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Morphometric Features of the River Network from the Bârlad Catchment

Ion ZĂVOIANU [1], Gheorghe HERIŞANU[1*], Nicolae CRUCERU[1]

[1] Spiru Haret University, Faculty of Geography, Bucharest
* *Corresponding author*, crucerunick@yahoo.com

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Abstract

After a brief presentation of the Bârlad catchment, the hydrographic network is analyzed using the Horton-Strahler classification system. From the amount of morphometric parameters, the drainage and the slope patterns are taken into consideration for the entire Bârlad catchment and for the 13 hydrometric stations in the catchment that have data on water flows and suspended sediments. From those there were chosen the Vaslui hydrometric station as representative for the geomorphologic units of the Bârlad catchment and the Feldioara hydrometric station for the Berheci catchment. Based on the analyzed patterns there were determined a series of morphometric parameters specific to the river network for all the 13 analyzed stations and from their comparison one can see obvious differences between the obtained values for the basins in the Central Moldavian Plateau and the ones in the Tutovei Hills.

Keywords: *morphometric patterns, hydrographic network, geometric progressions*

Rezumat. Caracteristici morfometrice ale reţelei hidrografice din bazinul Bârladului

După o scurtă prezentare a bazinului hidrografic Bârlad, reţeaua hidrografică este analizată folosind sistemul de clasificare Horton-Strahler. Dintre parametrii morfometrici, s-au analizat doar scurgerea şi pantele pentru întreg bazinul hidrografic al Bârladului şi pentru cele 13 staţii hidrometrice din bazin pentru care există date despre debitul lichid şi al sedimentelor în suspensie. Dintre aceste staţii, am ales staţia hidrometrică Vaslui ca fiind reprezentativă pentru unităţile geomorfologice din bazinul Bârladului şi staţia hidrometrică Feldioara pentru bazinul Berheci. În urma analizării modelelor au fost stabilite o serie de parametrii morfometrici specifici reţelei hidrografice pentru toate cele 13 staţii analizate; a analiză comparativă relevă diferenţe semnificative între valorile obţinute pentru bazinele din Podişul Central Moldovenesc şi cele din Colinele Tutovei.

Cuvinte-cheie: *model morfometric, reţea hidrografică, progresii geometrice*

Introduction

The progress of contemporary society in the context of sustainable development requires, among others, detailed knowledge of the physical environment as support for human social activities. In this context there are included the efforts of the scientific research to find and quantify a number of morphometric parameters of detail, and on their basis to compare the river catchments as basic units in all the actions of water resources management. To verify the methodology of morphometric characterization of the river network, the Bârlad catchment was used, being large enough and located on lithological formations with small differences in the resistance to erosion. The final aim of such tests is to find the relation between the agent, in this case the water, and the landforms generated during the evolution in time, thus to decode the information stored in the landforms.

The detailed studies carried out by the geographical school of Iaşi and Suceava (following the studies at the Stejaru Research Station- Piatra Neamţ) have clarified many issues concerning the knowledge of the entire complex of physico-geographical factors in the Bârlad catchment. The processes of torrential erosion and gullying have been investigated, the latter included in the comprehensive studies of dynamic geomorphology (Rădoane Maria, et. all., 1988; Ioniţă, 2000a; Hurjui et. all., 2008; Vasiliniciuc and Ursu, 2007 etc.).

The studies of the authors mentioned above are related to the spread and dynamics of gullies and landslides carried out by Rădoane Maria et. al., (1990, 1994, 2001), Ioniţă, (1997, 1999, 2000b), Hurjui, (2000, 2008), Niacşu, Ursu, (2007) etc. and conclude that the areas most susceptible to gullying dominate

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large surfaces in the Tutovei Hills and Fălciului Hills with a density reaching 2-3 km/km^2.

The morphometry of the hydrographic network as the main collector of surplus water from the slopes, however, is less often mentioned. The material and energy flow in the smallest to the largest catchments, contribute to measure a morphology represented by the network of river beds with morphometric features which can be determined and measured or calculated. Knowing these characteristics, an important step is made in the knowledge of the features of the physical environment as support for human social activities, currently conducted there.

A series of morphometric parameters were used to date, but only sporadically and disregarding their catchment controls. This paper aims at meeting this requirement using the morphometric analysis of the network from the entire Bârlad catchment and for sub-basins, seeking the achievement of some parameters that can be used successfully in their differentiation and individualization.

