Technical University of Civil Engineering Bucharest

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FACULTY OF HYDROTECHNICS

SUMMARY
Ph.D. Thesis

RESEARCH ON COMBATING SOIL EROSION THROUGH THE ARRANGEMENT OF HYDROGRAPHIC BASINS WITH ECOLOGICAL WORKS

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INTRODUCTION

Climate change in recent years has harmed rainfall. As a result of these changes, the drought period is quickly replaced by the rainy season. This phenomenon favored the appearance of floods with very high flows on the main watercourses, as well as on the secondary ones.

The modifications of the minor and major riverbed of the Siret River (lower course) and the main tributaries are due to the variation of flows, the natural evolution of the valley, the absence of some hydro-technical works, and the anthropic influence. The major riverbeds were extended by the action of lateral erosion and the collapse of the banks, and their deepening was achieved by lowering the elevation of the riverbed.

The Ph.D. thesis on **"Research on combating soil erosion through the arrangement of hydrographic basins with ecological works"** presents an analysis of the factors that determine the occurrence of erosion in the Siret river basin (lower course) and the influence of the behavior of some types of hydro-technical works to combat erosion.

The research methods approached are a combination of traditional research methods based on field measurements, and modern methods based on spatial analysis.

The thesis is structured on 9 chapters, a bibliography, and annexes.

Chapter 1 presents a study on the current problems of the erosion phenomenon, especially water erosion, and its global and national consequences.

Chapter 2 summarizes a series of theories and calculations of water erosion on agricultural land, riverbeds, and several factors that favor erosion.

Chapter 3 presents the study area, the evolution of the riverbed, and the highlighting of eroded areas, through satellite measurements and classical measurements with the interpretation of data obtained from the field.

Chapter 4 presents the analysis of alluvial transport and the analysis of erectional factors.

Chapter 5 presents a series of classic control works used nationally and worldwide in combating soil erosion and river basin development.

Chapter 6 presents a series of ecological works used to combat soil erosion and river basin management, especially the use of geosynthetic materials and the study of the use of geocontainers in combating erosion.

Chapter 7 presents an analysis of the use of gabion and geocontainer works in combating erosion and degradation.

Chapter 8 examines the implementation of geocontainer works to combat erosion and restore habitats in the eroded areas presented in Chapter 3.

Chapter 9 presents the evolution of ecological works to combat erosion in geocontainers, from a technical point of view, through the behavior evolution of the riverbed and the banks through satellite analysis and the method of analytical calculation.

Chapter 10 presents the general conclusions of the Ph.D. thesis, personal contributions, and research perspectives.

CHAPTER 1
CURRENT ISSUES ON WATER EROSION

1.1. Synthetic elements of the erosion phenomenon

The main factors that cause soil degradation can be grouped into two categories:
- *Natural factors:* landscape, climate, nature of the lands;
- *Anthropic or social factors* [10].

The mechanical process, which causes the phenomenon of soil or rock degradation, by detaching unconsolidated soil particles, removal, transport and storage, is called erosion [6].

1.2 The current stage of the erosion phenomenon

In our country, about 43%, i.e. over 6 million ha, of agricultural land is located on a slope and has the potential for degradation by water erosion [19].

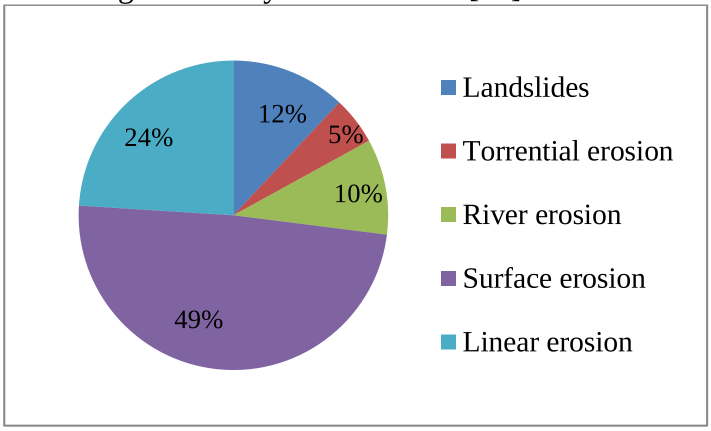

Fig.1.1. Percentage of water erosion and associated processes in Romania

1.3. Erosion

1.3.3. Types of erosion caused by the watercourse

Torrential erosion, linear erosion, regressive erosion, lateral erosion, bank collapse erosion, marine erosion, karst erosion or corrosion.

Fig.1.2. Linear erosion, Bănița brook

Fig.1.3. Lateral erosion, Putna river

Fig.1.4. Karst erosion, Zăbala river

CHAPTER 3
IDENTIFICATION OF EROSION AREAS BY CLASSICAL AND INNOVATIVE METHODS IN THE MIDDLE AND LOWER COURSE OF THE SIRET RIVER BASIN - CASE STUDY

3.1. General characteristics of the research area

3.1.2. Location and presentation of the Siret river basin

The Siret River is the largest inland river in Romania. It springs from the Forest Carpathians of Ukraine.
The total area of the Siret river basin is 44,871 km^2, of which 42,890 km^2 on the Romanian territory. The length of the Siret River on the territory of Romania is 548 km, and on the territory of Ukraine, 110 km [26].

According to the morpho-hydrographic and hydrological characteristics, the Siret river divides into three distinct sectors:
- *The upper Siret,* till the river enters the territory of our country at Văscăuţi, with an average drainage slope of 7%.
- *The middle Siret,* up to the Putna estuary, i.e. the plateau sector of the river with an average slope of 0.5%.
- *The lower Siret,* or plain sector, downstream of the Putna estuary, where the longitudinal slopes of the river decrease to 0.23% [21].

3.2. Analysis and modeling of eroded areas

3.3.1. Methods approached in the analysis and modeling of areas

The methods approached in modeling eroded areas merge modern means based on a spatial analysis performed with geographic aerial photography that used satellite imagery and remote sensing on the map generated by Google Earth software and traditional ones based on field measurements [137].

For the spatial tracking of the eroded areas, we used the geographical aerial photo interpretation, which realizes the connection between the satellite images and the remote sensing to generate results regarding the spatial location. It is used in fields such as geography, geomorphology, hydrology, and helps to quickly collect information, locate objects, update maps, but especially in research and monitoring of large and especially difficult to access and fragmented regions.

By using remote sensing we would identify, measure and analyze without direct contact, from a distance, the characteristics of the studied erosion areas. Remote sensing to identify objects uses photogrammetry, photo-geology.

For the analysis and evolution of eroded areas, we used Google Earth software which consists of a 3D virtual globe. It contains geographic information and aerial photographs, [167], being a search engine that helps researchers and scientists better track, analyze, and monitor changes around the globe.

Current or older maps and photographs taken with satellites (satellite images) and data are used to track the processes, thus allowing monitoring [169].
Monitoring of erosion areas by classical methods was performed using field measurements using the G.P.S Hi-Target and the total Leica station. The interpretation of the data obtained after the measurements was performed by the method of analytical calculation with AutoCAD and ProgeCAD programs on georeferenced maps in the ArcGIS program [70].
To follow the evolution of the works in geocontainers, of the process of alluvium accumulation, but also of the erosion process, data from several periods were used.

The data were taken using the G.P.S. which uses satellites as reference points to generate STERO 70 coordinates (X, Y, and Z). These coordinates, reported on reference plans, faithfully reproduce the topographic details of the field [166].

For the interpretation of the data and the tracking of the accumulation and erosion process we used the analytical calculation method, which is applied when the STERO 70 coordinates are known, compared to the other methods, ensures the highest accuracy.

The calculus relation of the area of a polygon with, "n" sides is:

$$2 \cdot S = \sum_{i=1}^{n} X_i (Y_{i+1} - Y_{i-1}) \quad (3.1)$$

Where:
S - surface area;
n - number of sides;
(X_i) - the abscissa of each point;
(Y_{i+1}) - the order of the next point;
(Y_{i-1}) - ordered by the previous point.

In order to obtain the level differences between the surfaces, it is necessary to know two points A and B, thus the relation:

$$\Delta HAB = B\ B\ ', \text{ sau } \Delta H_{AB} = H_B - H_A. \quad (3.4)$$

The values were obtained from measurements performed at different time intervals in monitored erosion areas.

The level difference can be positive or negative, depending on the altitude of the point and the direction considered. If HB> HA, then ΔHAB = HB - HA is positive, but ΔHBA = HA-HB is negative [73].

3.3. Presentation and analysis of eroded areas

3.3.3. Erosion of the left bank of Milcov river, Odobeşti locality, Vrancea county

Types and characteristics of erosion

In the studied area, the widening of the minor riverbed varies and is disheveled-braided. The transport of alluvium is high during floods. It comes from landslides upstream and downstream, the dominant source of alluvium being from the river banks.

Erosion processes are signaled at the base of both banks, and deposits are generally made in the center of the riverbed.

Lateral erosion acting on the steep bank sector of the riverbed influenced by the turbulent flow of water during floods, it is loaded with alluvium from landslides in the spring area and in the middle, transit with alluvium from river erosion. Erosion threatens socio-economic objectives (Odobeşti treatment plant) and agricultural land in the area.

Figure 3.1 shows the area with concavity on the map generated by Google Earth and the appearance of the erosion studied.

Fig.3.1. Aspect of left bank erosion, Milcov river, loc. Odobeşti, Vrancea County

Analysis and evolution of erosion by the spatial method

The spatial analysis method refers to the geographical environment seen as a complex system, which allows tracking in time the evolution of changes in the earth's crust [139].

Figure 3.2 shows the evolution of the erosion of the Milcov River banks, in 2015-2017, in the area of Odobeşti, where we marked the monitored area with reference points to represent the area and length of eroded areas each year. The map generated by Google Earth was used for representation.

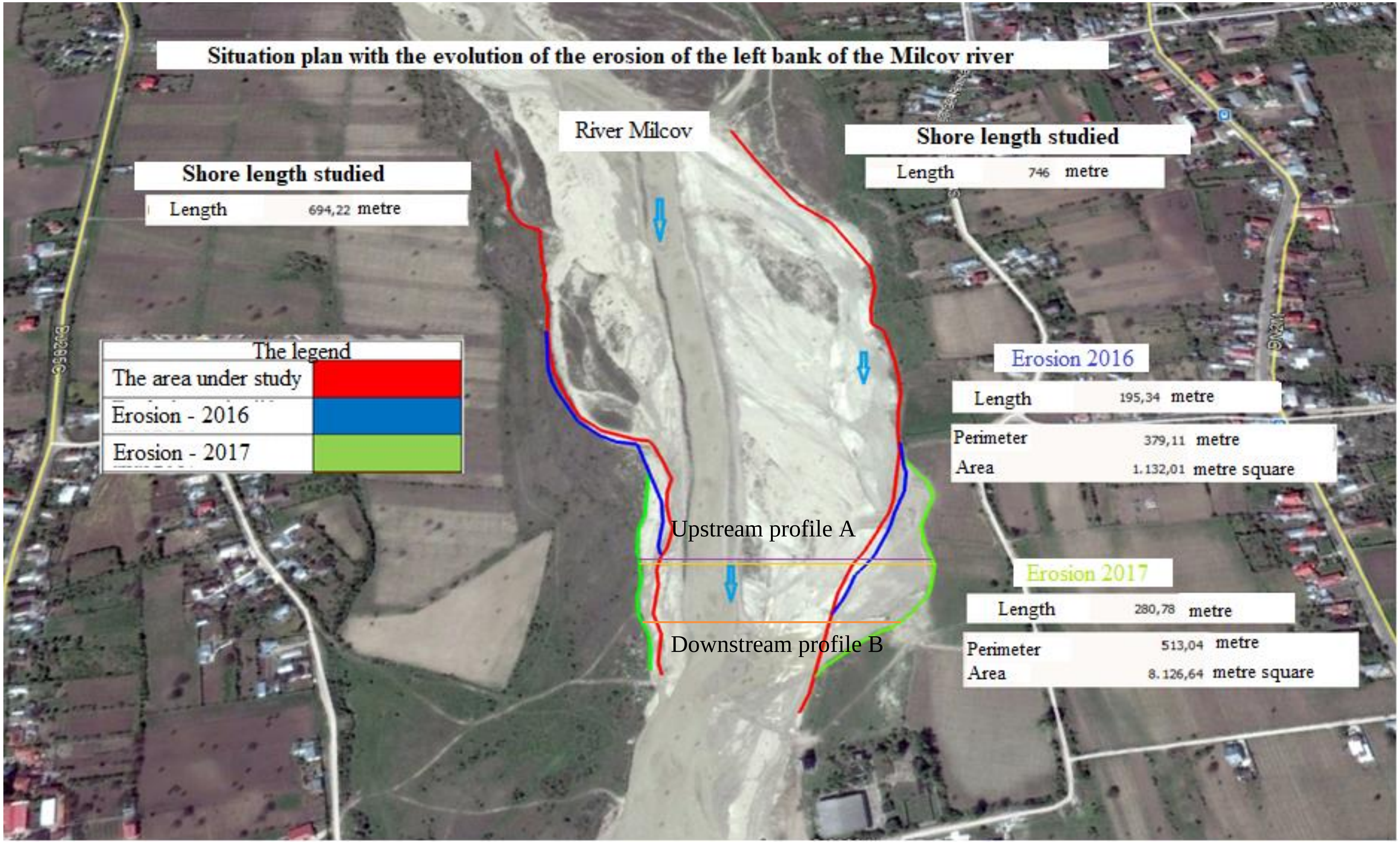

Fig.3.2. Spatial evolution of the erosion of the left bank of the Milcov river during 2015, 2016 and 2017 (Google Earth map)

Following the heavy rainfall from 2016-2017, floods with considerable flows were recorded on the Milcov River as a result of the river banks in the area of Odobeşti, they were heavily eroded and especially the left bank.

