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# Geomorphometric Analysis of River Basins in East European Russia Using SRTM and ASTER GDEM Data

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**Abstract:** The spatial database of geomorphometric indices with the scale of 1:200000 was created for the first time on the basis of a basin approach for the East of the Russian Plain European part. The basins built in a semiautomatic mode on the basis of SRTM DEM and Aster GDEM were used as OTE here. Using the abovementioned DEM the basic morphometric relief characteristics such as slope, slope length, vertical subdivision, river network density, LS factor were calculated. The mean values of these characteristics were calculated for basins. Using the vectorized map of geomorphological zoning, the belonging of basins to the was determined. On the basis of the obtained geographic information database the main statistics of morphometric relief characteristics are calculated and the results are interpreted using the existing scales and classifications. The dispersion analysis method revealed statistically significant associations for a number of characteristics with geomorphological regions. The regularities of spatial changes concerning considered geomorphometric characteristics were revealed. All studies were performed on the project Russian Science Foundation (RSF), geography and geoecology of rivers and river basins of the European Russia spatial analysis, estimation and modeling.

**Key words:** Relief morphometry, Russian plain, SRTM, ASTER GDEM, geomorphological areas

## INTRODUCTION

Information on relief morphometry is necessary to meet the challenges of the area geographic characteristics, its zoning, the assessment of erosion processes, the assessment of geo-environmental condition etc. Digital relief models which are based on regular coordinate grids, are widely used now by professionals working in various areas of geography and geomorphology (Maltsev *et al*., 2015; Yermolaev and Maltsev, 2014).

Hydrological and geomorphological studies are performed started in the mid-1970 by Dedkov and Mozzherin in the Department of Landscape Ecology at Kazan University. The main objective of this work at this stage is the creation of specialized GIS at different level of generalization, where river (drainage) basin acts as operational and territorial units.

The main purpose of this study is the performance of spatial analysis for several morphometric characteristics of the relief on the territory of the European part of Russia with the basin approach use. The basin approach at the geomorphometric analysis of the territory allows to describe as separate basins, so as the entire study area, acting as OTE.

**Research problems:** The calculation of morphometric parameters of relief in the basin geosystems of a studied area and the development of the corresponding spatial database; the statistical description of the results and their interpretation in accordance with the existing scales and graduations; the analysis of calculated characteristic spatial variability.

## MATERIALS AND METHODS

The following materials were used as the source ones: Relief digital model with the spatial resolution of 100 m on the Eastern territory of the European part of Russia, prepared on the basis of SRTM and ASTER GDEM data (Yermolaev *et al*., 2014). The vector layer of second order basin geosystems built in an automated mode according to abovestated DEM (Yermolaev *et al*., 2014); Hydrologically corrected DEM (Yermolaev *et al*., 2014). The hydrographic network from topographic maps with the scale of 1:100 000 in vector and raster formats. The calculation of values and attribute database increase was performed using Map Info 10.5, ArcGIS 10, WhiteBox GAT 3.2. Lindsay (2014) and Quantum GIS 6.4 programs.

Initially, the basin area was calculated in $km^2$ using map info. It should be noted that the calculation of areas and lengths "on the sphere" was used to minimize the impact of the projection on the results as well as for their compatibility with the field data. Further, a number of relief morphometric parameters was calculated for the basins.

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**Average slope:** Slope raster slope (in degrees) was developed on the basis of DEM in ArcGIS. The average value in the basins is calculated in QGIS using zonal statistics.

**LS topographic factor:** There are various methods for this indicator calculation (Wischmeier and Smith, 1978; Desmet and Govers, 1996; Kinnell, 2005; Moore *et al*., 1991). The factor was calculated in WhiteBox GAT program using "Sediment Transport Index" tool according to the following formula:

$$LS = (m+1)\times\left(\frac{A_s}{22.13}\right)^m \times \sin\left(\frac{B}{0.0896}\right)^n$$

Where:

$A_s$ = Specific catchment area
B = The local value of slope in degrees
m = Area value, usually taken equal to 0.4
n = Slope indicator, usually taken equal to 1.3

The following elements are developed for this in advance by hydrologically corrected DEM in Whitebox GAT package: local direction of flow model according to the algorithm "Deterministic 8" (O'Callaghan and Mark, 1984; Moore *et al*., 1991) and private catchment areas (Specific catchment area).

