Capability of applying morphometric parameters of relief in river basins for geomorphological zoning of a territory

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Abstract. Information about morphometric characteristics of relief is necessary for researches devoted to geographic characteristics of territory, its zoning, assessment of erosion processes, geoeological condition and others. For the Volga Federal District for the first time a spatial database of geomorphometric parameters 1: 200 000 scale was created, based on a river basin approach. Watersheds are used as a spatial units created by semi-automated method using the terrain and hydrological modeling techniques implemented in the TAS GIS and WhiteBox GIS. As input data DEMs SRTM and Aster GDEM and hydrographic network vectorized from topographic maps were used. Using DEM highlighted above for each river basin, basic morphometric relief characteristics such as mean height, slope steepness, slope length, height range, river network density and factor LS were calculated. Basins belonging to the geomorphological regions and landscape zones was determined, according to the map of geomorphological zoning and landscape map. Analysis of variance revealed a statistically significant relationship between these characteristics and geomorphological regions and landscape zones. Consequently, spatial trends of changes of analyzed morphometric characteristics were revealed.

1. Introduction
Information about relief morphometry is necessary for solving problems of the geographic characteristics of the territory, estimation of erosion processes and assessment of the geoeological condition, etc. [1, 2]. Also, importance of a quantitative analysis of the relief is due to its high informativeness in carrying out various types of local and complex geographical zoning. Relief is the basic characteristic when creating series of landscape maps.

Digital elevation models based on regular coordinate grids are widely used now by professionals working in various areas of geography and geomorphology [3, 4].

Hydrological and geomorphological studies were started in the mid-1970s by A.P. Dedkov and V.I. Mozzerin at the Department of Landscape Ecology of Kazan University. The main objective of these studies at this stage is the creation of specialized GIS at different level of generalization where river basin acts as an operational territorial unit. The basin approach in the geomorphometric analysis of the territory allows to characterize not only the relief of a single basin but the entire study territory acting as spatial unit. There are many databases for different regions of the Earth based on basins [4, 5]. The most well-known global base is HydroSHEDS produced by the World Wildlife Fund in 2006 [6]. At present, the authors registered a number of spatial databases of the morphometric characteristics of the relief on the territory of the Volga Federal District.
The main objective of the study is to assess the capability of using morphometric parameters of the river basin relief for geomorphological zoning. Main goals: 1. Definition of river basins belonging to geomorphological regions and landscape zones; 2. Finding out the dependence of the relief geomorphological characteristics on the geomorphological region and the landscape zone using variance analysis; 3. Analysis of spatial variability of geomorphological characteristics.

2. Material and methods

2.1. Study area
The research area is the Volga Federal District of the Russian Federation, located in the east of the Russian Plain. Its total area is 1 034 000 km². This choice is due to several reasons. First, the size of the study area should be large and the scale should correspond to the transregional and global generalization level. Secondly, the territory should cover different landscape zones and areas with various morphogenetic types of relief. This will allow to provide further spatial extrapolation of the research results to not observed territories. The study area is located in the upland and lowland landscapes of the temperate plains, extending from the subzone of the northern taiga in the North to typical steppes in the South.

2.2. Input data
As the main data, the spatial database of morphometric parameters of the relief of 68787 river basins of the 2nd order was used [7, 8].

To determine the patterns of spatial variability of the morphometric parameters of the relief the vectorized USSR geomorphological zoning scheme, edited by S.S. Voskresensky [9, 10], and landscape map of the USSR with 1: 2500000 scale were used [11].

2.3. Analysis methods
Initially, using ArcGis, codes of the corresponding geomorphological region and the landscape subtype were assigned to each basin (figure 1).

![Figure 1. Map of belonging of the basins to geomorphological regions](Code description look in the Table 1).
According to the geomorphological zoning scheme the region is located within three geomorphological countries: Russian plain, Novozemelsky-Ural plain and Turanskaya plain, including 7 provinces and 18 regions (Table 1).

