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Morphological Typology of Small Watershed in River Basins of Cultivation Area.

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ABSTRACT

The article proposed the technique of small watershed typification according to four morphometric characteristics, determining the energy of relief: average height, vertical segmentation, the density of ravine network and an average slope. An elementary catchment area is used as an operating-territorial unit. Ward's method was used to perform the typification. The zoning of catchment area allows to determine the ratio of different agricultural lands, to reduce the rate of soil erosion and the amount of sediments entering the channel of permanent and temporary streams through the slopes. The testing of technique was performed within the upper reaches of the r. Medveditsa basin and made it possible to distinguish 6 types of elementary catchments differing by relief energy, as well as to perform their ranking according to relief energy. The zoning map established as the result of the developed method use concerning elementary catchment types may be used for the improvement of land use structure based on the optimization of lands with different erosion hazard, and the inclusion in crop rotation, depending on their soil protection efficiency.

Keywords: river basin, erosion, morphological typology.

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INTRODUCTION

Relief is one of the main conditions which lead to the development of various natural processes on the Earth surface. It largely redistributes incoming solar radiation, determines the characteristics of a surface runoff development and the entire spectrum of slope processes, providing thereby the landscape differentiation even in local areas.

The analysis of the relief contribution into the functioning of geosystems requires its quantitative characterization. The most effective method of relief quantitative study is morphometric analysis. Nowadays the morphometric analysis of relief is performed using digital elevation models (DEM) and geographic information systems (GIS) and can be used in various fields. For example, the morphometric analysis and the simulation using DEM is applied to create digital soil maps [1], flood zone maps [2], for the modeling of vegetation distribution [3]. Besides morphometric analysis implemented in GIS is widely used for zoning. We mean the allocation of territorial units as the regions with similar characteristics under zoning. Currently, there are several areas of zoning, which use DEM and morphometric analysis. One may distinguish landscape zoning [4], used to highlight the structural elements of relief (thalwegs, watershed lines), the zoning of erosion land according to a set of morphometric parameters [5], the zoning at the development of maps concerning recent tectonic movements [6] and some other species.

The zoning of the territory is based on morphometric characters and can be performed for a variety of scale levels from continent parts to elementary slopes. The morphometric analysis is performed not only for the analysis of area relief, but also for the bottom of reservoirs [7, 8]. At a present stage of GIS development, morphometric zoning may be performed in a semiautomatic mode. There are five main methodological issues that need to be set [9] before work start:

- territorial unit selection;
- the selection of features, on the basis of which the relation of a territorial unit to a particular class will be performed;
- the selection of a mathematical algorithm that will be used for classification;
- the selection of proximity measure between classes;
- the determination of the number of classes, into which classification objects will be separated.

In order to optimize the land use within the developed plains of the temperate zone we developed the morphometric zoning of the territory, where the elementary catchment areas were used as operational and territorial units (OTU). The optimization of land use is considered by us as the organization of arable, pasture and grassland placement on the basis of their balanced relationship within a particular river basin, contributing to the minimization of land degradation due to erosion process development and the reduction of sediment and pollutant introduction into permanent streams and water bodies. At that we proceed from the fact that the morphometric characteristics of various small basins determine their erosion hazrd within a particular river basin. While an optimal placement of the various lands is able to minimize the loss of soil from the development of a sheet flood and linear erosions. At the same time, the combined analysis of the actual land use and its changes over the past decades for various small catchment areas will allow to assess the actual situation and compare it from with the best one in terms of soil fertility maintenance and surface water pollution reduction.

METHODOLOGY

The construction of catchment boundaries was carried out using GIS WhiteBox GAT [10] and a global digital relief model SRTM (Shuttle radar topographic mission). The model preparation algorithm well-known among GIS experts was applied to this model (step 1 on Figure 1) for the subsequent development of the map for the thalwegs of fluvial and constant drainage system (step 2 on Figure 1) and their watersheds (step 3 on Figure 1). A detailed description of the algorithm was first given in the article by J. Colligan and D. Mark [11].

In order to select a watershed type on the studied area, we used the set of the following 4 morphometric parameters: altitude; bias (slope); the difference between maximum and minimum height; the density of ravine network.

At the moment there is quite a number of morphometric parameters proposed for the quantitative characterization of the relief. The morphometric indicators and the methods for their obtaining using GIS and DEM are also presented in detail in many works of domestic [1, 4] and foreign researchers [12-16]. Among the most frequently used indicators one may highlight the following ones: height, tilt angle, exposure, profile and planned curvature, tangential curvature, etc.