Methodology

To determine the morphometric features of the hydrographical network in the Bârlad catchment, the information was used from the topographic maps at the scale of 1:25000, which we consider satisfactory for the degree of details it provides. The morphometric elements for the entire catchment of the Bârlad river and of sub-basins with hydrometric stations were obtained as follows:

- after digitizing the entire hydrographical network, (the vector of line type which contains in the database information such as: hydronym, order in Horton- Strahler system, length), it was verified topologically so that the vector do not have errors such as: intersections, overlaps, free segments etc.;
- gradually the start and end points of each river segment - Feature Vertices To Points – were generated in ArcGIS;
- altitudinal values were assigned to the two themes of point type mentioned above, taken from the numerical model of the land- Extract Values to Points – in ArcGIS;
- in the next step, using the Join function there was joined the information from the themes of point type, themes representing the hydrographic network- at this time, adding in the attribute table two more columns: H_{max}- with the altitude of the starting point of the stream segment and H_{min}- with the altitude of the final point of the stream segment;
- after operating in the database, from the subtraction of the 2 columns H_{max}-H_{min} resulted the differences of level of successively higher orders river segments (ΔH).

Once the digitizing was done, a ranking of the network of 2nd to 8th order river segments was done. There was started from the 1st order considered the river segment which morphologically has the ability to guide and organize the surface drainage. It is individualized by a springhead and on all the way it does not receive any tributary stream. From the junction of 2 segments of 1st order it results a segment of 2nd order and so on until reaches the river course of the highest order. In this classification there has been established a set of rules that are necessary to be applied in the ranking process. Thus, a course of a certain order can receive tributaries of lower orders without changing its order, which happens only if it junctions with another river segment of the same order.

The analysis of the hydrographic network from the Bârlad catchment can be done by taking into consideration the evolution in time of the drainage which eventually reached the current plan configuration which can be measured and studied to identify the most relevant issues. The entire catchment and the main course are of 8th order in the Horton-Strahler classification system (Fig. 1). Given the fact that the evolution of the hydrographic network follows a series of laws of probability and the morphometric elements of the river segments of each order can be analyzed, whereas their average sums and values form geometric progressions which can be checked very well. In this situation a lack of a term, of 1st order for example, can be obtained by calculation, reducing by half the working and classification time if one starts from 2nd order up.

The procedure is recommended because for the 2nd order segments there can be easily determined the starting point at the junction of 2 segments of 1st order while for the segments of 1st order setting the starting point raise problems due to the high degree of operator subjectivity, not being clearly emphasized morphologically.

By applying the mentioned methodology, during the digitization the entire network of river segments of the Bârlad catchment was classified, there was calculated their length and the differences of level of the each segment` s start and end points. In this way there were obtained a series of data which allowed the setting out of laws which define the drainage and slopes pattern.

