MORPHOMETRIC FEATURES OF RELIEF UNITS FROM BARLAD RIVER BASIN

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Key words: Bârlad river basin, morphometric models, drainage, slopes.

Abstract: Based on previous research, the paper makes a brief characterization of the geomorphological units of Bârlad river basin, respectively of Moldavian Central Plateau, Tutovei Hills and Fălciului Hills (except the northern part of Tecuci Plain). Then, using the Horton-Strahler classification system, were obtained for each unit the morphometric models of drainage and of slopes of the stream segments of successively increasing orders; the laws that define them verify well also on relief units, not only at the scale of the river basins. Based on the aspects resulted from the classification, on measuring the length and elevation differences of successive growing order segments of the river, the determination of average slopes was conducted. The law of slopes checks better, being the most dynamic morphometric element that is quickly adapting to changes of matter and energy flows through the river channels. Using these laws, we can calculate a series of morphometrical parameters, with variations from one unit to another, which can be used to differentiate and characterize those units.

Introduction

The future progress of society and sustainable development require a very good and detailed knowledge of the physical environment as support of social activities. It is known that for individualization of geomorphological units is required to consider a similarity of physical and geographical conditions that are typically expressed qualitatively. To compare and analyze these units on the basis of quantitative indicators, it is necessary to find a number of morphometric parameters to be identified. The scientific research efforts in this context are directed to find out and quantify a number of morphometric parameters of detail that can be used in characterizing and better understanding the geomorphological units.

To check the methodology was used the Bârlad river basin, large enough and located on lithologic formations with small differences in resistance to erosion. It is a drainage basin very well studied by the geographical school in Iaşi which has highlighted the geographical and physical conditions that make relief units to be

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different. This is one more reason for which this river basin was selected to try, by using morphometric models, to find a set of quantitative parameters to complete the characterization very well done so far.

The wide range of published works aimed to assess the overall environmental factors (Ungureanu, 1993; Băcăuanu, et all, 1980, and others) or the geomorphological units (Hârjoabă, 1968; Stănescu, Poghirc, 1992, and others). Detailed studies were undertaken on the heavy gully erosion, the most recent being included in vast studies of dynamic geomorphology (Rădoane Maria, Rădoane N, Ichim I., Surdeanu V., Ioniță I., Hurjui C., Nistor D., Petrovici G, Vasiliniuc I., Ursu A., Niacşu L. and others).

The studies of previously cited authors, related to the spread and dynamics of gullies and landslides, made by Rădoane Maria et. al. (1990, 1992, 1994, 1995); Hurjui, Dumitru, Petrovici, (2008); Vasiliniuc, Ursu, (2007); Niacşu, Ursu, (2007) and many others conclude that the areas most susceptible to gullying dominate vast areas of the Tutovei Hills and Fălciului Hills, with a density of about 2-3 km/km^2.

1. Methodology

To determine the morphometric network characteristics of Bârlad river basin, the information existing on topographical maps at scale 1:25 000 was used, which seems satisfactory for the degree of detail it provides. Based on the information contained by these maps, important elements for the basin morphometric aspect have been digitized, namely:

- river system (line vector-type containing in the database information such as: hydronym, order in the Horton-Strahler system, length, altitude for the start and end points for each segment of river);
- basin and inter-basin areas (polygon vector-type, the attribute table containing information relating to the order of river segment that it serves, the name of the basin, area and perimeter);
- elevation of the river segments heads (segment beginning - *start* and segment ending - *end*) and gauging stations (point-type vector).

The Digital Elevation Model was used to determine the altitudes of the *start* and *end* points of each river segment, in order to calculate the level differences of the river segments of successively increasing order.

2. Results and discussions

Bârlad River, a left tributary of the Siret River, gathers waters from an area of 7 253 km^2. The average altitude of the basin is 212 m, with a minimum of 15 m, in the floodplain near the confluence with the Siret and a maximum of 564 m, in Doroşanu Hill. The average slope of the basin is 5 per thousand, with small variations between the subunits of relief that drains (Panaitescu, 2008). In geomorphological terms, the basin overlaps the Moldavian Central Plateau in the north, the Tutovei Hills to the west, the Fălciului Hills in south-east and a small part of Tecuci Plain in the south.

