Geogr. Fis. Dinam. Quat.
27 (2004), 29-36, 8 figg., 8 tabb.

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QUANTIFICATION OF SOME ELEMENTS OF DRAINAGE BASINS IN ROMANIA

ABSTRACT: GRECU F., *Quantification of some elements of drainage basins in Romania*. (IT ISSN 1724-4757, 2004).

This paper debates on the major variables of drainage basin dynamics in the morphogenetic conditions of mid-latitude zones. The present study proceded from Horton-Strahler's hierarchy of drainage basins. As revealed by the complexity index, the confluence ratio of large basins developing in varied relief forms, is different. The higher order of magnitude, the better balanced a basin is, and reversely, the smaller order of magnitude, the greater its imbalance. It seems that the 4th-5th order basins are best suited for a dynamic geomorphic analysis. Basins originate mainly from 1st-order stream segments.

The coefficient that synthetically defines the dynamics of drainage basins I_r (I_r - completion index) stands for the number of stream segments, as well as for other variables, eg. length, surface and perimeter of drainage basins, and is it given by the progression ratio: I_r = 1 equilibrium (100%); I_r<1 (<100%) = undersized; I_r>1 (>100%) = oversized. The index of stream completion referes to the grade of basin completion in accordance with its order of magnitude, depending, in its turn, on the overall number of stream segments. The index of stream length completion shows the extent of basin completion in point of lengths (both for summed lengths and for average lengths).

The analysis focused on 19 basins lying in mountain zones, on crystalline or Mesozoic-Paleogene schysts, and 12 basins located in hills and tablelands, on Mio-Pliocene sediments.

Statistically-processed data suggest the following: the completion index of the number of segments taken into consideration reveals undersized basins as a rule; the other variables registering a statistically homogeneous population.

A correlation was established between the completion indexes refering to the number of river segments and lengths. The optimum correlation was found to be the linear one, i.e. 0.70.

KEY WORDS: Drainage basin, Order of magnitude, Length, Completion index, Mountain, Hill, Romania.

REZUMAT: GRECU F., *Cuantificarea unor elemente morfometrice ale bazinelor hidrografice mici din România*. (IT ISSN 1724-4757, 2004).

Lucrarea de faţă prezintă cele mai importante variabile morfometrice ale dinamicii bazinelor hidrografice situate în condiţii morfogenetice specifice zonelor temperate. Studiul are la bază ierarhizarea reţelei hidrografice în sistem Horton-Strahler şi se analizează: raţia de confluenţă şi indicele de realizare a bazinelor hidrografice mici dezvoltate în forme de relief variate. Întrucât bazinele cu ordin de mărime superior sunt bazine în echilibru, iar bazinele cu ordin de mărime inferior sunt frecvent în dezechilibru, sunt alese bazinele de ordinele 4 şi 5 pentru analiza dinamicii geomorfologice. La baza analizei stau segmentele şi bazinele de ordin 1.

Coeficientul care defineşte sintetic dinamica bazinelor hidrografice (*Ir*-indicele de realizare) pentru numărul de segmente, ca şi pentru alţi parametrii morfometrici (exemplu: lungimea, suprafaţa, perimetrele bazinelor de drenaj) este dat de raţia progresiei aplicată la penultimul termen al progresiei. Astfel, când *Ir=1* bazinul este în echilibru (realizare 100%); *Ir<1*(<100%) bazinul este subrealizat (pentru ordinul de mărime sau pentru lungimi); *Ir>1* (>100%) bazinul este suprarealizat (pentru ordinul de mărime sau pentru lungimi).

Indicele de realizare al numărului de segmente se referă la gradul de realizare al bazinului pentru ordinul de mărime respectiv şi depinde de numărul de segmente de râu. Indicele de realizare al lungimilor arată gradul de realizare (împlinire) din punctul de vedere al lungimilor (atât pentru lungimile însumate cât şi pentru lungimile medii).

Sunt luate în analiză 19 bazine hidrografice mici situate în zona montană (formată din şisturi cristaline mezozoice şi din şisturi şi sedimentar paleogen) şi 12 bazine localizate în dealuri şi podişuri (cu sedimentar mio-pliocen).

Analiza statistică a datelor ne permite următoarele concluzii: indicele de realizare al numărului de segmente luate în consideraţie relevă în general bazine subrealizate, alte variabile ne sugerează o populaţie relativ omogenă statistic.

Corelaţia stabilită între indicele de realizare al numărului de segmente şi al lungimilor relevă un indice de corelaţie optim pentru corelaţia liniară care este de 0.70.

CUVINTE CHEIE: Bazin de drenaj, Ordin de mărime, Lungime, Indice de realizare (împlinire), Munte, Deal, România.

