RESEARCH ON THE INTERCONNECTION OF THE MINOR RIVER BED WITH THE RIPARIAN AREA

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ABSTRACT: *The morphology of the minor bed is influenced by a number of natural and anthropogenic factors. The shape of the minor bed is conditioned by the geological structure and hydrological and hydraulic parameters of the flow. The minor river bed, in general, has a continuous morphological transformation of a natural type. The research carried out on three types of beds taken from the mountain area (Tazlăul Sărat River), hill (Moldova River) and plain (Bahlui River) highlighted the increasingly strong influence of anthropogenic factors on the morphology of the minor bed. The presence of economic facilities in the riparian zone influences the morphological change of the minor river bed. The research also followed the evolution of the minor bed in interconnection with the riparian zone. Morphological anthropogenic transformations generated by human and economic requirements appear on river sections.*

Keywords: *shape; morphology; natural factors; anthropogenic factors;*

1. Introduction

The research of the formation and evolution of riverbeds in various situations of natural or artificial exploitation is a continuous concern both on a national and global level (Ichim I. et al, 1989, Oprisan E., Tecuci I., 2014, Luca M. And Avram M., 2021, Bollati I.M. et al, Neuhold C. et al, 2009, 2014, US Army Corps Engine., 1993). The problem of the three-dimensional stability of the flow section in watercourses, but also the monitoring of morphological transformation phenomena through erosion and deposition processes, is a permanent field of research (Wang W.C. et al, Rinaldi M., 2003, (Ichim I. et al, 1989).

The minor bed of the rivers is structured from the land surface with low elevation where a continuous flow of water is formed with a free surface from the sources to the discharge in the upper water course (Ichim I. et al, 1989, Order 20115, 2001). The formation flow of the minor bed is a field of continuous research at the current stage (Opri an E., Tecuci I., 2014).

The climate changes that have occurred in the last period of time have modified a series of natural and anthropogenic risk factors that intervene in the evolution of natural riverbeds, but also of those equipped with regularization works (Avram et al, 2018, Avram M., 2020, Luca M and Avram M., 2017, Manolache A.V., 2018, Romanescu G. and Stoleru C., 2013 Santillan D. et al, 2020). A series of researches have analyzed the way of evolution over time of the bank defenses to the pronounced modification of the hydrological regime in the riverbeds (Luca et al, 2012). This situation has also determined a current change in the concepts of carrying out river regularization works (Avram M., 2020, Luca M., Avram M., 2021).

In the last period of time, the concepts of "continuous river" and "more space for rivers" are adopted, for the most adequate protection of the environment (Avram M., 2020). But in areas with social and human objectives, hydrotechnical works for the development of watercourses must be carried out. In this context, a corroboration of the works carried out in the riverbed with those located in the riparian zone must be carried out in order to reduce the risk factors that influence the environment. This paper presents the results of a series of researches regarding the interconnection of the minor river bed with the riparian area, through the lens of the existing risk factors and those generated by the anthropogenic environment.

2. Research material and method

The research material consists of three river sections selected from the hydrographic basins located in the eastern part of Romania. The selection criterion was the presence of processes of morphological transformation of the bed under the action of natural factors, but especially of anthropogenic ones from the riparian zone.

The researched riverbeds were selected according to the relief form traveled by the river:

- for the mountain area, a section of the Tazllăul Sărat river that crosses the territory of Zemes commune in Bacau county was selected (Luca M., 2016);
- for the hilly area, a section of the Moldova River near the town of Cordun in Neamt County was selected (Luca M., 2011);
- for the plain area, a section of the Bahlui River was selected, which crosses the territory from the outskirts of the city of Iasi, as well as from the city (Luca M., 2019).

Also, the selection of river sections was also achieved through the presence of some hydrological risk factors with a high weight, especially floods. The rivers Tazlăul Sărat and Moldova were selected in this category.

The research stages were the following:

1. Research in the field by taking topographical, hydrological, hydraulic and geotechnical data related to the river bed.
2. Analysis of the development of the riparian area, as well as the behaviour of existing construction works and installations.
3. Comparative analysis of the action of natural and anthropogenic risk factors in the research area, with the identification of those that have a greater weight in the degradation of the bed or the riparian zone.

