SPATIAL VARIATION OF STREAM POWER IN THE BUZĂU AND IALOMIŢA RIVER CATCHMENTS (ROMANIA)

G. MINEA[1], G. IOANA-TOROIMAC[1], L. ZAHARIA[1], R. ZAREA[2], M. BORCAN[3]

ABSTRACT. - Spatial variation of stream power in the Buzău and Ialomiţa River Catchments (Romania). Stream power is a parameter that quantifies river energy, respectively its work ability. The aim of this paper is to estimate the stream power of rivers from the Buzău and Ialomiţa catchments and to present the difficulties in calculating and interpreting its variation. Cross-sections accomplished by the National Administration "Romanian Waters" were used in fulfilling this objective, at hydrometric stations on the Ialomiţa, Prahova, Buzău, Bâsca Chiojdului and Bâsca Rivers. Based on these profiles, and using hydraulic methods, parameters like flow velocity, discharge and stream power were calculated. Analysis results indicate that the rivers draining the Carpathian and Subcarpathian regions are dynamic. They have a specific stream power of more than 150 W/m² and are susceptible to rapid evolution. In the Romanian Plain rivers are less energetic (a specific stream power below 40 W/m², excluding river sectors with braided trends and incised channels). Also they are characterized by a less intensive dynamic.

Keywords: stream power, bankfull discharge, river channel, Buzău River catchment, Ialomiţa River catchment.

1. INTRODUCTION

Stream power is a parameter that quantifies river energy, respectively its work ability (Bagnold, 1960).

Previous research show the usefulness of this parameter for the analysis of sediment transport capacity (Bagnold, 1960; Allen, 1977) and processes regarding the river channel morphology (Ferguson, 1981, 1987), especially its instability and bank erosion (Brookes, 1987), to characterise the floods (Baker and Costa, 1987) and for hydromorphological classifications (Schmitt, 2000).

In this context, this paper intends to be an exercise for estimating the stream power of some Romanian rivers, to show the spatial variation of this

[1] University of Bucharest, Faculty of Geography, no 1. N. Balcescu Blvd., District 1, RO-010041 Bucharest, Romania, e-mail: gabriel.minea@gmail.com, gabriela_toroimac@yahoo.com, zaharialil@yahoo.com
[2] "Romanian Waters" National Administration, Buzău – Ialomiţa Water Catchment Administration, no. 20 bis Bucegi St., RO-120208, Buzău, Romania, e-mail: razvan_zarea@yahoo.com
[3] National Institute of Hydrology and Water Management, no. 97 Bucuresti – Ploiesti Road, District 1, RO-013686, Bucharest, Romania, e-mail: bmihaela1978@yahoo.com

parameter on one hand, and the difficulties related to its estimation and its interpretation on the other hand.

After a brief presentation of the study area, data and used methods are shown, insisting on explaining the choices made in order to apply the formula for stream power. The obtained results first refer to stream power variations, and second to its hydrogeomorphological significance.

2. FIELD STUDY

This example of stream power calculation is applied on the Ialomiţa and Buzău River catchments, on the homonymous rivers and their tributaries: Prahova for Ialomiţa; Bâsca and Bâsca Chiojdului for Buzău (Table 1).

Two reasons underlie the choice of the study area. Firstly the two river catchments extend over several relief units with different characteristics (the Curvature Carpathians, the Curvature Subcarpathians and the Romanian Plain), which highlights a stream power variation, depending on the morphological characteristics of these relief units. Secondly, the analysis gets more interesting because of the neotectonic movements affecting the active region of the external Curvature of the Carpathians (Polonic, 2006), that could complicate the river processes on a long-term scale.