CONCEPT AND METHOD

The notion of drainage basin as a unitary, complex system has been studied sometime later, although as surface where the drainage network collects its waters from was first used by Neumann in the early 20th century (1900) in his drainage density determinations. Investigation into the drainage basins viewed as complex territorial units was boosted by the results of fundamental and applied re-

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search, mainly the general systems theory, Horton-Strahler's hierarchy of hydrographic networks (Horton, 1945; Strahler, 1952) and the modern morphological theories, especially the theory of fractals. In Romania, the mathematical relations applied mainly to certain morphometrical variables representative of basins in terms of their position, lithology, landforms and relationships with the other environmental components (Grecu & Zăvoianu, 1994). A history of the results obtained in differents schools shows hydrologists when to be firstly interested in morphometry, whereas geomorphologists should analyse and interpret the findings from a morphogenetic and morphodynamic viewpoint. For instance, the geomorphological interpretation of drainage basin morphometry is mainly based on a quantitative analysis and produces a morphodynamic explanation (Ciccacci & *alii*, 1992; Dramis & Gentili, 1975; Grecu, 1992; Ichim & *alii*, 1998; Bojoi & *alii*, 1998; Agnesi & *alii*, 2003).

The present paper aims at outlining the main morphometric variables concerning the dynamics of the basin as a complex system. The examined basins are located in the morphogenetic environment characteristic of mid-latitude zones (fig. 1a), the approach being sustained by the statistical analysis of a representative number of cases.

The Horton-Strahler's hierarchy of the drainage network constitutes the working basis of this paper (Zăvoianu, 1978) (fig. 1b).

In the light of this hierarchy structuring system, our drainage network analysis considers as 1st-order streams those having no tributaries; the junction of two 1st-order streams forming a 2nd-order stream, etc. This way of ordering streams enables us to assess the relationships between stream frequency, channel length and drainage surface, perimeter, etc. Besides, it allows the comparison of some elements of drainage basin dynamics in terms of size and morphogenetic conditions.