Table 3.1 shows the maximum floods during the floods recorded on the Milcov river during 2016-2017, and the land areas eroded by the floods.

Table no.3.1. Maximum flow rates during floods and eroded areas

The year	Q flood (mc/s)	Eroded surface (mp)	Length shore eroded (m)
2016	78	1.132	195
2017	13	9.348	280
Total		*57.533*	*1562*

For the spatial follow-up of the erosion evolution, we marked the right bank in 2016 with reference points.

Table 3.2 shows the evolution of the riverbed width based on satellite data from floods recorded on the Milcov river in the period 2015-2017, which shows a widening of the riverbed by 8 m in 2016 and a widening of the riverbed by 83 m , in 2017.

The monitored area is represented in purple on the map shown in figure 3.2.

Table no.3.2. Evolution of riverbed width based on satellite data

The year	Q flood (mc/s)	Windth bad riverbed (m)	Width shore eroded (m)
2015	0	164	0
2016	78	172	8
2017	13	255	83
Total		*255*	*91*

Analysis and evolution of erosion by the method of analytical calculation

At the beginning of 2016, we made two cross-sectional profiles in the field (upstream profile A and downstream profile B), values determined for each profile. These values were taken as reference points for monitoring the evolution of erosion.

By making the transversal profiles, (upstream profile A and downstream profile B) the eroded land surfaces following the important floods registered on the Milcov river were determined.

Figures 3.3 and 3.4 show the evolution of the transversal profile of the Milcov riverbed, in the area of Odobești locality, by overlapping the topographic points resulting from the measurements performed in the field with the help of G.P.S Hi-Target, during 2016-2017. The areas (upstream profile A and downstream profile B) where we did the measurements and monitoring are marked in orange on the map in figure 3.2.

Table 3.3 shows the length of the transversal profile of the riverbed in the (upstream profile A) area resulting from the measurements in the field and its evolution following the maximum flows during the floods recorded on the Milcov river during 2016-2017.

Table no.3.3. The evolution of the transverse profile of the (upstream A) riverbed resulting from classical measurements

Year	Q flood (mc/s)	Transverse profile width (m)	Eroded shore width (m)	Elevation (m) and thalweg position (right/left)
Originally	-	165	0	2,88/right
2016	78	175	10	3,13/left
2017	13	257	82	3,33/left
Total		*257*	*92*	*3,33/left*

Note: The data in Table 3.3 are interpreted as follows:

- At the beginning of 2016, the transversal profile of the riverbed in the (upstream profile A) area had a width of 165 m, the positioning of the thalweg was onto the left bank and the height of the slope was 2.88 m.
- Following the flood recorded on the Milcov River in 2016 with Q=78 m^3/s, the transversal profile of the riverbed in the (upstream profile A) area had a width of 175 m. That indicates a left bank erosion on a width of 10 m and a configuration change of the thalweg positioned to the left bank. The erosion acted on the width of the shore and the riverbed, with continuous evolution towards the base of the left bank, and the height of the slope being 3,13 m.
- The same year 2017.

Following the floods recorded in 2016-2017 on the Milcov river, the left bank in the upstream area was eroded over a width of 92 m.

Following the measurements and the overlapping of the elevations, an eroded surface of 8,260 m^2 and an eroded volume of 24,780 m^3 result in the period 2016-2017 in the (upstream profile A) area.

Figure 3.3 shows the evolution of the transversal profile in the (upstream A) area in the period 2016-2017.

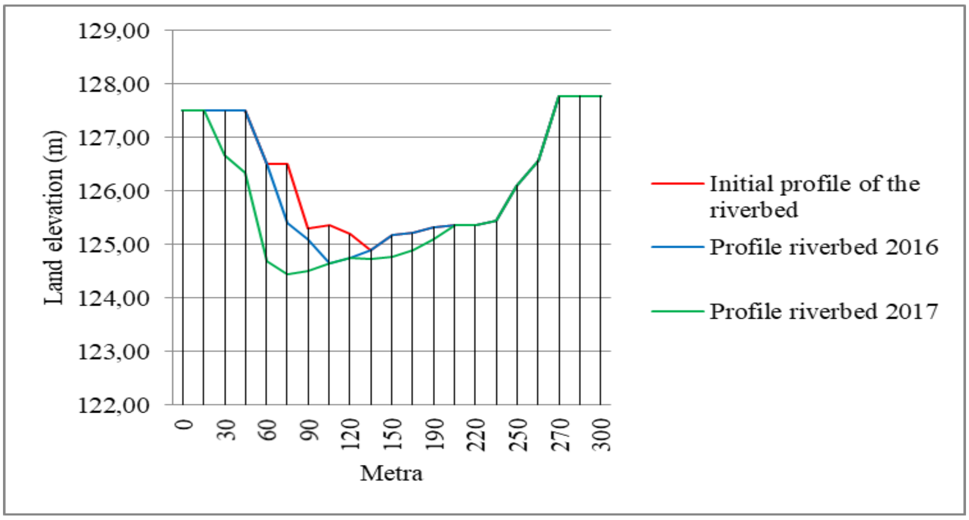

Fig.3.3. The evolution of the transversal profile in the (upstream A) area in the period 2016-2017

Table 3.4 shows the length of the transversal profile of the riverbed in the (downstream profile B) area resulting from the field measurements and its evolution following the maximum flows during the floods recorded on the Milcov River during 2016-2017.

Table no.3.4. The evolution of the transversal profile of the (downstream B) riverbed resulting from classical measurements

Year	Q flood (mc/s)	Transverse profile length (m)	Eroded shore width (m)	Elevation (m) and thalweg position (right/left)
Originally	-	160	0	2,25/right
2016	140	173	13	2,37/left
2017	13	181	8	2,45/left
Total		*181*	*181*	*21*

Note: The data in Table 3.4 are interpreted as follows:

- At the beginning of 2016, the transversal profile of the riverbed in the (downstream profile B) area had a width of 160 m, the positioning of the thalweg was onto the left bank, and the height of the slope being 2.25 m.
- Following the flood recorded on the Milcov River in 2016 with Q=78 m^3/s, the transversal profile of the riverbed in the (downstream profile B) area had a width of 173 m. That indicates a left bank erosion on a width of 13 m and a configuration change of the thalweg positioned to the left bank. The erosion acted on the width of the shore and the riverbed, with continuous evolution towards the base of the right bank, and the height of the slope being 2,37 m.

Following the floods recorded in the period 2016-2017 on the Milcov river, the left bank in the (downstream profile B) area eroded on a width of 21 m.

Following the measurements and the overlapping of the elevations, an eroded surface of 1,230 m^2 and an eroded volume of 2,706 m^3 result in the period 2016-2017 in the (downstream profile B) area.

Figure 3.4 shows the evolution of the transversal profile in the (downstream B) area in the period 2016-2017.

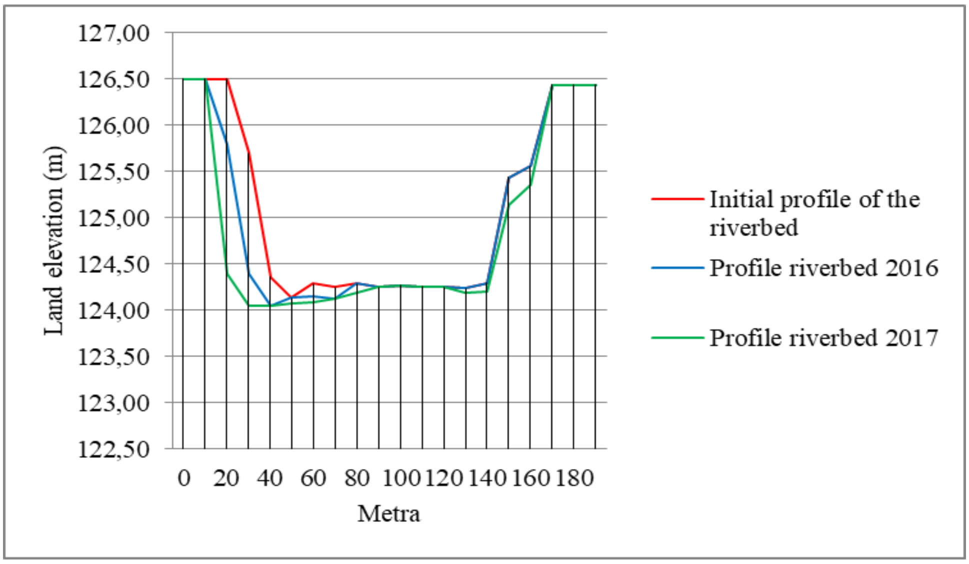

Fig.3.4. The evolution of the transversal profile in the (downstream B) area in the period 2016-2017

The overlapping of the transverse profiles results in differences in the elevations values, the thalweg, and the banks, which indicates that the erosion of the left bank of the Milcov river occurred under different intensities during floods with significant flows.

The overlapping of the profiles results in a total eroded land surface in both monitored points of 9,490 m^2, with a volume of 27,486 m^3.

Hydrological data

Following the processes of clogging and erosion, in the area of Odobeşti locality, the phenomenon of accentuated erosion of the river banks occurred mainly during the floods, when the river had high energy. The riverbed was completely covered by water, and the currents acted on the banks, both in their length and in the concavity area. The major flows transited by the Milcov river were in March-April in 2016, a Q = 78 m^3/s, and in June 2017 a Q = 13 m^3/s.

Figure 3.5 shows the hydrograph of the flood recorded on the Milcov river between March and April in 2016, where the river had a Q = 78 m^3/s, the average flow of the river being between 1-2 m^3/s.

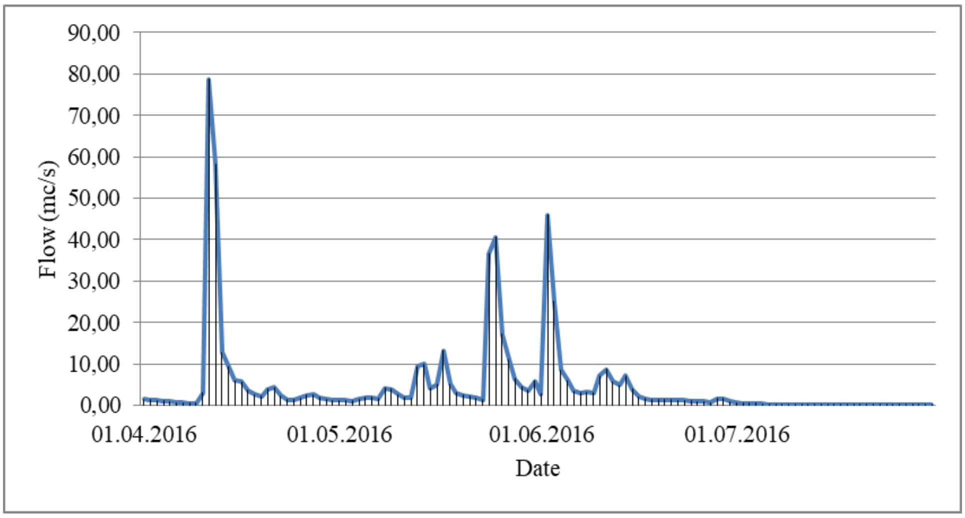

Fig.3.5. The flood hydrograph from 2016

Figure 3.6 shows the transport dependence of the solid flow (R) as a function of the liquid flow (Q). The representation highlights a power dependence between the solid flow (R) and the liquid flow (Q), the relation $R = 0{,}1534x^{2{,}2545Q}$, (R2 = 0.9858.)

During floods and in winter, the solid flow increases with the liquid flow, which proves that most of the alluvium comes from bank erosion and other source areas such as landslides.

