Zoning of the territory on the basis of morphometric analysis of basin geosystems

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Abstract. The problem of creating a geographic spatial database of morphometric indicators based on the basin approach for several rivers in the Krasnoyarsk region is considered. The division of the territory into catchment basins is carried out in a hierarchical system, up to the river tributaries of the 4-th order. The initial data for the construction of watersheds was a MERIT DEM Hydro digital relief model, vector data on the hydrographic network from A.P. Karpinsky All-Russian Research Geological Institute (VSEGEI) and Roscartography (Federal Agency of Geodesy and Cartography). In the process of data processing methods and algorithms of spatial analysis of relief and hydrological modeling, implemented in GIS software Whitebox GAT, QGIS and ArcGIS, were used. The main morphometric characteristics of the relief are calculated: slope, exposure of slopes; with the help of zone statistics for basins, the average values of these characteristics, the main statistics are calculated. We consider this work as the first stage in the creation of information support for the tasks of land use analysis, assessment of the natural resource potential of the region.

1. Introduction

The most important feature of the geographical environment is the territorial heterogeneity, which consists in a variety of natural conditions. The natural conditions of the components of the natural environment usually include climate, soil, topography, geological structure, flora and fauna of the area. An important component of natural conditions is also the physical and geographical location of the area, i.e. its location in a particular natural zone. The impact of natural conditions on life, work and household characteristics of the population is directly related to agricultural activities in the region. Each of these components of natural conditions have their own territorial zoning, and they have a different smallest territorial (natural) unit (district). For vegetation it is a forest area with certain characteristics, for climate it is a zone with different periods of duration of climatic features or temperature contrast. For terrain, these are areas with certain slopes, heights, or slope exposures. The choice of the smallest structural territorial unit, which will take into account all the heterogeneities of the territory is an urgent task [1, 2].

Belonging to the catchment area of a certain river determines the common structure of land use and is an important factor in land zoning. The possibility of splitting the main catchment basin into smaller
autonomous catchment basins of tributary rivers will allow forming information support of the land use structure for the analysis of territorial heterogeneity (natural resource potential) of the territory [3, 4].

The basis of the structure of land use is morphometry, which determines the nature of natural conditions and agricultural activities in the territory. The terrain determines the nature and direction of the flows of matter that form the natural landscape, which is changed by human activity [5]. Basin modeling site involves the calculation of a metric such as the value of the slope, slope exposure and various types of curvature of the earth's surface, the evaluation of the visibility area, etc. [6, 7]. These tasks can be effectively solved using geographic information systems (GIS) and digital elevation models [8, 9].

Digital terrain and elevation models (DTM, DEM) are derived from remote sensing materials and, due to their different means of production and processing methods, differ greatly from each other. The most famous DEMs are GTOPO30 (Global 30 Arc-second Elevation); SRTM (the Shuttle Radar Topography Mission); SRTM Void Filled; GMTED2010 (Global Multi-resolution Terrain Elevation Data 2010); ACE2 (Altimeter Corrected Elevations 2); ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) GDEM (Global Digital Elevation Model) [10]. However, all of these DEMs contain various accuracy errors [4], many of which have been eliminated in a new dataset: MERIT Hydrologically Adjusted Elevations (MERIT Hydro DEM) [11, 12].

This paper presents the results of the development of a model of land use structure based on basin modeling of the rivers of the Krasnoyarsk territory according to the digital relief model MERIT Hydro. The following research tasks were considered: 1) creation of a hierarchical scheme of watershed division of the studied territories; 2) calculation of morphometric indicators of relief in the basin geosystems of the Krasnoyarsk territory according to the MERIT Hydro DEM, and the formation of an appropriate spatial database; 3) statistical description of the results and their interpretation in accordance with existing scales and gradations [13, 14].

2. Materials and methods

The following data were used as input sources:

1. MERIT Hydrologically Adjusted Elevations DEM with spatial resolution of about ~90 m at the equator (http://hydro.iis.u-tokyo.ac.jp/~yamadai/MERIT_Hydro/).
2. Vector layer of catchment basins, built in automated mode using specialized hydrological modules of Whitebox GAT GIS software (http://jblindsay.github.io/ghrg/Whitebox/).
3. Hydrographic network data from different source topographic maps of 1:10 00 000, 1:2 500 000 scale from A.P. Karpinsky All-Russian Research Geological Institute (http://vsegei.ru/ru/info/topo/).

Based on cartographic data of different scales, maps of different detail, a hierarchical system of catchment division of the territory into levels of the 1st, 2nd, 3rd and 4th orders of catchment division was developed. The work used GIS Whitebox GAT, QGIS (with GRASS modules) and ArcGIS.

The data processing technology was as follows. At the first stage, the Breach Depressions tool carried out preliminary processing of the digital elevation model, which resulted in the formation of a DEM that is correct for hydrographic analysis. On the basis of these data, a number of intermediate layers of information were calculated: Flow Pointer, Flow Accumulation, Streams; all of them were in raster grid format. The next stage was the creation of semi-basins of a given size using the Sub-Basins construction algorithm. All these operations were performed in the WhiteBox GAT software. The formed catchments were exported to the QGIS program, where the correction and final processing of the data were performed. The ArcGIS GIS formed catchment basins of tributary rivers of the hierarchical system of the 1st, 2nd, 3rd and 4th levels of catchment division taking into account the detail of vector layers of the hydrographic network of different scales.

To work out the methodology for creating a model of the hierarchical structure of the catchment division, the initial data of the catchments of large rivers of the Krasnoyarsk territory – the Kan river and the Mana river were used.