**Slope length:** In order to calculate the length of slopes hydrologically corrected DEM and the drainage system in a raster format were used. The calculation was performed in WhiteBox GAT program using the "Downslope Distance to Stream" function. In order to get an average value of a slope length within each basin, the pixels which lie on the borders of watersheds were left only from the resulting raster with slope lengths.

The depth of dissection was calculated as the difference between the maximum and the minimum height in each basin. In order to determine the density of the river network, the total lengths of rivers were calculated in $km^2$ within each basin (on the basis of drainage network vector layer) using MapInfo and then their ratio to the basin area was calculated.

## RESULTS AND DISCUSSION

The analysis of the main morphometric parameters was performed. Originally the main statistical indicators were calculated (Table 1-9) (minimum, maximum, average, median, mode, mean-square deviation), the frequency histograms were built (Fig. 1-6) and the ranking of values was conducted in accordance with existing classifications or in an expert way, at the absence of such classifications. The maps were developed according to separate indicators and classifications.

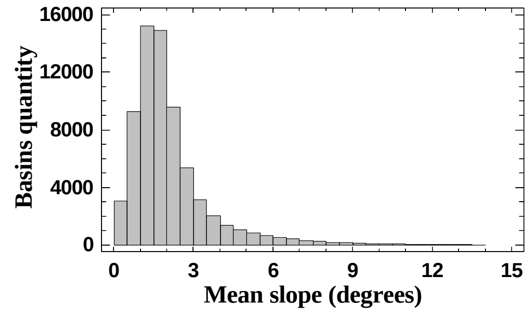


Fig. 1: Distribution of basins by slope

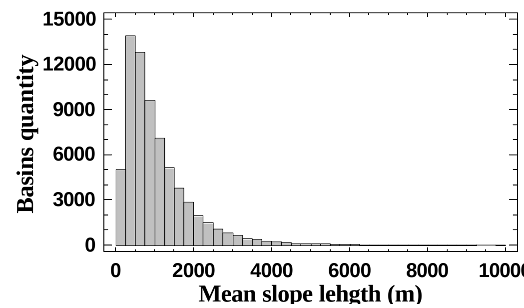


Fig. 2: Distribution of basins along slope length

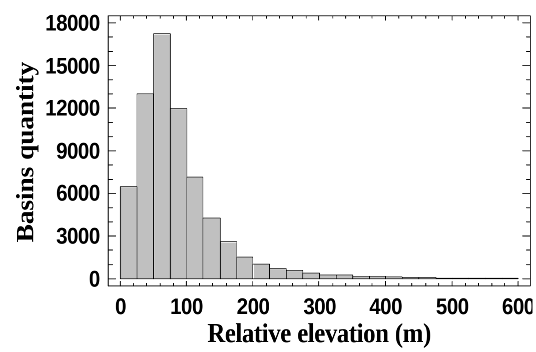


Fig. 3: Distribution of basins along dissection depth

Table 1: Main statistics (slope)

| Tests | Values |
|---|---|
| Minimum | 0.0005 |
| Maximum | 15.85 |
| Average | 2.08 |
| Median | 1.71 |
| Mode | 1.44 |
| MSD | 1.51 |

The total area of the studied area made 1,028,007.5 $km^2$. The scale proposed by Zhuchkova and Rakovskaya (1987) was used for the ranking of basins by slope (Table 2). Since, the classification is given