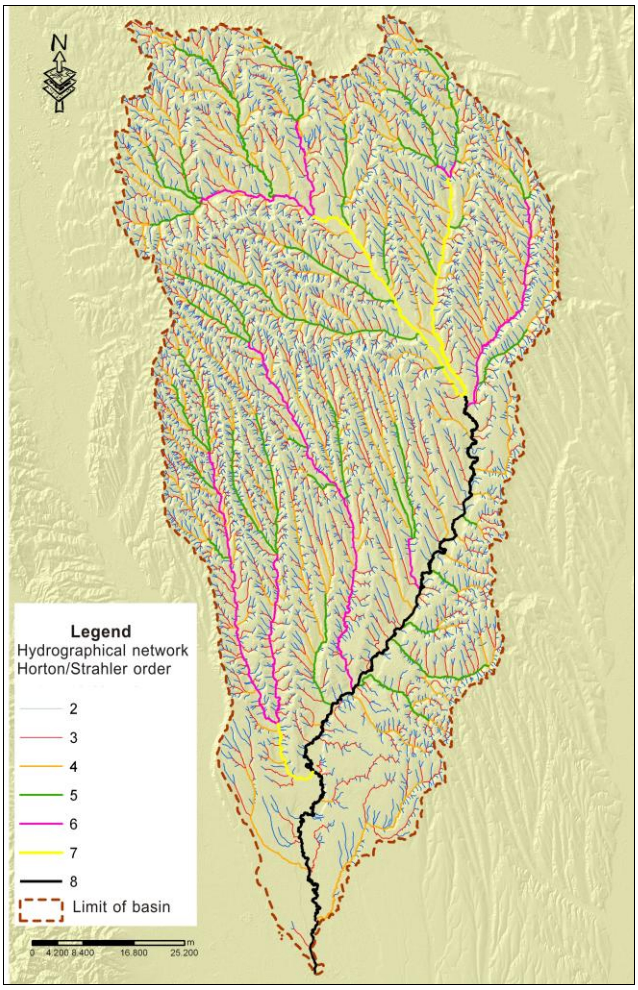

Fig. 1: Horton-Strahler classification of hydrographical network - Bârlad basin

In the case of the Bârlad catchment there were analyzed the morphometric patterns of drainage and slopes as well as the laws that determine them, both for the entire catchment and also for a series of sub- basins at the hydrometric stations which have determined the water flows and the suspended sediments.

To determine the morphometric features of the hydrographic network on catchments the law of the number of river segments was used. From the statistical analysis of the number of river segments of constantly higher order, it is noted that in the end there are obtained a series of data with 7 values corresponding from the 2nd to the 8th order. By representing these values in semi-logarithmic coordinates depending to the order, it is found that the number of river segments of successively higher order tends to form a decreasing geometric progression where the first term is given by the number of 1st order (2nd order) river segments and the ratio is given by the confluence ratio (Rc). To calculate the confluence ratio there are used the weighted arithmetic average through number of segments and the rule of chosen points (Fig. 2Aa). In this case the geometric progression ratio was determined by the method of chosen points, respectively for the values obtained for the 2nd and 4th order using the formula:

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

When using this formula there was taken into account the fact that to determine the ratios of these progressions there should focus on the lower orders which statistically speaking have the highest rate in comparison to the higher segments, which being in a very small number they may deviate more or less from the rule. The obtained series of data and their verification through graphic representation proves the fact that we have a decreasing geometric progression which states that the number of river segments of successively higher orders tend to form a decreasing geometric progression where the first term is given by the 1st order river segments and the ratio is the confluence ratio (Fig. 2Aa). Using the confluence ratio to calculate the values starting from one of the values involved in its determination, respectively the 2nd order, the differences appear to be very small and hence we can calculate the number of river segments of 1st order. In this case the high value of the confluence ratio shows a high degree of branching and relief fragmentation favored also by the relatively soft geological formations with a low resistance to erosion.

Study area

The Bârlad river, a left tributary of the Siret river covers a catchment area of 7253km^2, with an average height of 212 m and a minimum of 15 m (close to the confluence with Siret) and a maximum of 564m in the Doroşanu Hill. The average slope of the basin is of 5/1000 with small variations between the subunits of landform that it drains (Panaitescu E. V., 2008). The annual average flow is 10.4 m^3/s at the Tecuci hydrometric station, without receiving any important tributary to the mouth of the river.

In terms of geomorphology, the catchment covers the Central Moldavian Plateau in the north, the Tutovei Hills in the west, the Fălciului Hills in the south-east, and a small part of The Tecuci Plain in

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the south. The entire morphography is the direct result of the interaction between the geological structure, lithology and the subaerial agents. The geology is represented by sedimentary formations, dominated by sands, marls, clays intercalated with more consolidated layers of sandstones and limestone arranged in a dominant monoclinal structure. The tectonics within the basin does not show a significant mobility without consequences upon the current geomorphologic processes.

The current landforms resulted from the modeling of the Sarmato- Pliocene plain, which suffered tilting movements and a slight elevation, are fragmented and transformed into a region with a morphography dominated by structural plateaus, hills and even hilly aspect, arranged largely in interfluves generated by the tributaries of the Bârlad river with a consequent and less obsequent and subsequent orientation. The shape of the slopes varies from those rectilinear to the corrugated ones affected by intense degradation processes (landslides and gullying).

The declivity is dominated by low sloped areas which do not exceed 5° located on structural surfaces, generally with southern exposure, but there are values of declivity which exceed 20° on the escarpment slopes oriented generally north or north-west. The structural relief has the print of the interaction between the agents and the current processes on the geologic substrate. Given the general inclination of strata from north-north-west to south-south-east we notice that the structural plateaus and the escarpment ridges have also influenced the rivers` flow direction.

The sculptural landforms are determined by structural and lithological characteristics and by their modeling, carried out predominantly by the normal erosion of the hydrographic networks from the early forms to the well organized ones, being whether temporary or permanent.

