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QUANTITATIVE ASSESSMENT OF POTENTIAL SOIL EROSION IN THE EASTERN SIBERIA REGION (USING THE EXAMPLE OF THE MARKHA RIVER BASIN)

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Abstract:

*The paper presents the results of estimations of potential soil erosion in the basins of the small rivers of the Markha River watershed (the Lena River basin), using geoinformation technologies. The creation of specialized geoinformation database and GIS for the basins of small rivers of the Arctic watershed of the Asian part of Russia is considered in detail, in the scale 1: 1,000,000, adopted for the research, corresponding to the regional level of spatial detail. The source materials for filling the geodatabase were the following: digital model of relief (the unit of regular raster grid was 250*250 m), maps of climatic parameters, maps of land cover properties, maps of landscape structure, and types of land use. The prototype of created geodatabase was used for estimation of potential soil losses on the test site, in the conditions of a flat relief - in the Markha River basin. Calculations were carried out, using the mathematical formula, recommended by the Scientific-Research Laboratory of Soil Erosion and Channel Processes of the Moscow State University n.a. M.V. Lomonosov. This model provides for the calculations of soil losses by the following categories: soil losses from snowmelt runoff, soil losses from storm runoff, potential total soil losses. The maximum possible values of the potential soil losses were obtained. The next stage of calculations provided for additional calibration of input parameters, in particular, consideration of the types of land cover. The results of calculations were approximate to the actual values of soil losses. In order to verify the values of soil losses in the Markha River basin, the values of runoff of suspended sediments were used. The obtained values are quite similar and comparable. The information is new.*

Keywords: *the Arctic watershed, the Asian part of Russia, watershed of the Lena River, small river basins, the Markha River, GIS technologies, soil losses, runoff of suspended sediments.*

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INTRODUCTION:

The territory of the Arctic watershed of the Asian part of Russia is dissected by a dense network of rivers [1, 2]. At present, due to the economic development of the region, anthropogenic load on small river basins increases. However, these basins are not sufficiently studied geographically [3, 4]. The development of GIS technologies makes it possible to conduct predictive studies of the natural and resource potential of the region, on the basis of the creation of geodatabases, relevant to the river basins [3-8]. The literature review showed the absence of electronic maps, covering the territory of the Arctic basin of the Asian part of Russia [1]. The geodatabase, created with the help of the grant from the Russian Geographical Society "Creation of the cartographic-geographic information system "Rivers and river systems of the Arctic watershed of the Asian part of Russia", was used in the research. The basin of the river Lena was chosen as a model. The scope of the study: regional (corresponding to the cartographic scale of 1:1,000,000). This category includes small rivers of the first order, according to the classification of Filosofov-Strahler. The basic operational-territorial unit (OTU) is the river basin, due to the dominance of basin geosystems in the conditions of humid plains of the subarctic and temperate geographical belt, including Russia [5]. River basins, as geosystemic formation, provide the possibility of carrying out a multiscale mapping, based on the commensurability and generalization, due to the logical sequence of hydrographic network structure (upper-middle-lower parts) [5, 6]. One of the main ways to identify the patterns of development of water erosion of soils is the basin approach.

MATERIALS AND METHODS:

The test site is the Markha River. It runs on the territory of the Republic of Sakha (Yakutia). The catchment area is 89600 km^2, it is the left tributary of the Vilyui River [1, 2]. The basin of the river is located in the conditions of the flattened, dissected and elevated relief of the Vilyui, Central Siberian Plateau and Central Yakut Plain, with an average height of 509.1 m, according to the Baltic System (BS). In the north, the basin borders with the Arctic Circle; the dominant class of landscapes is flat; the types of landscapes are taiga (north-, middle- and south-taiga), mountain taiga forests (lightly-forested-taiga low-mountain relief). The types of land cover include the following taxa: taiga gley cryogenic, leached, calcareous, and humus carbonate. The types of land cover of the studied watershed are subdivided into 7 categories, among which forest plantations prevail (81.3%). They consist of dark and light coniferous evergreen and hardwood species, etc. The next category of land cover is herbaceous and shrub vegetation (7.95%), etc.

Creation of geospatial database of small rivers basins in the watershed of the river Markha includes the following operations: selection of the digital model of relief GMTED2010 (the unit of regular raster grid is 250*250 m); detection of the watershed boundaries; formation of a database by thematic cartographic materials: morphometric characteristics of relief, climatic parameters, land cover properties, landscape structure and types of land use [2, 6, 9]. One of the variants of using the resources of created prototype database can be applied for estimation of potential soil losses. The technology of calculation is based on the mathematical model of soil losses, recommended by the Scientific-Research Laboratory of Soil Erosion and Channel Processes named after N.I. Makkaveev, of the Moscow State University n.a. M.V. Lomonosov [10]. This model takes into account the soil losses from storm runoff (it is the formula of the universal soil loss equation (USLE), modified for the conditions of Russia) [11], as well as the soil losses from snowmelt runoff, based on the dependence of the State Hydrological Institute (SGI) [12]. Information from the created geodatabase is used as basic material in the model of soil loss: morphometric characteristics of the relief (length, steepness, exposure of slopes), climatic parameters (weather station coordinates, daily air temperature, precipitation), properties of land cover (structure class, stoniness, humus content, fractional composition, etc.), landscape structure (class, types, subtypes, etc.), types of land use (forest cover, water bodies, urbanized territories, etc.) [13].