3. Results and Discussions

The minor bed of water courses (Fig. 1) begins its evolution from the source and goes through phases of progressive development until it flows into the emissary. The evolution of the bed takes place under the action of a complex of natural factors and over an indefinite period of time. The action of natural factors was supplemented after a period of time by the action of man. Human-generated actions have used the river for various purposes, or protected itself from its aggressive intervention on material goods. In certain situations, there is a correlation between natural risk factors and anthropogenic risk factors that determine the evolution of the river bed over time.

The analysis carried out for the data collected from the field considered that the transformation of the river bed can be classified into "process-response systems" and "process-form systems" depending on the actions determined by the natural and anthropic embedding environment (Strahler, 1980, quoted by Ichim et al, 1989). The analysis was also extended to the way of interconnecting the evolution of the bed in conjunction with the riparian area. Between the subsystems there are reverse connections (feed - back).

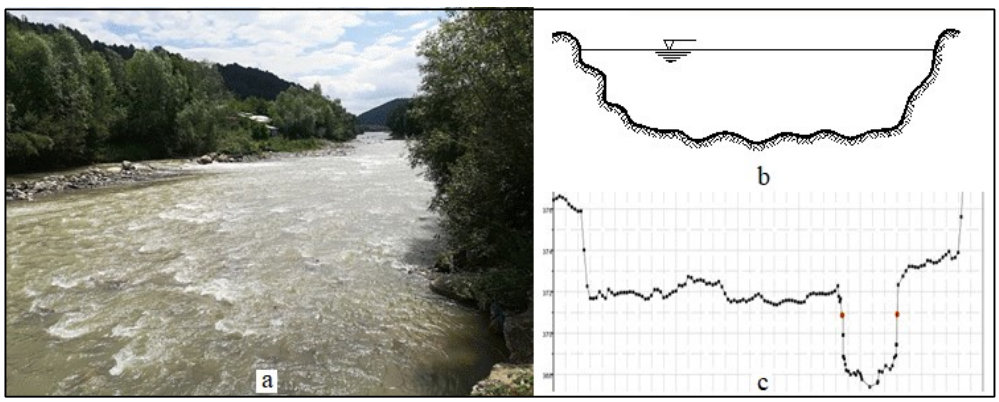

Fig. 1. Minor river beds in the Piedmont area: a – the natural image of the bed; b – general scheme; c – the topographical profile of the bed.

Since human settlements are mostly located on the banks of watercourses, in certain situations there is an interconnection between the two areas, namely the river bed and the riparian zone. The case studies followed the forms of interconnection and especially the weight of risk factors (natural or anthropogenic) on each area.

Case study I. The interconnection of the minor bed of the Tazllăul Sărat River with the riparian zone on the territory of Zemes commune in Bacau County. The upper course of the Tazlăul Sărat River is specific to the mountain area; the elevation of the land on the investigated river sections is in the range of 990 - 890 m.

The analysis of the research area highlighted the following characteristics of the bed of the Tazllăul Sărat River on the study section (Luca M., 2016, Luca M. and Avram M., 2017):

- the minor bed is relatively rectangular in shape, being formed in a layer of coarse alluvium, under which large stones and pieces of rock appear (Fig. 2);

- rapid floods with high flows frequently occur, which exceed the calculation probabilities of regularization and shore defence works;

- high water speeds generate intense erosion phenomena of the flow section;

- the regularization of the bed has been partially achieved, the shore defence is placed only on the protected sections; the shore defence is made of plain concrete walls (Fig. 2.a), reinforced concrete slabs and gabion boxes filled with stone (Fig. 2.b);

The riparian zone on the research sections highlighted the following characteristics (Luca M., 2016):

- a road located on the border of the river bank; the road is asphalted and is the only means of transport and connection between the river towns;

- steel pipes with diameters of 50 – 100 mm for the transport of crude oil and technological extraction fluids: the pipes are installed longitudinally in the river bed and bank.

Analysis of risk factors at the interconnection of the riverbed with the riparian area

A. Natural risk factors:

- rapid and frequent floods produced in the last 20 years, of which the ones in 2005, 2016, 2018 stood out;

- the 2016 flood on the Tazlăul Sărat River recorded a maximum flow of 342 m3/s (Table 1), a value approaching the probability of occurrence of 3%.

