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A SHORT-TERM ANALYSIS OF HUMAN AND HYDROLOGICAL IMPACTS ON MORPHOLOGICAL PARAMETERS OF BRAIDED RIVERS

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Abstract

The paper aims to analyse the relation between braided rivers dynamics and the most important responsible factors (human and hydrological), in order to understand the role of these control variables on the behaviour of river channels. The study quantifies the morphological adjustments, hydrological variations and artificiality of river channels on short-term (2005 – 2011). The study area is represented by 5 km-long reaches on Prahova, Slănic and Buzău rivers (in Curvature Subcarpathians for the first two and in the piedmont located at contact with the Romanian Plain for the last). Three categories of indicators were analysed: morphological (area and composition of the active braided channel; maximum and mean depth of the river channel at the bankfull stage); hydrological (bankfull discharge and 100 years return period discharge); artificial (number of weirs; length of gabions and canals; mining area within the active channel and the floodplain). They are quantified based on ortophotoplans (2005) and Google Satellite images (2011), cross profiles (2005 – 2011) and maximum annual discharges (for the last three decades) at gauging stations. The differences between 2005 and 2011 for each parameter were integrated into a classification and attributed scores (function of some thresholds) based on an adaption of the method of Rinaldi et al. (2013); we used the initial classification for the analysis of morphological and artificiality variations; we added new thresholds, classes and scores for hydrological variations. Prahova R. suffered the most dramatic morphological changes, followed by Slănic and Buzău: Prahova lost one third and Slănic, one quarter of the active area by lateral retraction, while Buzău widened the active area by 9%. The final score of morphological adjustments reached 33.3% for Prahova, 27.7% for Slănic and 5.5% for Buzău. In the case of Prahova R., these adjustments were determined mostly by human factors; in the two other cases, both natural and human factors were probably responsible. Prahova R. was the most affected by anthropic actions: the final score of the human pressure reached 42.8% for Prahova, 33.3% for Buzău and 14.3% for Slănic. This analysis confirms the simultaneity of impacts of hydrological and human factors. Yet, the method used is suitable for regional comparisons.

Keywords: river channel dynamics, human pressure, hydrological variability, scores, Romania

1. INTRODUCTION

The quantification of human pressure on hydromorphological river functioning is an intermediary phase aiming at answering the request of Water Framework Directive (WFD, European Commission, 2000) to achieve a good state of water bodies. Classical studies quantify the impact of anthropic actions by various methods and on various time scales, therefore making difficult to compare the case studies (Rădoane et al., 2013b). Recently, methodologies were created on national scale for understanding the physical processes and causes of river alterations, by comparing the current state with a reference one, considered quasi-natural (Ollero et al., 2011; Rinaldi et al., 2013).

Yet, understanding the impact of human factors on hydrosystems remains a scientific challenge: several human and natural factors are acting simultaneously (Liébault & Piégay, 2002; Rădoane et al., 2013a); long-terms and large study areas complicate the separation between the effects of human and natural factors (Ibisate et al., 2011); through the longitudinal connectivity of the river network, the effect of various controlling variables may be reflected downstream (Kondolf, 1997); in most cases, retroactions take place and rivers are in a certain stage of evolution (Simon, 1994).

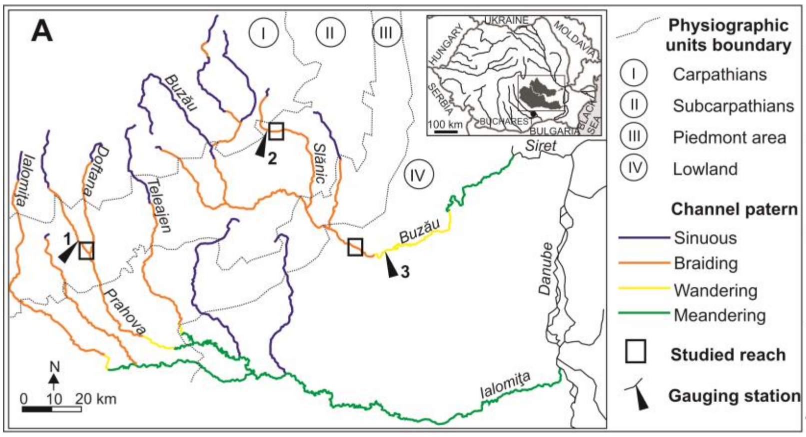
The highest impact of human factors is resented by braided rivers; braiding is the most dynamic, instable channel pattern and easily reacts to changes in inputs (Schumm & Meyer, 1979; Piégay et al., 2006). In addition, floods also may generate significant changes within the active tract (Arnaud-Fassetta & Fort, 2004; Bertoldi et al., 2010).