Table 2: Classification of basins by slope

| Average slope (grades) | Relief form | No. of basins (pcs) | The share from total number (%) | Area (km$^2$) | The share from total area (%) |
|---|---|---|---|---|---|
| **Plain territories** | | | | | |
| <1 | Flat (subhorizontal) plains | 12275 | 17.84 | 278995.11 | 27.05 |
| 1-3 | Weakly sloped plains (Very gentle slopes) | 44486 | 64.67 | 625584.4 | 60.83 |
| **Gentle slopes** | | | | | |
| 3-5 | Sloped plains | 5927 | 8.62 | 50411.24 | 4.90 |
| 5-7 | Very gentle slopes | 889 | 1.29 | 7056.35 | 0.69 |
| 7-10 | Average slopes | 177 | 0.26 | 814.01 | 0.08 |
| 10-15 | Steep slope | 18 | 0.03 | 25.84 | 0.00 |
| **Mountain territories (degrees)** | | | | | |
| <4 | Flat and almost flat surfaces | 1499 | 2.18 | 22441.57 | 2.18 |
| 4-10 | Gentle slopes | 3338 | 4.85 | 42678.98 | 4.15 |
| 10-20 | Downward slopes | 178 | 0.26 | 1 214.03 | 0.12 |

Table 3: Summary statistics (slope length)

| Tests | Values |
|---|---|
| Minimum | 100 |
| Maximum | 29778 |
| Average | 1092.47 |
| Median | 807 |
| Mode | 100.0 |
| MSD | 1051.12 |

Table 4: Classification of basins along the average length of slopes

| Average length of slopes in a basin (m) | Slope category | No. of basins (PCs) | The share from total number (%) | Area (km$^2$) | The share from total area (%) |
|---|---|---|---|---|---|
| 50-100 | Very short | 704 | 1.020 | 138.96000 | 0.010 |
| 100-200 | Short | 2707 | 3.940 | 1460.7400 | 0.140 |
| 200-500 | Average length | 15734 | 22.87 | 39137.150 | 3.810 |
| 500-1000 | Increased length | 22388 | 32.55 | 159399.86 | 15.50 |
| 1000-2000 | Long | 18913 | 27.50 | 349634.31 | 34.00 |
| 2000-4000 | Very long | 7069 | 10.28 | 326944.07 | 31.79 |
| >4000 | Extremely long | 1272 | 1.850 | 151292.41 | 14.75 |

Table 5: Main statistics (dissection depth)

| Tests | Values |
|---|---|
| Minimum | 0.1 |
| Maximum | 1054.15 |
| Average | 89.25 |
| Median | 71.13 |
| Mode | 40.03 |
| MSD | 75.12 |

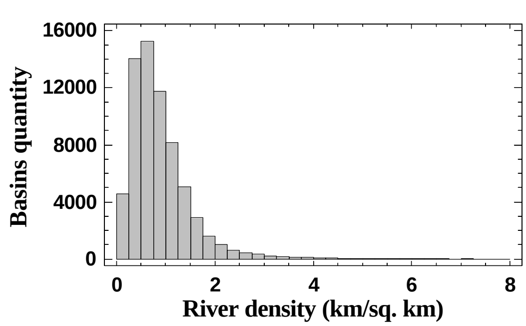


Fig. 4: The distribution of basins along river network density

separately for the plain and mountain areas the confinedness of basins to the platform complexes or orogens was determined in accordance with the Geomorphological map of the USSR at the scale of 1:2,500,000. Average length of slopes. Ranking (Table 4) was carried out in accordance with the classification of slopes along M.N. Zaslavsky's length (Zaslavsky, 1987).

**Dissection depth:** The scale of relative heights with 8 stages proposed by Kiryushin was chosen for ranking (Table 6). As the value of vertical dissection is calculated for elementary basins as in this study, the use of this scale is the most appropriate one. According to this scale the steps 1-5 are most typical ones for flat terrain, the steps 3-6 are most typical for foothills, the steps 4-6 for middle mountainous relief and the steps 6-9 for mountain relief.

**River network density:** In order to distribute the basins along the river network density researchers developed the scale based on this indicator volatility, depending on a landscape area (Table 8).