Table 1. Belonging of basins to geomorphological regions.

| Country          | Province                        | Region                                      | Number of basins, pcs. | Area, km²     | Region code |
|------------------|---------------------------------|---------------------------------------------|------------------------|--------------|-------------|
| Russian plain    | Northern Russian province       | Northern Dvina region                       | 5769                   | 42706.3      | 114         |
|                  |                                 | Timan Ridge Area                            | 849                    | 6503.8       | 115         |
|                  |                                 | Petchora Lowland area                       | 10                     | 175          | 116         |
| MidRussian province | Volga-Oka-Don Plain area      |                                             | 3993                   | 73296.2      | 135         |
|                  |                                 | Volga region Uplands and Ergeni             | 9847                   | 185402.2     | 136         |
|                  |                                 | Low Volga region                            | 1760                   | 80042.9      | 137         |
|                  |                                 | Upper Volga region                          | 35840                  | 460142.3     | 138         |
| South Russian province | Caspian depression area |                                             | 65                     | 5073.9       | 141         |
|                  |                                 | Sub Ural Plateau area                       | 536                    | 32316.2      | 144         |
| Novozemelsky-Ural plain | The province of Ural | Northern Urals steeply sloping ridgemidlands | 729                    | 8326         | 222         |
|                  | axial zone                      | The area of ridge-remnant low mountains of the Middle Urals | 394 | 5957.6 | 223 |
|                  |                                 | The area of middle ridge of the Southern Urals | 1795 | 21651.6 | 224 |
|                  |                                 | The area of low mountains and the plateaus of the Southern Urals and Mugodzhur | 1443 | 30356.8 | 225 |
| West Urals province | Parm area |                                                                                     | 2568 | 12691.8 | 231 |
|                  |                                 | The Ufa-Chusovskaya area                    | 1911                   | 15350.8      | 232         |
|                  |                                 | Sim Nugush ridge-remnant region             | 977                    | 11904.7      | 233         |
|                  |                                 | The area of the Ural-Tobolsk Plateau        | 240                    | 25848.4      | 241         |
|                  |                                 | Turgay Plateau area                         | 61                     | 10260        | 331         |

Due to a large number of regions the analysis was carried out separately for the Russian Plain country and Novozemelsky-Ural country. Besides, the basins belonging to Petchora lowland areas (total count is 10 pieces), the Caspian depression (total count is 65 pieces) and the basins belonging to the Turan plain (total count is 61 pieces) were excluded from analysis due to their insignificant amount.

To identify the dependence of the values of morphometric parameters on their belonging to a particular geomorphological area the analysis of variance was used where parameters acted as a dependent variable and specific geomorphological region acted as a factor.

The average length of slopes and the river network density parameters do not demonstrate the dependency on geomorphological regions. Under conditions of flat type of relief of the studied territory it was difficult to expect a different result. These parameters reflect indirectly the conditions of humidification. Consequently, their location is related to the landscape zones. In this regard, for the average length of the slopes and the density of the river network the presence of a connection with natural zones was analysed. For this aim, the analysis of variance was also carried out where the subtypes of landscapes were acted as factors (figure 2). To reduce the number of classes all mountain landscapes were joined into one type.
3. Results and discussion

According to the analysis of variance results it can be argued that during the transition from one geomorphological region to another such morphometric values as mean height, relative elevation, slope steepness, and LS factor [12] vary statistically significant. In all cases, the between-group dispersion is significantly larger than within-group and p-value is less than 0.05.

As can be seen from the graph (figure 3), the maximum heights within the Russian Plain are observed in the basins located in the regions corresponding to uplands of anticlises, and partially on synclises with inversion relief. Basins with minimal values belong to downfolds.

