Comparative analysis of morphometric variables of river basins based on digital terrain modeling in GIS

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Abstract. The results of a comparative morphometric analysis of the relief of river basins, made on the basis of a digital elevation model (DEM) in software environments QGIS and SAGA GIS, are presented. The basins of the Polnoy Voronezh and the Chembar rivers became the objects of digital modeling and calculations. The first basin is located on the Oka-Don Lowland with a relatively flat relief, the second is significantly dissected and located on the Volga Upland. A hypsometric map is constructed and the distribution of the surface area of the basins in terms of absolute height is shown. Calculations of leading morphometric variables were made for the rivers Polnoy Voronezh, Chembar and their tributaries, whose catchment areas exceed 50 km². Among these variables: the shape and slope of the longitudinal profile, river fall, vertical dissection, the average gradient of catchment slopes Based on the principles of basin nature management, the obtained quantitative data on the relief can be useful for carrying out balance calculations of the movement of liquid and solid runoff, determining the living conditions of aquatic organisms within catchments, developing projects for soil and water protection measures, improving the structure of land use, and implementing projects to preserve the species biodiversity of river ecosystems.

1 Introduction

There are many variables describing the geometry of the relief of geosystems, including river basins. A number of publications examine methods for calculating morphometric variables using geoinformation applications, including digital terrain modeling tools [1-3]. The development of geographic information systems (GIS) opens up opportunities for in-depth analysis of the structure of river basins, their typification and formalization for the development of recommendations on rational nature management in a particular territory [4].

Geoscience researchers are most interested in small-order watersheds, including small river basins [5]. Usually, watersheds of the first three orders are used as objects of geomorphological studies at different scales of initial topographic data [6-8]. With a drainage area of more than 50 km^2 and a channel length of more than 10 km, as a rule, the

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watercourse acquires a constant flow and is considered a river [9]. In addition, watercourses with a channel length of less than 100 km are defined as small rivers [10]. Thus, small rivers can be defined as watercourses from 10 to 100 km long and a drainage area of 50 km^2 or more. According to the Strahler system [5], on a map scale of 1:100000, such watercourses will mainly be of the 3rd or 4th order.

The data obtained in the course of the work on the morphometry of basins are necessary to clarify the calculations of water availability of territories, the organization of rational land use, the development of a complex of anti-erosion measures. When planning agricultural production territorially based on the basin approach, in particular when organizing the placement of agricultural land, it is necessary to take into account slope indicators in order to minimize soil erosion and pollution of water bodies.

In this paper, the structure of river basins is considered according to the following morphometric characteristics: the shape and average slope of the longitudinal profile, the fall of the river, vertical dissection, the average gradient of catchment slopes.

2 Materials and Methods

The aim of the study is to analyze the erosion hazard of catchments of middle river systems on high and low plains.

To achieve the aim, the following tasks were set:

- to identify typical river systems of approximately equal size on the low and high plains;
- create DEMs for river basins with a marked river network;
- to analyze the altitude distribution of areas in the studied basins;
- calculate the main morphometric variables and describe the structure for catchments with an area of more than 50 km^2.

The initial data were topographic maps of a scale of 1:100000. The terrain images were vectorized in the QGIS software environment, taking into account the specified scale, a river network was built. Based on the obtained vector data, two DEMs of the studied basins were created in the SAGA GIS software environment.

The objects of study were the basins of the Polnoy Voronezh and Chembar rivers, located in the same forest-steppe climate zone, characterized by a similar catchment area, but different geomorphological conditions of the relief. These are typical medium-sized rivers located within the low-lying flat and elevated plain of the forest-steppe zone of Russia.

In the basins of the Polnoy Voronezh and Chembar rivers, we have identified tributaries with a catchment area of more than 50 km^2 for analysis for erosion hazard and development of recommendations for economic use.

The Polnoy Voronezh is a medium-sized river within the Oka-Don Lowland in the north-west of the Tambov Region. It originates on the border between the Tambov and Ryazan regions, at the confluence with the Lesnoy Voronezh river it forms the Voronezh river – a tributary of the Don. The basin has a submeridional orientation and a pronounced asymmetry, stretching from the northeast to the southwest. The terrain is flat and poorly divided, there are many depressions in the catchment area. The hydrographic network is better developed on the left bank. The catchment area is 2142.7 km^2. The length is 187.7 km.

The Chembar is a medium-sized river located in the south-west of the Penza region within the Kerensko-Chembarskaya Upland (the outskirts of the Volga Upland). Before the confluence with the tributary Maly Chembar, it is called Bolshoy Chembar. The left and largest tributary of the Vorona river (Don basin). The catchment area is highly dissected and generally has a sublatitudinal orientation. River valleys are cut to a great depth and

open up ground water, coming out in the form of numerous springs. The length of the river is 120.5 km, the catchment area is 2027.6 km^2.