In the plateau, the current processes are located mainly on slopes and especially on the escarpment ones. Among the dominant processes in the Bârlad Plateau, there are noted landslides, torrents and gullies and sheet wash. The landslides are on almost all the catchment area, but have higher dimensions in the south of Central Moldavian Plateau and sporadically in other subunits (Vasiliniciuc and Ursu, 2007).

Results and discussions

From the measurement of the river segments length for each order, summed by orders, a range of data is obtained which represented on the same graph, also on the logarithmical coordinates depending on order, and it highlights also a decreasing geometric progression. It states that the amounts of the summed lengths of the river segments of successively higher orders tend to form a decreasing geometric progression where the first term is given by the sum of the first order segments length and the ratio by the measured and summed length ratio (RL) (Fig. 2Ab). To calculate the summed lengths ratio, the same rule applies as for the number of river segments.

Comparing the range of the summed lengths to the number of river segments a third set of data is obtained representing the average length of river segments. It states that the average lengths of river segments of successively higher orders tend to form an increasing geometric progression where the first term is given by the average length of first order segments and the ratio by the average lengths ratio (r_l) (Fig. 2 Ac). In this case the ratio can be determined by the multiplication of the confluence ratio (R_C) and the summed lengths (R_L).

Another important element for the development of transport and accumulation processes of erosion along water courses is the slope of the river segments network which can be determined by using data obtained from the use of the same classification system. In the case of Bârlad catchment, the law of watercourses length included in the drainage pattern which can be checked very well with only a single deviation, respectively a higher value for the river segments length of the last order (Fig. 2Bb).

To calculate the slopes it is necessary to determine the rules by which the sums of the differences of level of the river segments of different orders vary. For this, in testing areas there were determined for each river segment of higher order the height of the start and end points and there were compared with those extracted from the Numerical Model of Land using GIS.

The insignificant differences between the obtained values in the two ways, it allowed using the latest method, easing substantially the work. From summing up the differences of level by order, there were achieved a series of seven values which represented in logarithmical coordinated outlines the law of sums of differences of level. This states that the sums of differences of level of river segments of successively higher orders tend to form a decreasing geometric progression where the first term is represented by the sum of the differences of level of the first order, and the ratio is given by the ratio between the differences of level (R_H) (Fig . 2Ba).