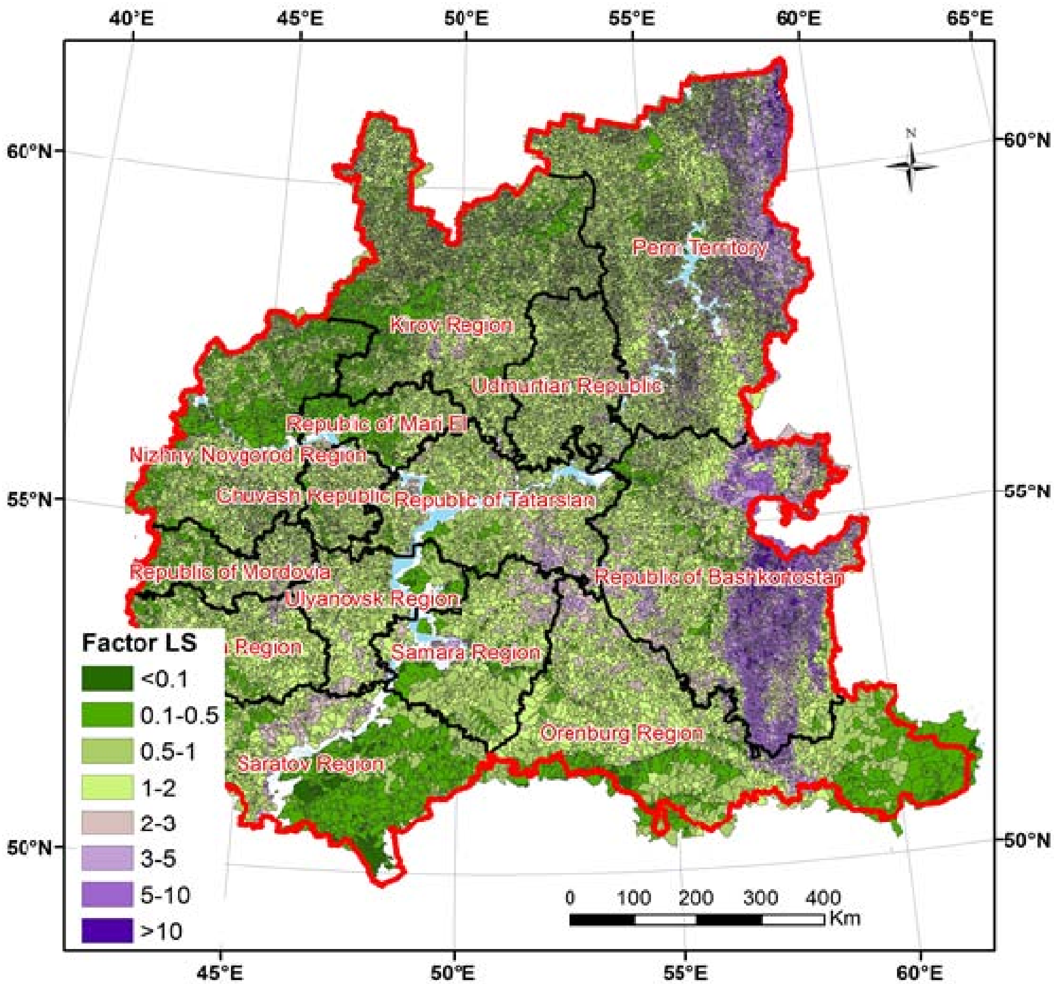


Fig. 5: Map of LS factor average values

Table 6: Classification of basins along dissection depth

| Vertical dissection (m) | Step | No. of basins (pcs) | The share from total number (%) | Area (km²) | The share from total area (%) |
|---|---|---|---|---|---|
| <5 | 1 | 1089 | 1.580 | 682.14000 | 0.070 |
| 5-10 | 2 | 1440 | 2.090 | 2474.9200 | 0.240 |
| 10-25 | 3 | 3969 | 5.770 | 16239.180 | 1.580 |
| 25-50 | 4 | 13029 | 18.94 | 100773.43 | 9.800 |
| 50-100 | 5 | 29267 | 42.55 | 397033.80 | 38.61 |
| 100-200 | 6 | 15637 | 22.73 | 397733.13 | 38.71 |
| 200-300 | 7 | 2726 | 3.960 | 76243.060 | 7.410 |
| 300-500 | 8 | 1319 | 1.920 | 27242.060 | 2.650 |
| >500 | 9 | 311 | 0.450 | 9585.7800 | 0.930 |

**LS factor:** The gradation was chosen for LS factor (Fig. 5, Table 10), used by European ESDAC system (European Soil Data Centre) as part of the work on the calculation of this index across Europe (Panagos *et al*., 2015). The applicability of this gradation is conditioned by the use of the same DEM (SRTM and ASTER GDEM) at the calculation and the comparability of territorial coverage.