3 Results

To describe the distribution of the surface of the two model basins by absolute height, hypsometric maps were formed with the height of steps of 20 meters, which corresponds to the cross-section of the relief on a topographic map at a scale of 1:100000. Figure 1 shows the hypsometric indicators of the basins of the Polnoy Voronezh and Chembar rivers. Figure 2 shows the DEMs of these basins.

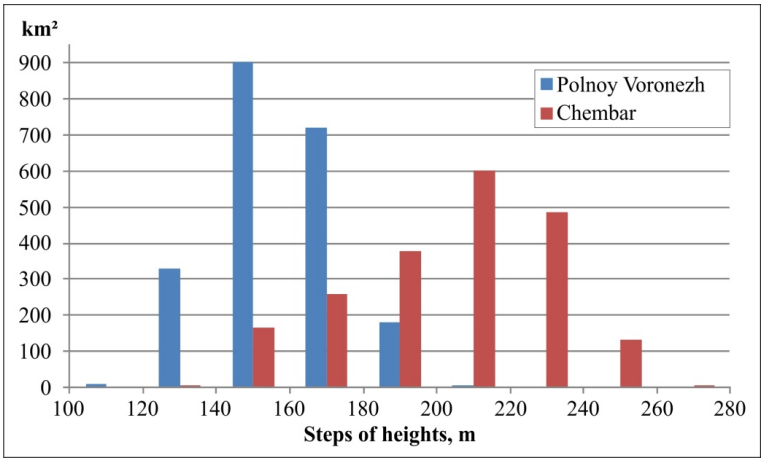

Fig. 1. Histogram of the altitude distribution of areas in the basins of the Polnoy Voronezh and Chembar rivers.

As can be seen, the basins under consideration are characterized by a very different distribution of catchment areas by absolute height. In the Polnoy Voronezh basin, three-quarters of the flow-forming surface is concentrated at altitudes of 140-180 meters above sea level, and 42% of the basin area is located in the range of 140-160 meters. There is no such pronounced tiered structure in the Chembar basin, the catchment areas are evenly distributed over a large range of heights. The largest shares of 30% and 24% occupy territories at altitudes of 200-220 and 220-240 meters, respectively. But the shares are also significant in the intervals of 160-180 and 180-200 meters, totaling 31%.

A set of variables is calculated for each river based on the created DEM (Table 1). The longitudinal profiles of the channels of the considered watercourses are constructed and their shape is characterized.

Table 1. Results of morphometric analysis of watercourses and their catchments with an area of more than 50 km^2 in the basins of the Polnoy Voronezh and Chembar rivers.

River	Vertical dissection, m	Fall of the river, m	Longitudinal slope of the river		The average gradient of catchment slopes	
			‰	sm/km	‰	°
Polnoy Voronezh	**90**	**57**	**0.30**	**30.37**	**12.07**	**0.7**
Yaroslavka 2	43	35	1.35	134.77	10.99	0.6
Ozerki	46	38	2.80	279.62	8.01	0.5
Yaroslavka 1	58	40	1.17	117.16	10.4	0.6

Malaya Yaroslavka	41	27	1.77	177.28	10.02	0.6
Cheboksar	54	44	3.03	303.24	10.1	0.6
Untitled near the v. Zapadnaya Starinka	55	45	2.39	239.23	8.22	0.5
Surena	86	64	1.03	102.56	12.7	0.7
Dalnyaya Surena	76	58	1.73	173.13	10.42	0.6
Lazovka	40	30	1.44	144.37	8.76	0.5
Chembar	**129**	**101**	**0.84**	**83.79**	**26.71**	**1.5**
Levka	94	55	2.19	218.77	25.27	1.4
Malaya Levka	91	49	3.23	323.22	38.06	2.2
Yunga	105	79	2.82	282.14	26.93	1.5
Shmarukha	83	66	2.49	248.68	23.54	1.3
Nyanga	87	46	2.76	275.94	19.52	1.1
Maly Chembar	108	61	1.65	165.00	39.58	2.3
Tyoplaya	89	31	3.83	382.72	35.11	2
Macha	92	72	1.26	125.94	19.35	1.1
Bolshie Ozerki	60	47	3.60	360.15	13.13	0.8