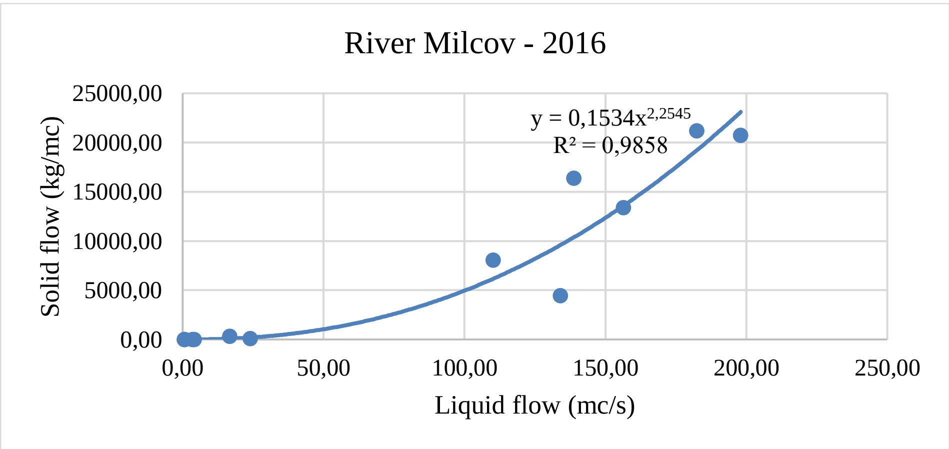

Fig.3.6. Dependence of solid flow transport on liquid flow in 2016

CHAPTER 4
STUDY OF ALLUVIAN TRANSPORT AND EROSION FACTORS IN THE SIRET HYDROGRAPHIC BASIN MIDDLE AND LOWER COURSE

4.1. Analysis of the evolution of alluvium transport on the Milcov rivers

4.1.4. Characteristics of the Milcov River

The surface of the Milcov river basin is 444 km^2 with a length of 79 km, and the general flow direction is NW-SE. Milcov springs from Monteoru mountain, from an altitude of 1040 m and flows into the Putna river, at Răstoaca, at an altitude of 23 m.

The upper course crosses a narrow valley to Mera, the middle course (transit area) starts from Broşteni, to Câmpineanca, the valley changes its appearance becoming wide and spreading the eroded material on both banks, and the lower course starts from the area of Goleşti locality, up to the area of Răstoca locality, at the mouth of the river Putna, the riverbed narrows and becomes meandering (figure 4.1).

On the Broşteni-Odobesti-Golesti sector, the Milcovul river receives several tributaries on the right side: Badei Valley, Mera, Dilgovul, Seacă Valley, Dalhauti, which have a torrential and non-permanent flow regime.

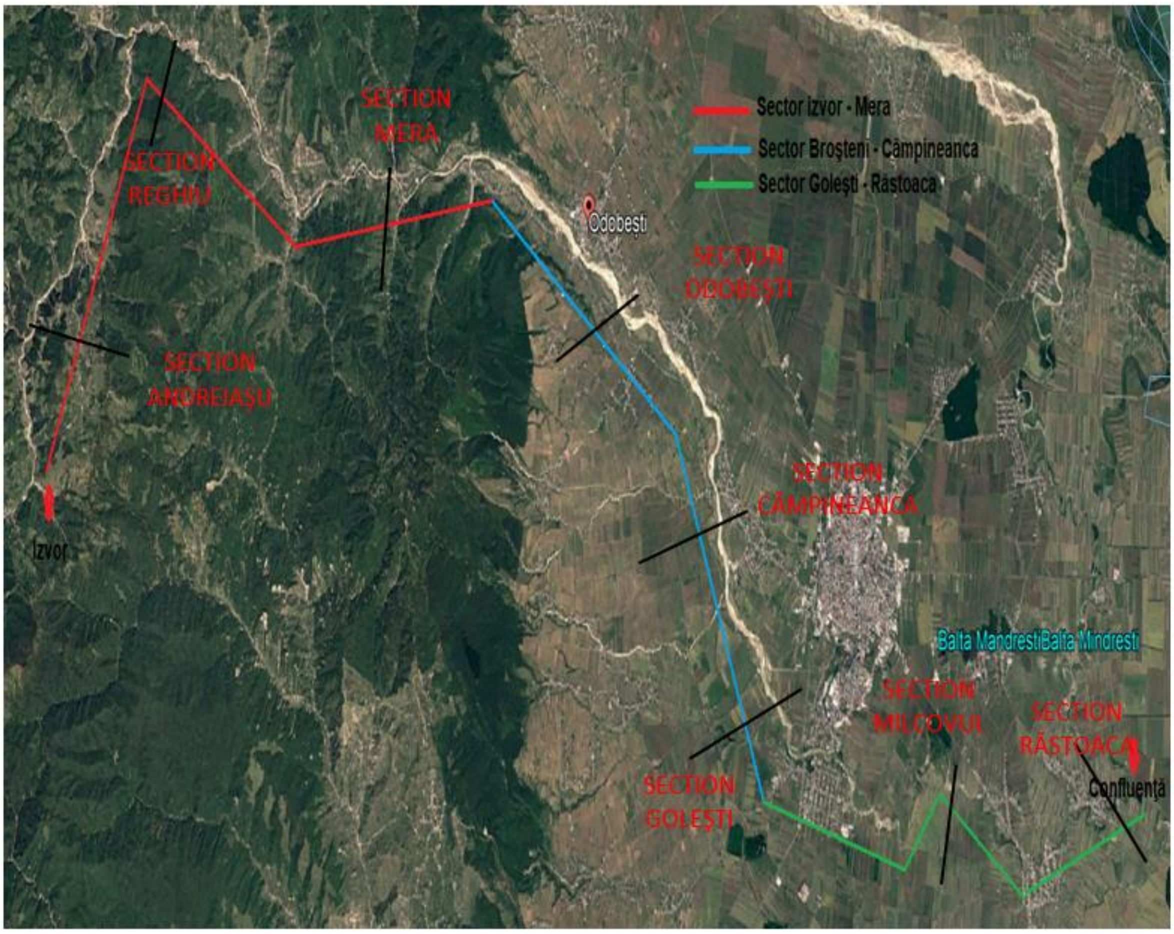

Fig.4.1. Milcov river map and sectors analyzed

From a geomorphological point of view, the studied area is located in the N-E extremity of the Romanian Plain. It has the character of a great depression, underlined by the sinking of the surrounding units under Quaternary Pliocene cover, on contact lines that play an important role in the genesis and morphodynamics of the relief.

Due to the fragility of the rocks in its receiving basin, the massive deforestation, the presence of numerous ravines, the steep slopes and the torrential floods of the valleys that reach its bed, the eroded material transported by Milcov is very large.

Longitudinal profile

The shape of the real longitudinal profile of the Milcov river is a rupture profile, the first most important rupture is visible upstream in the spring area where the river has a well-defined major riverbed. In this area there is a change of slope between the upper part of the river and the rest of the profile.

There is a slight deformation of the profile with the penetration into the Milcov riverbed of some more important tributaries (Valea Badei, Mera, Dilgovul, Valea Seacă). In this area, the upward trend of the riverbed is confirmed. In this area, the movement of sediments plays a special role in the evolution of the riverbed (figure 4.2).

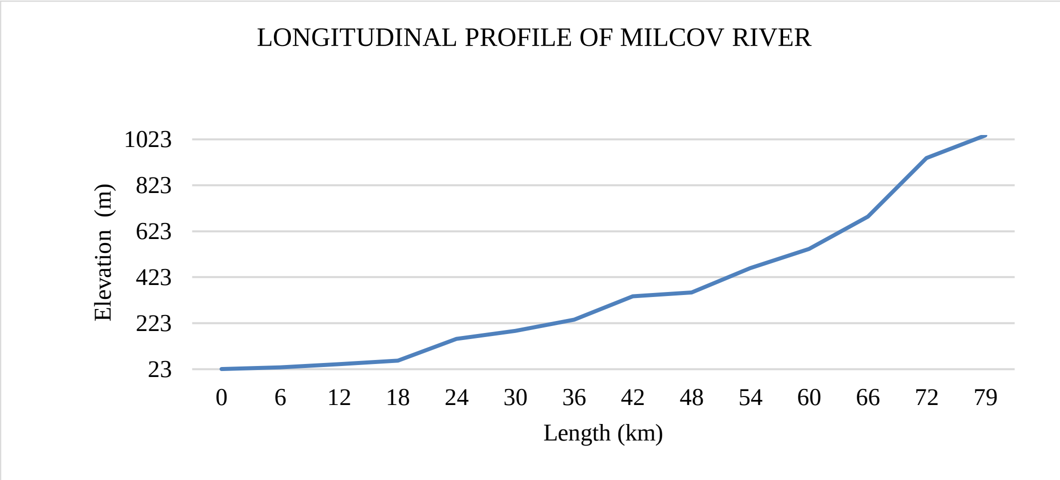

Fig.4.2. Longitudinal profile of the Milcov River from the source to the source

In conclusion, the longitudinal profile of the Milcov River is sensitive to the rate of transfer of alluvium from the slope to the riverbed, being slightly deformed by gratification in the transit area, the river not having sufficient competence to remove the material brought by tributaries and degradation to the source.

The shape of the cross section

Following the measurements, the cross section of the minor riverbed of the Milcov River has a relatively stable shape which can be identified by a "shape coefficient", determined between the surface of the riverbed section and the surface of a geometric shape (parabola, rectangle, trapezoid). enter that section. The Milcov riverbed has the shape of a cross section, generally trapezoidal and is a feature of riverbeds deep in cohesive clay-dusty materials.

Figure 4.3 shows the shape of the cross section of the Milcov River in different areas from downstream to upstream, resulting from topographic measurements.

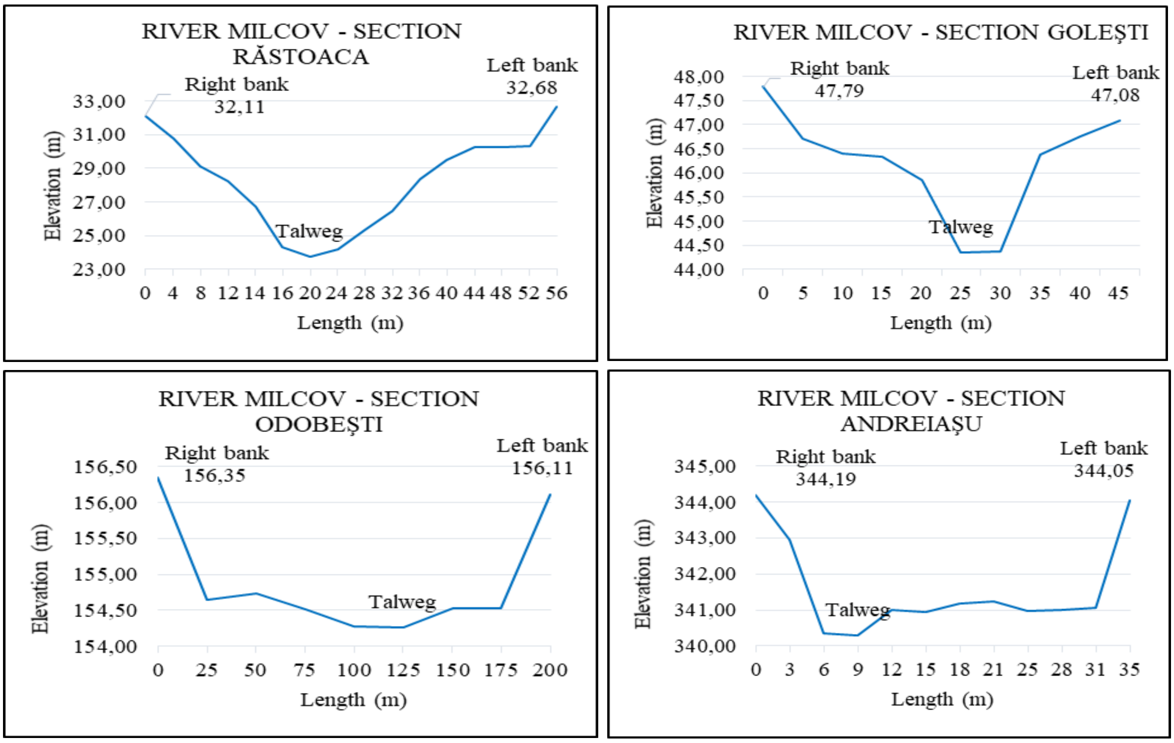

Fig.4.3. The shape of the cross section of the minor bed of the Milcov River in different areas

The shape coefficient, calculated as the relationship between the surface of the riverbed section and the surface of a trapezoid inscribed in the section, recorded values between 0.87 and 0.91, on the Milcov River.

The Milcov riverbed consists of deposits, made up of gravel and boulders in the upper part and relatively fine in the lower part, which reflects the type of solid flow transported by the river.

On many sectors of the river, especially on the middle course (in the transit part) and the lower part, the cross section changes annually, being favored by floods and anthropogenic intervention through the execution of works.

Figure 4.4 shows the evolution of the cross section of the Milcov riverbed in the transit area, which changes annually, especially during floods.

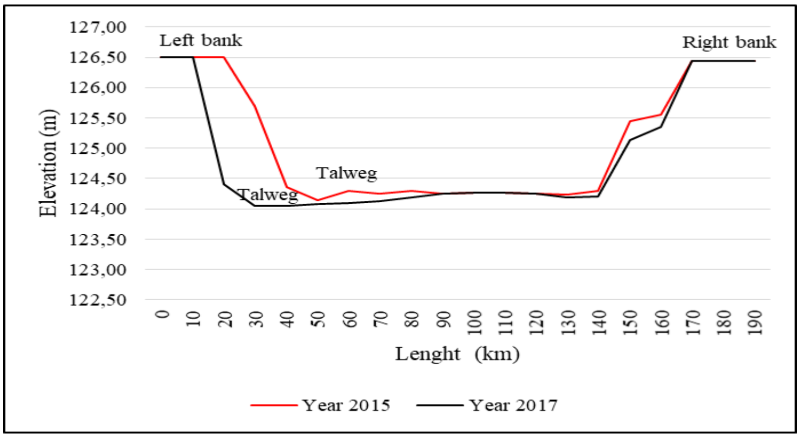

Fig.4.4 The evolution of the cross section of the Milcov riverbed in the area of Odobești locality

The Milcov riverbed has a cross section with varying degrees of asymmetry.
The measurements show the oscillating character of the riverbed, more and more accentuated as the slope decreases and the length of the river increases. The development of the asymmetry of the cross sections is favored especially by the floods with important flows and the transport of alluvium.