Geological formations are sedimentary, dominantly being sands, marls, clays interspersed with harder sandstone and limestone layers arranged in a monocline structure. Tectonics within the basin does not have a high mobility and has reduced consequences regarding current geomorphological processes. The current landscape resulted from the modeling of the Sarmatian-Pliocene plain, which suffered a slight tilting motion and also slightly raised, being then fragmented and transformed into a region morphographically dominated by structural plateaus, hills and even a hilly layout, largely in the form of interfluves created by Bârlad's tributaries, oriented predominantly consequently and less obsequently or subsequently. The slope profiles are varied, from those appearing as linear to those affected by intense degradation processes (mainly landslides and gullying). The landscape is dominated by low-sloping areas, not exceeding 5° localized on structural surfaces, generally with southern exposure, but there are also present values exceeding 20°, generally corresponding to the cuestas facing north or north-west.

The analysis of Bârlad river system was realized on orders of magnitude as compared with Horton-Strahler classification system, and therefore the entire basin and consequently the main course is of 8th order. Knowing the fact that the evolution of the river undergoes a series of laws of probability, the morphometric elements for each order of river segments can be analyzed statistically; they form geometric progressions that check well, with a very good correlation coefficient. In this situation it may happen that a missing-term, respectively of 1st order, can be obtained by calculations, thus reducing long working hours if the classification is based on the order of 2 and up. The procedure is recommended since the starting point of second-order segments can easily determine by the union of two segments of first-order, while setting the start point for the first order segments may be difficult, because it is not morphologically clear and implies a degree of operator subjectivity.

After digitizing and prioritizing all network segments for Bârlad river basin, length, difference in altitude of start and end points of each segment were calculated and there have been obtained several series of data that revealed the laws which define the drainage and slopes models.

Seven rows of values have been obtained for the entire Bârlad river basin, starting from the 2nd order to the 8th. These values have been used to determine morphometric models for each geomorphological units (not for river basins), to see to what extent a number of these parameters can also be used to characterize relief units from this point of view. Morphometric models for Central Moldavian Plateau, Tutovei Hills and Fălciu Hills have been drawn up.

The Moldavian Central Plateau. Also known as the Sarmatian Plateau (David, 1922) or Bârlad High Plateau (Mihăilescu, 1932), it has an area of 3175.6 km^2 (43.8% of the studied area) and is located in the northern part of the basin. It is a structural plateau, dominated by Sarmatian horizons (especially Bessarabian). The dominant geomorphological processes are represented by landslides, fierce gully erosion and sometimes slope washing on bare lands. The resulting shapes are modeled in deposits of clay, shale or sands with limestone intercalations and sandstones with relatively low resistance to erosion. The landforms are represented by structural plateaus, with higher altitudes, and are affected by slope processes. Interestingly enough is that Băcăuanu et all. (1980) suggests a reduction from 75% to 25% of the area covered by forests only in the last two centuries, an action that likely affected the degree and speed of fragmentation.

To determine the morphometric characteristics of the hydrographic network for relief units, the analysis started from the law of the number of stream segments of the river in growing series, concomitantly with the digitization and classification of the network. Thus, for this case, it appears that the relief supports two basins of the largest order (seven), so the rows of data will consist of six terms, following that the first term to be obtained by further calculations. Then, by representing in semi-logarithmical coordinates the number of river segments for each order in relation to the size, it appears that the values tend to form a decreasing geometric progression in which the first term is given by the number of river segments of firstly measured order (order two) and the ratio is the confluence ratio (Rc). To calculate the ratio of confluence, the average value, weighted by the number of segments or the rule of chosen points is used (Fig. 1Aa). In this case, the ratio of progression was determined by the method of chosen points, respectively the values obtained for the 2nd and 4th order, using the relation:

$$\mathrm{Rc} = \sqrt{N2/N4}$$

It should be noted here that in both cases the focus should be on the lower orders, which statistically have the highest rate in relation to the upper segments, which being in small numbers may deviate more or less from the rule. Using the confluence ratio to calculate the values from one of the values involved in its determination, it can be seen that the differences are very small and hence the possibility that the number of river segments of the first order can be calculated. The high value of the confluence ratio shows a high degree of branching and of relief fragmentation, as favored by geological formations with a low resistance to erosion.