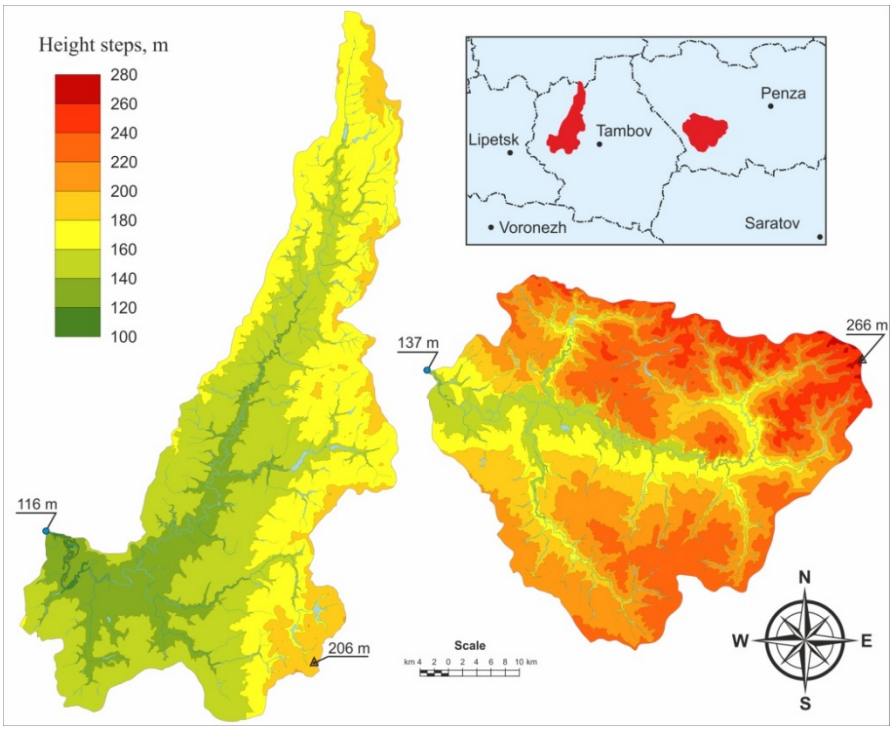

Fig. 2. DEMs of the basins of the Polnoy Voronezh (left) and Chembar (right) rivers.

Small rivers in the basins of Polnoy Voronezh and Chembar have 2-4 orders according to the Strahler-Filosofov system with a predominance of the 3rd order. Polnoy Voronezh and Chembar are rivers of the 5th order.

From the calculated variables, one can see the contrast of the morphometric structure of the low-lying and elevated plain river basins. Chembar surpasses Polnoy Voronezh in the average slope of the riverbed almost three times, in the average gradient of the catchment slopes – more than twice.

At the tributaries of the Polnoy Voronezh, the lowest average slope of the catchment slopes was about 0.5° and the greatest slope is observed at the Surena river in the south-eastern part of the basin, where the elevation marks reach 206 meters above sea level. There are no rivers in the Chembar river basin with an average gradient of the catchment slopes of less than 0.8°, and this indicator exceeds 2° in the tributaries of the Malaya Levka and Maly Chembar.

The longitudinal profiles of the twenty studied watercourses tend to have a smoothly concave shape, which is typical for the rivers of the developed plains. The greatest steepness of the profile line can be observed in the upper course, and the smallest – in the lower part. The strongly concave longitudinal profile of the Chembar river characterizes the substantial embeddedness of its valley. The shape of the profile of the Polnoy Voronezh river demonstrates the small slopes of the riverbed and the shallow cut of the main valley in this territory.

4 Discussion

The calculation of the complex of variables of slopes and dissection of the relief for the river basins presented in this work was performed for the first time.

The basin of the Polnoy Voronezh river is quite safe in terms of erosion, the steepness of its slopes is small, the river valleys are wide and shallow. Due to the small longitudinal slopes of the rivers with their low water content and flow rate, the main problem here is seen in the siltation and overgrowth of water vegetation of the channels, their transformation into a system of lakes that connect during periods of floods. The fight against such phenomena consists in clearing riverbeds and carrying out related water protection measures.

The significant steepness of the slopes and the deep occurrence of erosion bases in the Chembar river basin indicate a high erosion potential. It is necessary to pay attention to catchments with an average gradient of slopes with more than 2°, which can be considered erosive and dangerous. In each particular case, it may be advisable to carry out special soil protection measures, refuse to plant row crops, transfer part or all of the territory of a small catchment area to a less erosive and dangerous category of land, for example, reorientation from arable land to hay or pasture.

5 Conclusion

As a result of the research carried out, a method for calculating the morphometric variables of the surface of catchments was developed using the example of two morphologically dissimilar rivers within the Oka-Don Lowland and the Volga Upland. The level of detail of the DEM, formed on the basis of topographic maps at a scale of 1:100000, ensures the adequacy of the results of the morphometric analysis of low-order catchments.

With regard to the basins modeled in this work, we can say that the obtained data on the morphometry of the relief are useful for calculating the water availability of territories, organizing rational land use, and developing a set of anti-erosion measures. Assessing the slope indicator of a terrain is important to reduce soil loss from water erosion and the flow of washed-out sediments into the channel network when placing agricultural land within the drainage area. In addition, morphometric variables of river basins are factors that largely

determine the structure and functioning of aquatic ecosystems, which is important for planning biodiversity conservation measures.

The technologies of digital terrain modeling and morphometric analysis implemented in GIS applications, in the context of basin organization of nature management, are effective tools for searching and implementing geoecological solutions.

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