In order to identify the pattern of the spatial variability the morphometric parameters of relief were compared with USSR geomorphological zoning scheme, edited by S.S Voskresensky. According to this scheme, the region is located within three geomorphological countries: Russian plain, Novozemelsky-Ural plain and Turanskaya plain, including 7 provinces and 18 regions (Table 11).

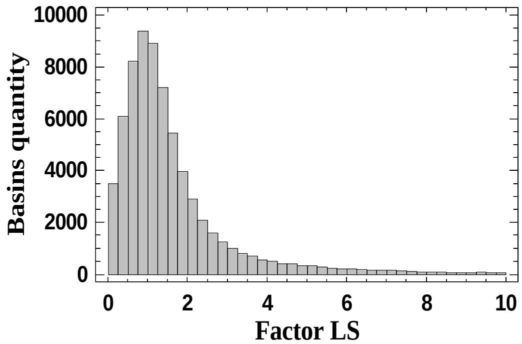


Fig. 6: Distribution of basins according to LS factor

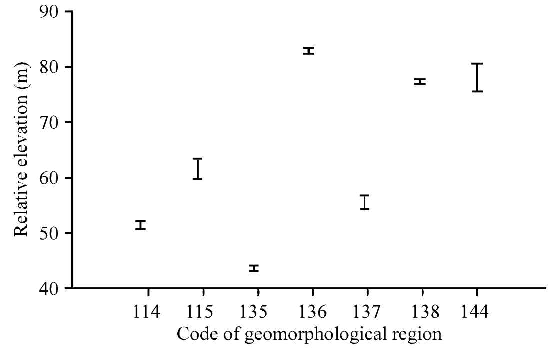


Fig. 7: The independence of Dissection depht on the geomorphological region of Russian plain

In order to identify the values of morphometric parameters dependence on their affinity to a particular geomorphological area the dispersion analysis was used where indicators acted as a dependent variable performance and specific geomorphological areas acted as a factor.

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

According to dispersion analysis results it can be argued that during the transition from one geomorphological area to another such morphometric values as slope, the depth of dissection and LS factor vary significantly. In all cases, the between-group dispersion is significantly larger than intragroup and $p<0.05$.

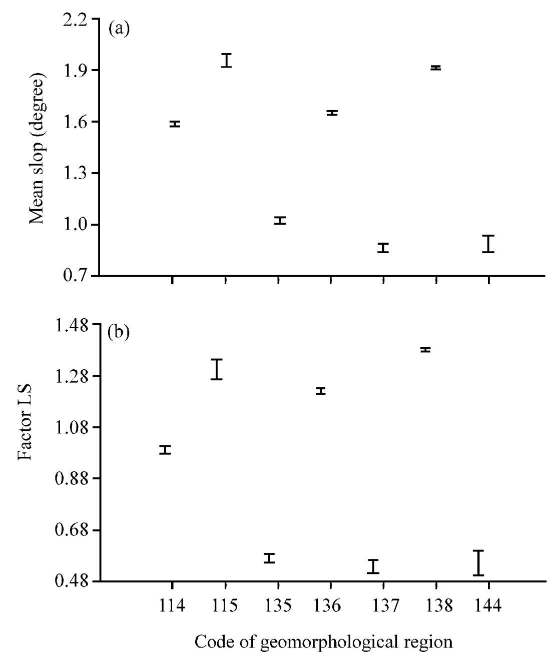


Fig. 8: a, b)The dependence of slope steepness (on the left) and Ls factor (on the right) on the geomorphological region of the Russian Plain

**Dispersion analysis results:** Low values of dissection depth 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 (Fig. 7). Average slope values and, accordingly, LS factor behave slightly differently (Fig. 8).