The digital model of tilt angles was derived on the basis of studied area DEM and ArcGIS software product, where the tilt angle calculation algorithm is applied, set out in Baradj P. and R. McDonald works [17].

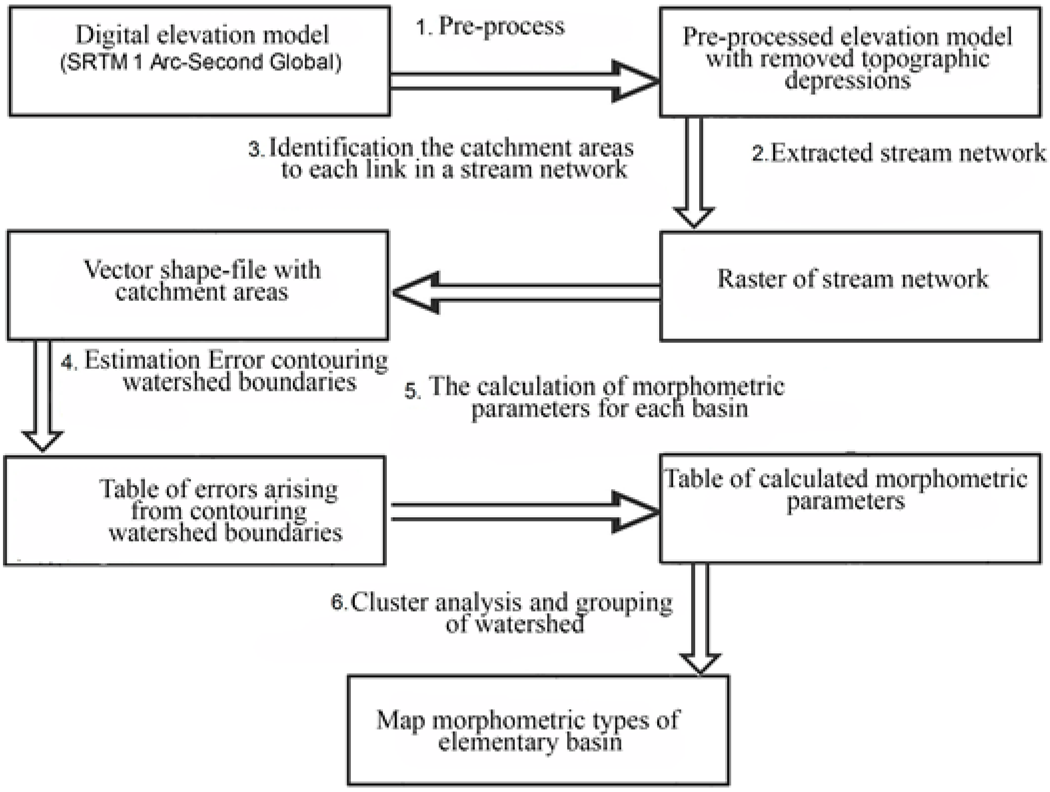

Fig. 1. Block diagram of the steps of the proposed methodology

An average height within the basin, the differential between the maximum and the minimum height was calculated in the same software product. The density of ravine network was calculated according to the formula 1.

$$G = \frac{\sum l_b}{F} \quad (1)$$

where G is the valley network density $\sum l_b$ is the sum of thalweg of fluvial valley and the network within the elementary catchment (m) [18], F - the elementary catchment area (km^2).

During the next stage of works, based on the previous stage of morphometric parameters an automated typification of elementary catchments was formed with the assigning of a class number to each elementary catchment.

Ward's method was used to perform typification, i.e. to classify elementary catchments to one of the classes.

The increase of object distance square sum to the centers of classes derived from their combination is taken in this method as the distance between classes. Unlike other methods of analysis for the estimation of distances between classes, the methods of variance analysis are used here. At each step of the algorithm these two classes are combined, which leads to minimum increase of the objective function, i.e. an intra-group sum of squares. This method is aimed at the combination of closely located classes and "strives" to create the classes of small size.

At the moment, along with the classification algorithms, there are also the measures of proximity or the distances between classes, which are used in the classification algorithms: "Euclidean distance"; "Manhattan distance"; "Chebyshev distance"; "power distance", etc. "Euclidean distance" was used in our work as the distance measure in Ward's method.