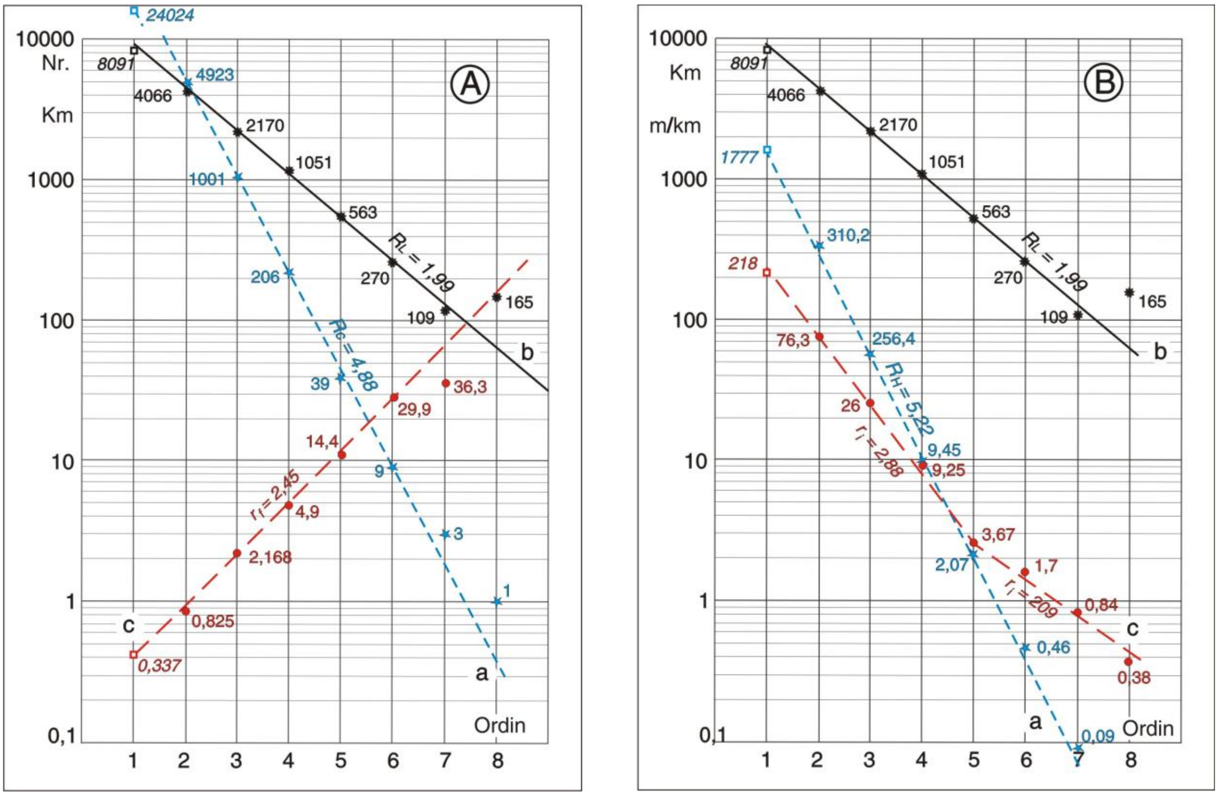

Fig. 2: The Bârlad Catchment. A. The drainage pattern; a, the law of the number of river segments, b, the law of the summed lengths by order (in km); c, the law of average lengths (in km), B. The slopes pattern; a,the law of sums of differences of level (in km)

Knowing that the slope of a stream is given by the ratio of the difference of level and the main course length, this reasoning may be also applied in the case of law of sums of differences of level and the sum of length of different orders courses (Fig. 2Bc). Thus, by the simple relation between the two rows of data of corresponding order, we may obtain a third set of data of the average slopes of streams which also represented in the same graph in logarithmical coordinates outlines the law of average slopes which can be formulated as follows: the average slopes of the successively higher order watercourses tend to form a decreasing geometric progression where the first term is given by the average slope of first order segments and the ratio by the slopes ratio (r_i) (Fig. 2Bc). The ratio can be easily determined as the ratio of the ratios of the two laws of the sums of differences of level and of the summed lengths (Zavoianu I., 1974, 1985, 2006).

The same result is reached also if instead of the summed values there is used the geometric progressions of the average differences of level and of average lengths of courses of successively higher orders. In the case of the average slopes of river segments of different orders it is found to be the law which verifies the best, and can be explained if we consider the fact that the slope is the most dynamic morphometric element, able to adapt quickly to environmental conditions and matter and energy flow moving through the catchment and bed rivers networks. In this case there is found that two line segments are different from the slopes law, respectively one segment from the 1^{st} to the fifth orders and the second segment of line for higher orders with a value of slope coefficient less than 2.08 instead of 2.88 (Fig. 2Bc). The difference between the lower orders slope much higher and the higher slopes which is lower, can be explained by differences between the drainage regime of lower order segments where the temporary drainage and the more powerful erosion processes over time are predominant, while at the higher order courses predominates a drainage regime more balanced with a decrease in the

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intensity of erosion processes and the predominance of transport and accumulation processes which highly contribute to reduce slopes and to configure a different pattern of evolution.

To check whether the laws thus defined in the case of large catchments are also valid for sub-basins at the hydrometric stations that control catchments with very different surface sizes, there have been seen more sub-basins carved also in sedimentary formations with small differences in the resistance to the subaerian agents action. The Bârlad catchment was analyzed at the Vaslui hydrometric station located entirely in the Central Moldavian Plateau where the erosion action of the hydrographic network has encountered the resistance of the deposits of clays, marls, sand with oolitic limestone and sandstones intercalations. From the second highest landform in Bârlad Catchment, The Tutovei Hills carved in unconsolidated deposits of sands, loamy sands, clays and marls (Jearenaud J. Saraiman A., 1995) there was studied the Berheci catchment at the Feldioara hydrometric station.

The morphometric pattern of the drainage of the Bârlad catchment at the Vaslui hydrometric station suits well to lower orders streams with minor deviations in the case of the higher ones (Fig. 3A).

The law of the river segments of successively higher order can be checked very well with the exception of the seventh order segment which deviates (Fig. 3Aa). Calculating the total number of the river segments of successively higher order, there is found very small differences compared to the measured values, in this case we may conclude that the seventh order course is made only in proportion of 49%, requiring yet lower orders segments to fully realize the order that it has.