Table 1. ***Morphometrical features of the studied rivers and their catchments (according to data from Atlasul cadastrului apelor din România, 1992)***

River	Data about river					Data about catchment	
	L (km)	H (m) source	H (m) confluence	Ir (‰)	C_s	A (km^2)	H_m (m)
Ialomiţa	417	2310	6	15	1.88	10350	327
Prahova	193	1100	56	5	1.24	3738	541
Buzău	302	1250	8	4	2.27	5264	505
Bâsca Chiojdului	42	1340	239	26	1.28	340	668
Bâsca	76	1510	395	15	1.65	783	110

L = length, H = altitude, Ir = river slope, Cs = sinuosity coefficient, A = area, H_m = mean altitude.

3. DATA AND METHODOLOGY

Bagnold (1960) deduces that the stream power (Ω) corresponds to the transformation of flow potential energy into kinetic energy, and proposes the next formula (1):

$$\Omega = \rho \cdot g \cdot Q \cdot I \qquad (1)$$

where:

Ω represents the stream power (W/m);
ρ is the water density that is equal to 1000 g/cm^3;
g is the gravitational acceleration equal to 9.8 m/s^2;
Q (m^3/s) is the liquid discharge and
I (m/km) is the water slope.

Specific stream power (ω), shown in formula (2), represents the distribution of the stream power per unit of width of the river bed (Bagnold, 1977), and is used for comparisons between river beds with different sizes (Ferguson, 1981):

$$\omega = \frac{\Omega}{b} \qquad (2)$$

where:

ω (W/m²) is the specific stream power;
Ω (W/m) is the stream power and
b (m) is the width of the river bed.

The intermediate parameters of these formulas were calculated based on the cross-sections made by the "Romanian Waters" National Administration (2010) at hydrometric stations (Figure 1), and on individual field observations. The choice of the hydrometric stations (h.s.) and of the analyzed transverse profiles depends on their availability from the database of the mentioned institution.

