Erosion Equation and the National Hydrology Institute’s model the following maps were developed at the Moscow State University: "Erosion hazardous lands of Russia" with a scale of 1: 1,500,000; "Erosion hazardous at the agricultural lands of Russia" with a scale of 1: 5,000,000, and map of "Soil Erosion" at a scale of 1: 10,000,000. These maps were developed for the Ecological Atlas of Russia. The "Erosion-hazardous lands of Russia" map shows the average annual intensity (in t/ha per
year) of the total modern soil erosion in cultivated lands and natural forage lands. Estimation of erosion potential of the relief was carried out by a point-statistical method using maps of scale 1: 25,000 [3].

At present time, geoinformation systems are used to calculate erosion losses of soils using modern models. Many assessments of potential soil losses for large areas have been carried out recently for the territory of Europe [5, 6, 7] as well as in other areas - in the Eastern Basin in China [8] with the use of this approach.

2. Study area
The European territory of Russia (ETR) is located within the East European plain and is bounded from the west by the state border of the Russian Federation from the east by the Ural mountains, from the north by the coastal line of the Arctic Ocean, from the south by the Caucasian mountains and by the coastal line of the Black and Caspian seas. The total area of the territory is about 4 million km². This territory is located within several landscape areas: tundra, forest-tundra, forest, steppe, forest-steppe, semi-desert. The total area of cropland in this area is about 650,000 km². The population of this territory is about 95 million people.

3. Methodology
Mathematical modeling was used based on the methodology developed by the soil erosion laboratory of the Moscow State University to assess soil erosion. The essence of the methodology for estimating soil erosion losses proposed by the Moscow State University is set out in several monographs [9]. Therefore, here we will not elaborate on the technique in detail, but will present it in abbreviated form.

So, the soil erosion is estimated as the sum of erosion losses from rainwater runoff (Wd) and the flow of meltwater (Wt) in the proposed method. In turn, each of these indicators depends on a number of factors: average annual erosion potential of rainfall (EPR), conventional units; erosibility (soil erodibility), t/ha per EPR. Relief factor, which is a function of slope, slope length and shape; erosion index of the crop or crop rotation; H – a layer of surface slope runoff, depending on the water supply in the snow, precipitation during snow melting and the drain factor, mm. This technique has already been tested to calculate the potential loss of soil within the territories located on the European territory of Russia [10], but for the whole territory the technique is used for the first time.

4. Original data
Several raster models have been created to prepare the database for calculations: slopes, slope lengths, soil erodibility, erosion potential of rainfall (EPR), water reserves in snow, intra-annual redistribution of rainfall, land use.

4.1. Land Use Model
All calculations were carried out within the limits of arable land ETR. The situation of arable land was determined using the land-use model "TerraNorte RLC v.3" developed by the Space Research Institute of the Russian Academy of Sciences. This model is updated annually and we used the current version of the model for 2014. A full description of the methodology for developing this model is given in the article "Estimation of the area of fires on the basis of the integration of satellite data of different spatial resolution MODIS and Landsat-TM/ETM +" [11], while arable land was allocated on the basis of locally adaptive classification and perennial signs of decoding [12].

4.2. Terrain parameters
The raster patterns of slopes and slope length were prepared based of the global relief model GMTED2010. A detailed description can be found in the technical report of the creators of the model [13]. The model of the relief is distributed in parts (tiles), 12 parts were downloaded from the site https://lta.cr.usgs.gov/GMTED2010 for execution on the ETP. This model of relief has already been used to construct the boundaries of the catchments of the European territory of Russia [14], but for the
first time it is used to calculate the potential soil loss. Based on the obtained DEM in the GIS ARCGIS 9.2, such characteristics of the relief as the slope and length of the slopes were calculated.

4.3. Soils
The "Unified State Register of Soil Resources of Russia (UGRSR)" was used, which is available at http://egrpr.esoil.ru/ for the preparation of data on the properties of the soil. A detailed description of the content of register is presented in the collective monograph [15]. A detailed description of the creation of a geo-information database of this register is presented in several articles of the employees of the Dokuchaev’s Institute [16, 17].