Trends in cross-section asymmetry are common to riverbed bed morphology.

Granularity of riverbed deposits

The minor riverbed of the Milcov river recorded similar granulometric characteristics between the riverbed and the two banks. The bed of the Milcov riverbed is generally made of gravel, their size increasing slightly from downstream to upstream.

If at the beginning the granulometric differentiation between the bed and the banks of the riverbed is almost not realized, in the transit area the riverbed and the banks are formed by mixtures of gravels and boulders with fine alluvium, and downstream the riverbed and banks are formed by fine alluvium.

Following the measurements for determining the granularity of the alluvium from the bed of the Milcov riverbed, in the sections Răstoaca, Milcovul, Goleşti, Câmpineanca, Odobeşti, Mera, Reghiu and Andreiaşu (spring-discharge) the percentage related to the diameter of the alluvium is with a diameter between 0.05 - 80 mm (figure 4.5).

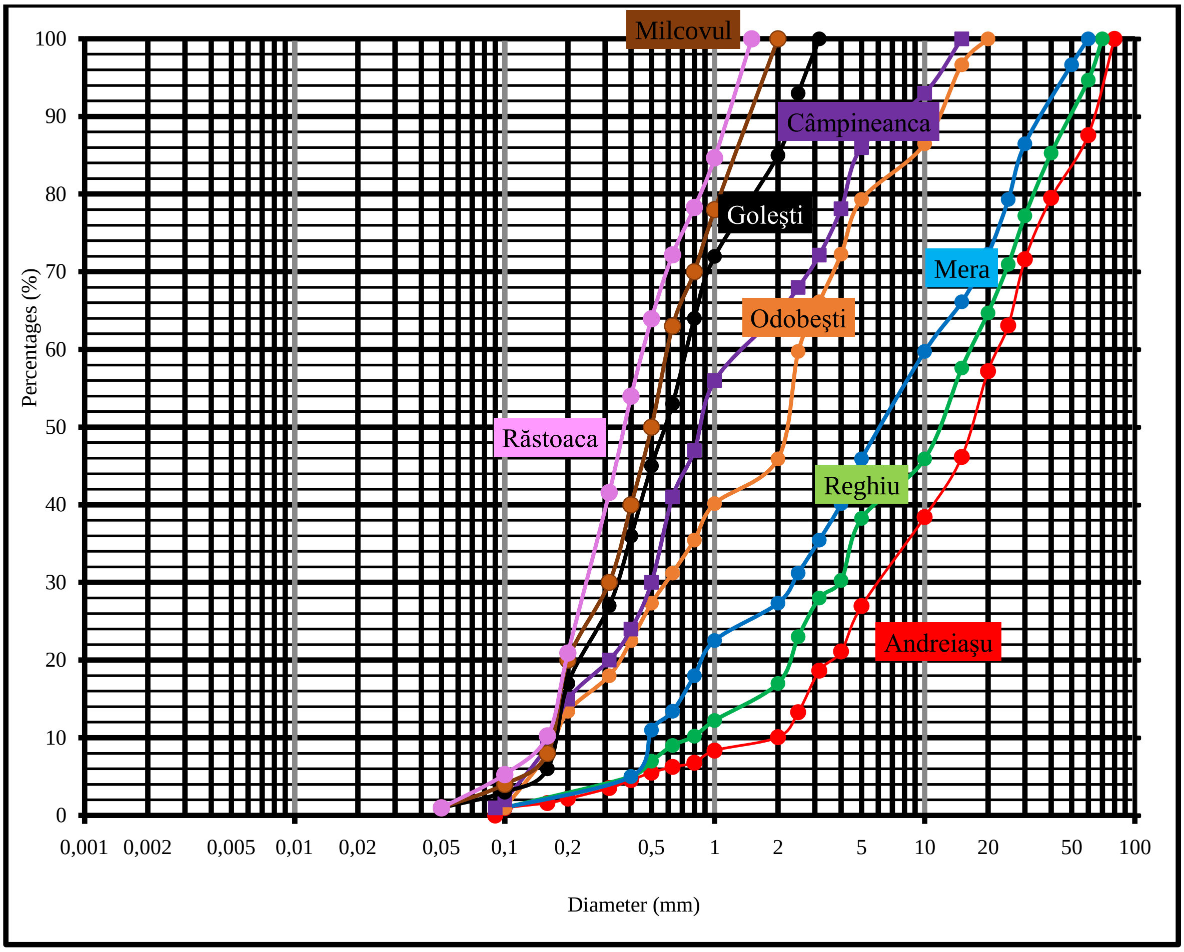

Fig.4.5. Granulometric curve of alluvium along the Milcov River (in measured profiles)

The general trend of the variation of the diameter of the alluvium in the bed of the riverbed is the same as for the longitudinal profile, where there is an increase in the size of the alluvium along the river downstream to the upstream.

Table no.4.1. Synthesis of the distribution of alluvium along the Milcov river

Section	km	d_{60}	d_{10}	$C = d_{60}/d_{10}$	d_{50}
Răstoaca	0	0,45	0,17	2,65	0,38
Milcovul	12	0,60	0,175	3,43	0,50
Golești	24	0,70	0,178	3,93	0,58
Câmpineanca	36	1,40	0,18	7,78	0,88
Odobești	48	2,50	0,18	13,89	2,20
Mera	60	10,0	0,50	20,0	6,0
Reghiu	72	17,0	0,80	21,25	12,0
Andreiașu	80	22,0	2,0	11	18,0

The distribution of alluvium along the riverbed resulting from the granulometric curves of the alluvium (table 4.1) in the monitored sections highlights the increase of the degree of non-uniformity (d_{60} / d_{10}) from downstream to upstream from 2.65-21.11.

The graphical representation of the distribution of the average diameter (d_{50}) along the riverbed highlights its increase from downstream to upstream (figure 4.6).

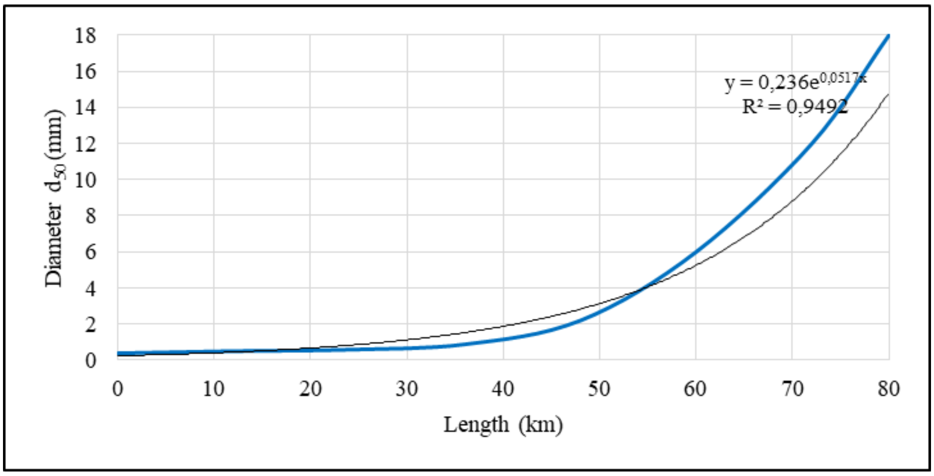

Figure 4.6. Distribution of the average diameter (d_{50}) along the riverbed

This distribution highlights an exponential dependence, the relationship obtained is $y = 0{,}2361e^{0{,}0299x}$, ($R^2$=0,9619).

Conclusions

In the spring area, the Milcov river has a narrow and relatively symmetrical riverbed.

In the discharge area, the Milcov riverbed becomes strongly meandering, and the banks are heavily covered with vegetation.

The shape of the cross-section of the Milcov riverbed is generally trapezoidal, but has different degrees of asymmetry from source to outflow.

In the middle course area, the Milcov riverbed changes its shape annually, especially during major floods.

In the middle course area, the banks of the Milcov river erode heavily, and the riverbed tends to widen annually.

4.2. Multicriteria analysis regarding the factors that favor the appearance of erosions in the Siret river basin, middle and lower course

4.2.1. Multicriteria evaluation methods

Multicriteria analysis is used to assess erosion factors in the Siret river basin based on well-established criteria. Multiple criteria can be considered simultaneously in the analysis.

4.2.2. Criteria for evaluating water erosion

Within the methods of ranking the erosion factors, the objectives pursued are specified and the attributes or indicators corresponding to each objective are identified, by applying the "Multicriteria Decision Matrix (MCDM)".

The stages of the matrix are:
1 - setting goals;
2 - identification of criteria;
3 - defining the criteria;
4 - ranking / weight;
5 - allocation of scores for each option;
6 - performing calculations.

1. Set goals

In order to perform a multicriteria analysis on the impact of water erosion in the Siret River Basin, middle and lower course were analyzed rivers: Siret River downstream of Movileni (Galati County) to Năneşti Vrancea County, Trotuş river Vrânceni, Bacău county until it flows into the Siret river, the Putna river, the Zăbala river, the Râmnicu Sărat river and Milcov.
The main objectives of the multicriteria analysis are:
- Identification of the main erosion factors;
- Analysis of erosion factors;
- Hierarchy of erosive factors;
- The influence of erosion factors on the behavior of the riverbed.

2. Identify the criteria

In order to perform a multicriteria analysis on the impact of water erosion in the Siret River Basin, middle and lower course, the following criteria were ranked:
A. The extent to which water erosion contributes to the increase in the volume of alluvium.
B. The extent to which water erosion affects the environment.
C. The extent to which water erosion contributes to the reduction of land areas.
D. The extent to which water erosion affects the inhabitants and objectives of the area.

3. Factors analyzed

- Natural factors: *Hydrological factors, Climatic factors, Geological factors.*
- Anthropogenic factors: *Land use, Works of art, Exploitation of mineral aggregates.*

4. Hierarchy/weights

Depending on the impact that the specific water erosion has on each river analyzed on the four analyzed criteria, a weight is given in the multicriteria evaluation thus.

A - 1;
B - 2;
C - 2;
D - 3.

5. Allocation of scores

The scores used are integers between 1 and 4:

1 - insignificant;
2 - reduced;
3 - moderate;
4 - extreme.

6. Perform calculations

Multiply by column, item by item, and add values. The amount is the value of that option. The maximum amount shows the most influential option.

$$\max\left(\sum_{opțiune} pondere_{criteriu} * punctaj\right) \qquad (4.1)$$

Result

Figure 4.7 shows the diagram with the values obtained by the influence of natural and anthropogenic erosion factors on the analyzed rivers in the Siret river basin, middle and lower course.

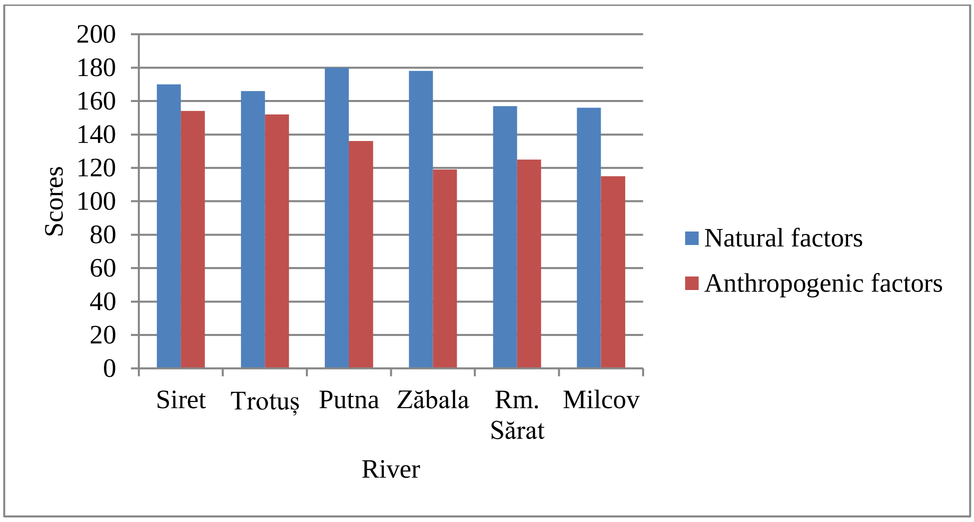

Fig.4.7. The influence of natural and anthropogenic erosion factors on the analyzed rivers

Following the results obtained, the Putna and Zăbala rivers are the most affected by erosion factors and especially the natural ones.

The Siret and Trotuş rivers have approximately equal values for both natural and anthropogenic factors, but the rivers have not been studied in full length.

Figure 4.8 shows the diagram with the influence of natural and main anthropogenic erosion factors on the analyzed rivers in the Siret river basin, middle and lower course.