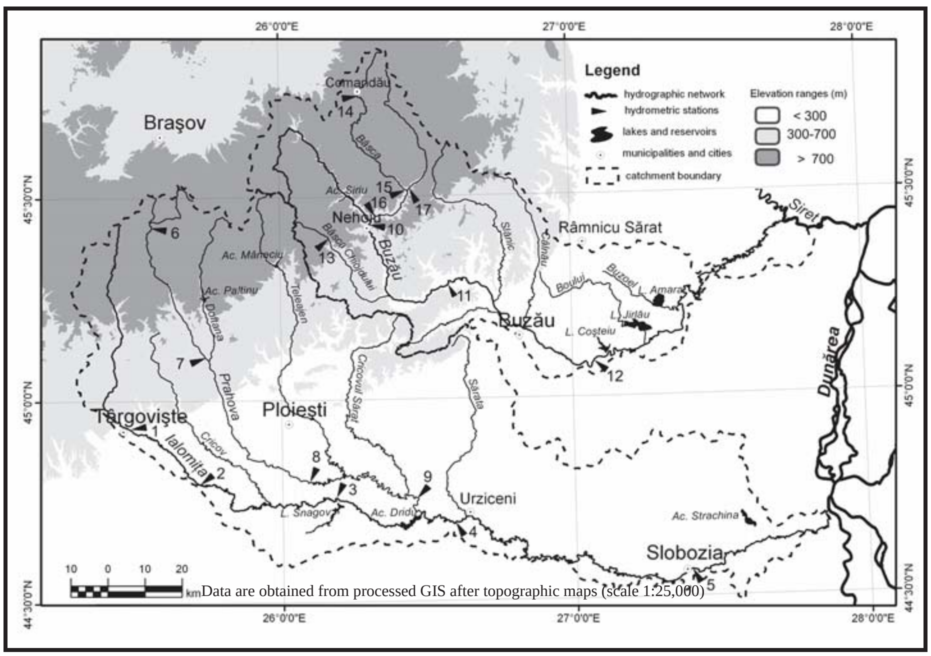

Figure 1. ***Location of the studied hydrometrical station:***

1 = Ialomiţa at Târgovişte h.s., 2 = Ialomiţa at Băleni-Români h.s., 3 = Ialomiţa at Siliştea Snagov h.s., 4 = Ialomiţa at Coşereni h.s., 5 = Ialomiţa at Slobozia h.s., 6 = Prahova at Buşteni h.s., 7 = Prahova at Câmpina h.s., 8 = Prahova at Halta Prahova h.s., 9 = Prahova at Adâncata h.s., 10 = Buzău at Nehoiu h.s., 11 = Buzău at Măgura h.s., 12 = Buzău at Baniţa h.s., 13 = Bâsca Chiojdului at Chiojdu h.s., 14 = Bâsca at Comandău h.s., 15 = Bâsca at Varlaam I h.s., 16 = Bâsca at Bâsca Roziliei h.s. and 17 = Bâsca Mică at Varlaam II h.s.

Depending on the use of stream power in various types of analysis, the discharge used in this formula may have certain significations. It can be a maximum discharge with recurrences probability or a peak discharge reached during a flood. In order to characterize the river bed, the discharge taken into consideration in this paper corresponds to the bankfull discharge; it is also considered the most significant discharge in fluvial geomorphology (Astrade and Bravard, 1999). For this purpose, firstly, the bank full level is determined and then the parameters used in the stream power formula are calculated.

3.1. Low-flow channel delimitation

Low-flow channel delimitation is based on cross-sections at hydrometric stations, and on field observations. The difficulty was to establish the channel banks. Two criteria were taking into account: topographic and vegetation criteria, which complete one another.

From topographically point of view, in most cases, the bank would be the connection between the river bed and the floodplain. But if the floodplain is missing, and there is a direct transition from the river bed to the terrace or slope, this criterion can't be applied.

Therefore, this criterion is supplemented by the vegetation one: the bank limit corresponds to the transition from alluvial bed (or rock bed) to vegetation. This criterion is secondary and strongly dependent on flow and phenophase variations (e.g. during flooding the riparian vegetation of the floodplain can be covered by alluviation).

Also if the two banks are not symmetrical, the less high bank is taken into account, so that both sides of the floodplain will not be flooded. After that the bank-full is drawn, which joins the two banks and it's relatively parallel to the water surface.

3.2. Estimation of the hydraulic parameters of the river bed

After the delimitation of the river bed, its morphometric parameters are estimated based on the same cross-sections. The bankfull discharge is estimated on the Manning-Strickler, formula (3), according to Navratil (2005):

$$Q = S \cdot v = S \cdot k \cdot \left[\frac{\left(R^{\frac{2}{3}} \cdot I^{\frac{1}{2}} \right)}{n} \right] \qquad (3)$$

where:

S is the cross-sectional area taken into account (in m^2);

k is a constant equal to 1 in the International System of Measures Units;

R is the hydraulic radius equal to the ratio between cross-sectional area and wetted perimeter (in m);

I is the slope of water surface (in m/m)(value that was measured during the transverse profiles attainment, and which doesn't corresponds necessarily to the bank-full),

n is the roughness coefficient calculated based on the formula of Strickler (4) according to grain size d_{50} or estimated on the existing tables:

$$n = \frac{d_{50}^{\frac{1}{6}}}{21{,}1} \quad (4)$$

where:

n is the Strickler roughness coefficient and

d_{50} , the median bed-material grain size (in mm).

For the hydrometric stations along the Prahova River, d_{50} granulometry was measured using a quadrant of 1 m^2, positioned near the main river bed, at a depth of 10 cm. The measurement of the gravel and cobbles was done by using a calliper. On the field, sand and clay particles were separated using sieves. Their mass was estimated using a balance. For precision, some sand and gravel samples were transported and re-examined in the Geomorphology Laboratory of the Lille University 1.