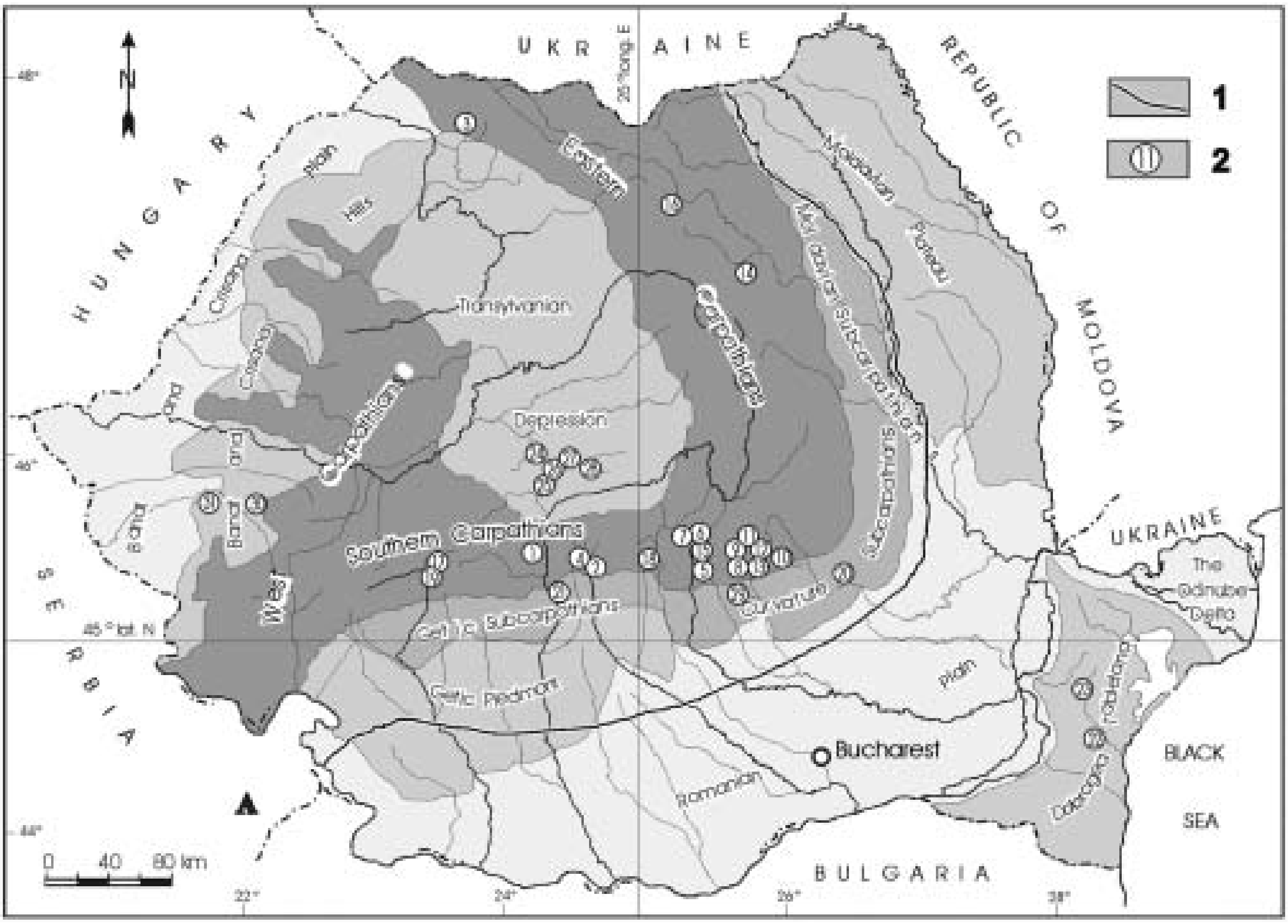

FIG. 1a - Physiographic units of Romania (grey areas), limit between orogen and platform (1) and drainage basins location (2). 1. Lotrioara; 2. Limpedea; 3. Borcut; 4. Cumpăna; 5. Izvorul Dorului; 6. Mălăeşti; 7. Tigăneşti; 8. Valea Stânii; 9. Pârâul Alb; 10. Pârâul Chiojd; 11. Pârâul Şipote; 12. Pârâul Zăvoarele; 13. Telejenel; 14. Pintic; 15. Valea Cerbului; 16. Sărişor; 17. Câmpa; 18. Bătrâna; 19. Polatiştea; 20. Sărătel; 21. Momei; 22. Valea Seacă; 23. Casimcea; 24. Slimnic; 25. Zăvoi; 26. Hârţa; 27. Zlagna; 28. Albac; 29. Crasna; 30. Fata; 31. Cherăstău.

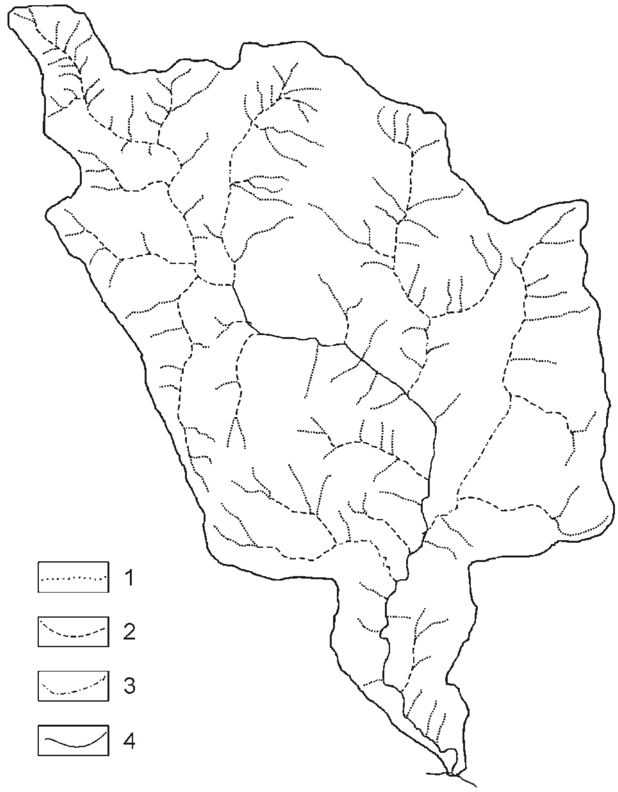

FIG. 1b - Sărătel basin drainage morphometric model.