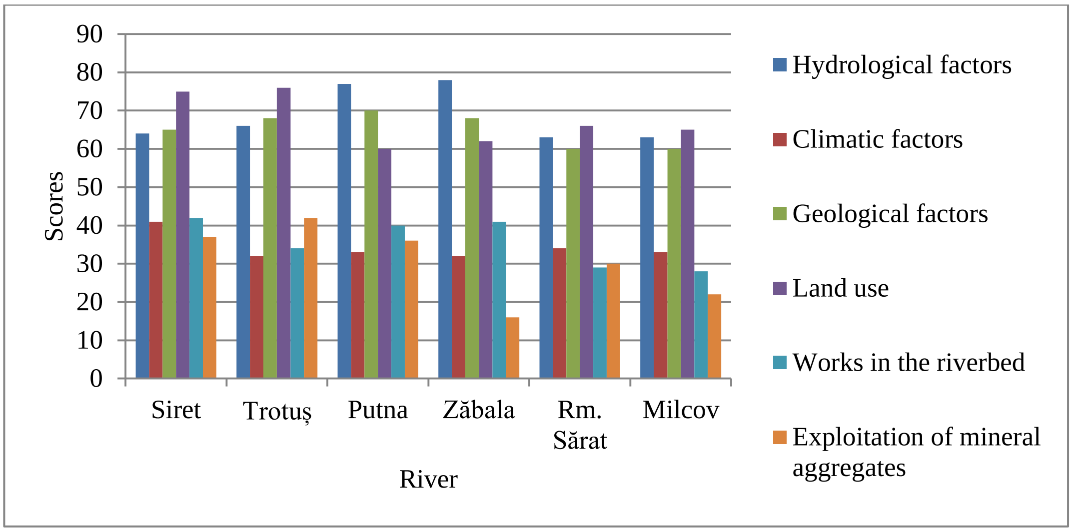

Fig.4.8. Diagram with the influence of natural erosion factors and main anthropogenic factors on the analyzed rivers in the Siret river basin middle and lower course

Following the results obtained, the main natural erosive factors are the hydrological and geological ones, and the anthropogenic ones are the land use and the works in the riverbed.

Climate factors have the least influence as natural factors and the exploitation of mineral aggregates as anthropogenic factors.

Figure 4.10 shows the diagram with the results obtained by the influence of erosion factors on the criteria analyzed on each river.

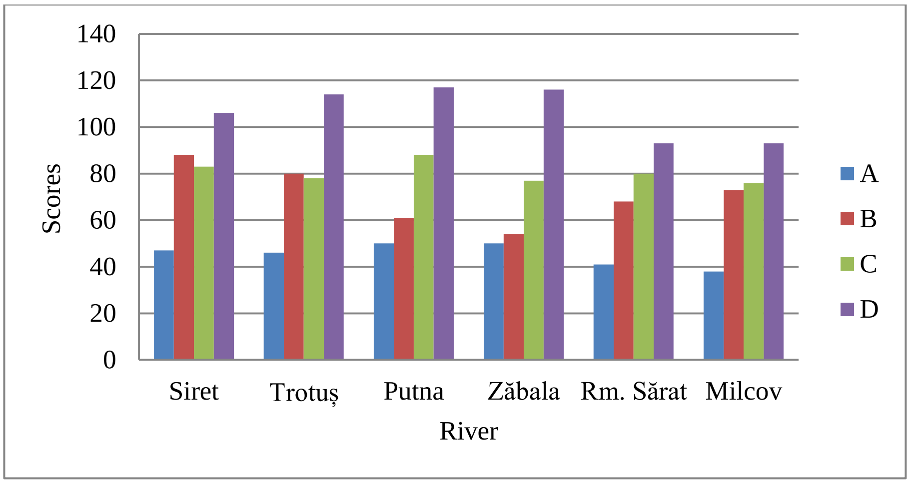

Fig.4.9. Diagram with the results obtained by the influence of erosion factors on the criteria analyzed on each river

Following the results obtained on all the analyzed rivers, criterion (D) is the most affected by the influence of erosion factors and criterion (A) is the least affected.

CHAPTER 6
ECOLOGICAL WORKS TO COMBAT SOIL EROSION IN RIVER BASINS

6.1. Ecological consolidation defense works from classical materials

The works with ecological roles have the central purpose of using material resources to ensure the favorable development and conservation of plants, animals, and fish in habitats.
The materials used to combat soil erosion that do not create environmental disturbances are: - wood, stone, and geosynthetic materials.

6.2. Defense works of geosynthetic materials

Geosynthetic products are being produced in a wide range of different shapes and materials.

The role of using geosynthetics: soil stabilization, roadbed reinforcement, strengthening embankments, building retaining walls, landslide protection.
The main product categories are geotextiles, geogrids, geoforms, geomembranes, geocells, geocomposites, geocontainers, anchoring nets [148].

6.3. Geotextile works to combat erosion

Concrete mattresses
Geo-tubes
Geotextile bags

6.3.1. Geocontainers

Geocontainers are generally made of geotextile materials of polypropylene or other polymers.

** Usages:*
- Protection of bridge infrastructures against local outflows, protection of floodplains, bottom sills, hydro-technical works, protection of banks, beaches.

** Advantages:*
Geocontainers offer easy adaptation to many applications in the field of hydro-technical works, bringing the following advantages:
- They replace the classic solutions of embankments or bottom thresholds and reduce the realization costs regarding the materials and labor involved;
- Reducing the execution times of works and simplifying operations;
- The solutions that use geocontainers have proven, in practice, to be ecological and environmentally friendly solutions;
- They have an optimal resistance/elongation ratio and effortlessly adapt to the irregularities of the support layer;
- Geocontainers made of non-woven geotextiles are well resistant to mechanical shocks, deforming and absorbing the impact force;

CHAPTER 7
COMPARATIVE ANALYSIS OF SOLUTIONS USED IN COMBATING EROSION

7.2. Forms of degradation of erosion control works - case study

7.2.1. Degradation of gabion works

Overturning gabion works

** Cause:*

- High flows of the watercourse that have exceeded the canopy of the work;
- Transport of coarse alluvium during floods that affected the mattress at the base of the work;
- Instability of the filling behind the work.

Sliding degradation

** Cause:*

- High flows of the watercourse that have exceeded the canopy of the work;
- Unstable terrain on which the work was based;
- Instability of the filling behind the work.

Degradare prin scăderea cotei talvegului

** Cause:*

- High level differences between source and discharge;
- Exploitation of mineral aggregates.

Degradation caused by incorrect execution

Improper execution and foundation of gabion works can cause damage and degradation of the work.

Degradation caused by the transport of alluvium and floats

During floods, the transport of coarse alluvium and floats or floaters is much higher than when river flows are low.

In areas with spontaneous forest vegetation in the minor riverbed or the area of the banks during floods, the banks are eroded, and the trees are displaced and then transported.

7.2.2. Degradation of works in geocontainers

Degradation of the geocontainer itself

Degradation of the geocontainer itself is generally caused by incomplete filling and the material with which it is filled.

Forms of damage to the geocontainer:

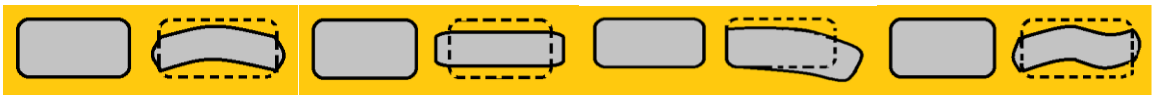

Fig.7.1. bending flattening leaning "caterpillar" effect

Degradation of works by lowering the elevation of the thalweg

A problem of the degradation of the hydro-technical works located on the undeveloped rivers is the riverbed evolution.

The most significant damages caused to the hydro-technical works are the decrease of the elbow of the thalweg, this damaging the works, or even they can be completely destroyed. The most common phenomenon of degradation by lowering the elevation of the thalweg is undermining.

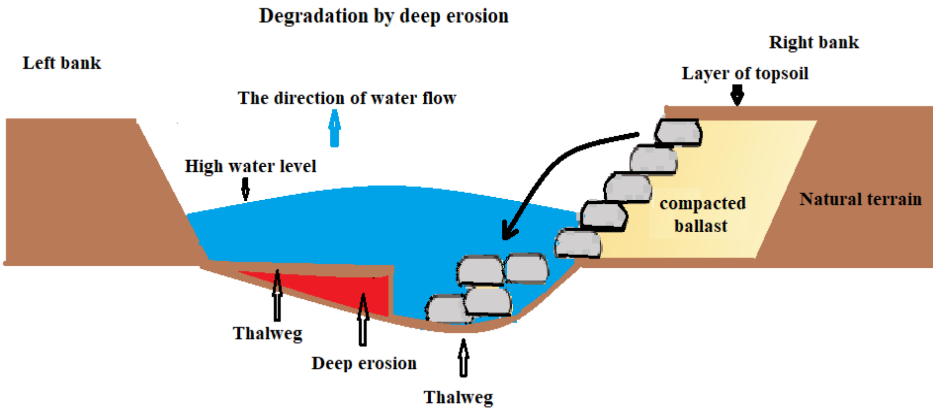

Fig.7.2. Degradation of geocontainer work by lowering the elevation of the thalweg

Geocontainers can be moved out of the work when the work is performed transversely in the form of a spike, the energy of the water hits it, and by lowering the elevation of the thalweg.

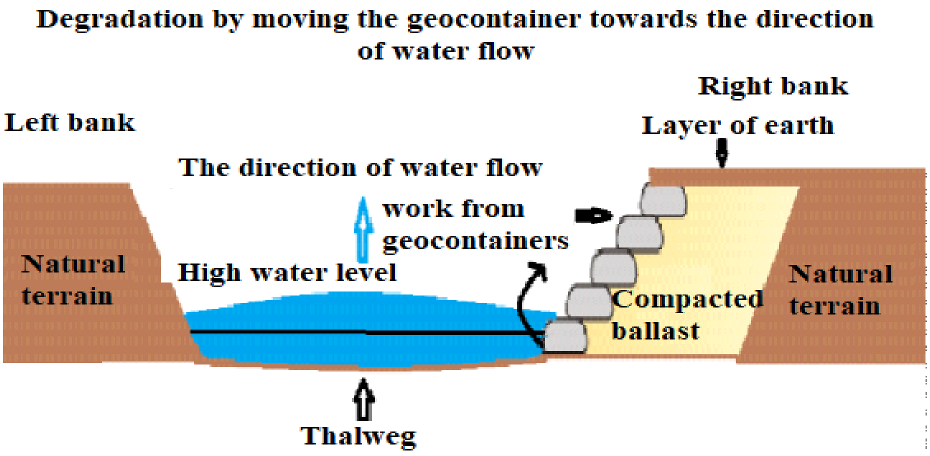

Fig.7.3. Degradarea lucrării de geocontainere prin deplasarea geocontainerului

Degradation through vandalism

Vandalism is an action that involves the intentional destruction or damage to property.
Geocontainer works can be vandalized through:
- Cutting the bags;
- Arson.

Fig.7.4. Degradarea prin vandalism, tăierea sacilor şi incendiere

Degradation by breaking seams

The thread used to sew geocontainers, if it is of lower quality, on contact with water rots, and the seam is destroyed.

By destroying the seam, the material in the geocontainer is washed and transported by water. The speed with which the sand is lost depends on the position of the seam and how the geocontainer is placed.

Degradation caused by sharp or angular objects

The sharp or angular objects during the loading of the geocontainer or its manipulation in the accomplishment of the work pierce the geotextile. In time, the material inside it is washed by water, and the "caterpillar" phenomenon can appear.

Degradation caused by float transport

Following the field verifications in the areas with studied geocontainer works, the degradation phenomenon caused by floats is identified in the case of transversal works (spikes).

7.3. Analysis and behavior of the geotextile from which the geocontainers are made

To compare the behavior of the evolution in time of the geotextile used in the manufacture of geocontainers, the measurement of different geotextile samples was performed.

The first measurement was made on a geotextile sample not used in the works, with a thickness between 0.5 and 0.6 cm.

Due to the climatic conditions in Romania and the transport of alluvium and floats, the geotextile is affected to a greater or lesser extent by these factors.

The geotextile sample used in a geocontainer work on the Siret River was analyzed in order to see the evolution of the geotextile. This geocontainer is located at the top of the work and has been in contact with U.V. rays and the alluvium transported by the Siret River.

Figure 7.5 shows that the geotextile after a lifetime of about 8-10 years, under climatic conditions and sediment transport, is affected, and its thickness has decreased to about 0.3

cm. It is vulnerable or even destroyed by, where the phenomenon of degradation or damage to the work in geocontainers also appears.

Fig.7.5. Geotextile degraded by U.V. and alluvium transport

Another analysis and measurement were performed on a geotextile sample degraded by floats transported by the river during floods.

Floaters transported by the river affect the work in geocontainers by breaking the geocontainers or reducing the density of the geotextile where the phenomenon of migration or washing off sand from the geocontainers can occur, which can lead to damage to the work in the geocontainers.

Figure 7.6 shows that the geotextile loses its density, is fluffy, and increases its thickness from 0.5-0.6 cm to 0.7-0.8 cm, which leads to the weakening of the fabric and helps to wash sand.

Fig.7.6. Geotextil afectat de plutitori

CHAPTER 9
THE EVOLUTION OF ECOLOGICAL WORKS TO COMBAT WATER EROSION

9.1. Methods approached in the analysis and modeling of the work behavior

The methods used to model eroded areas are a combination of modern methods based on spatial analysis with aerial photographic interpretation using satellite imagery and remote sensing on the map generated by Google Earth software and traditional methods based on field measurements made using the device Hi-Target GPS and Leica Total Station [167].