The study analyse the braided rivers dynamics in relation with hydrological and human factors, aiming at understanding their role on river channels behaviour and contributing to regional comparisons. The study is based on quantifying the morphological adjustments, hydrological variations and artificiality of river channels during a certain time. We worked on short-term and on small reaches to make easy the interpretation. The method was common for the studied river reaches; the interpretation was particular for every case study.

2. STUDIED AREA AND PERIOD

The study relies on three examples of rivers: Prahova, Slănic and Buzău (Figure 1A). Prahova and Buzău are second order tributaries of the Danube, while Slănic is a tributary of Buzău River. Prahova River springs from the Curvature Carpathians, crosses the Subcarpathians, a piedmont area and the lowland of the Romanian Plain; at Câmpina gauging station, it has braided pattern, medium lateral instability, high competence and stream power (Figure 1B). Slănic River is mostly a Curvature Subcarpathians' watercourse; at Lopătari gauging station, it has braided pattern, high lateral instability, medium competence and stream power. Buzău River comes down the Curvature Carpathians, crosses the Subcarpathians, a piedmont area and the lowland of the Romanian Plain; at Banița gauging station, it has medium lateral instability, competence and stream power. Among the three rivers, the most competent, in terms of specific stream power, is Prahova, followed by Slănic and Buzău.

Spatially, we worked on small braided reaches of approximately 5 km-long. They are located in the proximity of a gauging station: downstream Câmpina gauging station on Prahova R., at the confluence with its tributary Doftana; downstream Lopătari gauging station on Slănic R.; upstream Banița gauging station on Buzău R. As temporal scale, we worked on the interval 2005 – 2011, because it is a dynamic period in terms of human actions on rivers. Several interventions took place in order to insure protection against floods: gabions to reduce the lateral erosion and therefore the risk for national and departmental roads on Prahova and Slănic rivers (Ioana-Toroimac, 2009; Ioana-Toroimac et al., 2013b). In addition, the extractions of gravels and sands, in-stream and from the floodplain, intensified on Middle Buzău River (Salit & Ioana-Toroimac, 2013).



B

No	River of GS	F (km²)	H_{med} (m)	ω (W/m²)	Q_0 (m³/s)
1	Prahova at Câmpina	476	1106	710	8.3
2	Slănic at Lopătari	85	937	64	0.8
3	Buzău at Banița	3980	670	28	29.6

Figure 1. Study area. A) Studied catchments' location in Romania (in the frame up, right) and the position of analysed river reaches. B) Main hydromorphological characteristics. Channels patterns adapted from Ioana-Toroimac et al. (2012). Catchment area (F) and mean altitude (H_{mean}) at gauging stations (GS) (source: INMH, 1974). Physiographic unit and specific stream power (ω) from Ioana-Toroimac et al. (2013a). Mean multi-annual discharge (Q_0) according to data from "Romanian Waters" National Administration (1960 – 1998)

2. DATA AND METHODOLOGY

2.1. Indicators for morphological, hydrological and human factors variations

The study relies on the analysis of three types of indicators.

a) Indicators reflecting the morphological functioning of the braided channel:

- For lateral dynamics analysis, we calculated the total area of the braided channel and also of the river branches, alluvial bars and vegetated islands (covered by shrubs). We considered that the active part is formed of river branches and active alluvial bars and the inactive part is represented by vegetated islands and margins. We compared the braided channel in 2005 and in 2011 to determine the abandoned and reactivated areas (based on images on Table 1). We transformed the differences in percentage.