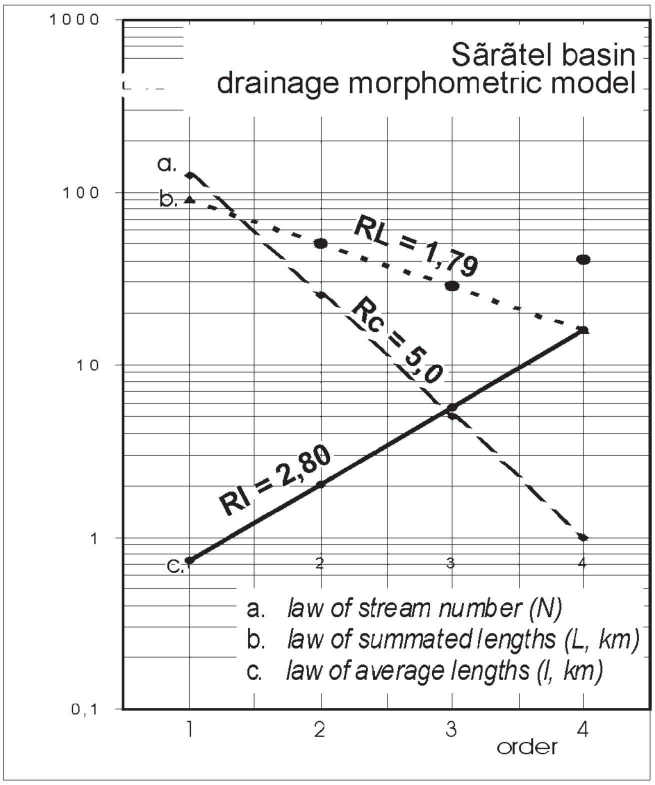

FIG. 1c - Sărătel basin according to the Horton - Strahler classification system.

The 1st-order stream analysis is applicable to both formal elements, like the mapping of a river network from topographic charts (scale 1:25.000) and its comparing to the realy conditions on the ground, and to elements of substance, their geomorphological role being comparable to that of «the cell in a biological tissue» (Baulig, 1959).

Some genetic elements can be explained by means of Horton's Law and lots of examples sustain this assertion. Schumm & *alii*, 1995 for instance, demonstrated the role of ground waters in the formation of steepheads by bringing the argument of the higher bifurcation ratios (R_c = 5; R_c = 6; R_c = 14) of 1st and 2 nd -order streams as against to those having ordinary values (3 to 4).

The present analysis covers 19 drainage basins located in a mountainous zone with a crystalline schysts or Mesozoic-Paleogene sedimentary bedrock, and 12 hills or tablelands basins overlying a Mio- Pliocene sediment cover (fig. 1a).

The following morphometric elements have been statistically processed (for drainage morphometric model, fig. 1c):

- order of basin magnitude
  - confluence ratio R_c (Hirsch, 1962);
  - index of stream completion I_n (order of basin magnitude);
- the elements of lengths
  - ratio of summed lengths R_L (Horton, 1945; Strahler, 1952)
  - ratio of average lengths R_l (Horton, 1945; Strahler, 1952)
  - completion index of summed lengths I_L
  - completion index of average lengths I_l

The paper fails calculate various the different morphometric elements, as they are well-known in the geomorphological literature (Zăvoianu, 1985).

ORDER OF BASIN MAGNITUDE

The order of basin magnitude is given by the order of the lower segment lying at the mouth of the mainstream. This approach referring to 4-th and 5th-order basins seemed to be the most appropriate for comparative and dynamic insights.

The higher the order of magnitude, the better balanced the basin is; as a rule, lower-order basins (1st-3rd) have a torrential character, being in a stage of disrupted imbalance, in other words, a higher frequency of balance-imbalance states prevails.

The *confluence ratio* (Hirsch, 1962) was obtained by starting from lower-order streams towards the higher-order ones. The confluence ratio is similar to bifurcation ratio (Horton, 1945; Avena & *alii*, 1967). It may be computed by various methods (Haggett & Chorley, 1969, after Zăvoianu, 1978, 1985); for example, it represents the arithmetical mean of individual ratios:

$$Rc = \frac{Rc1 + Rc2 + Rc3 + Rc4 + ... + Rcn}{n}$$

This approach is more relevant than the bifurcation one which must necessarily start from the highest-order stream. The fact that calculations leave out of the lower-order tributaries of the main stream is not relevant, because they are actually included in the overall summations per basin. Moreover, by using *the hierarchical anomaly index*, it enables us to check and correct the possible errors (Avena & *alii*, 1967).

The findings indicate a higher relative frequency of 3.1- 4 R_c values in the mountain regions (57.89%), while values of 4.1 to 5 (41.66%) and even over 5 (25.00%) are dominant with basins in the hill and tableland zones (tables 1, 2, 3).