9.2. Evolution and analysis of works in geocontainers

9.2.3. Milcov river bank consolidation, Odobeşti locality, Vrancea county

Analysis and evolution of erosion by the spatial method

Figure 9.1 shows the evolution of the work in geocontainers and its effect on the banks and the profile of the Milcov riverbed, in the period 2018-2019, in the area of Odobești.

In order to follow the behavior of the Milcov riverbed, we marked with reference points the monitored area to represent the eroded surface and length of the right bank for each year. The map used for representation was generated by Google Earth.

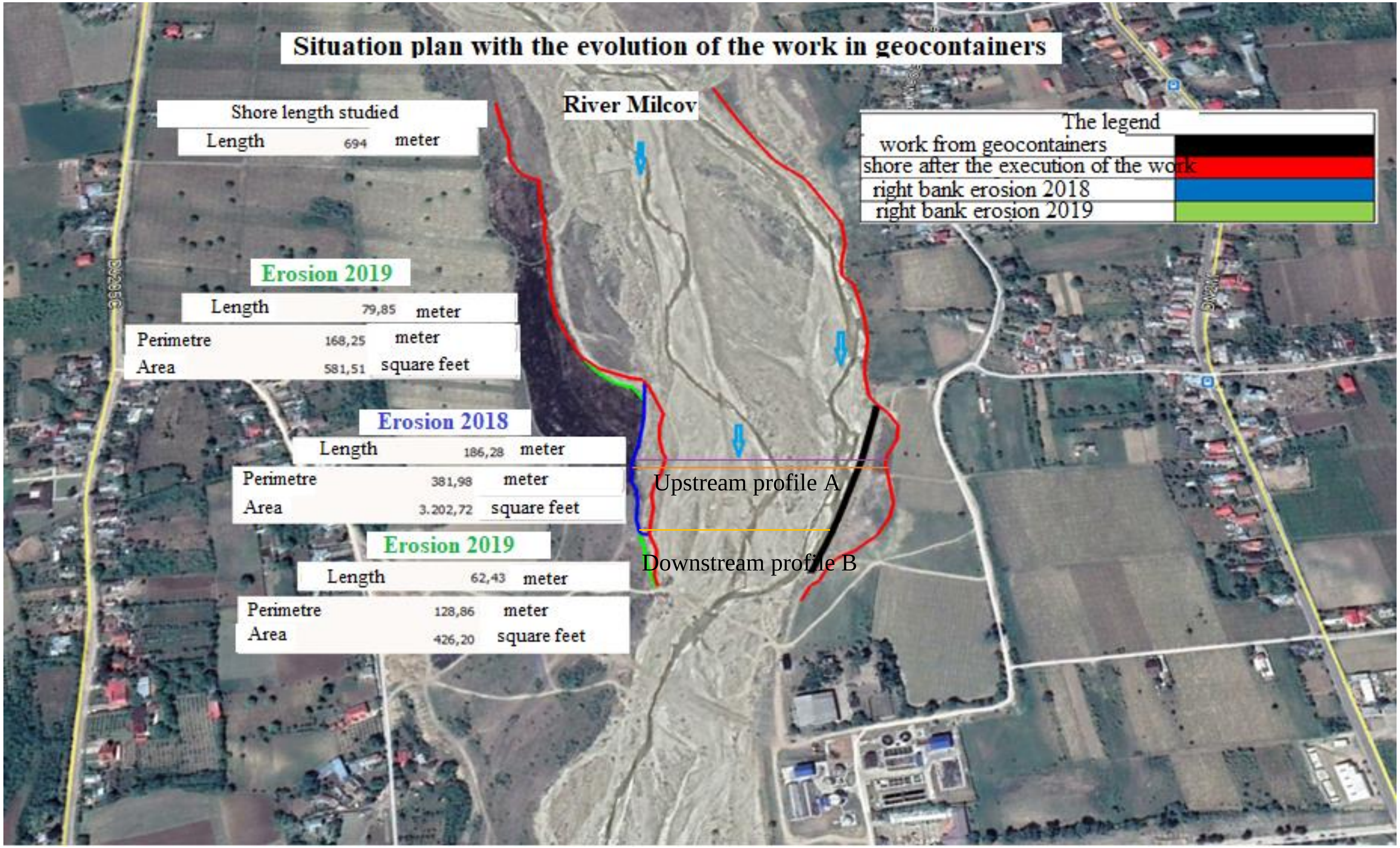

Fig.9.1. Spatial evolution of geocontainer work between 2018 and 2019 (Google Earth map)

Table 9.1 shows the maximum floods during the floods recorded on the Milcov River, in the period 2018-2019, and the eroded land areas on the right bank following the floods.

Table no.9.1. Maximum flow rates during floods and eroded areas

The year	Q flood (mc/s)	Eroded surface (mp)	Length shore eroded (m)
2018	22	3.202	382
2019	13	1.008	142
Total		*4.210*	*524*

For the spatial follow-up of the erosion evolution, we marked the right bank in 2018 with reference points.

Table 9.2 shows the width of the transversal profile of the riverbed and its evolution following the execution of the work on the left bank and the floods recorded on the Milcov River, in the period 2018-2019.
The monitored area is represented in purple on the map shown in figure 9.1.

Table no.9.2. The evolution of the transversal profile of the riverbed

The year	Q flood (mc/s)	Windth bad riverbed (m)	Width shore eroded (m)
2018	22	208	5
2019	13	213	0
Total		*213*	*5*

Analysis and evolution of erosion by the analytical calculation method

At the beginning of 2018, we made 2 transversal profiles in the field (upstream profile A and downstream profile B) the values being determined for each profile, these values were taken as reference points for following the evolution of the work in geocontainers located on the left bank and right bank behavior.

Figures 9.2, 9.3, 9.4 and 9.5 show the evolution of the transversal profile (upstream profile A and downstream profile B) of the Milcov riverbed, in the area of Milcov locality, by overlapping the topographic points resulting from field measurements using GPS Hi- Target, in the period 2018-2019.

Table 9.3 shows the width of the transversal profile of the riverbed in the (upstream profile A) area resulting from the measurements in the field and its evolution due to the worksite and the floods registered on the Milcov river in the period 2018-2019.

Table no.9.3. The evolution of the transverse profile of the (upstream A) riverbed resulting from classical measurements

Year	Q flood (mc/s)	Transverse profile width (m)	Eroded shore width (m)	Elevation (m) and thalweg position (right/left)
Originally	-	206	0	3,68/left
2018	22	211	5	3,93/right
2019	43	215	4	3,93/right
Total		*215*	*9*	*3,93/right*

Note: The data in Table 9.3 are interpreted as follows:

- At the beginning of 2018, the transversal profile of the riverbed in the (upstream profile A) area had a width of 206 m, the positioning of the thalweg was onto the left bank and the height of the slope was 3,68 m.
- After protecting the left bank with geocontainer works, following the flood recorded on the Milcov River in 2018 with Q=22 m^3/s, the transversal profile of the riverbed in the (upstream profile A) area had a width of 211 m. That indicates erosion to the right bank on a width of 5 m and a configuration change of the thalweg positioned to the right bank. The erosion acted on the width of the shore and the riverbed with continuous evolution towards the right bank, the height of the slope being 3,93 m.
- Same year 2019.

Following the floods recorded in 2018-2019 on the Milcov river, the right bank in the (upstream profile A) area was eroded over a width of 9 m.

Following the measurements and the overlapping of the elevations, an eroded surface of 1,517 m^2 and an eroded volume of 4,551 m^3 result in the period 2018-2019 in the (upstream profile A) area.

Figures 9.2 and 9.3 show the evolution of the transversal profile of the riverbed after the execution of the work in the (upstream A) area in the period 2018-2019.

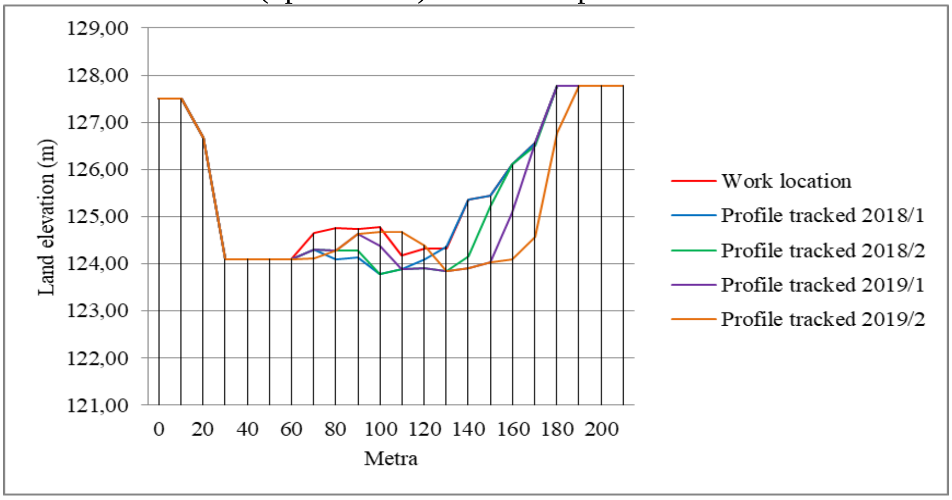

Fig.9.2. The evolution of the transversal profile in the period 2018-2019 (upstream A) area

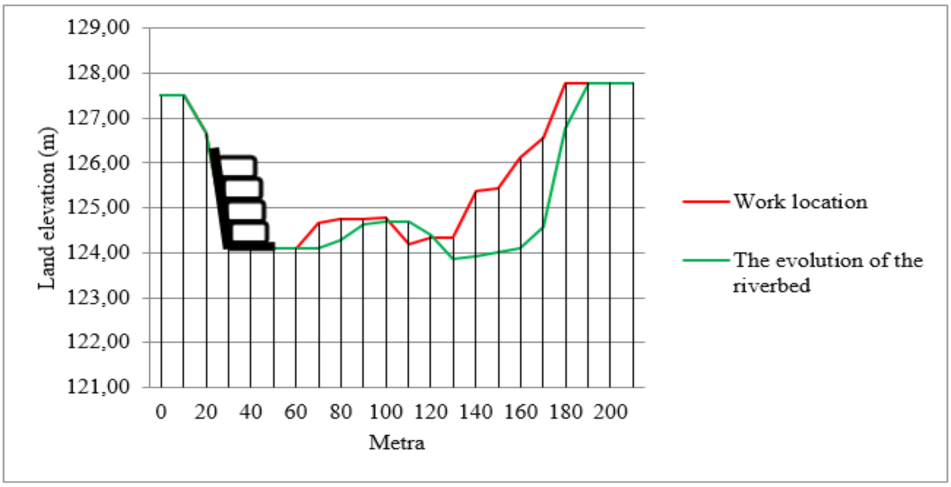

Fig.9.3. The worksite and the clogging evolution, (upstream A) area

Table 9.4 shows the width of the transversal profile of the riverbed in the (downstream profile B) area resulting from the field measurements and its evolution due to the worksite and the floods registered on the Milcov river in the period 2018-2019.

Table no.9.4. The evolution of the transverse profile of the (downstream B) riverbed resulting from classical measurements

Year	Q flood (mc/s)	Transverse profile length (m)	Eroded shore width (m)	Elevation (m) and thalweg position (right/left)
Originally	-	152	0	2,45/left
2018	22	163	11	2,63/right
2019	43	176	13	2,63/right
Total		*176*	*24*	*2,63/right*

Note: The data in Table 9.4 are interpreted as follows:

- At the beginning of 2018, the transversal profile of the riverbed in the (downstream profile B) area had a width of 152 m, the positioning of the thalweg was onto the left bank and the height of the slope was 2,45 m.
- After protecting the left bank with geocontainer works, following the flood recorded on the Milcov River in 2018 with Q=22 m^3/s, the transversal profile of the riverbed in the (downstream profile B) area had a width of 161 m. That indicates erosion to the right bank on a width of 11 m and a configuration change of the thalweg positioned to the right bank. The erosion acted on the width of the shore and the riverbed with continuous evolution towards the right bank, the height of the slope being 2,63 m.

Following the floods recorded in 2018-2019 on the Milcov river, the right bank in the (downstream profile B) area was eroded over a width of 24 m.

Following the measurements and the overlapping of the elevations, an eroded surface of 1.954 m^2 and an eroded volume of 5.446 m^3 result in the period 2018-2019 in the (downstream profile B) area.

Figures 9.4 and 9.5 show the evolution of the transversal profile of the riverbed after the execution of the work in the (downstream B) area in the period 2018-2019.