4. RESULTS

4.1. Bank-full discharge

The values of the bank-full discharge and of the stream power (Table 2) are characteristic for the moment of the cross-sections attainment and can vary because of the river dynamics, especially during floods. Moreover, Rădoane and Rădoane (2009) show vertical instability of the channels from the Eastern Carpathians rivers, and Ioana – Toroimac (2009) and Ioana – Toroimac *et al.* (2010) notes the river bed narrowing of the Prahova River.

In the case of the rivers and h.s. studied, the bank-full discharge generally increases from upstream to downstream, due to the location of most of the h.s. in areas of stable and single river beds. An exception is the Băleni - Români h.s. on Ialomiţa River where bank-full discharge is 430 m^3/s, higher than the bank-full discharge at Siliştea Snagovului h.s. (224 m^3/s); this fact is explained by the river's tendency to braid at Băleni - Români h.s.

The bank-full discharge can be used, in some cases, for the flood risk management. For example the bank-full of Prahova River at h.s. Adâncata corresponds to flooding stage (defined as the level at which begins the flooding of the first socio-economical facility, according to Dobrot and Stănescu, 2002).

In case of the Buzău River at Baniţa h.s. the same situation is not valid, because the channel seems to be strongly incised and the bank-full stage is higher than the flooding stage, drawn for the downstream sector. For this reason the discharge corresponding to the flooding level was calculated using the same method.

Table 2. ***Hydraulic parameters of the river beds*, stream powers and specific stream powers for the studied rivers***

River/ hydrometric station	Relief unit	Data of the cross-sections	S (m²)	I (‰)	Q (m³/s)	Ω (W/m)	b (m)	ω (W/m²)
Ialomiţa at Târgovişte		28.07.2009	91	1	197	1930	52	37
Ialomiţa at Băleni -Români	Romanian Plain	09.10.2009	102	3,5	430	14749	58	254
Ialomiţa at Siliştea Snagov		09.09.2009	92	0,5	224	1098	35	31
Ialomiţa at Coşereni		02.10.2009	109	0,4	265	1039	57	18
Ialomiţa at Slobozia		25.09.2009	332	0,1	794	778	62	13
Prahova at Buşteni (natural)	Carpathian	29.03.2006	23	7,6	50	3724	16	233
Prahova at Buşteni (arrangement)		29.03.2006	53	7,6	175	13034	17	767
Prahova at Câmpina	Sub-carpathian	16.01.2006	102	5,5	233	12559	50	251
Prahova at Halta Prahova	Romanian Plain	27.02.2006	164	0,8	290	2274	48	47
Prahova la Adâncata		05.01.2006	166	0,5	278	1362	58	23
Buzău at Nehoiu	Carpathian	24.09.2009	61	8,2	131	10527	45	234
Buzău at Măgura	Subcarpathian	03.09.2009	162	3,4	305	10163	71	143
Buzău at Baniţa	Romanian Plain	-	406	0,7	1020	6997	109	64
Buzău at Baniţa (flooding stage)		-	210	0,7	369	2531	97	26
Bâsca Chiojdului at Chiojdu	Subcarpathian	13.07.2009	85	15,1	280	41434	49	846
Bâsca at Comandău		26.07.2009	46	3,4	51	1699	21	81
Bâsca at Varlaam I		24.09.2009	28	20,1	86	16940	22	770
Bâsca at Bâsca Roziliei	Carpathian	24.09.2009	81	8,6	217	18289	39	469
Bâsca Mică at Varlaam II		24.09.2009	28	17,2	77	12979	24	541

S = cross-section area; I = water slope; Q = bankfull discharge; Ω = stream power; b = bank-full width; ω = specific stream power.
*calculated from cross-sections at hydrometric stations from "Romanian Waters" National Administration.

4.2. Spatial variation of the stream power on relief units

Regarding the spatial variation of the specific stream power, the first observation refers to the general decrease of its value from upstream to downstream, in close dependency with decreasing of slope value and grain size.