The higher R_c values found in hilly areas are correct, meaning they standy for greater basin dynamics than in the

TABLE 1 - Confluence ratio and completion index (%) of the number of stream segments and lengths for drainage basins located in the Carpathian Mountains

Drainage basins	Location	Order of magnitude	R_c	I_n	R_L	R_l	Completion index I_L	I_l
Lotrioara	Lotru Mts.	5	5.24	133	2.07	2.53	65	48.8
Limpedea	Fagaras Mts	5	4.00	60	1.70	2.35	234	46.7
Borcut	Eastern Carpathians	4	4.08	122	1.79	0.45	73	58
Cumpana	Fagaras Mts.	5	3.65	82	1.87	1.95	80	97
Izvorul Dorului	Bucegi Mts.	5	5.3	34	1.57	3.71	61	21.52
Malaesti	Bucegi Mts.	4	3.4	58	2.27	3.5	74	93
Tiganesti	Bucegi Mts.	4	4.9	40	2.55	1.9	21.2	53
Valea Stanii	Ciucas Mts.	4	4.05	74	2.06	1.8	35.25	83
Paraul Alb	Ciucas Mts.	4	3.57	84	1.85	1.9	34	73
Paraul Chiojd	Ciucas Mts.	4	3.3	60	2.13	1.9	93	78
Paraul Sipote	Ciucas Mts.	4	3.05	65	2.27	1.12	79	64
Paraul Zavoarele	Ciucas Mts.	5	3.25	61	1.98	1.72	89	72
Telejenel	Ciucas Mts.	5	4.67	107	2.21	2.05	35	68
Pintic	Ceahlau Mts.	4	3.46	57	2	1.73	51	87
Valea Cerbului	Bucegi Mts.	5	4.67	107	2.11	2.16	147	73
Sarisor	Dornelor Depression	5	2.80	127	2.17	1.29	244	177
Campa	Petrosani Depression	5	3.68	81	2.14	2.05	51	75
Polatiştea	M.Parâng	4	4,95	101	1,89	2,72	67,27	69,1
Batrana	Iezer Mts.	5	3.6	55	2.26	1.59	72	129

TABLE 2 - Confluence ratio and completion index (%) for drainage basins located in hilly regions

Drainage basins	Location	Order of magnitude	R_c	I_n	R_L	R_l	Completion index I_L	I_l
Saratel	Subcarpathians	4	5	100	1.79	2.8	38	44
Momei	Subcarpathians	4	5.07	46	2.15	2.36	22	115
Valea Seaca	Casimcea Plateau	4	3.29	91	1.26	2.39	96	80
Casimcea	Casimcea Plateau	5	4.65	64	1.67	3.74	96	63
Slimnic	Transylvanian Tableland	5	4.4	25	2.8	1.57	26	101
Zavoi	Transylvanian Tableland	5	4.58	65	1.65	2.77	114	176
Hirta	Transylvanian Tableland	5	3.70	80	1.75	2.16	88	108
Zlagna	Transylvanian Tableland	5	3.70	80	1.95	1.90	55	68
Albac	Transylvanian Tableland	5	5.49	37	1.55	3.54	89	120
Crasna	Subcarpathians	5	4.79	41	1.91	2.5	29.3	69.9
Fata	West Hills	4	4.11	72	2.02	0.91	59.5	43.79
Cherastau	West Hills	4	3.65	109	1.98	0.54	192	41.7

TABLE 3 - Confluence ratio R_c frequency, by value classes

No.	Value classes for R_c	Absolute frequency Mountain	Absolute frequency Hills and tablelands	Relative frequency % Mountain	Relative frequency % Hills and tablelands
1.	Under 3	1	–	5.26	–
2.	3.1-4	11	4	57.89	33.34
3.	4.1-5	5	5	26.31	41.66
4.	Over 5	2	3	10.54	25.00

mountain zones where R_c is smaller, some confluence ratios being under 3. Noteworthy: R_c cannot take a value below 2. The same conclusion is reached by analysing R_c averages (3.98) in the mountains and 4.36 in hills and tablelands) (tables 2, 3, 8) (fig. 2).

THE INDEX OF STREAM COMPLETION

The index of stream completion designates the grade of basin completion in accordance with its order of magnitude, depending in its turn on the overall number of stream segments.The index is calculated as a ratio between the last but one term and the last term of the progression, which consists of the series of numbers of stream segments of successively increasing order, the first term of the progression being the number of 1st-order segments, and the progression ratio standing for the confluence ratio as calculated above. The simplified formula of the index of stream completion reads:

$$I_n = N_{n-1} / R_c$$

where N_{n-1} - the value of the last but one term of the progression; R_c - the confluence ratio.
The model for calculating I_n for 5^{th} order drainage basin is

	N_1	N_2	N_3	N_4	N_5	R_c	I_n
measured	145	41	11	3	1	3.5	
calculated	148	40	11	3	0.85		85%

where $I_n = N_4 / R_c = 3/3.5 = 0.85$ (85%). The calculated value for the number ofstreams for the five number is 0.85, means the completion index is 85%. Although, the basin is developed for the 5 th order in 85%.