4.4. Climate
There has been an increase in annual precipitation in both summer [18] and winter [19] in recent years. For the warm period of the year from 1960 to 2015 there is a tendency for an increase in precipitation capable of causing soil erosion (intensity> 10 mm / day) [20, 21]. A significant reduction in the snow melt slope flow is observed in study area despite the increase in the amount of precipitation in the cold period [22, 23].

Therefore, for calculations we decided to create our own cartographic model of the spatial distribution of the erosive potential of rainfall on the EPR. The EPR model was created on the basis of daily observations of precipitation at 239 climate stations that were conducted from 1965 to 2015, and function 1 [24]. Data on precipitation were downloaded from the official site of the Russian national climate agency "RIHMI-WDC" (meteo.ru)

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R30 = 3.19 e^{0.006P}
\]

where P is the mean annual sum of the precipitation bed of daily precipitation exceeding 10 mm. in the warm season (the warm season is determined by the average daily temperature above 0 degrees).

Raster models of water reserves in snow and a raster model of intra-annual distribution of erosion potential of rainfall were created on the basis of maps developed in MSU [9].

5. Results and discussion
The erosion on the territory of the ETR varies widely and can reach thousands of t/ha per year (table 1). At the same time, the average amount of soil loss on the arable land is 11 t/ha per year. About half of the territories are located in conditions where the erosion value does not exceed 0.5 t/ha per year (figure 1) and among the remaining territories the largest area is occupied by territories characterized by losses from 10 to 15 t/ha per year. In general, we can say that the distribution of erosion histogram is close to the normal distribution (if the first range is considered separately). If we take into account the soil protection coefficients of vegetation which for some basins of the considered landscape zones vary from 0.2 to 0.4 for rain erosion and from 0.57 to 0.84 for snow melt erosion, and also taking into account the fact that the arable land ER is located within the climatic zones where at present moment losses from rain erosion significantly exceed the loss of soils from snow melt erosion, then the average annual losses on the ETR taking into account the vegetation’s coefficients can be estimated at 3.3 t/ha per year. The data obtained can be to compare with the data of recent studies in the European Union [6, 25]. The average soil losses in European Union according different researches range from 2.6 to 2.76 t/ha per year. The soil losses in European Union were estimated for the all land use, but in our case the studies were performed only within arable land.

Table 1. Statistics of the soil erosion loss on the arable land.

|                | Minimum | Maximum | Mean | Standart Deviation |
|----------------|---------|---------|------|--------------------|
| European Russia| 0       | 3574.66 | 11.03| 24.14              |
Figure 1. Frequency histogram of the soil erosion loss at the arable land of European Russia.

Figure 2. Spatial distribution of the magnitude of soil erosion within the European part of Russia (1-river, 2 state borders, 3- subjects borders of the Russian Federation, 4-populated areas).
Table 2. Statistics of the soil erosion loss within landscape zones

| Landscape zones  | Mean   | Standard deviation | Maximum  |
|------------------|--------|--------------------|----------|
| Forest           | 20.92  | 34.93              | 1435.26  |
| Forest-steppe    | 10.84  | 22.73              | 3127.04  |
| Steppe           | 8.13   | 17.69              | 880.55   |
| Semi-desert      | 4.7    | 9.51               | 373.24   |

Analyzing the spatial distribution of potential soil losses, according to the administrative units of the Russian Federation traditionally having large areas of arable land (figure 2), it can be said that the smallest erosion values characterize such subjects of federation as Tambov; Saratov; Volgograd; Voronezh regions. The Republic of Tatarstan, Tula, Oryol, Kursk, Belgorod regions, as well as Stavropol and Krasnodar Krai have high values of erosion soil losses. Also high and very high values of soil losses are on the North Caucasian subjects of the federation, as well as subjects of the federation located mainly in the forest landscape zone.