- For vertical dynamics analysis, we estimated the maximum and mean depth of the main channel at the bankfull stage on cross profiles (Table 1); the mean depth correspond to the ratio between the area and the width of the channel. We calculated the average of the differences between succesive cross profiles.

b) Artificiality indicators for 2005 and 2011 (based on images on Table 1), chosen in function of the particularities of the study area. They concern mostly the river channel:

- Number of weirs per 1000 m.
- Length of bank protection, in percentage of the total length of the river reach.
- Length of canals, in percentage of the total length of the river reach.
- Mining activity (in-stream and within the floodplain), estimated as a qualitative indicator – absent, moderate or intense – based on expert judgment.

c) Indicators reflecting the hydrological features of the river:

- We estimated the bankfull discharge (Qb) based on Manning equation (equation 1, Manning, 1889). The parameters of the cross section (e.g. area, hydraulic radius) are computed for the most recent available cross profile at every gauging station. The gradient of the thalweg is estimated based on topographic maps 1/25000. The roughness coefficient is estimated based on available tables relying on the information on riverbed granulometry marked on the edge of the cross profiles (Arcement & Schneider, 1984).

  $Q_b = Av = AkR^{0.67}S^{0.5}n^{-1}$ (equation 1),

  where Q_b (m^3/s) is the bankfull discharge, A (m^2) is the cross-sectional area, v (m/s) is the mean velocity, k is a constant equal to 1 in the International System of Measurements, R (meters) is the hydraulic radius equal to the ratio between cross-sectional area and wetted perimeter, S (m/km) is the gradient of the thalweg and n is the roughness coefficient.

- We estimated the 100 years return period discharge (Q_{100yr}), based on the series of maximum annual discharges (the periods are mentioned on Table 1) and using Pearson III distribution (Ponce, 2014).

Table 1. Data used in the study
(GS: gauging station; P-C: Prahova at Câmpina; S-L: Slănic at Lopătari; B-B: Buzău at Banița; NACLR: National Agency for Cadastre and Land Registration; RWNA: ”Romanian Waters” National Administration)

<table>
<tr><th>Indicator</th><th>Data</th><th colspan="3">Period/Date</th><th>Properties</th><th>Providers</th></tr>
<tr><td rowspan="2">Morphology
Artificiality</td><td>Ortophotoplan</td><td colspan="3">2003 – 2005</td><td>0.5 m
Stereo 70</td><td>NACLR</td></tr>
<tr><td>Satellite image</td><td colspan="3">2011</td><td>2.5 m
Pseudo-Mercator</td><td>Google Satellite</td></tr>
<tr><td rowspan="3">Morphology
Hydrology</td><td>GS</td><td>P-C</td><td>S-L</td><td>B-B</td><td rowspan="3">Bankfull stage - transition from bare sediments to vegetation</td><td rowspan="3">RWNA</td></tr>
<tr><td>Maximum annual discharge</td><td>1962 – 2007</td><td>1970 – 2011</td><td>1965 – 2010</td></tr>
<tr><td>Cross profiles</td><td>Jun/05/2005
Aug/21/2005
Oct/19/2005
Jan/19/2006
Aug/17/006
Nov/11/2006
Mar/27/2007
Sep/10/2007
Feb/13/2008
Aug/29/2008
Nov/12/2008
Mar/30/2009
Jul/29/2009
Feb/25/2010
Aug/19/2010
Jan/20/2011
Oct/26/2011</td><td>Aug/11/2009
Jun/04/2010
Sep/06/2010</td><td>Oct/11/2006
Sep/08/2009
Nov/15/2010
Aug/16/2011</td></tr>
</table>

2.2. Classification of the intensity of variations

We separated classes of intensity and attributed scores for every indicator.

- For morphological adjustments and artificiality, we adapted the methodology and, therefore, we used the expert judgment of Rinaldi et al. (2013) (and other references therein) (Table 2 and Table 3).
- For hydrological variations, we created a new approach. First, we took into account two thresholds with morphogeneous relevance and frequently used: Q_b which is responsible for changes within the river channel (Leopold et al., 1964); Q_{100yr} which is responsible for changes within the floodplain (Masson et al., 1996). Second, we separated three classes based on these thresholds: negligible changes associated to discharges inferior to Q_b; moderate changes associated to discharges between Q_b and Q_{100yr}; intense changes associated to discharges exceeding Q_{100yr}. Third, we attributed scores, which take into account the number of annual hydrological events outrunning the thresholds (Table 4).