Fig.9.4. The evolution of the transversal profile in the period 2018-2019, (downstream B) area

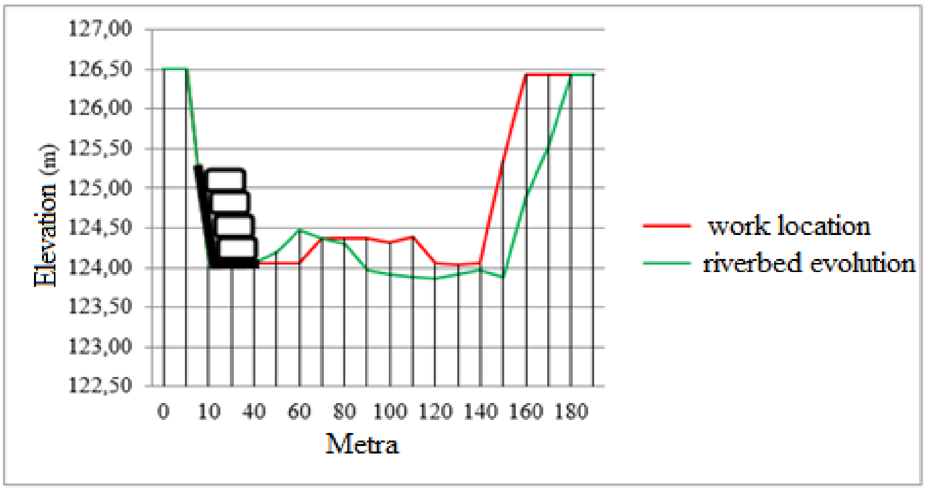

Fig.9.5. The worksite and the clogging evolution, the (downstream B) area

By interpreting the data from the topographic measurements, we can see how the morphology of the Milcov riverbed profile changes by clogging the left bank area where the work is located and by erosion of the opposite bank favored by the worksite, but also by the floods recorded on the Milcov river.

The overlapping of the profiles results in a total eroded land surface in both monitored points of 3.462 m^2 , with a volume of 9.997 m^3.

The alluvium deposits formed in the work area - but also downstream and upstream of it - were favored by the floods registered on the Milcov river, by the position and capacity of the work. The solid material is deployed to work. It comes from shore erosion, but most of it comes from the frequent landslides upstream. They are transported by floods over distances of about 5-10 km. The bulkiest amounts of alluvium are deposited mainly in the upstream part of the work, where the riverbed is wider, the opposite bank is concave, and functions as a natural groin.

In the downstream area, the alluvium is scarcer because the riverbed is narrower.

The difference between the thalweg elevation level and the level of deposits is between 0.60-1.20 m.

In the work area, the formed alluvial island has a total area of 46,370 m^2, with a volume of 37,096 m^3.

Hydrological data

Following the processes of clogging and erosion, in the area of Odobeşti locality, the phenomenon of accentuated erosion of the right bank of the Milcov river occurred, especially during the floods, when the river had high energy, the riverbed was entirely covered by water, and the currents acted on the shore. The main flows transited by the Milcov river were in the period June-July in 2018, a Q = 22 m^3/s, and in the period April-May 2019, a Q = 13 m^3/s.

Figure 9.6 shows the hydrograph of the flood registered on the Milcov river during June-July in 2018, a Q = 22 m^3/s, the average flow of the river being between 1-2 m^3/s.

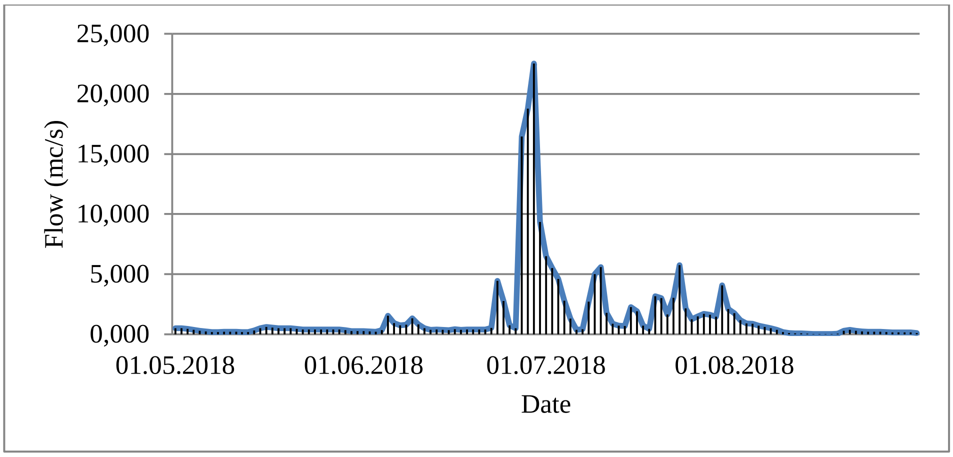

Fig.9.6. The flood hydrograph from 2018

Figure 9.7 shows the transport dependence of the solid flow (R) as a function of the liquid flow (Q). The representation highlights a power dependence between the solid flow (R) and the liquid flow (Q), the relation obtained R = 0,3454x^{2,1452Q}, (R^2 = 0.9725).

During floods and in winter, the solid flow increases with the liquid flow, which proves that most of the alluvium comes from bank erosion and other source areas such as landslides.

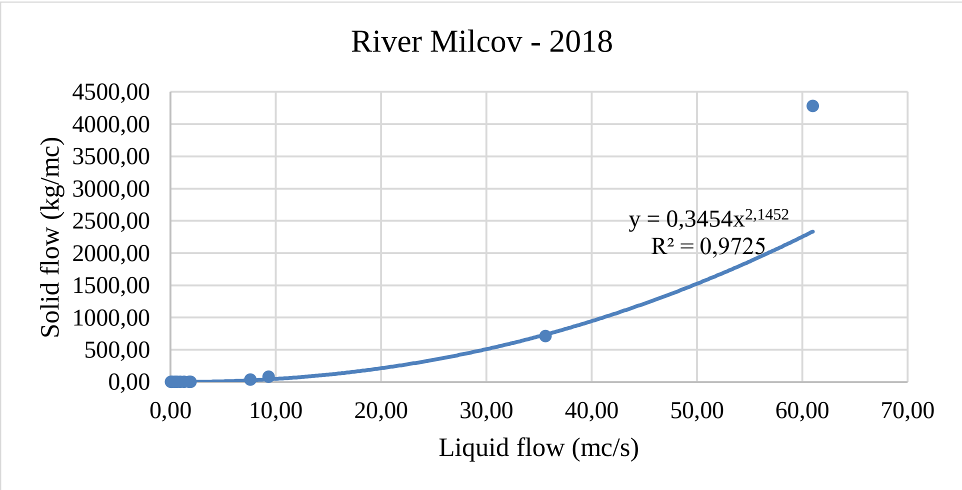

Fig.9.7. Dependence of solid flow transport on liquid flow in 2018

Figure 9.8 shows the evolution of the work and the clogged area.

Fig.9.8. The evolution of alluvium deposits in the work area

9.3. Evolution and analysis of works in geocontainers on the environment

To follow the process of habitat restoration and the development of the vegetal and animal population and to monitor the behavior of the works from geocontainers on the habitats from the riverbed, the *indirect* and *direct* methods were used.

For the *indirect* monitoring of the behavior of geocontainer works, the *ecological method* was used, by performing biological measurements on tree mass, growth rates, annual growth of planted seedlings, and observations on the presence of sensitive species that react quickly to increasing pollutants such as St. John's wort or nettle.

To follow the development of the planted *aspen* seedlings and to make observations of their behavior, the diameter of the tree was measured with the help of the forest block (calipers).

Following in situ measurements, the development of poplar seedlings was about 2.5 cm in ϕ each year and about 1 m in height.

The results of the measurements are presented in figure 9.9.

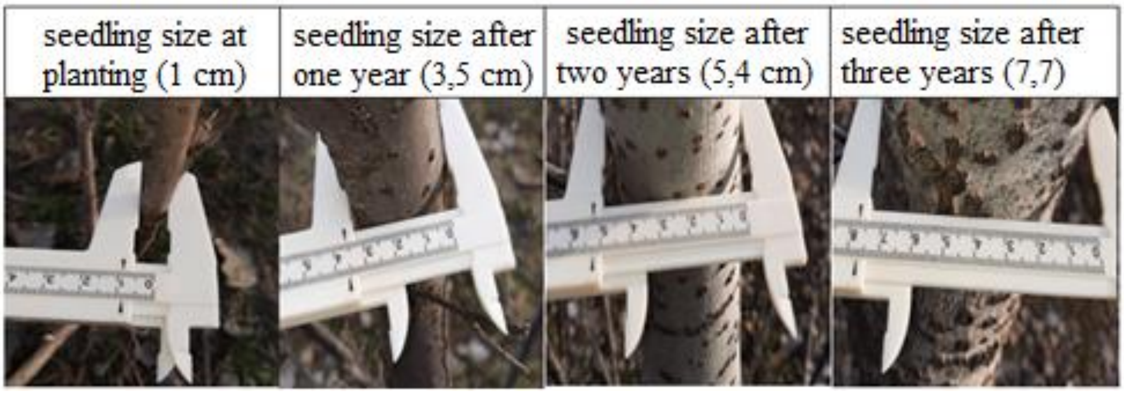

Fig.9.9. Annual development of poplar seedlings

In addition to the aspen seedlings planted, new poplar seedlings from other species also appeared and developed spontaneously.

Fig.9.10. Development of spontaneous plants and shrubs in the areas with geocontainer works

Following the observations made in the field, the presence of sensitive species, naturally occurring such as St. John's wort and nettle, was found on the geocontainer works (figure 9.11).

Fig.9.11. The appearance of sensitive species on geocontainer works

In addition to these sensitive species, other sorts of native, perennial plants are present and have a rapid development and multiplication.

For *direct* monitoring, which uses satellite images, Google Earth Pro software was used, which generates an aerial photo and allows a phenomenon to be tracked over time.

The monitoring was carried out during 2017-2020, wherein in 2017, at the end of the execution of the works, there was no grassy or forest vegetation in the monitoring area. In 2018, the grassy vegetation appeared spontaneously behind the site of the work. In the period 2019-2020, in addition to the grassy vegetation, spontaneous species of poplar and alder have appeared, which develop on the work of geocontainers and the alluvium deposits between the spikes.

Figure 9.12 shows the evolution of vegetation development on geocontainer works in the period 2017-2020.

Fig.9.12. Vegetation development on geocontainer works

CHAPTER 10
CONCLUSIONS, CONTRIBUTIONS AND RESEARCH PERSPECTIVES

10.1. Conclusions

The doctoral thesis analyzes the processes of water erosion in riverbeds, as a case study of the river basin of the Siret river, middle and lower course with its tributaries. In this context, the factors that produce this phenomenon are evaluated and it proposes solutions to combat erosion by implementing specific hydrotechnical works. Ecological solutions for erosion protection are proposed using geocontainer works as they integrate harmoniously into the natural environment. A special requirement for the use of ecological works from geocontainers resulted from the fact that part of the studied area belongs to protected natural areas.

Chapter 1. In the development of the thesis we started the general analysis of soil erosion, focusing on erosion in river basins and especially in riverbeds.

The extensive documentation shows that this phenomenon has a wide spread over the entire surface of the planet, generating significant negative effects on ecosystems, human settlements, respectively on works of art located in riverbeds. The need to study, understand and model this phenomenon led to the development of a comprehensive theory on the interdependence of factors that contribute to the development of water erosion, resulting in calculation relationships and concepts used for design, sizing, implementation of measures to minimize this phenomenon.

Chapter 3 is devoted to an extensive case study on the identification of eroded areas in the Siret river basin using classical and innovative methods. Monitoring of erosion areas by classical methods was performed by field measurements using GPS Hi-Target and the total Leica station, at different time periods, especially following floods on the watercourse, and the interpretation of data obtained after performing its measurements. performed by analytical calculations using the AutoCAD and ProgeCAD programs on maps georeferenced in the ArcGIS program.

Google Earth software was used to spatially track eroded areas.

On the Milcov river in Odobești locality following the floods of 2015-2017, the erosion processes manifested themselves at the base of both banks and especially at the base of the left bank, where it endangers the Odobești treatment plant and the agricultural lands in the area.

For the spatial follow-up of the erosion evolution, we marked the right bank in 2015 with reference points, where there is an widening of the riverbed by 8 m, in 2016 and an enlargement of the riverbed by 83 m, in 2017.

In order to follow the evolution of erosion by classical methods, at the beginning of 2016, 2 transversal profiles were made in the field (upstream profile A and downstream profile B, fig.3.3 and 3.4) the values of the land elevation being determined for each profile.

At the beginning of 2016, the cross-sectional profile of the riverbed in the monitored area (upstream profile A) was 165 m wide. width of 92 m, resulting in a width of the riverbed of 257 m.

At the beginning of 2016, the cross-sectional profile of the riverbed in the monitored area (downstream profile B) was 160 meters wide. width of 21 m, resulting in a width of the riverbed of 181 m.

An important erosive factor is the accumulation of alluvium in the riverbed which is achieved by erosion produced by the river or by lateral input. Reducing water velocity due to lower slopes or obstacles decreases transport capacity and thus begins the process of alluvial accumulation.

Within the riverbed, it is possible to delimit an alluvium on the bottom of the minor riverbed, in which the coarser materials dominate, and an alluvium within the major riverbed, with fine materials, coming from the suspension. The riverbed accumulations favor the erosion phenomenon, especially in the discharge area, in the concavity of the banks.

An important role in the development of erosions has the variation of the liquid flow, during the floods it entraining and transporting the non-cohesive materials from the shore area. Another factor that frequently influences the appearance and development of erosions is the influx of alluvium from landslides in the upstream area of the watercourse but also the deposition of alluvium from the transit and confluence area, which influences the direction of water flow to a shore or another.