In the Carpathians and Subcarpathians areas the specific stream power is superior to 150 W/m². The highest values are given by the water slope high value (15-20 m/km) at Varlaam I h.s. and Varlaam II h.s. on Bâsca and Bâsca Mică Rivers, and Chiojdu h.s. on Bâsca Chiojdului River.

These high values of the stream power are shown by the high competence of the rivers. For example, in the middle and lower part of the Bâsca River

Catchment, the high competence is demonstrated by the boulders, cobbles, gravels deposits, stocked and sorted, from the riverbeds (Photo 1), and by the hydrogeomorphological effects of floods on riverbeds and slopes.

Only one hydrometric station makes an exception: Comandău h.s. on Bâsca River, which is characterized by a specific stream power of 81 W/m^2. This is due to the relatively low slope of water surface (3.5 m/km), crossing the Comandău Depression.

Another particular case is the Prahova River at Buşteni h.s., for which the stream power is estimated in two situations: the real situation where the right bank is changed by the human actions (protected by concrete slabs; Photo 1) and the reconstructed situation with the natural right bank, based on field observations in order to have an image of the river natural dynamics for comparisons with other rivers.

In the Romanian Plain, the specific stream power values at hydrometric stations varies between 13 and 40 W/m^2, decreasing from upstream to downstream. Two stations make an exception: Baniţa h.s. on Buzău River and Băleni – Români h.s. on Ialomiţa River:

- at Baniţa h.s., the river bed is characterized by a specific power stream of 64 W/m^2, high value compared with those noted above, due to channel incision; if the bankfull is replaced by the flooding level, then specific stream power is 26 W/m^2;
- at Băleni – Români h.s., specific stream power is 254 m^3/s; this high value is explained by the channel's tendency to braid on this area, indicating the need to consider, in future research, this particularly sectors of the rivers crossing the Romanian Plain.

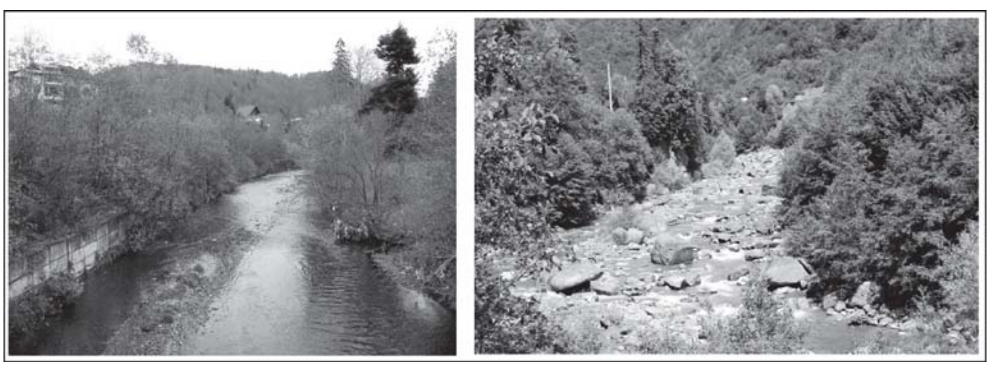

Photo 1. ***Differences between the granulometry of the alluvial deposits on Prahova River at Buşteni h.s.***
(left; 20.X.2007) and on Bâsca River upstream of Varlaam I h.s. (right; 10.VIII.2010).

5. DISCUSSIONS AND CONCLUSIONS

The obtained results show some hydrogeomorphological features of the studied rivers and can be a base for future research regarding river beds dynamics.

According to the diagram drawn by Leopold and Wolman (1957), which takes into account the bankfull discharge and the water surface slope, the studied rivers tend to braid at crossing of the Carpathian and the Subcarpathian, while crossing the Romanian Plain, they tend to meander, the exception being the Băleni – Români h.s. on Ialomiţa River (Figure 2). Ferguson (1981, 1987), believes that a specific stream power lower than 60 W/m² indicates less dynamic channels in comparison to a specific stream power higher than 120 W/m² which indicates dynamic rivers beds with a low sinuosity. According to Wasson *et al.* (1998), river courses with a specific stream power below 35 W/m² react slowly (time scale of 30 years) to human adjustments (calibration, stability thresholds, etc.), while those with a high specific stream power (over 35 W/m²) react more quickly (time scale of 10 years) to the same changes.

