The Application of GIS Technologies and Remote Sensing Data to Determine the Morphometric Features of the River Basin: The Case of the Upper Part of the Charysh River

O V Ostanin†, G S Dyakova and A S Lebedeva

1 Altai State University, 61 Lenina pr., Barnaul 656049 Russia

E-mail: ostanin_oleg@mail.ru

Abstract. The paper focuses on the possibilities of using the technology of geographic information systems (GIS-technologies) and data on the Earth remote sensing to determine the morphometric parameters of the river basin on the example of the upper part of the Charysh River (Russia). The authors conclude that a river basin is a holistic natural complex in which all physical parameters are interdependent and have specific features for each basin. Geographic information methods are used to study hydrological objects and in the modeling of drainage basins as natural compound complexes. In combination with GIS technologies, remote sensing methods are convenient for deciphering and assessing the hydrological situation of territories. For the upper part of the Charysh River basin, a complex of morphometric calculations was performed. Based on DEM and satellite images, thematic layers for GIS were built, and the thematic layers were designed as maps.

Keywords: Water supply · Water management · GIS · Remote sensing data analysis · Digital elevation model · Morphometry of river basins

1. Introduction

Nowadays, GIS technologies are attractive due to the speed and accuracy of cartometric work and calculations. This technology can exclude random measurement errors during their performance, and, if possible, present the results in a visual and easily perceived cartographic form [5]. Geoinformation methods and methods for remote sensing data analysis are widely used in landscape, resource, hydrological, geological, and geomorphological research. Their use is convenient for identifying the relationships between the components of the territory, building maps, and conducting visual and quantitative analysis of specific indicators (e.g., river basins). The river basin is the most important natural object, which largely determines human life. It can act as the central territorial unit in zoning territories, assessing erosion processes, and environmental studies. The use of geoinformation and remote sensing methods for studying the hydrological features of river systems allows one to fully reveal and characterize the basin as a natural geosystem with complex internal connections.

Knowledge of the morphometric features of the river basin makes it possible to competently use the resources available within it. This knowledge should be used to predict and overcome situations unfavorable for a person and the economy and ensure the rational use of natural benefits and their improvement.
1.1 Study Area

The Charysh, a left tributary of the Ob River, flows through the territory of the Altai Republic and the Altai Krai. The river takes its beginning from the slopes of the Korgon Range at an altitude of 1,800 meters and flows into the Ob near the village of Ust-Charyshskaya Pristan. The length of the river is 547 km, the area of the water basin is 22,200 sq. km [3]. The upper part of the water collection (up to 60% of the area) is mountainous. From the north, the river is limited by the Baschelak ridge, from the east – the Terekta (highest point – 2,927 m), from the south – Korgonsky, Tigiretsky (highest point – 2,007 m), and Kolyvansky (highest point – the mountain of Sinyukha (1,206 m)) ridges, with an average height of 1,800–2,500 m. Boundaries in flat terrain are drawn along the hills between the tributaries of the Charysh, the basins of the Alei River, and along the Kolyvan Uval. Morphometric analysis was carried out for the upper part of the Charysh.

2. Materials and Methods

The use of digital elevation models [DEM] and satellite data for their construction brings a morphometric description of the surface to a qualitatively new level. DEM, as a source of morphometric descriptions, have been of interest since their inception. In recent decades, techniques for a versatile morphometric analysis of territories based on DEM data were developed. Therefore, the labor intensity of geomorphological mapping saw a decrease. The accuracy of DEM constructed from the used remote sensing data is quite sufficient for performing common operations of morphometric analysis in a scale series common for the study of typical geomorphological objects, e.g., river basins of different orders [7].

The geoinformation method allows for calculating various features of river basins based on DEM. Such DEM as Shuttle Radar Topographic Mission (SRTM), with a spatial resolution of 90 m, and Advanced Land Observing Satellite (ALOS), with a spatial resolution of 30 m, were used as input data.

The calculations were performed in the program ArcGIS (ESRI Inc, USA), using the instrument Spatial Analyst. The obtained results (morphometric maps) have a raster data format, the construction method of which and their interpretation have their features. We obtained the following morphometric features of the basin:

- **Slope** – the ratio of the river’s fall in any of its sections to this section’s length. In ArcGIS, the slope is the rate of change in elevation for each cell in the digital elevation model. It is the first derivative of the DEM.
- **Exposure** (the slopes’ orientation) – the location of slopes of mountains, valleys, and other positive and negative landforms in relation to the cardinal points and the horizon plane. The tool sets the slope direction of the maximum rate of values variation from each cell to adjacent. The exposure is the first derivative of bias.
- At some point on a surface, the curvature is described as the curvature of a line formed by the intersection of the earth’s surface and a plane of a certain orientation that passes through a given point. Horizontal (planned), vertical (profile), and (average, general) curvature are commonly used in hemorphometric analysis. The curvature is derived from exposure in a given direction.
- **Flow direction**. To obtain hydrological features of the surface, it is possible to determine the flow direction from each cell of the raster. In ArcGIS, this operation is performed using the Flow Direction tool. The direction of flow is determined by the direction of the steepest descent, or maximum depression, from each cell.
- **Flow Accumulation** calculates the flow as the total weight of all cells flowing into each cell down the output raster slope. Cells with high total runoff are areas of concentrated runoff. They can be used to define watercourse channels.
- **Drainage area** (drainage basin) – an area bounded by watersheds, within which surface and
groundwater runoff is directed towards a natural watercourse or reservoir [2]. The boundaries between watersheds are called flow demarcation lines. The estuary is the lowest point along the watershed boundary.