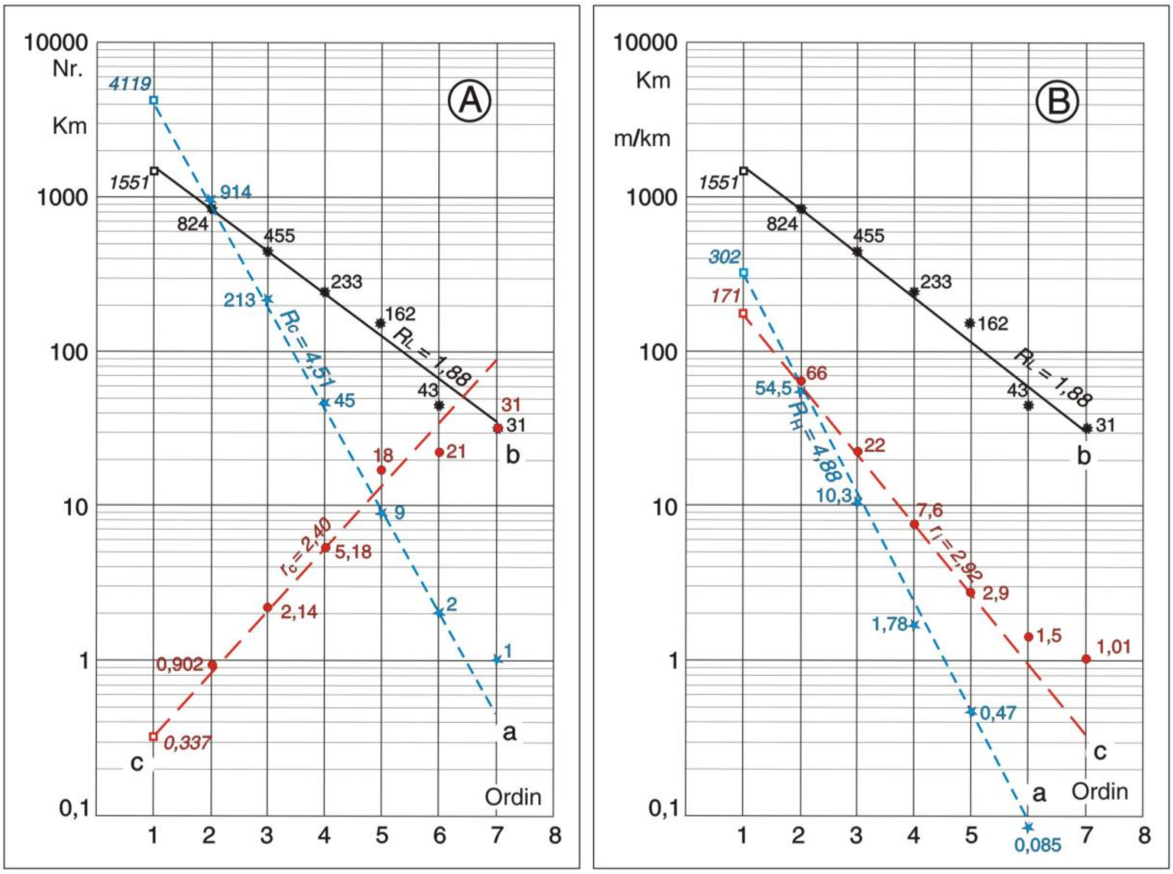

Fig. 3: The Bârlad catchment at the Vaslui hydrometric station. A. The drainage pattern; a, the law of the number of river segments; b, The law of the summed lengths by order (in km); c, the law of average lengths (in km); B. The slopes pattern; a, the law of differences of level sums (in km); b, the law of summed lengths by order (in km); c, the law of average slopes (in m / km)

The law of the sum of river segments length of successively higher order can be well verified up to 4th order with small deviations for the 5th and 6th orders which reflects upon the law of the average lengths (Fig. 3Ab,c). The fact that the morphometric laws can be checked well for the lower orders allows the determination of values for the first order and the calculation of indices in order to characterize the catchments.

For the slopes morphometric pattern, we already have the law of sums of river segments lengths of successively higher order, and we will determine the law of the summed differences of level also by orders of the river segments. These values (in km), represented in semi-logarithmical coordinates verify very well the law of differences of level with a small deviation of the values for the 4th and 7th orders (Fig. 2Ba). The third law of the pattern determined as a result of the ratio between the sequence of the summed differences of level and of the lengths sums is the law of the average slopes of successively higher order river segments (Fig. 3Bc). In terms of the environmental factors from the Central Moldavian Plateau, this law checks very well for the lower orders from two to five but the values are deviating for the last two orders, indicating a tendency to define a second straight line as it may be indicated in the case of the entire catchment (Fig. 3Bc).