The 1-st level of catchment division consists of large rivers of the Krasnoyarsk territory. River Kan – 1 number, Mana – 2. The 2-nd level is the major tributaries of the 1-st level rivers, the numbering was
taken through the dividing "point", so for the river Cannes, the tributary of the river Agul has the number 1.16. The 3-nd level divides the watersheds of the 2nd level into constituent tributaries, so for example, the Little Agul river has the number 1.16.10 and is a tributary of the Agul river. The 4-th level is more detailed, the Little Agul river is subdivided into another 64 basins of the 4-th level (figure 1).

Figure 1. Unique numbers of watersheds of study area in the Krasnoyarsk territory.

The calculation of the main statistical indicators of morphometric characteristics of the relief for each catchment area was carried out in the AcrGIS GIS. The average values are calculated using the Zonal Statistics tool. The values of statistical morphological characteristics of the relief are calculated for each level of the hierarchical system of watershed division through "Queries" and "Filters".

3. Results and discussion

The generated data refer to the catchment areas of two rivers in the Krasnoyarsk territory, which are watercourses of the Yenisei river. In total, 513 basin geosystems were allocated in the studied territory of two catchments of the Kan and Mana rivers, including both the basins of small rivers and their interflow spaces. The total catchment area of the Kan river is 36926 km$^2$, the number of 2-nd level catchment divisions is 7, 3-rd level catchment divisions is 40, and the number of 4-th level catchment divisions is 437. The total catchment area of the Mana river is 9392 km$^2$, the number of 2-nd level catchment division is 1, 3-rd level catchment division is 13, and the number of 4-th level catchment division is 94.

In the process of implementation of developed database structure of the hierarchical system of drainage division, which contains information about the main morphometric parameters of the topography of each watershed (figure 2).

The analysis of the main morphometric indicators of the relief of river basins is carried out. Initially, the main statistical indicators (minimum, maximum, average, standard deviation) were calculated. Also, the ranking of indicators in accordance with existing classifications or expert in the absence of such. In accordance with the classifications, the corresponding thematic maps for each indicator are constructed.

Average height. Basic statistics: Kan – minimum height = 189 m, maximum = 1760 m, average = 588 m, standard deviation = 336 m. Mana – minimum height = 365 m, maximum = 1310 m, average = 696 m, standard deviation = 237 m. When ranking pools by average height (table 1) the standard classification of relief by absolute height was used.

Based on the ranking of pools by average height, a thematic layer was obtained (figure 3).
Figure 2. Hierarchical system of catchment division based on MERIT Hydro DEM.

Table 1. Classification of basins according to the height.

| River | Average height, m | Form of relief | Catchment basins, pcs | Part of the total number, % | Area, km² | Part of total area, % |
|-------|-------------------|----------------|-----------------------|-----------------------------|-----------|-----------------------|
| Kan   | 0–200             | Lowlands       | 1                     | 0,23                        | 3,03      | 0,01                  |
|       | 200–500           | Hills          | 260                   | 59,50                       | 23477,58  | 63,58                 |
|       | 500–1000          | Low mountains  | 116                   | 26,54                       | 6896,93   | 18,68                 |
|       | 1000–2000         | Middle mountains | 60                     | 13,73                       | 6550,78   | 17,74                 |
| Mana  | 0–200             | Lowlands       | 0                     | 0,00                        | 0,00      | 0,00                  |
|       | 200–500           | Hills          | 18                    | 19,15                       | 1082,76   | 11,53                 |
|       | 500–1000          | Low mountains  | 61                    | 64,89                       | 6597,77   | 70,25                 |
|       | 1000–2000         | Middle mountains | 15                    | 15,96                       | 1711,93   | 18,23                 |
Figure 3. Thematic layer ranking pools by average height.

Average slope. Statistics and frequency histograms (figure 4) are obtained for each basin. To rank pools by slope the scale proposed by M. N. Zaslavsky was used [7].

Figure 4. Ranking basins of Kan (left) and Mana (right) rivers on the slope.

Similarly, information on the exposure of slopes was processed. Statistical distributions for each individual hierarchical level of the catchment division system are obtained.

The resulting model of the hierarchical structure of the catchment division, consisting of heterogeneous indivisible territories of the 4-th level basins, will allow adding other spatial data obtained from remote sensing and ground-based studies to the database. Such as information on climate (average
annual air temperature, average long-term temperature maxima per year, average rainfall, etc.), soil composition, vegetation cover (forest type, ploughing of the basin, pool tinning, waterlogging of the basin, etc.), geological structure, landscapes, etc.

This work is the first stage of a comprehensive study of the territory to identify heterogeneous areas of the Krasnoyarsk territory, which will further form the information support of the land use structure for the analysis of the natural resource potential of the territory.

4. Conclusions

Global digital elevation models based on remote sensing data and processed by GIS software tools allow to receive rather reliable data on quantitative characteristics of the relief of large territories. They make it possible to perform the spatial analysis of the relief in order to clarify its morphology, allow for thematic and complex zoning. With the use of these tools for the first time on the territory of the Krasnoyarsk territory, in particular for the Kan and Mana rivers, a model of the hierarchical structure of the catchment division was developed and a spatial database of morphometric relief indicators for 513 basins of small rivers was created. In the course of the study, the distribution and basic statistics of key morphometric parameters of the relief are considered. Catchment basins were ranked according to these parameters in accordance with existing classifications or expert. A series of relevant thematic maps were compiled.

Thus, the study obtained adequate data on the morphometry of the relief in the basin geosystems of the Krasnoyarsk territory. On their basis, a database of spatial data was formed, which can be used for hydrological and geomorphological modeling, geocological assessment of the territory, creation of a landscape map and a number of other tasks.

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