Stream ordering is a method of assigning a numerical order to links in a stream network. This order is a method for determining the types of classification of streams based on the number of their inflows.

The use of the above tools allows one to obtain raster data for the entire basin. For the convenience of calculations (e.g., determining areas or lengths), it is necessary to digitize the received data, i.e., translate it into a vector data format. This was done using the “Raster to Polygons” or “Raster to Lines” tools and the Convert toolset.

3. Results
The theoretical prerequisite for modeling geospace within the boundaries of the river basin is its allocation as an independent unit of geographic space [7, 8]. According to F. N. Milkov [4], the riverbed and the adjacent territory, from which the river collects surface and underground runoff, form a complex natural system in the landscape plan – a paragenetic basin system. The main feature of this system is the orderliness of its constituent elements. The water flow (moving from the upper reaches to the mouth of the river) and the direction of the solid flow (first moving from the watersheds to the river valley and then along the mouth), together with the channel flow, form a single dynamic system of the river basin in its longitudinal and transverse planes.

The basin model consists of drainage basins of a different order. The components of a drainage basin are its relief and the configuration of the network of runoff lines. The relief is the main factor of the runoff because its features determine the surface runoff from the territory [6].

When analyzing the relief of the upper part of the Charysh River basin, the basin’s morphometric parameters were determined. The DEM data allowed us to find the hypsographic curve of the upper part of the Charysh River basin (figure 1).

![Figure 1](image)

**Figure 1.** The hypsographic curve of the upper part of the Charysh River basin according to the DEM. **Source:** Developed by the authors.

A morphometric relief model was constructed to describe the basin’s relief. The isolines were drawn at 250 m intervals to analyze the quantitative features of the relief. The hypsometric map reflects the elevation levels of the surface. The territory is gradually increasing from 959 to 2,460 m above sea level. The largest percentage of the area is occupied by territories located in the range of heights from 1,100 to 1,500 m above sea level.

The hypsometric elevation map, compiled in GIS, is represented by raster and vector layers with
attributive information for each object contained in it. The raster layer contains DEM with layered elevation coloring and shaded relief. Contours and elevations represent vector layers. The “horizontal” layer contains the following attributive information: object code (according to the nomenclature of symbols of the state geographic information center [SGIC]), object name (main, thickened, and intermediate horizontal), horizontal value (absolute height above sea level). The vector layer “elevation mark” contains the following attributive information: object code (according to the nomenclature of SGIC), object name (height mark, peak, etc.), own name of the object (name of a peak, mountain, hill, rise), and height value (absolute height above sea level).

**A map of slope angles of surfaces** is compiled in the form of raster and vector layers with attribute information. The raster layer contains information about the angles of inclination of surfaces with the pixel-by-pixel coloring of their values. The vector layer is a digitized raster layer of this map. It shows slope value (in degrees) and polygon area (in sq. km).

Sub-horizontal slopes (slope of the surface 0°–1°) are valley bottoms and watershed surfaces. Their area is 8.6%. The steepness of the slopes increases with the rise in the mountains. Thus, within the Korgon ridge (in the western part of the considered territory), there are very steep slopes (up to 49° (0.2% of the area)).

Slopes of medium steepness (slope of the surface 8°–15°) are widespread, which occupy 32.6% of the area. Steep slopes (16°–35°) occupy 26.6% of the surface, gentle (5°–8°) – 17.2%, and very gentle (2°–4°) – 14.7%.

**A map of slope angles of surfaces** is compiled in the form of raster and vector layers with attributive information.

**The exposure map** contains information about tilted surfaces facing a particular cardinal direction. Depending on the exposure, all DEM cells were classified according to eight cardinal points and one class “plane,” the slope value of which is 0°. Thus, it is possible to designate the northern slopes that can be used to equip ski tracks and the southern slopes, where we can observe active spring snowmelt with accompanying erosion.

Sub-horizontal surfaces (“plane”) occupy 1.3 sq. km (0.1% of the area). The least slopes are observed in the northern exposure, which occupies 165.1 sq. km (9.5% of the area). Most slopes are presented in the northeastern exposure (265.6 (15.3% of the area)). The slopes of other exposures are presented in relatively equal proportions (figure 2).