As a representative catchment for the Tutovei Hills, the Berheci catchment was chosen at the Feldioara hydrometric station with a pronounced degree of elongation. The analysis of the drainage morphometric pattern in this case proves that all the three laws of the number of river segments, of the sums of lengths and of the average lengths of river segments of successively higher order, can be checked well enough (Fig. 4Aa, b, c).

The deviation from the law of the lengths for the 3rd and 6th orders with higher values in comparison to what would foreshow the law may be a consequence of the elongation degree of catchments and drainage valleys.

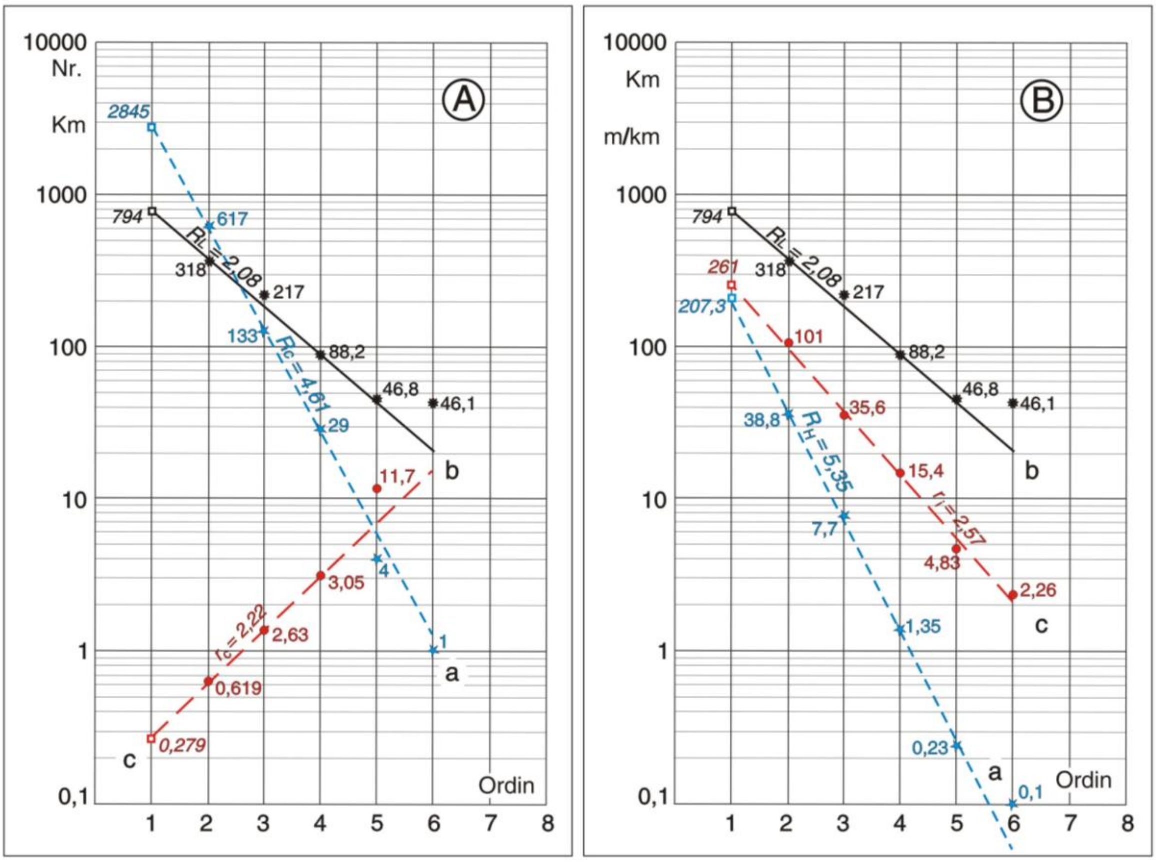

Fig. 4: The Berheci catchment at the Feldioara hydrometric station. A. The drainage pattern; a, the law of the number of river segments; b, the law of summed lengths by order (in km); c, the law of average lengths (in km); B. The slopes pattern; a, the law of sums of differences of level (in km); b,the law of summed lengths by order (in km); c, the law of average slopes (in m / km)

The slopes morphometric pattern defined by the law of differences of level and the one of the sums of river segments length configures the law of average slopes (Fig. 4Ba,b,c). The representation of the obtained values in logarithmical coordinates shows the fact that the slopes law is the law that best verifies, being the most dynamic in adapting to the conditions provided by the environmental factors and particularly to the flow of matter and energy flowing through the bed rivers network.