Table 2. Indicators of morphological adjustments: classes and scores

Indicator	Classes	Scores	Prahova		Slănic		Buzău	
			Value	Score	Value	Score	Value	Score
Channel pattern	No change	0	-	0	-	0	-	0
	Change to a similar channel pattern	3						
	Change to a differente channel pattern	6						
Area of the braided channel	No change (<15%)	0	-32	3	-26	3	+9.2	0
	Moderate change (15-35%)	3						
	Intense change (>35%)	6						
Area of the river branches	No change (<15%)	0	-41	6	-41	6	+2	0
	Moderate change (15-35%)	3						
	Intense change (>35%)	6						
Area of the active bars	No change (<15%)	0	-26.3	3	-23	3	+15.3	3
	Moderate change (15-35%)	3						
	Intense change (>35%)	6						
Area of the vegetated bars	No change (<15%)	0	+82	6	+19	3	-	0
	Moderate change (15-35%)	3						
	Intense change (>35%)	6						
Maximum depth	Negligeable change (<0.5 m)	0	-0.19	0	Insufficient data	0	-0.26	0
	Moderate change (0.5-3 m)	4						
	Intense change (3-6 m)	8						
	Very intense change (>6 m)	12						
Mean depth	Negligeable change (<0.5 m)	0	-0.22	0	Insufficient data	0	+0.10	0
	Moderate change (0.5-3 m)	4						
	Intense change (3-6 m)	8						
	Very intense change (>6 m)	12						

2.3. Quantification of changes

We quantified the final score (S_{FINAL}) for every group of indicators: the sum of scores (S_{SUM}) across the sum of maximum scores (S_{MAX}), multiplied by 100 in order to obtain a percentage (equation 2).

$S_{FINAL} = 100 S_{SUM} S_{max}^{-1}$ (equation 2)

Low values of S_{FINAL} correspond to the absence of morphological changes, absence of morphogeneous floods (smaller than Q_b) and absence of significant human interventions during the analysed interval. High values of S_{FINAL} correspond to considerable morphological changes, exceptional floods (superior to Q_{100yr}) and an important anthropic transformation of the river during the analysed interval. The three scores are compared in order to understand the functioning of the river channel during a certain time.

Table 3. Indicators of artificiality: classes and scores
(No: number; L: lenght)

Indicator	Classes	Scores	Prahova		Slănic		Buzău	
			Value	Score	Value	Score	Value	Score
No weirs	Absence	0	-	0	-	0	0.4	4
	Low density (<1/1000 m)	4						
	High density (>1/1000 m)	6						
L bank protection	Absence/localized	0	20	3	5	3	-	0
	Protection on <33% of the lengh of the banks (sum of two banks)	3						
	Protection on >33% of the lengh of the banks (sum of two banks)	6						
L canals	Absence	0	50	3	-	0	-	0
	Changes on <10% of the reach lenght	2						
	Changes on >10% of the reach lenght	3						
Mining	Absent (A)	0	M	3	M	3	-	0
	Moderate (M)	3						
	Intense (I)	6						

Table 4. Indicators of hydrological variability: classes and scores
(No: number of annual events during the analysed interval)

Indicato r	Classes	Scores	Prahova		Slănic		Buzău	
			N	Score	N	Score	N	Score
Floods	Negligeable changes < Qb	0 x No events	-	0	3 x 3	9	3 X 2	6
	Moderante changes Qb – Q 100 years	3 x No events						
	Intense changes > Q 100 years	6 x No events						

3. RESULTS

Prahova R. suffered a narrowing process, losing about 32% of its active area, 26.3% of the active bars and 41% of the branches (Figure 2). In consequence, the vegetated islands extended. However, the hydrosystem remained locally active, some areas of the floodplain being reactivated by erosion (Figure 3). Vertically, it registered a slight incision (0.22 m for the mean depth and 0.19 m for the maximum depth). This morphological dynamics is reflected by a S_{FINAL} of 33.3% (Figure 4). We consider that this evolution is related mainly to human pressures (S_{FINAL} 42.8%); canals were constructed in order to derive water from Prahova and Doftana towards a microhydro; in-stream extractions of gravels and sands intensified; bank protections (gabions) were built in order to protect the installations for mining activities. No floods exceeding Q_b were recorded.