In general, analyzing the potential loss of soil from planar soil erosion, we can say that it decreases when moving from the forest landscape to the semi-desert zone (table 2). This, in our opinion, can be explained by the contraction of the average annual layer of surface runoff with a shift to the south, and by the predominance of soils in the south of the study area that are well cemented with a high content of humus and have a structure that is well resistant to erosion.

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References

[1] Walling D E 1983 *Journal of Hydrology* **65** 209-237.
[2] Lal R 2001 *Land Degradation & Development* **12** 519-276
[3] Litvin L F 2002 *Geography of soil erosion in agricultural land of Russia* (Moscow, Akademkniga) p 255
[4] Karydas C G, Panagos P and Gitas I Z 2014 *Int. J. of Digital Earth* **7** 229–250
[5] Boardman J and Poesen J. 2006 *Soil Erosion in Europe* (John Wiley and Sons, UK) p 855
[6] Panagos P, Borrelli P, Poesen J, Ballabio C, Lugato E, Meusburger K, Montanarella L, Alewell C 2015 *Environmental Science & Policy* **54** 438-447
[7] Ballabio C et al 2017 *Science of The Total Environment* **579** 1298–1315
[8] Wu Y and Chen J 2012 *Science of The Total Environment* **441** 159-168
[9] Larionov G A 1993 *Erosion and deflation of soils* (Moscow, Moscow State University Press) p 200
[10] Maltsev K A, Yermolaev O P and Mozzhherin V V 2014 *AHS-AISH Proceedings and Reports* **367** 326–332
[11] Bartalev S A, Egorov V A, Efremov V Yu, Loupian E A, Stysenko F V and Fitman E V 2012 *Sovremennye problemy distantsionnogo zondirovaniya Zemli iz kosmosa* 2 9-27
[12] Bartalev S A, Egorov V A, Loupian E A, Plotnikov D E and Uvarov I A 2011 *Komp’yuternaya optika*. (Samara RAS Press) I 103-116.
[13] Danielson J J and Gesch D B 2011 *Global multi-resolution terrain elevation data 2010 (GMTED2010)* (U.S. Geological Survey Open-File Report) pp 26
[14] Ermolaev O P, Malt’tsev K A, Mukharamova S S, Kharchenko S V and Vedeneeva E A 2017 *Geography and Natural Resources* **38**(2) 131–138
[15] *Unified State Register of Soil Resources of Russia* 2014 (Moscow, Soil Institute V.V. Dokuchaeva) p 768
[16] Rukhovich D I, Koroleva P V, Kalinina N V, Vil’chevskaya E V, Simakova M S, Dolina E A and Rukhovich S V 2013 *Eurasian Soil Science* **3** 251–267
[17] Rukhovich D I, Wagner V B, Vil’chevskaya E V, Kalinina N V and Koroleva P V 2011 *Eurasian...*
[18] Groisman PYa, Knight R W, Easterling D R, Karl T R, Hegerl G C and Razuvaev V N 2005 *J. Clim.* **18** 1326–50

[19] Shiklomanov I A and Georgievsky V Yu 2002 *The impact of anthropogenic climate change on the hydrological regime and water resources: Climate change and its consequences* (St. Petersburg, "Nauka Press").

[20] Zolina O 2011 *Transactions of RAS* **5** 690-695

[21] Chizhikova N A 2016 *Eroziomnyye, ruslovyye i ust'yevyye protsessy* (Erosion, river bed and estuarine processes) (Nizhny Novgorod) pp 251-258 (in Russian)

[22] Litvin L F, Golosov V N, Dobrovolskaya N G, Ivanova N N, Kiryukhina Z P and Krasnov S F 1998 *Soil erosion and channel processes* **11** 57–76

[23] Petelko A I, Golosov V N and Belyaev V R. 2007 *Experimente of design of system of counter-erosion measures* (Moscow, MSU Press)

[24] Kanatyeva N P, Krasnov S F and Litvin L F *Modern changes of climatic factors of erosion in the northern adventure* (Moscow, MSU Press) **17** 14-28

[25] Bosco C, de Rigo D, DeWitte O, Poesen J and Panagos P 2015 *Nat. Hazards Earth Syst. Sci.* **15**(2) 225–245