By the measurement of the length of the river segments of each order, we obtain a range of data plotted on the same graph, also in semi-logarithmical coordinates, that also highlights a decreasing geometric progression. It states that the summed length of river segments of successively increasing orders tend to form a decreasing geometric progression in which the first term is given by the summed lengths of the first order segments and the ratio by the successively summed lengths ratio (R_L) (fig. 1Ab). To calculate the ratio of summed length, the rule is the same as for the number of river segments.

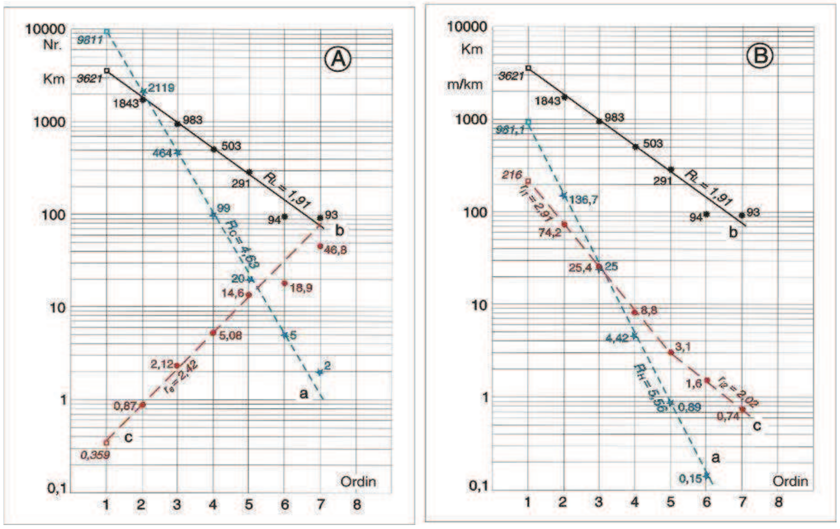

Fig.1 - The Moldavian Central Plateau; A. the drainage model; a, the law the number of stream segments; b, law of summed length on orders (km); c, the law of average lengths (in km) B. The slopes model; a, the law of summed elevation differences (km); b, the law of summed lengths on orders (km); c, the law of mean slopes (in m/km).

By making the ratio between the sequence of summed lengths to the number of river segments of successively increasing order, a third set of data is obtained, which represents the average length of river segments. It shows that the average lengths of stream segments of successively higher orders tend to form an increasing geometric series in which the first term is given by the average length of segments of the first order and the ratio by the average length ratio (r_l) (fig. 1Ac). In this case, the ratio is also given by the quotient of the ratio of confluence (R_C) and the summed length one (R_L).

Another important element for the development of the processes of erosion, transport and accumulation along water courses is the slope of the river network segments that can be determined from data obtained by using the same classification system. In the case of the Moldavian Central Plateau, there is the law of the length of watercourses involved in the drainage pattern that checks well, with a single deviation, that is a lower value for the length of river segments in the 6^{th} order (fig. 1Bb). To calculate the slopes, it is necessary to determine the rules according to which the sums of the differences in altitude of the river segments of different orders vary**.** For this, test areas have been set, and we determined start and end points elevation for each river segment and compared the results with those extracted from the Digital Terrain Model using GIS technology. The differences between the two sets of values were not significant and thus the second method was used, substantially easing the work. By summing up the differences in level for each order, we obtained a range of six values, also represented in semi-logarithmical coordinates that outlines the law of the summed differences of elevation. This states that the summed falls of river segments of successively higher orders tend to form a decreasing geometric progression in which the first term is the summed fall of first order and the ratio is the ratio of successive summed falls (R_H) (fig. 1Ba).