In general, a pattern is preserved, but the minimum values of slopes are observed in basins dedicated to Subural 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 horizontal dissection. Thus, the predominance of the territory areas with the slopes close to zero, provides low values at an average deviation calculation. On the contrary, the average slopes 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.

Table 7: Main statistics (river network density)

| Tests | Values |
|---|---|
| Minimum | 0 |
| Maximum | 9.15 |
| Average | 0.88 |
| Median | 0.73 |
| Mode | 0 |
| MSD | 0.69 |

Table 8: Classification of basins according to river network density

| River network density (km km$^{-2}$) | No. of basins (pcs) | The share from total number (%) | Area (km$^2$) | The share from total area (%) |
|---|---|---|---|---|
| <0.2 | 4692 | 6.820 | 236044.89 | 22.95 |
| 0.2-0.4 | 9271 | 13.48 | 326211.85 | 31.76 |
| 0.4-0.6 | 12833 | 18.66 | 231071.59 | 22.47 |
| 0.6-0.8 | 11486 | 16.70 | 116545.44 | 11.33 |
| 0.8-1 | 9101 | 13.23 | 59370.010 | 5.770 |
| 1-1.2 | 6827 | 9.920 | 29753.840 | 2.890 |
| 1.2-1.4 | 4749 | 6.900 | 14870.900 | 1.450 |
| 1.4-1.6 | 3024 | 4.400 | 7003.6700 | 0.680 |
| >1.6 | 6804 | 9.890 | 7135.3100 | 0.690 |

Table 9: Main statistics (LS factors)

| Tests | Values |
|---|---|
| Minimum | 0.000 |
| Maximum | 21.25 |
| Average | 1.66 |
| Median | 1.20 |
| Mode | 0.97 |
| MSD | 1.67 |

Table 10: Classification of basins according to LS factor

| LS factors | No. of basins (pcs) | The share from total number (%) | Area (km$^2$) | The share from total area ( %) |
|---|---|---|---|---|
| <0.1 | 923 | 1.34 | 7628.9900 | 0.74 |
| 0.1-0.5 | 8652 | 12.58 | 193018.95 | 18.77 |
| 0.5-1 | 17617 | 25.61 | 311217.38 | 30.26 |
| 1-2 | 25568 | 37.17 | 334481.55 | 32.57 |
| 2-3 | 7872 | 11.44 | 93871.040 | 9.130 |
| 3-5 | 4805 | 6.990 | 49346.320 | 4.800 |
| 5-10 | 2955 | 4.300 | 35023.920 | 3.410 |
| >10 | 395 | 0.570 | 3419.3500 | 0.330 |

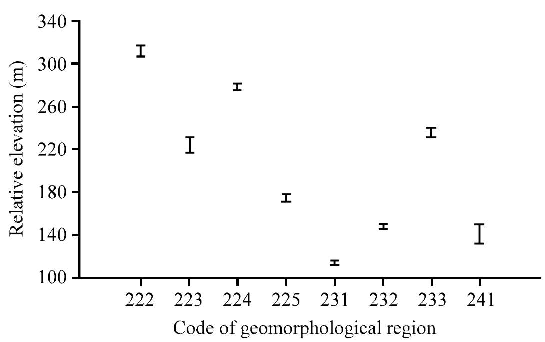


Fig. 9: The dependence of dissection depth on the geomorphological area of Novozemelsky-Ural country

The basins located within the Novozemelsky-Ural country are also identified as statistically significant patterns of spatial variability concerning relief morphometric characteristics. The maximum values of dissection depth correspond to the midland Province of the Urals axial zone. Minimum vertical dissection is noted in lowland areas and plateaus (Fig. 9). Relatively high