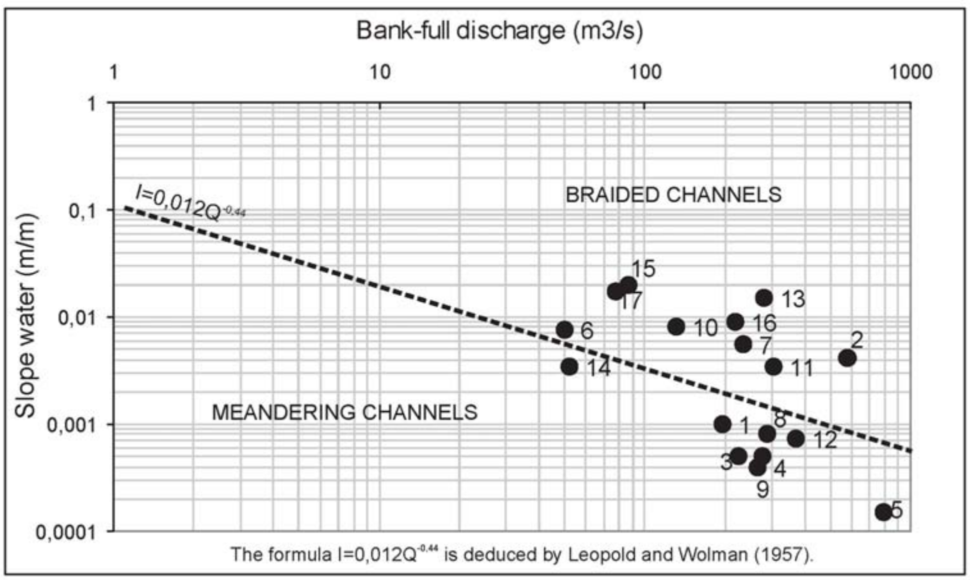

Figure 2. ***Relationship between bank-full discharge, slope water and channel pattern according to Leopold & Wolman (1957)***

1 = Ialomiţa at Târgovişte h.s., 2 = Ialomiţa at Băleni-Români h.s., 3 = Ialomiţa at Siliştea Snagov h.s., 4 = Ialomiţa at Coşereni h.s., 5 = Ialomiţa at Slobozia h.s., 6 = Prahova at Buşteni h.s., 7 = Prahova at Câmpina h.s., 8 = Prahova at Halta Prahova h.s., 9 = Prahova at Adâncata h.s., 10 = Buzău at Nehoiu h.s., 11 = Buzău at Măgura h.s., 12 = Buzău at Baniţa h.s., 13 = Bâsca Chiojdului at Chiojdu h.s., 14 = Bâsca at Comandău h.s., 15 = Bâsca at Varlaam I h.s., 16 = Bâsca at Bâsca Roziliei h.s. and 17 = Bâsca Mică at Varlaam II h.s.

In conclusion, the rivers that cross the Carpathians and the Subcarpathians are dynamic and susceptible to easily record river bed modifications, due to hydrotechnical works, while those crossing the Romanian Plain (except braided sectors), are less dynamic and they react slowly to hydrotechnical works from river beds. These results characterize the studied rivers at a small spatial scale. Therefore we suggest improving the relevance of this type of analysis by increasing the number of transversal profiles, especially in sectors with braided channels.