In order to assess the accuracy of watershed boundaries development we performed the comparative analysis of watershed boundaries constructed according to the described procedure and manually according to topographic maps.

The part of the r. Medveditsa basin located in the north-eastern forested parts was used for comparative analysis. During this phase of the work 36 elementary catchment areas were digitized according to topographic maps the areas of which were compared to the areas of elementary catchments created according to the proposed technique.

During the performed qualitative analysis of the obtained map it was found that the boundaries developed manually are in a good agreement with the boundaries conducted automatically. The quantitative analysis showed that the maximum error does not exceed 12%, and the average one does not exceed 3%. Thus the greatest mistakes are characteristic for the catchment areas of less than 10 km^2, and insignificant mistakes are characteristic for the catchment area of 10-20 km^2.

STUDY TERRITORY

The catchment area of the r. Medveditsa (closing the section line in the city of Atkarsk) was selected as the object of study. R. Medveditsa basin is included in the river Don basin and is located in the lower and flatter south-western part of the Volga Region Upland. The area of the catchment part for which this technique was applied makes about 3619.7 km2. This catchment area is located at the altitudes of 160-260 m above sea level, the average height makes 228 m. The slopes of the catchment area have a small slope, two degrees on the average. However, the ridge of high hills appears on the watershed of r. Medveditsa and r. Tereshka in the eastern part of the catchment area.

The formations of Cretaceous and Paleogene (limestone and marl) are widespread in the upper reaches of the basin. The modern look of r. Medveditsa basin dates back to the Pleistocene age and is associated with glaciation. During the period of glaciation the river valley was filled with glacial deposits. The meltwaters of retreating glacier led to the formation of a large number of modern bars. The soils on the slopes of the catchment area interfluve are leached black earth. Gray forest soils dominate in the north-eastern part.

The catchment area territory of r. Medveditsa headwaters is used extensively in agriculture. Most of the catchment area is currently occupied by arable land (62%), meadows (19%) and forests (17%). The share of water bodies and settlements is presented by 3% of the total water catchment area. Small changes took place during the past 30 years of an investigated water catchment land use due to the reduction of cultivated land area.

RESULTS

982 of the first order elementary catchment areas were revealed in the basin of the r. Medveditsa (above the city of Atkarsk section line). Their area ranges from 0.02 to 19.27 km^2 and the average catchment area makes 3.7 km^2.

The set of 4 morphometric characteristics was obtained for each elementary catchment area: the average height of the basin (m), the average slope of the basin (degrees), the differential between the minimum and maximum height (m), the density of ravine network (m/km^2).

Thus, geoinformation database was developed, which includes elementary catchment area objects and 5 fields of attribute information table for each elementary catchment. In addition to 4 listed above morphometric parameters it also has the serial number of the catchment.

Elementary catchments were classified on the basis of these morphometric parameters. At the moment there is no single correct a priori division into classes. Most researchers agree that it is necessary to try different options for division. Two cases may be considered as a good option of a breakdown into classes: the characteristics of one class of objects are significantly different from the characteristics of another class of objects or have the opportunity of a meaningful interpretation of each selected class.

In our case the use of different number of classes was tested in the course of classification: from 5 to 10. During the use of the class 7,8,9 and 10 the evaluation of statistical significance concerning the differences of average morphometric parameters between classes showed that there are classes, which differ insignificantly from statistical point of view. In the case of class 5 and 6 use, they differ significantly. We used the variant of elementary catchment set breakdown into 6 classes for future work. Further development of a thematic map using the information about a catchment area class allows to create the map concerning the elementary types of basins, united in morphological areas (Figure 2). The average characteristics of different catchment areas are shown in Table 1.

The largest number of Type 1 elementary catchments (339) is located mainly in the lower part of the left gentle slope of r. Medveditsa (Figure 2). These are the basins with the lowest values of height and height difference and one of the lowest average values of tilt angles (Table 1). At the same time, this class catchment areas has the highest value of ravine system separation density. This ratio of morphometric parameters can be attributed to this type of catchment areas with the lowest relief energy. Therefore, the slopes of these catchment areas are most suitable for the cultivation of erosion-prone tilled crops.