**Figure 2.** The diagram of the distribution of slopes of different exposure in the upper part of the Charysh. 
*Source:* Developed by the authors.
S, SW, W, NW, and “plane”), and (3) area polygon.

The flow direction map is a delineation of slopes, the surface flow from which flows in one cardinal direction. We identified eight flow directions. The eastern slopes occupy 164 sq. km (9.6%), south-eastern – 157 sq. km (9.2%), southern – 322 sq. km (18.8%), south-western – 192 sq. km (11.2%), western – 202 sq. km (11.8%), northwest – 157 sq. km (9.2%), north – 322 sq. km (18.8%), and northeast – 195 sq. km (11.4%). The predominance of the southern and northern directions of runoff and slopes (18.8% each) indicates the sub latitudinal location of the mountain ranges that form the territory’s relief and determine its runoff. The slopes in the southwestern, western, and northeastern directions are slightly larger than the area of the slopes in the southeastern and northwestern directions.

The flow direction map is presented in the form of raster and vector layers with attributive information. The vector layer is a digitized raster exposure layer containing the following attributive information: azimuth (in degrees), cardinal direction (in eight cardinal directions: N, NE, E, SE, S, SW, W, NW, and “plane”), and area polygon.

The stream order map contains information on the development of the valley lines system. When a map is automatically generated in the ArcGIS program, watercourses without tributaries are referred to as watercourses of the first order. When two watercourses of the first order merge, a watercourse of the second order is formed, etc. This stream ordering scheme is called “ascending” and is calculated in ArcGIS using the Strahler method.

The stream order map (figure 3) is presented in the form of raster and vector layers with attributive information. The raster layer contains information about the order of the stream with the pixel-by-pixel coloring of their values. The vector layer is a digitized raster layer of this map containing the information about stream order and stream length (in km).

![Figure 3. The order of watercourses in the upper part of the Charysh River. Source: Compiled by the authors.](image-url)
4. Discussion

Digital elevation models allow, with varying degrees of detail (depending on the selected spatial resolution of the DEM), to establish several parameters and features of the river basin, which, in turn, forms the basis for spatial analysis and identification of hydrological and geomorphological processes occurring on its territory (including such dangerous processes as erosion, slope, and avalanche formation, etc.). These parameters also help to learn the features of the local climate.

Thus, the speed of the river flow depends on the slope. It also determines the intensity of erosion, features of surface runoff, and the amount of solar energy entering the territory (which determines the territory’s microclimatic features).

The exposure characterizes the orientation of the river basin concerning the flow of sunlight. It determines insolation, the amount of radiation received by the earth’s surface. The exposure is an essential factor of the river basin’s local climate (microclimate), as it determines the location of the slopes in relation to the prevailing winds (windward and leeward slopes) and in relation to sources of moisture (large hydrological objects).

Areas with negative plan curvature are responsible for concave areas (accumulation areas are valley bottoms). Areas with positive planned curvature characterize convex areas (valley sides, ridges, and ledges marked with material drift. The greater the curvature (without taking into account the sign), the more concave or convex the surface is and vice versa.

The practical convenience of determining the total curvature is that it equally characterizes both mechanisms of accumulation. The slope of the surface characterizes the relative intensity of material drift, and the exposure characterizes its direction. Thus, the vertical curvature determines the patterns of erosion and accumulation, while the horizontal curvature determines the runoff’s spatial heterogeneity. Simultaneous consideration of both helps to better understand the patterns of redistribution of the material over the surface in liquid or solid form [1].

The “Total Runoff” tool allows one to identify all channels – permanent and temporary streams, avalanche trays, mudflow channels, etc.

The determination of the order of watercourses allows not only to establish a hierarchical structure of runoff in the territory but also indirectly indicates the water content of rivers. Some features of watercourses can be deduced only by considering their order.

5. Conclusion

A river basin is a holistic natural complex in which all physical parameters are interdependent and have specific features for each basin. Any basin has morphometric indicators (area, length, width, slope, exposure, the relative height of the catchment area) and hydrological features of the basin (the direction of flow, order of streams, and total flow). Geographic information methods are used to study hydrological objects and in the modeling of drainage basins as natural compound complexes. In combination with GIS technologies, remote sensing methods are convenient for deciphering and assessing the hydrological situation of territories.

For the upper part of the Charysh River basin, a complex of morphometric calculations was performed. Based on DEM and satellite images, thematic layers for GIS were built (hypsometric, surface inclination angles, exposure, flow direction and order of watercourses, and a hydrological map of the territory). The thematic layers were designed as maps.

Morphometric information is an essential resource for:

- Monitoring, modeling, and subsequent overcoming of emergencies unfavorable for humans and their economy, in particular, hydrological emergencies and landslides;
- Rational use of land and development of agriculture;
- The design of transport routes and engineering structures;
- The development of a network of specially protected natural areas and recreational facilities.
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