B. Anthropogenic risk factors are represented by the advanced wear of coastal defense

Table 1. Maximum flows with probability of occurrence on the Tazlaul Sarat River at the Lucacesti Hydrometric Station (W.B.A. Siret, 2016)

Q_{max} (m^3/s)	year 2016		Q_p			
	Q_m	p (%)	$Q_{max\ 1\%}$	$Q_{max\ 2\%}$	$Q_{max\ 5\%}$	$Q_{max\ 10\%}$
Value	342	≈ 3	545	425	290	200
Q_m – measured flow; Q_p – debit with the probability of occurrence; p – probability of occurrence.						

Fig. 2. Tazlăul Sarat River bed interaction - riparian area: a - degradation of the bed and the county road, Chiosa area; b – the degradation of the riverbed and the county road in the ”Maxim's canton” area (Luca M., 2016)

works, the absence of riverbed maintenance works and the lack of coastal defense rehabilitation works.

In some sections, the river bed has great vertical depths (2.50 – 3.50 m) and is formed in alluvial sedimentary rocks positioned on layers of metamorphic rocks. This fact required the construction of high-height vertical defense constructions, such as the supporting walls made of concrete. The coastal defense constructions were executed before 1989, and over time they were degraded by the actions of the surrounding environment (Fig. 2). At the same time, the absence of current repair works, maintenance works, but also rehabilitation works, determined the total degradation of the shore defenses (Luca M., 2016).

The flood produced in June 2016 on the Tazlăul Sărat River produced multiple phenomena of erosion of the bed and the riparian area related to the section that crosses the localities of the Zeme commune (Todera , Hartopanu, Chiosa and Zeme). Erosion occurred vertically and horizontally in the bed. The vertical erosion exceeded the elevation of the foundation of the shore defense in the areas of Chiosa (Fig. 3.a) and Maxim's Canton (Fig. 3.b). This situation allowed the penetration of the water jet under the bank defense in the Maxim Canton area and the erosion of the resistance structure of the riparian road (Fig. 3.b). The horizontal erosion determined the destruction of the bank defense and the advance of the bed in the bank (Fig. 3.a).

Also, the erosion of the bed and the bank determined the uncovering of pipelines for transporting technological fluids (Fig. 3) and the risk of water and land pollution with petroleum products. The analysis of data collected from the field and processed over a period of time revealed a strong influence of natural risk factors, which are predominant over anthropogenic ones in the research area on the Tazlăul Sărat River.

Case study II. The interconnection of the minor bed of the Moldova River with the riparian zone on the territory of the Cordun locality in Neamt county. The lower course of the Moldova River is characteristic for the area of high hills, where the elevation of the land is between 400 - 600 m. The analysis of the research area highlighted the following characteristics of the Moldova River bed (Fig. 4, Fig. 5) (Luca M., 2011):

- the minor bed is regularized and has a relatively double-trapezoidal shape; the banks are equipped with defensive works made of large concrete slabs (on the upper part) and gabions filled with river stone (on the lower part);
- the support of the river bed consists of coarse alluvium (ballast, loamy sand); the major bed is extended unilaterally towards the right bank;
- the bed is traversed by frequent floods with flows with high probabilities of overflow;
- high water velocities occur in the bed even at maximum flows, but also at medium flows: this situation generates phenomena of hydrodynamic erosion and sedimentation.

Fig. 3 Tazlaul Sarat River bed interaction - riparian area: a - degradation of the bed and the county road, Chiosa area; b – the degradation of the riverbed and the county road in the ”Maxim's canton” area (Luca M., 2016)

Fig. 4. General view of the bed section on the Moldova River with the water catchment and in the riparian area (photo Luca M., 2020)

The riparian zone on the research sector presented the following characteristics (Fig. 4, Fig. 5) (Luca M., 2011):

- a water catchment is located on the left bank; the bed was equipped with works to raise the water level, direct the water current and dissipate the excess energy generated by the change in flow conditions; the works carried out in the riverbed are composed of: spillway, energy dissipater, ridge berm, water intake channel for capturing and discharging the surplus and others;

- at the border of the bank there is an exploitation road with a road surface made of ballast.

Analysis of risk factors at the interconnection of the bed with the riparian zone on the Moldova River.