![Figure 2. Landscape subtypes: 1 – Middle taiga; 2 – Southern taiga; 3 – Subtaiga (With broad-leaved and small-leaved-coniferous forests); 4 – Broadleaved forests and Forest-steppe; 5 – Typical steppes; 6 – Dry steppes; 7 – Semideserts; 8 – Mountains.](image)

![Figure 3. The dependence of average height and height range on the geomorphological region of Russian Plain.](image)

Low values of relative elevation are observed in the basins located in the areas with an accumulative type of relief; it is increased in basins dedicated to the areas with erosion-denudation relief.

Average slope steepness values and, accordingly, LS factor behave in slightly different way (figure 4). In general, a pattern is the same for both factors but the minimum values of slope steepness
are observed in basins located on Sub Ural plateau with a large depth of vertical dissection. This can be explained by two factors: the prevalence of such relief elements as plateau and low drainage density. Thus, the domination of the territory areas with the slopes close to zero degrees, provides low values at calculation of average slope steepness. On the contrary, the average steepness in the basins located in Northern Dvina region are higher than expected ones at low values of vertical dissection. This is explained by the high density of the river network and therefore by a large number of slope complexes.

![Figure 4](image-url)  
**Figure 4.** The dependence of slope steepness and LS factor on the geomorphological regions of the Russian Plain.

For basins located within the Novozemelsky-Ural country statistically significant patterns of spatial variability of the morphometric characteristics of the relief are also revealed.

Maximal values of the height (figure 5) are observed in the basins corresponding to the mid-mountains where the highest ridges and massifs are concentrated. Significantly smaller heights are observed in basins belonging to low-mountain areas. The maximum values of relative elevation correspond to the midland Province of the Urals axial zone. Minimum vertical dissection is noted in lowland regions and plateaus. Relatively high values in Sim Nugush ridge-remnant region is explained by the alternation of sharply outlined ridges with narrow and deep depressions.

![Figure 5](image-url)  
**Figure 5.** The dependence of average height and height range on the geomorphological area of Novozemelsky-Ural country.

This also explains the high values of average slope steepness (and consequently LS factor) in the basins which are located in this region (figure 6). The values of these factors in other geomorphological regions give quite a logical picture. Maximum deviations correspond to middle mountains, lower ones correspond to low mountains, and the minimal ones are observed in the Ural-Tobolsk Plateau characterized by aligned relief.

Such factors as average length of slopes and the river network density have an inverse dependence: the higher the density of horizontal dissection the shorter the slopes of river valleys. The density of the river network in the plains reaches a maximum in the taiga zone, and, is as it should be, decreasing to the North and South. The lowest river density is typical for the Caspian depression. With the shifting to
the south (to the zone of forest-steppes and steppes), the density of the river network reduces and the number of temporary streams gradually grows. When the height goes up (on the hills, on the mountains) the density of the river network increases [13].

Figure 6. The dependence of slope steepness and LS factor on the geomorphological regions of Novozemelsky-Ural country.

As we can see on the graph (figure 7), the density of rivers is systematically reduced when moving from the zone of southern taiga and mixed forests to the zone of deciduous forests and forest-steppe, steppe and further to the semi-desert. It is primarily caused by climatic factors. In mountain landscapes high values of this factor are observed.

Figure 7. The dependence of mean slope length and river density on landscapes subtype.

The average length of the slopes, in contrast, increases in the row: southern taiga and mixed forests (mountain landscapes) - broad-leaved forests and forest-steppe - steppe - semi-desert.

The method of variance analysis revealed statistically significant relations of morphometric characteristics of relief with geomorphological regions and landscapes. Spatial variability trends of considered geomorphometrical characteristics, identified during the study on the basis of a basin approach, confirm the basic regularities described by other researchers.

Despite the fact that morphometry of the relief does not always explain its genesis, connection with geomorphological regions revealed for the four parameters, allows to assume that they can be used for geomorphologic zoning of the territory.

Acknowledgements
The work was supported by the Russian Science Foundation (project No. 15-17-10008)

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