In addition, thematic cartographic materials on climatic parameters were used: erosion potential of precipitation (EPP), intra-annual distribution (zones) of EPP [10], and manuscript map of water reserves in snow, kindly provided by the workers of the Scientific-Research Laboratory of Soil Erosion and Channel Processes named after N.I. Makkaveev, of the Moscow State University n.a. M.V. Lomonosov.

RESULTS AND DISCUSSION:

Created geodatabase of the boundaries of small river basins of the Lena River watershed became the basis for estimation of potential soil losses, as a result of water erosion of slope-anthropogenic origin. The value of the potential total soil losses, without taking into account the types of land cover in the basin of the Markha River, is 12.6 t/ha/year. It corresponds to an average degree of erosion [1, 13, 14]. The maximum possible value is 1314.7 t/ha/year. The second stage of calculation of soil losses involves the use of correction factor of land cover type (Landcover) [4, 7, 15, 16]. As a result, the map was obtained, showing the spread of soil losses in the studied area at the present time (Figure 1).

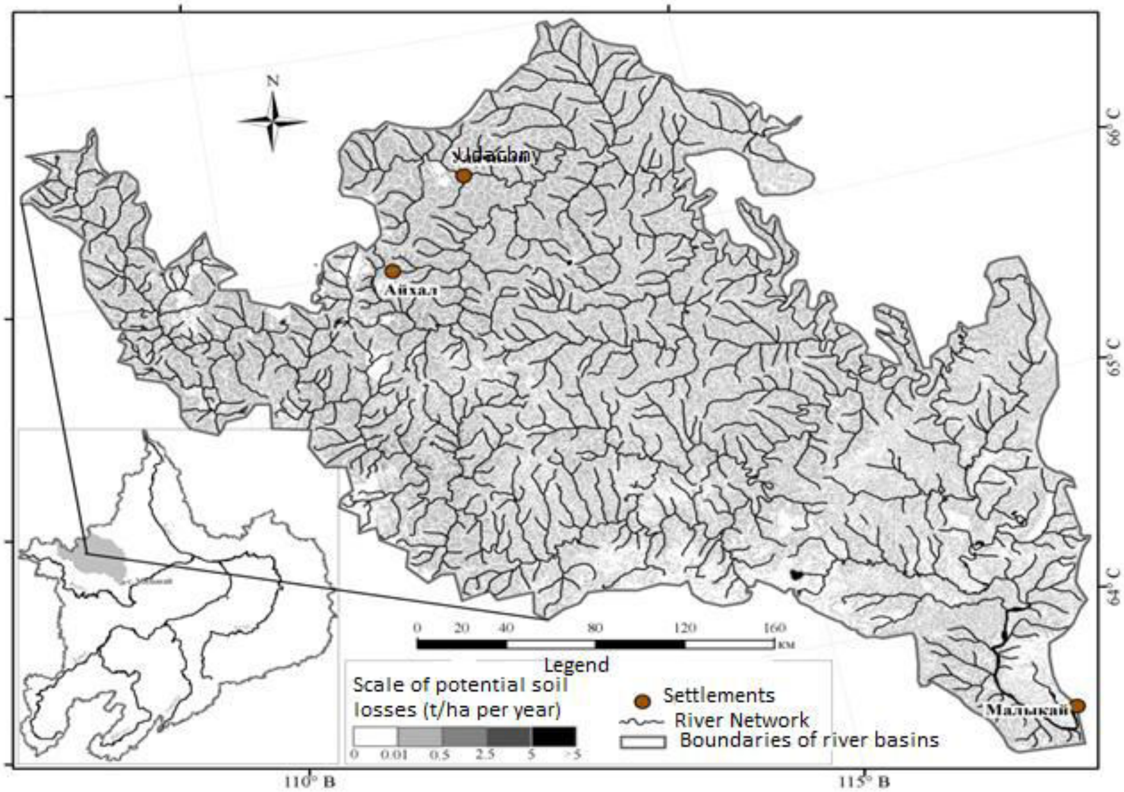

Figure 1. The map of total soil losses, taking into account land use in the basin of the Markha River. Inset map of the Lena River basin and position of the river Markha there.

Estimation of soil losses, taking into account the types of land use in the basin of the Markha River, shows an average of 0.04 t/ha/year, that indicates a very low load of water erosion. The maximum possible rate of soil loss within the surveyed watershed was 7.8 t/ha/year. This value is widespread within small territory, fragmentarily represented near the settlement Aikhal, sporadically in the upper and the middle reaches of the Markha River. Taking into account the use of land, the average value of soil loss rate in the basin of the Markha River is up to 0.5 t/ha/year (Figure 1). It is developed at 99.1% of the area of the studied watershed (Table 1).