A. Natural risk factors:

- rapid and frequent floods produced in the last 30 years; maximum flows were recorded at the Tupilati Hydrometric Station in 1991, 2005, 2016, 2018 (Table 2);

- intense erosion and sedimentation phenomena in the minor river bed; they are favoured by the weakly cohesive foundation of the bed (ballast, gravel and sand-loam layers).

B. Anthropogenic risk factors:

- the water catchment construction located on the left bank is the main anthropogenic risk factor; this imposed a calibrated bed, bank protections and a series of hydrotechnical constructions located in the bed: in this situation, the bed became a channel for the rapid transit of the water current (Fig. 4);

- the use of the riverbed with a series of constructions and installations determined the partial degradation of the living conditions for the aquatic environment and that of the riparian zone;

- the lack of works to rehabilitate the water catchment, but also of the shore defence, contributes to the continuous degradation of the environment (Fig. 5).

The analysis of the data collected from the research section on the Moldova River over a relatively long period of time revealed a strong influence of anthropogenic risk factors, which are predominant over natural ones.

The follow-up of the interconnection of the Moldova river bed with the riparian area was carried out over a period of 12 years (2010 - 2022).

Table 2. Maximum flows on the Moldova River at SH Tupilati (WBA Siret, 2018)

Year	1991	2005	2008	2010	2014	2018
Q (m^3/s)	1402	1154	695	965	521	1200

Case study III. The interconnection of the minor bed of the Bahlui River with the riparian zone in the metropolitan area of the city of Iasi, Iasi County. The average course of the Bahlui River is specific to the plateau area. The research section is located at the border of the city of Ia i, and a commercial complex is located on the riparian area of the right bank.

Fig. 5. Moldova River bed interaction - riparian area: a - condition of the bed in the area of the water catchment construction; b – the state of the riparian area, the left bank protection and the downstream catchment bed (photo Luca M., 2020)

The river section is partially regularized.

The analysis of the research area highlighted the following characteristics of the bed (LucaM., 2019):

- the minor bed is of a parabolic shape in natural mode and of a compound type (parabola + trapezoidal and mixed trapezoidal) in arranged mode (Fig. 6);

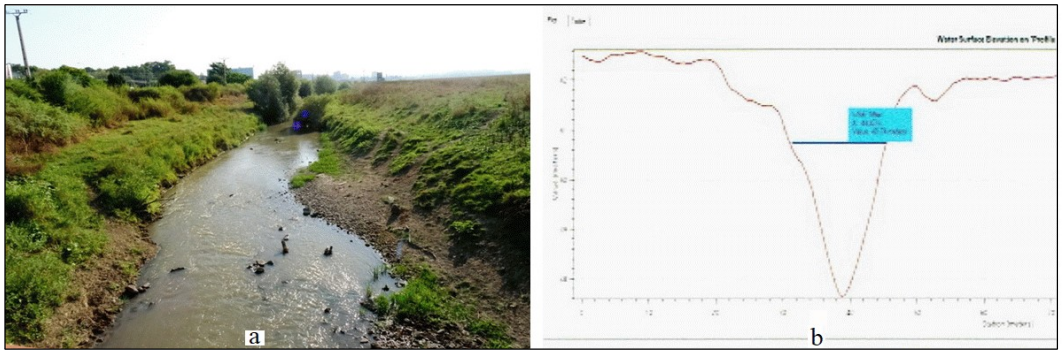

Fig. 6. Characteristic elements of the bed of the Bahlui River on the research section: a – the image of the natural bed in its natural state; b – topographical scheme of the bed (Luca M., 2019)

- the water speed has low values at the average flow rate (0.7 – 0.9 m/s); local phenomena of erosion and sedimentation appear along the research section;

- the flow on the research section is controlled by the Podu Iloaie Reservoir and the polders in the Letcani area.

The riparian zone on the research sector presents the characteristics (Luca M., 2019):

- the regularization works followed the calibration of the bed along the length of the platform of the commercial complex; the right bank was profiled with 1:1 slopes, and a berm was built in the middle (Fig. 7.b);

- the research section is bordered by two bridges made of reinforced concrete;

- on the berm are located the constructions and installations for the drainage of rainwater collected within the commercial complex; rainwater is discharged into the Bahlui River through four discharge constructions (DC); DC1 and DC4 are located near the bridges (Fig. 7.a), and DC2 and DC3 on the right slope of the research section (Fig. 7.b).