Slănic R.'s active area narrowed by 26% and also the alluvial bars and river branches, while the vegetated islands grew by 19% (Figure 2). Still, it has the most intense braiding activity – almost 80% of the area of the braided channel being represented by alluvial active bars. S_{FINAL} of morphological variations reaches 27.7%. Slănic R.'s dynamics is related to, both, hydrological and human factors. Still, the role of the natural ones seems to be more intense – S_{FINAL} 25% for hydrological factors comparing to 15% for the anthropic ones (Figure 4). Slănic R. endured three floods exceeding Q_b. In consequence, gabions were built to protect a departmental road.

In opposite, Buzău R. registered a slight widening, shown by the extension of the active area by erosion, up to 9%; the alluvial bars extended also by 15.3% (Figure 2). The vertical dynamics is not obvious: +0.10 m for the mean depth and -0.26 m for the maximum depth. S_{FINAL} of these morphological adjustments is 5.5%. This dynamics may be put on the account of both human (S_{FINAL} 33.3%) and hydrological (S_{FINAL} 16.6%) factors (Figure 4). The mining activity intensified and two weirs/bridges were built in order to easily cross the river for extraction purposes. Meanwhile, two floods exceeding Q_b perturbed the hydrosystem.

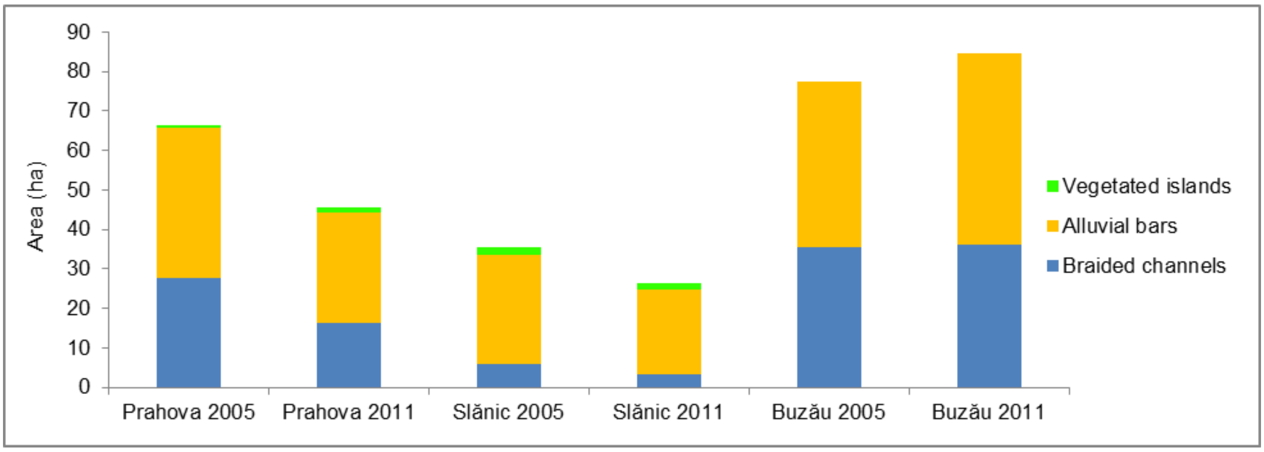
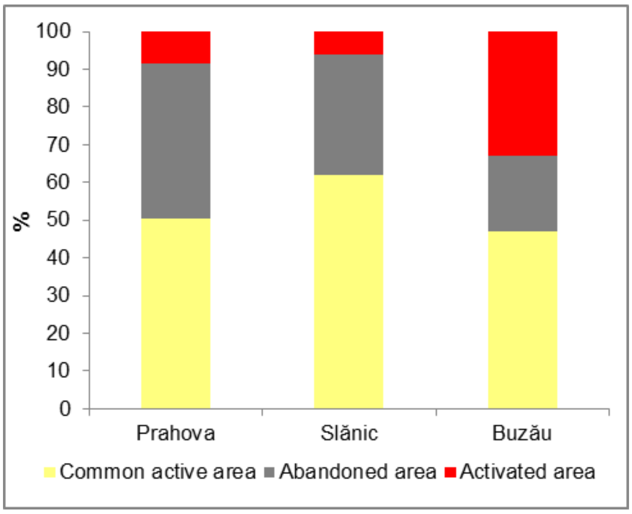


Figure 2. Composition of braided channels of Prahova, Buzău and Slănic rivers in 2005 and 2011