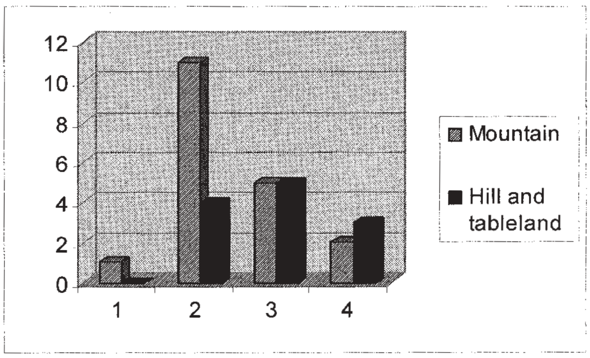

FIG. 2 - Absolute frequency of confluence ratio R_C, by value classes (table 3).

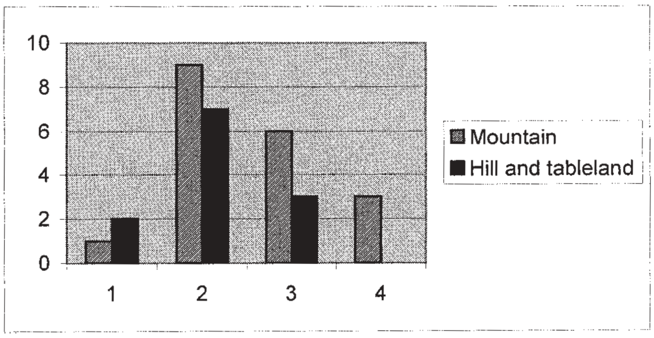

FIG. 3 - Absolute frequency of index of stream completion *In,* by value classes (table 4).

The values rendered by the index of stream completion in mountain basins is higher (74.10) than in the hills (67.5) (table 8). However, the morphogenetic conditions, apparently beeing more uniform, differ in regard of rock hardness and possible reshufflings of the drainage network.

Therefore the variation interval should be supplemented by other statistical analyses such as the arithmetical mean and the relative frequency. These two statistical variables show mountain basins to be closer to a state of balance (in over 27% of the studied basins I_n = 81-120%) than the hill or tableland ones (for the same I_n values the frequency is 25). The highest relative frequency of the index of stream completion for the order of magnitude in both categories of basins is represented by the class with I_n = 41-80%, indicating that basin dynamics is augmented by favourable tectonic, petrographic and climatic conditions (tables 1, 2, 4) (fig. 3).

Any further ramification of the drainage network is expected to produce changes within the system without, however, leading to a leap to a higher order of magnitude. Under these conditions, headward erosion plays a major role in 1st- order streams. Deep or linear erosion is important as well, sience it gets more active in the hill basins underlain by soft, low erosion-resistant rocks.

TABLE 4 - Index of stream completion frequency in drainage basins I_n, by value classes

No.	Value classes for I_n	Absolute frequency Mountain	Absolute frequency Hill and tableland	Relative frequency % Mountain	Relative frequency % Hill and tableland
1.	Under 40	1	2	5.55	16.67
2.	41 - 80	9	7	50.52	58.33
3.	81 - 120	6	3	27.27	25.00
4.	Over 120	3	–	16.66	–

INDEX OF BASIN COMPLETION BY LENGTH OF STREAM SEGMENTS

In order to assess this index it is absolutely necessary to compute the ratio of summed lengths and the ratio of average lengths. By measuring the length of each stream

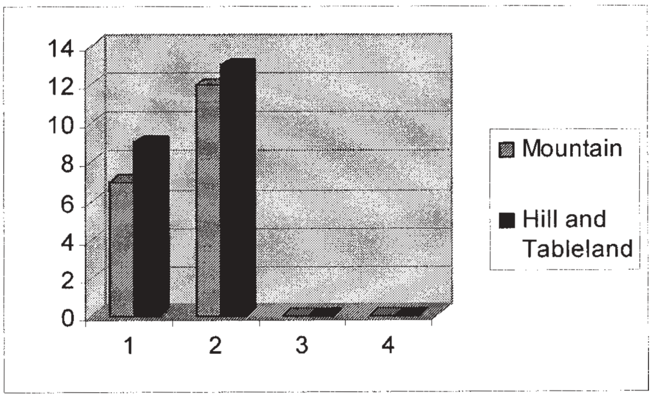

FIG. 4 - Absolute frequency of the ratio of summed lengths R_L, by value classes (table 5).

segment and summing the obtained values by order of magnitude, one finds a set of values which, plotted on semilogarithmic scales, establishes a law which reads as follows: the sum of stream segments of successively increasing orders tends to form a decreasing geometrical progression where the first term is given by the sum of 1st-order stream segments L_1, and ratio R_L by the ratio of *summed lengths* (Horton, 1945; Strahler, 1952; Zăvoianu, 1978; Grecu, 1980; & *alii*).