The main provocative factor of the erosion phenomenon in the studied areas was the liquid flow, especially during floods, it has a very large variation, compared to the average flow, it acts on the banks of the riverbed creating pressures during the level increase, erosion and landslide.

In the case of the Milcov river, landslides are one of the most important processes in the supply of alluvium, which are transported and stored in the downstream areas. The contribution of landslides as sources of alluvium is significant when the supply of materials takes place directly to the riverbed, these landslides cause significant disturbances in the morphology of the riverbed, favoring the erosion process, to the west bank and by transporting alluvium. In the studied areas, the lack of woody vegetation in the shores area has a contribution to the development of erosion.

The use of classical measurement methods provides high accuracy, is relevant to the field situation, but requires travel each time measurements are made. Innovative monitoring methods do not require field trips, they can be performed on a large scale and over very long distances, but they are relative and in some cases do not match the reality on the ground. The use of innovative methods requires connection to the Internet and software for interpreting data.

Chapter 4. Sampling of alluvium from the three studied rivers was done through field campaigns, using equipment and technology appropriate to this process. The aim of these campaigns was to determine the particle size distribution of alluvium along the three rivers, on the monitoring sectors. For each river, monitoring sections were defined, spaced 8-12 km apart. The parameters of the cross sections of the rivers were measured and their profile for each section was represented. The natural section is assimilated as trapezoidal, and on this basis the shape coefficient was calculated, which has similar values for all motorized sections (0.80 - 0.90).

The variation of the diameter of the alluvium in the riverbed is large along the three sectors of the monitored rivers. In the upper sector with a large general slope, with frequent petrographic and structural changes in shape, the diameter of the alluvium is between 0.1-80 mm.

The representation of the granulometric curves for the monitored sections highlights, as expected, the increase in the diameter of the alluvium from downstream to upstream. The degree of unevenness of the garnulometric curves has the same tendency, increasing from 3 to 28 for the Milcov and Râmnicu Sărat rivers. The monitored section of the Siret River was expected to behave slightly differently in view of the influence of upstream accumulation, although the general trend is the same, but with smaller variations in variation.

The variation curves of the average diameter - d_{50} - are similar for the three monitored rivers, and are also similar to these variations reported in the literature. The law of variation is exponential and demonstrates a very good correlation with the theoretical distribution resulting from the respective exponential equation, also demonstrated by the correlation coefficients very close to the value 1.

Starting from the documentation made in the thesis, from the results of field investigations and observations carried out on the three sectors that constituted the case studies, we proposed a multicriteria analysis for ranking the factors that govern the erosion of the riverbed. The following criteria were considered:

A. The extent to which water erosion contributes to the increase in the volume of alluvium,
B. The extent to which water erosion affects the environment,
C. The extent to which water erosion contributes to the reduction of land areas,
D. The extent to which water erosion affects the inhabitants and objectives of the area.

Scores and weights were added to these depending on their importance. The factors considered are grouped into two categories: natural factors (9 factors) and anthropogenic factors (9 factors).

Multicriteria analysis shows that the most important natural factors in erosion are hydrological factors with a total score of 411 points, the most representative being the variation of liquid flow and geological factors with a total score of 391 points, the most representative being the structure of the banks. .

The analysis of the obtained results shows that criterion D - affecting the inhabitants and objectives of the area - has the greatest influence in the case of natural factors (63 points), and criterion B - affecting the environment - has a dominant influence in the case of anthropogenic factors (43 points).

Among the most important anthropogenic factors in the production of erosion are the use of land with a total score of 404 points, the most representative being the exploitation of forest vegetation and riverbed works with a total score of 214 points, the most representative in this case being the accumulation lakes.

Following the multicriteria analysis, it results that on the rivers Putna, Zăbala, Râmnicu Sărat and Milcov the main natural factor is the hydrological one, the variation of the liquid flow being representative. On the analyzed rivers the temperature is not an essential factor in the production of erosions. For the Siret and Trotuş rivers, the main natural factor is the geological one, being representative, in this context, the structure of the banks.

The multicriteria analysis model developed was applied taking into account the specifics of the rivers in the river basin that constituted the case study - the river basin of the Siret River - but it can be used for any other basin, considering the scores according to the specifics and local conditions of the basin. respectively. This model of analysis makes it possible to highlight the factors that need to be given priority attention in adopting measures to minimize the effects of erosion.

Chapter 7 presents a comparative, technical analysis of the use of classical gabion works and ecological works with geosynthetic materials, geocontainers, in order to combat the erosion phenomenon.

There are many forms of degradation of gabion work and natural and anthropogenic factors can be caused. The wire and mesh used in gabions can be destroyed by transporting alluvium and floats during floods, but also environmental factors favor their degradation. In acidic or saline environments, gabions cannot be used due to the rapid degradation of the materials from which they are made. Damaged gabion works can no longer be repaired or reused and do not allow the development of fauna and flora.

In order to evaluate the behavior of the geotextile used in the manufacture of geocontainers over time, the measurement of different geotextile samples was performed. The first measurement was made on a sample of geotextile not used in the works, which has a thickness between 0.5 and 0.6 cm. It has a lifespan of about 8-10 years, in variable climatic conditions and sediment transport is affected, and its thickness has decreased to about 0.3 cm and is vulnerable or even destroyed, hence the phenomenon of degradation or damage of of the work.

Another measurement was made on a sample of geotextile that was degraded by floats that are transported by the river during floods, where it shows that the geotextile loses its density, is fluffy and increases its thickness from 0.5-0.6 cm at 0.7-0.8 cm, which leads to loosening of the fabric and helps to wash the sand.

A new measurement was made on a sample of geotextile in direct contact with water where it is highlighted that the geotextile is not affected by U.V., floating rays and maintains its original thickness, filling with fine alluvium carried by the river.

Chapter 9 presents the evolution of ecological works, from geocontainers applied in eroded areas and the evolution of the monitored riverbeds in the Siret river basin.

Monitoring of erosion areas by classical methods was performed by field measurements using GPS Hi-Target and the total Leica station, at different time periods, especially following floods on the watercourse, and the interpretation of data obtained from measurements - performed by analytical calculations with AutoCAD and ProgeCAD programs on georeferenced maps in the ArcGIS program.

We used Google Earth software to spatially track eroded areas.

On the Milcov river for the spatial follow-up of the erosion evolution, we marked the right bank in 2018 with reference points where there is a widening of the riverbed, the left bank being eroded over a width of 5 m, in 2019.

In order to follow the evolution of erosion by classical methods, at the beginning of 2018, 2 transversal profiles were made (upstream profile A and downstream profile B, fig.9.2 and 9.4) the values of the land elevation being determined for each profile.

At the beginning of 2018, the transversal profile of the riverbed in the monitored area (upstream profile A) had a width of 206 m, due to the location of the work on the left bank, the floods recorded in 2018-2019, on the Milcov river, favored erosion right bank in the monitored area (upstream profile A) on a width of 9 m, the profile of the riverbed having a width of 215 m.

At the beginning of 2018, the transversal profile of the riverbed in the monitored area (downstream profile B) was 152 m wide, due to the location of the work on the left bank, the floods recorded in 2018-2019, on the Milcov river, favored erosion right bank in the monitored area (downstream profile B) on a width of 24 m, the riverbed profile having a width of 176 m.

n addition to the liquid flows, the dependence of the solid flow transport on the liquid flow for each river was also analyzed.

Following the analyzes and measurements performed in the field, it is recommended to avoid the use of geocontainers in the high slope area of the land, because the transport of alluvium is in large quantities, the level of the gutter decreases relatively quickly, and this phenomenon can undermine work.

Geocontainers are also vulnerable in areas where floating transport is frequent, favored by rapid floods and landslides in the mountains. Floaters can cause cracks (cracks) in geocontainers and as a result the material inside is washed and the work can be degraded.

Longitudinal works in geocontainers are indicated to be carried out in areas where there are no hydropower accumulations, so that there is no risk of lowering the riverbed, and the works may collapse.

In the case of works in epic geocontainers, they must be as short as possible and as close as possible to each other in order to favor rapid clogging, and the phenomenon of erosion must not appear behind the work.
The work of longitudinal geocontainers or regularization in the form of epium, performs well on rivers that do not exceed a flow (Q) of 500 m^3/s, with a slope of the land of up to 10%.

In carrying out the works in the geocontainers, it is necessary to execute the fascine mattress, founded under the level of the trough in order not to appear the leaking phenomenon, and the work to be undermined. It is recommended to arrange a slope of 1/1.5 - 1/3, when carrying out the work in geocontainers, and the favorable position of the geocontainers, compared to the watercourse is transversal.

Sharp or angular materials should be avoided when filling geocontainers, as this may cause them to break and leave the geocontainer filled. The migration of sand in geocontainers determines the mechanism, "caterpillar", it has a significant influence on the stability of geocontainers, therefore, it is recommended that the geocontainer be 90% filled with a material with a particle size between 0.2-5 cm , so that the sand does not pass through the geocontainer and the geotextile is not broken when it is filled or put into operation.

The transport of coarse alluvium consisting of gravel and boulders is easier to retain in the case of longitudinal works, in the area of rivers with low and medium flows, it does not affect the material from which the geocontainer is made.

In order to avoid the degradation of the geotextile by UV rays, it is indicated to cover the geocontainers with vegetal soil, this allows the development of the plants, but also avoids degradation of the work by vandalism.

Geocontainer works can successfully replace classic gabion works or other technical solutions that involve very high costs of execution or acquisition, behave well during floods, are not degraded by alluvial transport, are not affected by soils or saline waters and in in case of the occurrence of the degradation phenomenon, by undermining the work is punctually damaged, due to the mobility and elasticity of the geocontainers.

Geocontainer works can be used as ecological solutions to combat erosion, because they behave well in the natural environment, allowing the installation and rapid development of plants and trees. In this way, the developed vegetation ensures the harmonious framing of the work in the ecosystem and its protection against degradation factors.

10.2. Contributions

- Analysis of erosion factors in the Siret Hydrographic basin, lower course and identification of the causes of the appearance and development of the erosion phenomenon, caused by natural or anthropogenic factors.
- Analysis of the evolution of erosion in the Siret Hydrographic basin, lower course, on the three case studies with the help of satellite and classical measurements; formulating useful conclusions for understanding this phenomenon and for designing solutions to minimize the impact of water erosion.
- Processing and analysis of hydrological data, flows, alluvium transport and assessment of the dependence of the solid flow on the liquid one, from the Siret Hydrographic basin, lower course, registered at the hydrometric stations, from Vrancea and Buzău county.
- Development of an erosion protection model using geocontainers, technically and economically favorable for implementation in the riverbed section.
- Proposing a multicriteria method of prioritizing the natural and anthropogenic factors that govern water erosion.

- Comparative study of the solutions used to combat erosion; evaluation of the advantages and disadvantages of the studied solutions; formulating conclusions regarding the criteria for their implementation.
- Proposing and implementing ecological works from geocontainers in the studied erosion areas located in special protection areas; monitoring their behavior over time; drawing conclusions on the feasibility of this solution;
- Analysis of the causes and forms of degradation of geocontainers used in the protection of riverbeds against erosion; formulating criteria to improve their design and implementation.
- Analysis of the behavior of geotextile and works in geocontainers in the natural environment in the Siret river basin.

10.3. Research perspectives

- Research on the use and evolution of cement-stabilized geocontainers as substitute solutions for prefabricated and rockfill;
- Development and analysis of behavior, new models of geocontainers to combat erosion and restore the environment. (figure 10.1)
- Analysis of the transformation and use of recycled materials in the realization of technical solutions to combat erosion.

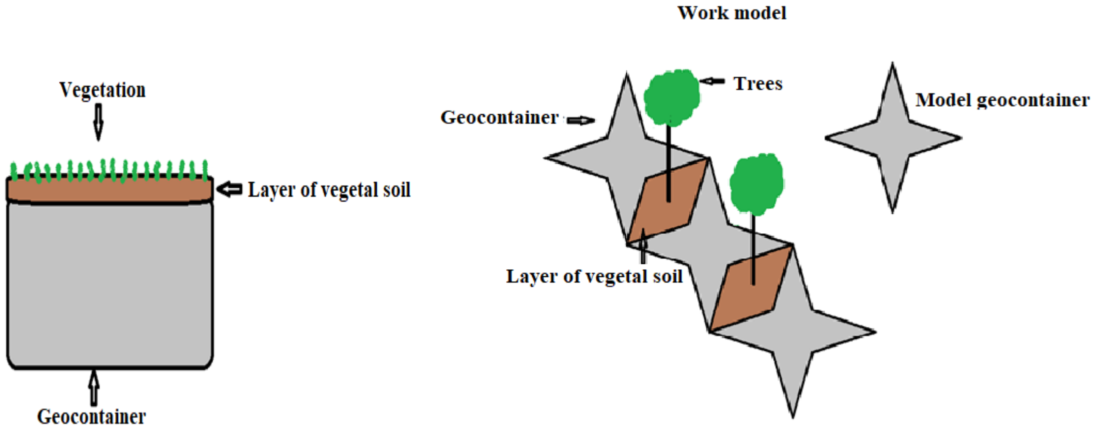

Fig.10.1. New models of geocontainers

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