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The determination of the patterns for all the hydrometric stations which have data on water flows and suspended sediments of the Bârlad catchment and their checking proves the fact that these morphometric laws can be analyzed both on catchments at confluences and at the hydrometric stations to be correlated with the liquid and solid flow. Based on the drainage morphometric pattern there was calculated the frequency of the river segments as ratio between their total number and the area controlled by the hydrometric station, the length of first order segments and the drainage density. In the slopes morphometric pattern there was calculated the average slope of the first order segments and the average slope of the entire network of rivers from the studied catchment. The average length of slope drainage, important for the calculation of drainage time on the slope, it was calculated using the formula recommended by Horton (1945) as being equal to the reverse of the double of the drainage density.

From the analysis of the specified parameters in the catchments controlled by the hydrometric stations there can be seen that there are some differences between the catchments located in the Central Moldavian Plateau and the ones in the Tutovei hills. There can thus be seen that the frequency of the river segments in the Tutovei Hills is almost double than that from the Central Moldavian Plateau, while the length of the first order segments is higher in the Plateau. There are obvious differences in terms of drainage density that has values between 2.06 and 2.33 km/km^2 in the Central Moldavian Plateau while in the Tutovei hills it can reach up to 4 km/km^2. Differences can be observed also in the analysis of the slopes of the first order river segments and of the average slopes of the network for the whole catchment controlled by hydrometric stations. An important factor for the processes of drainage on slope is the length of the drainage on slope. If it has lower values it implies a fast gathering of waters in the bed rivers network, while a high value implies a longer duration for crossing the slope, so small lengths of slope drainage associated with reduced lengths and large slopes of 1st order watercourses favor the rapid process of formation of flood waves during downpours and a high power of erosion and transport (Table 1).

Table 1 The morphometric features of the hydrographic network at the hydrometric stations in the Bârlad catchment

River	Station	Sb (km^2)	$Fr_{s.}$	l_1 (m)	Dd (km/km^2)	i_1 (m/km)	$i_{m.r}$ (m/km)	l_{sp} (m)
Sacovăţ	Şofroneşti	295.8	3.20	361	2.06	147	79.9	243
Bârlad	Negreşti	805.7	3.25	369	2.06	180	100.9	243
Bârlad	Vaslui	1537.1	3.45	361	2.15	147	112	233
Bârlad	Bârlad	3988	3.85	354	2.24	212	124	223
Bârlad	Tecuci	6791	4.34	340	2.36	222	133	212
Vasluieţ	Codăieşti	170.2	3.84	380	2.33	203	121	214
Tutova	Plopana	15.3	6.73	472	3.95	246	172	126
Tutova	Rădeana	172.7	6.83	485	4.13	253	183	121
Berheci	Feldioara	514.6	7.05	279	3.06	261	162	163
Zeletin	Galbeni	403.7	7.35	291	3.17	254	201	158
Racova	Ivăneşti	180.9	4.63	344	2.54	261	155	197
Durduc	Frenciungi	158.1	4.15	320	2.25	193	110	222
Simila	Băcani	246.7	5.05	235	2.21	267	145	226

Sb – the controlled area; $Fr_{s.}$- frequency of river segments; l_1 – the lenght of 1st order segments; Dd – the drainage density; i_1 – the slope of the 1st order segment; $i_{m.r}$ – the average slope of the entire segments network in the catchment area; l_{sp} – the length of the drainage on slope.

Conclusions

From the analysis of the morphometric patterns determined for the Bârlad catchment and for the sub-basins within the Central Moldavian Plateau and the Tutovei Hills, there can be concluded that in all the cases, the morphometric laws can be verified very reliably for the lower order basins and with small deviations in the case of the higher ones (higher than five). All physical-geographical factors and in particular rocks and the geological structure have a bearing on the degree of relief fragmentation and on the size of some morphological parameters.

The checking in good conditions of the morphometric laws that define the drainage and the slopes of the rivers network allows the calculation of indices that can be used both to characterize the situation in the catchments and with practical purposes related to the assessment of the hydric potential of the territory. From the analysis of these indices, in the Bârlad catchment there are significant differences between the values of the parameters calculated for the sub-basins located in the Tutovei Hills compared with those from the Central Moldavian Plateau, having a higher intensity of erosion processes in the former case.

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