Table 1: Distribution of values of water erosion of soils in the Markha River basin

Intervals of water erosion of soils, t/ha/year	Water erosion of soils, without taking into account the types of land use		Water erosion of soils, taking into account the types of land use	
	Area, km^2	Share of total area,%	Area, km^2	Share of total area,%

0-0.01	36417	45.2	39053.4	49,9
0.01-0.5	109.06	0.1	38517.6	49,2
0.5-2.5	3018.4	3.7	733.8	0,9
2.5-5	4987.4	6.2	7.1	0 (0,01)
5-10	8668.3	10.8	0.6	0 (0,0008)
10-50	22596.3	28.1	-	-
50-100	3772.1	4.7	-	-
100-1000	944.4	1.2	-	-
>1000	0.6	0 (0.0007)	-	-
Total	80513.6	100	78312.5	100

It should be noted, that comparing of the background rate of water erosion of soils, taking into account the land use (<0.5 t/ha/year) for the occupied area (99.1%), with calculations without the correction factor of land cover, shows the spread of the given rate of soil loss (<0.5 t/ha/year) slightly less than on the half of the territory (45.3%) of the Markha River basin (Table 1). We can assume that significant change in the balance is a consequence of the absence of mass plowing of the watershed slopes, and high forest cover of the territory. As a result of agricultural actions - plowing - the influence of rain (storm) runoff on the soil increases, i.e., the energy of raindrops, formerly extinguished on the crowns of trees, without obstruction reaches the surface of fertile soil layer, thereby causing and repeatedly increasing the process of water erosion of soils.

Verification of calculations accuracy of the potential soil losses of the Markha River basin was carried out, taking into account the sediment delivery rate, in comparison with the data on the average annual runoff of suspended sediments, recorded at hydrological posts [1]. There are generalized data on the rate of sediments delivery from slopes to the river bed, equal to 10-15% of the potential soil losses in the basin [17].

The comparison was carried out, using a vector map of suspended sediments runoff of Northern Eurasia river basins [18]. According to the map, a single hydrological station Malykay is in the Markha River basin. Its catchment area is 89,600 km^2, and it completely covers the territory under study.

Table 2: Comparison of the calculated value of total soil losses, taking into account the land use with the average annual discharge of suspended sediments in the Markha River basin

Name of the hydrological station	v. Malykay
Area of the basin, km^2	89600
Estimated value of sediment delivery to the river network from the slopes of the basins, t/km^2/year [2]	2.7
Runoff of suspended sediments t/km^2/year [3]	3.6

The value of the total soil losses, taking into account the land use (Table 2) and the contribution of sediments of channel origin to the total runoff of sediments, is consistent with the data of suspended sediments discharge [19]. The flow of sediments into the channel network, under conditions of flat relief, directly depends on the change in the structure of land use [20]. At the present time, the value of soil losses in the Markha River basin is relatively low, due to the dense leaf canopy of forest vegetation. The catalyst for increasing the mass of soil losses from the slopes of the basin is the liquidation of vegetation cover, for exploitation of the land for agricultural purposes, through mass plowing of the slopes.

One of the possible solutions to the problem is to prevent potential soil losses, occurring at catastrophic speed (more than 500 t/ha/year). The following methods can be used for this purpose: stiffening the intervals of soil loss degree; prohibition of plowing along the edge and sides of the slopes; selective and considered cutting of forest vegetation, etc.

SUMMARY:

1. Geo-information database and geographic information system (GIS) of the boundaries of small river basins of the Lena River watershed were created.
2. The calculation of potential soil losses in the Markha River basin was carried out, as a test site of

the Lena River watershed, located in the conditions of a highly dissected elevated relief.
3. In order to verify the accuracy, a comparison of the values of soil losses with the calculated values of the runoff of suspended sediments, recorded at hydrological stations, located in the drainage basin of the Lena River, was carried out.

CONCLUSION:

Geo-information database of the Markha River catchment basin (a tributary of the Lena River, the Arctic watershed of the Asian part of Russia) was created. The scale of the study was 1: 1,000,000 (regional spatial detail). The filling of the geodatabase with the information was carried out, using the following electronic cartographic materials: morphometry of the relief, climatic, landscape parameters, maps of land cover. The prototype of geodatabase was used in the calculations of soil losses. The calculations were carried out, using the mathematical model of soil losses, recommended by the Scientific-Research Laboratory of Soil Erosion and Channel Processes of the Moscow State University n.a. M.V. Lomonosov. The values of potential soil losses were obtained, without taking into account the use of land. They showed the average degree of erosion (12.6 t/ha/year). Additional calculations were carried out, taking into account the types of land use. The application of correction coefficient of land cover types in the calculations significantly reduced the soil losses to "zero" values (0.04 t/ha/year). The verification of values of water erosion of soils was carried out in comparison with the values of suspended sediments runoff. Taking into account the channel component in the balance of sediments runoff, the estimated value of sediments delivery rate to the river network from the slopes of the basins at the Malykay station (2.7 t/km^2) is very similar to the estimated runoff of suspended sediments (3.6 t/km^2/year). The resulting quantitative indicators are comparable.

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