Knowing that the slope of a stream is given by the ratio of the difference in elevation and the main course length, this reasoning may be applied also in the case of the laws of summed elevation differences and of the summed length of segments of different order (fig. 1Bc). Thus, by the simple ratio between the two rows of data for corresponding orders, a third set of data is obtained: the average slopes of watercourses, which were represented on the same graph in semi-logarithmical coordinates. The law of the average slopes can be formulated as it follows: the average mean slope of stream segments of successively higher orders tend to form a decreasing geometric progression in which the first term is the average mean slope of the first order segments and the ratio is the ratio (r_i) of successive average mean slopes (Fig. 1Bc). The ratio can be easily determined as the quotient of the ratios of the two laws and the elevation differences and summed lengths (Zavoianu, 1985). The same result is reached if, instead of the summed values, the geometric progressions of the averages of falls and the average lengths of courses are used. As for the average slopes of the river segments of different order it was found this is the law that best verifies, perfectly true if we consider the fact that the slope is the most dynamic morphometric element, able to quickly adapt to flows of matter and energy circulating in the catchments area and in riverbeds. In this case it is worth noting that two lines separate from a law of slopes, one for the 5^{th} order and the other for higher orders, with a value of slope coefficient less than 2.02 instead of 2.91 (fig. 1Bc).

Tutovei Hills. This geomorphological unit occupies the west-central and southern parts of the basin and extends over an area of 2840.2 km^2. From the morphostructural point of view, it is located on a complex foundation, the contact between the base of the Moldavian Platform and the north-west part of the Bârlad Depression. The rocks belong to the Upper Sarmatian and to the Pliocene. Large areas are covered by Meotian deposits with cinerea at the base, covered by unconsolidated deposits of sand, loamy sand, clay and marl (Jearenaud, Saraiman, 1995). They are covered by Pontian and Dacian deposits and Villafranchian gravels and reddish sands; loess is present as a final coverage.

The morphometric patterns for Tutovei Hills have been determined using the same methodology (fig. 2AB). As for the drainage model, the law of the number of segments of the river checks well for lower orders, but the 5th order there should have been more river segments (fig. 2Aa).

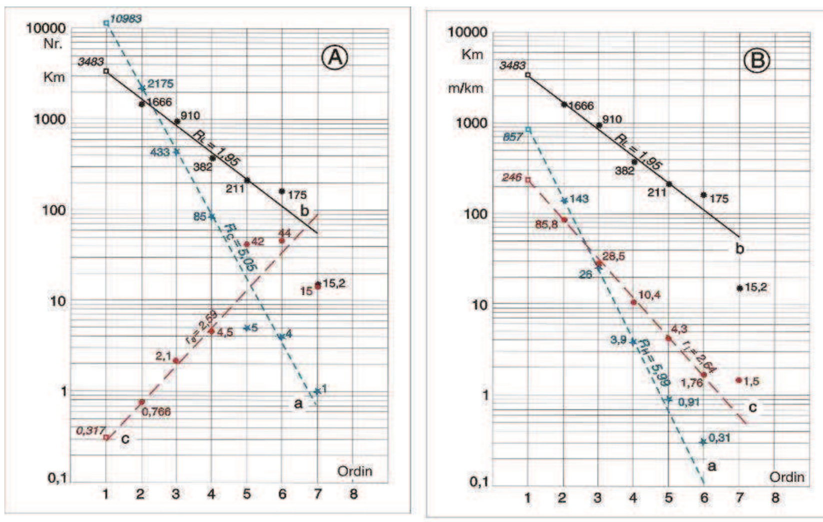

Fig. 2 - Tutovei Hills; A. the drainage model; a, the law the number of stream segments; b, law of summed length on orders (km); c, the law of average lengths (in km) B. The slopes model; a, the law of summed elevation differences (km); b, the law of summed lengths on orders (km); c, the law of mean slopes (in m/km)

The same situation is true with regard to summed lengths for lower order segments but the values for the 6th and 7th orders differ (fig. 2Ab). The deviations of the values from the law, for higher orders, influence the law of the average lengths, which does not check for the lower orders only (less than the 4th order, inclusive) (fig. 2Ac).

The slope model, which is even more dynamic, checks much better, even though the values of the average slopes of the last two orders deviate considerably. In this case, the values corresponding to the 6th and 7th orders usually deviate, while the average slope of the 6th six and respects the rule ant those for the 7th order deviate very little (fig. 2BA, b, c).

Fălciului Hills. Located on the left side, this unit lies over the south-eastern part of the studied area, as longitudinal strips parallel to the Bârlad valley. From a morphostructural perspective, the basement consists of two well-defined units, the Bârlad Depression and the Moldavian Platform, both covered by Miocene-Pliocene

Chersonian and Bessarabian deposits, predominantly in the northern part, and Romanian ones in the south.