REFERENCES

1. Allen, J.R.L. (1977), *Changeable rivers: some aspects of their mechanics and sedimentation*. In Gregory Y K., River channel changes, Wiley, Chichester, 15-45.
2. Astrade, L. şi Bravard, J.P. (1999), *Energy gradient and geomorphological processes along a river influenced by neotectonics (the Saône river, France)*, Geodinamica Acta, 12, 1, 1-10.
3. Bagnold, R.A. (1960), *Sediment discharge and stream power: a preliminary announcement*, US Geological Survey Circular, 421.
4. Bagnold, R.A. (1977), *Bedload transport by natural rivers*, Water Resources Research, 13, 303-312.
5. Baker, V.R. şi Costa J.E. (1987) *Flood power*, In Mayer L., Nash J. (Eds.), *Catastrophic flooding*, Allen and Unwin, Boston, 1-21.
6. Brookes, A.(1987), *River channel adjustments downstream from channelization works in England and Wales*, Earth Surface Processes and Landforms, 12, 337-351.
7. Ferguson, R.I. (1981), *Channel forms and channel changes*. In Lewin J. (Eds.), British rivers, Allen and Unwin, London, 90-125.
8. Ferguson, R.I. (1987), *Hydraulic and sedimentary controls of channel pattern*. In Richards K. (Eds.), *River Channels, Environment and Process*. Blackwell, London, 130-155.
9. Ioana-Toroimac, G. (2009), *La dynamique hydro-géomorphologique de la rivière Prahova (Roumanie): fonctionnement actuel, évolution récente et conséquences géographiques*, Teză de doctorat în geografie, Universitatea Lille 1, 341.
10. Ioana-Toroimac, G., Dobre, R., Grecu, F. & Zaharia, L. (2010), *Evolution 2D de la bande active de la Haute Prahova (Roumanie) durant les 150 dernières années.* Revue Géomorphologie: relief, processus, environnement, n°3, 275-286.
11. Leopold, L.B. & Wolman, M.G. (1957), *River channel patterns: braided, meandering and straight*, Rap. tech. US Geological Survey, US government printing office, Washington, 76.
12. Navratil, O. (2005), *Débit à pleins bords et géométrie hydraulique : une description synthétique de la morphologie du cours d'eau pour relier le bassin versant et les habitats aquatiques*, Thèse de Doctorat en Mécanique des Milieux Géophysiques et Environnement, Institut National Polytechnique de Grenoble, 308.
13. Polonic, G. (2006), *Procese geodinamice care au influenţat activitatea ariilor sursă de material detritic ale Bazinului Dacic*, Proiect Ceres, Contract 4-246/2004, Raport Final, Institutul Naţional pentru Geologie şi Geoecologie Marină GeoEcoMar, pag. 310-319, http://www.geoecomar.ro/publications/influenta.pdf, accesat la data: 24.XI.2009.
14. Rădoane, M. & Rădoane N. (2009), *Procese fluviale*, http://fig.usv.ro/www/pagini /doctorat/radoane_maria/articole_rad/Procese%20fluviale,%20Monografia%20carpatica.pdf, accesat la data: 7.II.2011.
15. Schmitt, L. (2000), *Typologie hydro-géomorphologique fonctionnelle de cours d'eau. Recherche méthodologique appliquée aux systèmes fluviaux d'Alsace*. Thèse de Doctorat en Géographie, Université Louis Pasteur, Strasbourg, 217.
16. Stănescu, V. A., & Drobot R. (2002), *Măsuri nestructurale de gestiune a inundaţiilor*, Editura HGA, Bucureşti.
17. Wasson, J.G., Malavoi, J.R., Maridet, L., Souchon, Y., & Paulin, L. (1998), *Impacts écologiques de la chenalisation des rivières*. Editions Cemagref, 160.
18. *** (1982), *Harta topografică a României, scara 1:25000*, R.S.R., Direcţia Topografică Militară, Ediţia a II-a, MApN, Bucureşti.
19. *** (1992), *Atlasul cadastrului apelor din România, Partea I, II*, Ministerul Mediului, Aquaproiect S.A., Bucureşti.
20. *** (2010), "Romanian Waters" National Administration.