Analysis of risk factors at the interconnection of the bed with the riparian zone on the Bahlui River:

B. Anthropogenic risk factors:

- the main anthropogenic risk factor with influence on the bed and riparian area of the Bahlui River is represented by the operation mode of the four rainwater discharge constructions (DC1, DC2, DC3 and DC4) located in the riparian area and on the river bank;

Fig. 7. Bahlui River bed interaction – right bank riparian zone: a – bank erosion by the degraded state of DC4; b – the degradation state of DC1 (Luca M., 2019).

Table 3. Flows with exceedance probability (p) on the Bahlui River in the research section (Luca M., 2019)

p (%)	0,1	1	5
Q (m^3/s)	420	150	60

- the discharge construction DC4 is partially degraded on the final section; the analysis carried out in the field revealed the loss of stability of the exhaust channel due to the suffusion phenomenon formed in the foundation and the supporting soil layer of the construction;

- the outlet channel at DC4 broke into pieces, and the transported rainwater eroded the riparian area and the river bank; the shore protection in the area of the evacuation construction was totally destroyed (Fig. 7.a); due to the faulty operation of the drainage construction, the hydrodynamic erosion of the bank also occurred, and the river bed advanced into the bank;

- the degradation of the drainage construction, the bank protection and the combined erosion of the water from the river and that of the drainage channel produced the partial stripping of the bridge abutment;

- the outlet channel at DC1 is totally degraded on the cooling section with the Bahlui river, so that the rainwater discharges directly onto the river bank and causes its erosion;

- the discharge channels at DC2 and DC3 are partially degraded (Fig. 8), a situation in which the water is discharged directly onto the river bank.

The analysis of the researched risk factors at the interconnection of the Bahlui River bed with the riparian area occupied by the drainage

Fig. 8. Bahlui River bed interaction - right bank riparian area: a - rainwater storage tank and discharge with DC2 in the bed; b – overview of degraded structural states of DC2 (year 2019) (Luca M., 2019)

construction revealed a strong influence of anthropogenic risk factors in the degradation of the bed in the bridge area. Anthropogenic risk factors became predominant over natural ones in the research case considered.

Climate changes in the last period of time have produced a marked change in the existing natural risk factors in the hydrographic basins in the eastern part of Romania. This aspect was also highlighted by the research conducted on three types of minor riverbeds for rivers formed in mountain areas, high hill and lowland.

The results of the research highlighted the interconnection of the functioning of the minor river beds with the existing economic objectives in the riparian area. The interconnected functioning of the two systems, river bed - riparian zone, under the action of a complex of risk factors, creates reverse connections (feed - back). These connections, or the interconnected functioning of the two systems, determine positive or negative situations for one of the systems, and even for both systems.

The natural risk factors that have intensified in the last 40 years are high-frequency flash floods and high rates of erosion of the bed-structuring material.

The research carried out has shown that many times the anthropogenic risk factor causes an important degradation of the minor bed. In this context, the human factor must review its intervention mode, but intervene with a complex of works to create hydraulic stability in the operation of the minor bed.

The absence of regularization works, bank protection, but also the realization of rehabilitation and modernization works of the existing constructions in the bed contribute to ensuring hydraulic stability.

4. Conclusions

1. The parameters of the minor river bed are continuously modified under the action of natural and anthropogenic risk factors existing at a certain time, temporally, in the evolution of the water course.

2. The results of the conducted research highlighted the interconnection of the functioning of the minor river beds with the existing social and economic objectives in the riparian zone. The interconnected operation of the two systems often creates a hydraulic instability in the mode of existence of the minor river bed.

3. Anthropogenic risk factors have become predominant in the last period of time on the watercourses in the localities area. Among them can be listed: the location of water intakes in the bed or the riparian area, the regularization works of the bed, the absence of maintenance operations of these works, the inappropriate exploitation of the ballast and others.

4. The minor riverbed often interacts with the landscaped riparian area in the form of road, railway, urban area, economic area and others. Many times this interaction causes aggressive actions between the river bed and the type of development of the riparian area.

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