The streams of this relief unit are generally short and their basins do not have a high degree of elongation as if in Tutovei Hills but have a high degree of fragmentation. Proceeding to the classification of river segments and their properties analysis, we found that there are five river segments of the highest order and the law of the segment number in growing sequence is checking very well (fig. 3Aa). The law of river segments length in growing sequence is also checks well, with a small allowance for the summed lengths of the five order courses (Fig. 3Ab). The ratio of the two rows of data gives the ratio for the law of the average lengths of river segments in increasing sequence of their orders (fig. 3Ac).

For the slopes model, we used the law of elevation differences summed for each order and the law of the summed lengths, both having a high degree of trust, so that the values for the first order will be as close to land reality (fig. 3Ba, b). The ratio of the two rows of data gives the law of average slopes of the river segments of successively increasing order, which is perfectly verified in this case, even for the largest order basins (fig. 3Bc).

The determined morphometric patterns and the fact that the used laws verified in almost all cases the allowed us proceed to calculating the values for the river segments of the first order and some parameters that can highlight the features of these three units of relief in this regard. Thus, when compared with one another, the calculated values of the morphometric model, for all the three relief units do not differ substantially from the drainage basin as a whole. The first stands, however, the Tutovei Hills, with the highest values and Moldavian Central Plateau holds the last place because its surface lithology, more resistant to erosion as compared with other two units.

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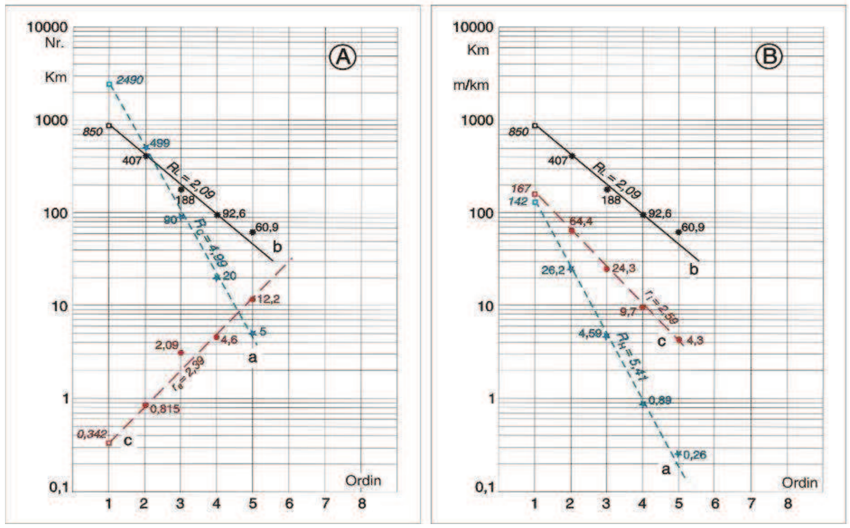

Fig. 3 - Fălciului Hills; A. the drainage model; a, the law the number of stream segments; b, law of summed length on orders (km); c, the law of average lengths (in km) B. The slopes model; a, the law of summed elevation differences (km); b, the law of summed lengths on orders (km); c, the law of mean slopes (in m/km)

The comparative analysis of the law of mean slope of the channel network in growing sequence for all the three relief units highlights a number of differences. Thus, the progression of slopes is best checked for the Moldavian Central Plateau, where the river segments of the 6th and 7th orders are placed on another line segment, with slopes much smaller as compared with lower orders (fig. 1Bc). A report of the slopes as high was found for Tutovei Hills, but in this case only the segment of 7th order has a deviation from the line joining the ones of lower orders (fig. 2Bc). The lowest growth rate of the slopes from one order to another can be found in the cases of the river segments in Fălciului Hills having the lowest value of the ratio (fig. 3Bc).

The frequency of the first order river segments, calculated as the ratio between the number of segments of the first order and the surface of the relief units shows a larger number of segments in Tutovei Hills, which has a number of 3.87 segments per km^2, followed by Fălciului Hills, with 3.42 segments and the Moldavian Central Plateau, with 3.09 segments per unit area (tab. 1). This is explained if we consider that the Moldavian Central Plateau formations are slightly more resistant to erosion as compared with other two relief units.