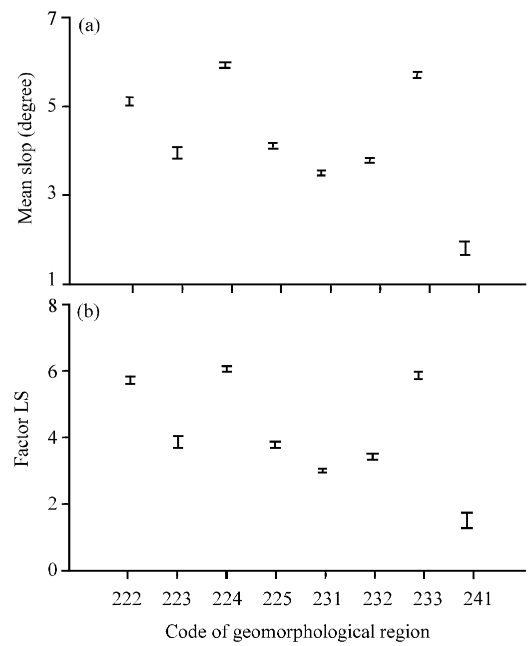


Fig. 10: a, b) The dependence of steep slopes (on the left) and LS factor (on the right) on the geomorphological area of Novozemelsky-Ural country

values in Sim Nugush ridge-remnant area is explained by the alternation of sharply outlined ridges with narrow and deep depressions. This also explains the high values of slope average steepness (and consequently LS factor LS) in the basins which are located in this region (Fig. 10).

The values of these factors in other geomorphological areas give quite a logical picture. Maximum deviations correspond middle mountains, low ones correspond to low mountains, and the minimum ones are observed in the Ural-Tobolsk plateau, characterized by aligned relief.average length of slopes and the river network density indicators do not demonstrate the dependency on geomorphological regions.

Table 11: Belonging of basins to geomorphological areas

| Country/Province | Region | No. basins (pcs) | Area ($km^2$) | Region code |
|---|---|---|---|---|
| **Russian plain** | | | | |
| Northern Russian province | Northern Dvina region | 5769 | 42706,25 | 114 |
| | Timan Ridge Area | 849 | 6503,79 | 115 |
| | Pechora Lowland area | 10 | 174,99 | 116 |
| Mid Russian province | Volga-Oka-Don plain area | 3993 | 73296,2 | 135 |
| | Volga region Uplands and Ergeni | 9847 | 185402,24 | 136 |
| | Low Volga region | 1760 | 80042,87 | 137 |
| | Upper Volga region | 35840 | 460142,33 | 138 |
| South Russian province | Caspian depression area | 65 | 5073,87 | 141 |
| | Subural plateau area | 536 | 32316,23 | 144 |
| **Novozemelsky-Ural plain** | | | | |
| The province of Urals axial zone | Northern Urals steeply sloping ridge-midlands | 729 | 8326,98 | 222 |
| | 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 | 21651,61 | 224 |
| | The area of low mountains and the plateaus of the Southern Urals and Mugodzhar | 1443 | 30356,78 | 225 |
| West Urals province | Parm area | 2568 | 12691,84 | 231 |
| | The Ufa-Chusovskaya area | 1911 | 15350,79 | 232 |
| | Sim Nugush ridge-remnant region | 977 | 11904,69 | 233 |
| **East Urals province** | | | | |
| The area of the Ural-Tobolsk plateau | 240 | 25848,4 | 241 | |
| Turanskaya plain | Turgay Betpakdalinskaya 331 province | Turgay Plateau area | 61 | 10260,04 |

## CONCLUSION

For the first time a spatial database of these morphometric parameters for the watershed basins of the 2nd order was created. A quantitative and a spatial analysis of the calculated indicators was performed. The method of dispersion analysis revealed statistically significant relationships of these characteristics with geomorphological areas. Spatial variability trends of considered geomorphometrical characteristics identified during the study on the basis of a basin approach confirm the basic laws described by other researchers.

Thus, adequate data on relief morphometry in the basin ecosystems of the European part of Russia were obtained which can be used for the hydrological and geomorphological modeling, the geo-ecological assessment of the territory and for a number of other tasks.

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