Table 3. The average characteristics of catchment area types

Type (number of basins)	Height (m)	Slope (degree)	The density of valley network (km / km2)	Altitude (m)
1(339)	188.8	1.6	2.64	27
2(151)	225.6	1.4	2.43	34
3(144)	207.9	1.8	2.40	58
4(193)	253.1	1.9	2.30	55
5(136)	226.8	2.6	2.27	80
6(19)	263.4	4.4	1.98	99

The smallest by number 6-th type of elementary catchments is characterized by morphometric parameters determining its greatest relief energy. At the same time, this type of catchment areas differs by minimum value of ravine system separation. This type of catchment areas prevails in the upper parts of r. Medveditsa basin and a number of its left-bank tributaries. The catchment areas of this type are the least suitable for the use of their sloping areas as arable lands. Only at the use of complex anti-erosion measures the plowing of this catchment area sloping land is possible. The rest 4 types of elementary catchment areas (2,3,4,5) occupy an intermediate position between the above listed ones in terms of the relief energy potential. The territorial attachment of 1 and 2 types of catchment areas within r. Medveditsa basin is revealed while the left bank of a more sloped part of the basin is dominated by the catchment areas of 3,4,5 type, characterized by lower relief energy potential.

The resulting zoning map of catchment area types can be used in applied purposes to develop the recommendations for optimal land use in the r. Medveditsa basin. The performed ranging of catchment area types according to energy relief allows to estimate the actual ratio of arable, pasture, grassland and arable lands with the division of the latter depending on the set of crops used in crop rotation according to the degree of their soil protection characteristics, and on the basis of obtained information to optimize the allocation of arable land and a set of grain, forage and row crops based on soil erosion reduction and sediment supply with transported pollutants into permanent watercourses.

SUMMARY

The proposed method of river basin zoning based on the typification of elementary catchment areas according to 4 morphometric parameters determining the energy of their relief, allows to determine the optimal ratio of processed (arable land) and weakly damaged (pastures) and undisturbed (forest, meadow) cultivated plains within river basins allowing minimize the rates of soil loss from an arable land and minimize the proportion of sediment transported from the slopes into permanent streams during the formation of surface runoff on slopes.

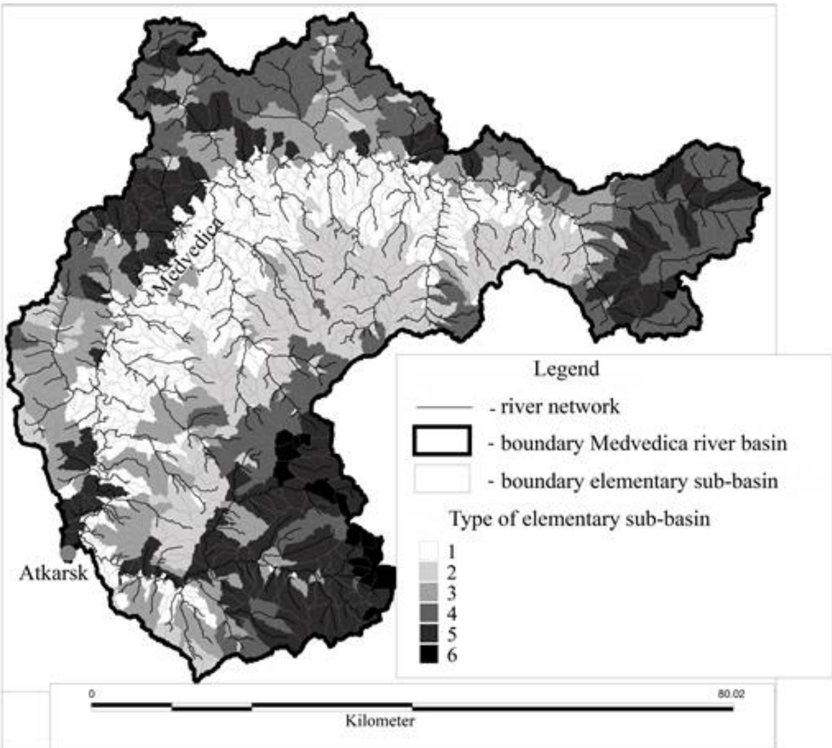

Fig. 2. Map of morphological zoning basin of Medvedica river (above Atkarsk)

The tested methods within the upper reaches of the r. Medveditsa basin allowed to reveal six types of elementary catchment areas differing by relief energy and to carry out their ranking according to relief energy. The zoning map of elementary catchment area types established as a result of the developed method use may be applied for the improvement of land use on the basis of land optimization with different erosion hazard, and the inclusion in the rotation of crops, depending on their soil protection efficiency.

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