The average lengths are defined by the progression of the number of segments and the progression of summed lengths.A third series is obtained by the ratio of the first two, which is an increasing geometrical progression in which R_l ratio is the relation of the ratios of the previous two series

$$R_c / R_L = R_l$$

The statistical analysis of R_L values for hill and mountain regions outlined their absolute and relative frequencies. Both the mean values and the relative frequency values were found to be higher in mountain basins than in the hill and tableland ones. The arithmetical mean is: 2.77 in the mountain basins and 1.87 in the hill and tableland basins.This finding shows that stream segments in mountain basins need being longer in order to jump from one magnitude class into another (tables 1, 2, 5, 8) (fig. 4).

TABLE 5 - Frequency of the ratio of summed lengths by value classes, R_L

No.	Value classes for R_L	Absolute frequency Mountain	Absolute frequency Hills and tablelands	Relative frequency % Mountain	Relative frequency % Hills and tablelands
1.	1-2	7	9	36.85	66.67
2.	2.1-3	12	3	63.15	33.33
3.	3.1-4	–	–	–	–
4.	4.1-5	–	–	–	–

The picture is similar for average lengths R_1, which are higher in the mountain basins than in the hill and tableland ones, with a maximum of 3.71 in the former and of 3.74 in the latter case. The minimum stands at 0.54 in the hill and at 0.45 in the mountain basins (table 6, fig. 5).

TABLE 6 - Frequency of the ratio of average lengths by value classes R_l

No.	Value classes for R_l	Absolute frequency Mountain	Absolute frequency Hills and tableland	Relative frequency % Mountain	Relative frequency % Hills and tableland
1.	0-1	2	2	10.54	16.66
2.	1.1-2	10	2	52.60	16.66
3.	2.1-3	5	6	26.31	50.02
4.	3.1- 4	2	2	10.55	16.66

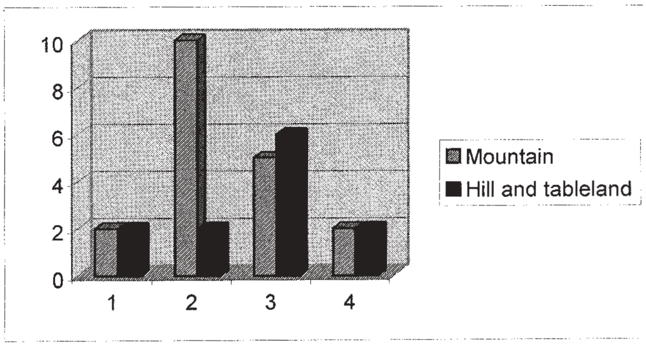

FIG. 5 - Absolute frequency of the ratio of average lengths R_l, by value classes (table 6).

The index of stream length completion shows the extent of basin completion in point of lengths (both for *summed lengths* and for *average lengths*). This index is calculated as the ratio between the values of the last but one term and the last term of the progression by a the series of lengths. The simplified computing formula is:

$$I_L = N_{n\text{-}1} / R_L$$

where N_{n-1} - the value of the last but one term of the progression, R_L = ratio of lengths.

Statistical figures for the indexes of summed lengths and of average lengths indicate that basins situated in hill regions, where rocks are low erosion - resistant, are better balanced in regard of lengths (table 8) (fig. 6, 7).

The index of summed lengths completion in mountain basins, where lithology is more uniform, falls into a wider variation interval (223) than in the hills (163).

TABLE 7 - Frequency of completion index of the summed lenghts I_L and of average lengths I_l

No.	Value classes for I_L	Absolute frequency Mountain	Absolute frequency Hills and tablelands	Relative frequency % Mountain	Relative frequency % Hills and tablelands
1.	Under 40	4	4	21.05	33.33
2.	41-80	10	2	52.63	16.66
3.	81-120	2	5	10.54	41.66
4.	Over 120	3	1	15.78	8.35

No.	Value classes for I_l	Absolute frequency Mountain	Absolute frequency Hills and tablelands	Relative frequency % Mountain	Relative frequency % Hills and tablelands
1.	Under 40	1	–	5.26	–
2.	41-80	12	7	63.17	58.30
3.	81-120	4	4	21.05	33.30
4.	Over 120	2	1	10.52	8.40