The average length of segments of the first order, as an indicator of intensity discharge processes, derived from the law of average length, ranks Tutovei Hills first, with the lower value for the length of the first order segments (317 m), followed by Fălciului Hills (342 m) and the Moldavian Central Plateau, with 359 m (tab. 1). The small length of the river channels of the first order means a shortening of the time for concentration of waters collected from the slopes, and therefore floods will form sooner, especially if the slopes of first order segments have the highest values as compared to all segments of higher orders.

Tab. 1 - Morphometric parameters for the geomorphologic units in Bârlad River Basin

Parameters / Unit	Moldavian Central Plateau	Tutovei Hills	Fălciului Hills
Area (km^2)	3175,6	2840,2	727,7
Frequency of the 1st order segments	3,09	3,87	3,42
Length of the 1st order segments (m)	359	317	342
Drainage density (km/km^2)	2,31	2,20	2,20
Length of overland flow (m)	217	228	227
Slope of the 1st order segments (m/km)	216	246	167
Average slope of channel network per unit (m/km)	126	165	109

Drainage density as a ratio between the total length of river segments of all orders and the area of the relief unit highlights the Moldavian Central Plateau, with 2.31 km/km^2, while Tutovei Hills and Fălciului Hills have the same value of drainage density, of 2.20 km/km^2.

Length of overland flow is another important element influencing the intensity of the liquid and solid flow process and therefore the rate of evolution. Computed as the inverse of the double value of drainage density (formula proposed by Horton in 1945), the resulted values are very close for Tutovei and Fălciului Hills (228 m), while the value for the Moldavian Central Plateau is 217 m (Zavoianu, 2006). The process of the flood wave formation has two components. The fist one is time to drain the slope which depends on its length and the second refers to the time required accumulated water to drain through the network of river channels. So, the shorter the overland flow, the faster the water reaches the network of channels and thus shortens the time of flood waves to form.

The slope of the first order segments also favors the concentration of flow and hence the formation of flood waves. This element is different, too for the three landscape units; its higher value (246 m/km) was found in the Tutovei Hills, followed the Moldavian Central Plateau (216 m/km) and Fălciului Hills, with the lowest value of 167 m/km (tab. 1).

The average slope of the whole network of river channels can be calculated using data obtained from the law of summed elevation differences and the law of summed lengths (Zavoianu, I., 1985). The values obtained this time are different for the three landscape units, in the sense that the highest average slope of all river segments of the network is the highest (165 m/km) in Tutovei Hills, followed by the Moldavian Central Plateau (126 m/km) and only 109 m in the Fălciului Hills / km (tab. 2).

The analysis all elements shows that the first place is taken by Tutovei Hills, geomorphological unit that has the highest frequency and shorter length of river segments of the 1st order, which in the presence of higher slopes of the first order segments and of the entire network of rivers imposes a shortening of time required by waters to flow along the network drainage river channels. This implies a potential for rapid concentration of water and the generation of flood waves with high amplitude and high power. Higher slopes of the river channels in successively increasing order show an increased hydraulic energy which implies a higher power of erosion and transport, and therefore a tendency for faster evolution.

Conclusions

The application of Horton-Strahler classification system and determination of morphometric patterns of drainage and average slopes for the Bârlad river basin as geomorphological unit proved that the laws that define these models are checked very well even if you the analysis is made at the scale of relief units. The detailed study has shown that even under small variations in rock resistance to erosion, at the scale of whole the basin, the results can differentiate a number of parameters that can be used in the characterization and individualization of the studied units. If the parameters have very similar values, equal or slightly different, these can be generated by a similarity of environmental conditions.

The fact that models checked very well allowed the determination of quantitative parameters values of which differ from one unit to another and can be used to differentiate and characterize these relief units.

From the performed analysis and comparison of calculated parameters, the Tutovei Hills significantly individualize, with a series of parameters having noticeable higher values, which can be explained both by its lithology and surface drainage evolution from the original surface up to the present. All analyzed parameters show a more pronounced evolution of this drainage area, as well as large quantities of silt in suspension.

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