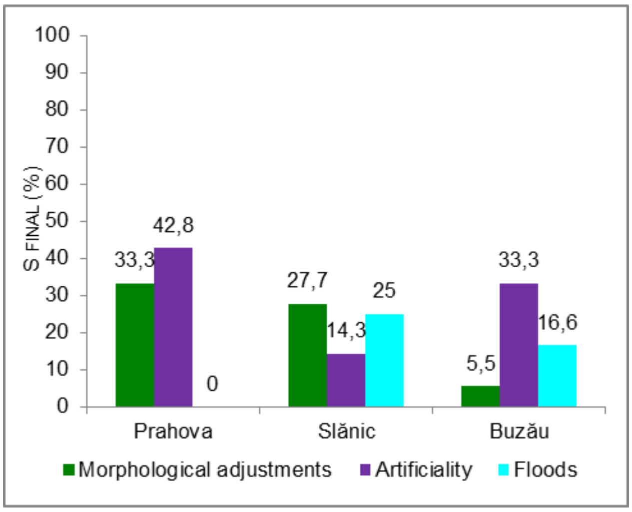


Figure 3 (left). Dynamics of the hydrosystems: abandoned and activated areas
Figure 4 (right). Scores S_{FINAL} of morphological, human and hydrological indicators' variations (based on tables 2, 3 and 4)

4. DISCUSSION

Prahova R. suffered the most dramatic morphological changes, followed by Slănic and Buzău rivers. This evolution may be related to the competence of these rivers in terms of specific stream power – Prahova has the highest energy, while Buzău has the lowest one. This confirms the interest for using specific stream power for "natural" rivers' typologies (Schmitt, 2004; Ioana-Toroimac et al., 2013a).

Prahova R. is the most impacted by human pressures, followed by Buzău and Slănic. This result confirms the usefulness of this type of method for achieving the goal of WFD (Rinaldi et al., 2013).

In opposite, Slănic R. is the most affected by natural factors, followed by Buzău. This confirms that it is sensitive to hydroclimatic events – widening during crises versus resilient contraction (Ioana-Toroimac et al., 2013b); this is specific to quasi-natural rivers from the upstream parts of catchments, in mountain regions, with high braiding activity and whose functioning is depending on sediments (Arnaud-Fassetta & Fort, 2004; Arnaud-Fassetta et al., 2005; Brousse et al., 2011).

This method, based on classification and scoring, put in perspective the results and allowed regional comparisons of morphological, hydrological and human factors variations. Comparing to the method of Rinaldi et al. (2013), we gave the same importance to natural and human variations. Still, the method didn't separate the role of natural versus human factors, confirming the simultaneity of their impacts. More than that, it is only quantitative, quantifying the changes; the qualitative aspects (i.e., narrowing, widening, degradation, aggradation) need to be shown separately.

Nevertheless, the results must be carefully interpreted, because of several data and methods difficulties. We ignored the adjustments which took place between the two extreme moments of the analysed interval. We couldn't evaluate the state of the hydrosystem at the beginning of the analysis, because of the lack of orthophotoplans' precise date. We couldn't delimit with precision the active-channel's borders, because of the quality of the images (i.e., colours, shadows). The method would be more accurate is others parameters were computed, in the floodplain and on neighbour slopes: natural changes within the habitats (i.e., from pasture to shrubs or forest), various types of embankments, changes in land use.

5. CONCLUSION

This paper analysed the impact of human and hydrological variables on braided river channels on short-term. It employed a methodology aiming at quantifying the changes of some morphological, hydrological and artificiality indicators. The morphology was analysed through the area and the composition of the braided channel. The hydrological factors were represented by floods; due to rapid erosion or accumulation processes, they determine adjustments within the river channel. The quantified anthropic factors are: weirs, banks protections, canals and mining activity in-stream and in the floodplain; they determine changes in flow and sediment load, therefore within the river channel.

Braided rivers, like Prahova, Slănic and Buzău, appeared to be quite sensitive to changes on short-term. Still, it remains difficult to separate the role of each factor within river channel morphological adjustments. Between 2005 and 2011, morphological changes of Prahova river channel were mostly related to human pressure, while on Slănic R., the role of natural factors in prevalent; Buzău R. reacted less intense to human and hydrological variations.

These methodology is suitable for regional comparisons. It can be adapted to quantify human pressure and to determine the hydromorphological quality of Romanian rivers.

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