TABLE 8 - Statistical analysis of morphometric variables

Statistical data	R_C Mountain	R_C Hill	R_L Mountain	R_L Hill	R_l Mountain	R_l Hill
Amplitude	2.5	**2.2**	0.98	**1.54**	3.26	**3.2**
Arithmetical mean	3.98	**4.36**	2.77	**1.87**	1.91	**2.26**
Median line	4.05	**4.6**	2.11	**1.75**	1.85	**2.5**
Module	3.1	**4.7**	2.9	**1.75**	1.25	**2.3**

Statistical data	I_n Mountain	I_n Hill	I_L Mountain	I_L Hill	I_l Mountain	I_l Hill
Amplitude	78	**84**	222.8	**162.7**	155.48	**134.3**
Arithmetical mean	74.10	**67.5**	84.51	**75.4**	77.16	**82.78**
Median line	40	**41**	78	**88**	75	**80**
Module	57	**72**	70	**80**	74	**80**

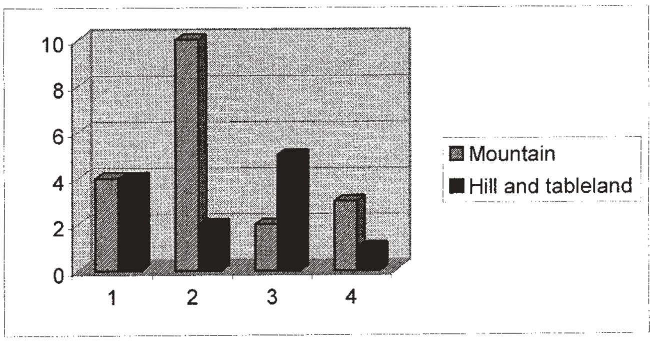

FIG. 6 - Absolute frequency of completion index of the summed lengths I_L, by value classes (table 7).

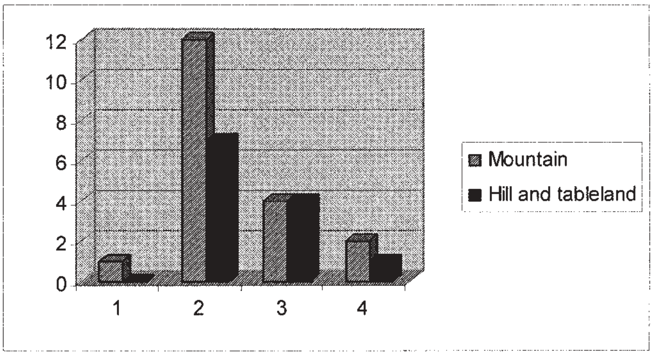

FIG. 7 - Absolute frequency of completion index average lengths I_l, by value classes (table 7).

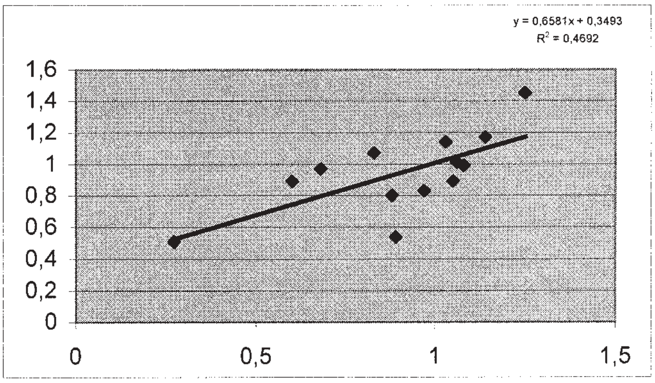

FIG. 8 - The correlation between completion index of stream number and completion index of lenghts for hills and tablelands basins.

CONCLUSIONS

- The present study procedeed from Horton-Strahler's hierarchy of drainage basins, focusing on the 4th and 5th-order catchments.
- The index of basin completion by number of stream segments shows that basins are generally undersized, but the other variables suggest a statistically homogeneous population.
- The completion index for mountain, hills and tablelands basins presents several differentiations.
- A correlation was established between the completion index of number of strem segments and that of stream lengths (fig. 8).The most relevant correlation proved to be the linear one, the correlation coefficients of 0.70, the critical value of signification with the Fischer and Student tests (Hammond & McCullagh, 1977).
- The index of drainage basin completion with regard to the number and length of the drainage network is quite significant, highlighting the present situation and trends in the hydrographic system dynamics.

- This three index (I_n, I_L, I_l) reveals the dynamic state of basins.They must analyse separately and together.For example, Saratel drainage basins have I_n = 100, is in equilibrum for the order of magnitude (for strem number) which it have. For summed lenghts I_L = 38 and average lenghts I_l = *44*, the drainage basin is undersized. This thing allow a strong regressive erosion and elong of river network but the drainage basin will not change the order of magnitude.

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(Ms. received 15 July 2003; accepted 15 February 2004)