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ANALYSIS OF PHENOMENELS WITH HYDROLOGIC LARGE RISK IN THE HYDROGRAPHIC BASIN OF THE TROTUŞ RIVER

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Abstract: The paper presents an analysis of the high hydrological risk phenomena formed in the hydrographic basin of the Trotuş River in the last period of time. The Trotuş River and the tributaries are monitored by 21 hydrometric stations. Precipitation volume processing indicated a number of risk factors that have prevailed over the last 20 years. The hydrological data processing revealed the presence of several flood flows in the same year. The effects of the floods have materialized through the excessive degradation of river bedside regulation and shore defence works. The floods of the past 25 years have resulted in the destruction of a large number of economic and social objectives in the Trotuş River area, as well as human losses. Parameters of hydroclimatic risk highlighted by research are represented by torrential precipitations, floods with high probability, high frequency of high-flow flows, formation of high erosion velocities of the bed, etc. Parameters of hydroclimatic risk impose special conditions for the design of river regularization and shore defence.

Keywords: river, precipitation, flow, flood, regularization works

Introduction

Globally, a series of climatic changes have occurred over the past 30 years and have produced negative impacts on the environment. Climate change is present in Romania and influences the annual distribution of precipitation and flow in the river basin. The seasonal change of meteorological parameters creates phenomena with high hydroclimatic risk in the river basin. The risk phenomenon influences the formation and evolution of flows and levels on rivers, causing flood waves with disaster effects. Altered hydrological parameters continuously influence the

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morphological evolution of the river and the behavior of the buildings in the riverbed and the riparian.

The hydrological regime in the Siret River basin is characterized in the last period of time by the high frequency of the floods. The floods produced in recent years on the Trotus River and its tributaries have caused significant economic damage and human loss.

Elements of hydrological risk modify intensively river morphology in transverse and longitudinal section. The stability of bed constructions (bridges, adjustments) and shorelines (defence works, dams) are changing from one flood to another.

This aspect was noted on the Trotuş River and its tributaries. Hydrological risk factors affect the existing habitat in the minor and major river bed. The amount of flood damage has become very high in recent years, which has forced the allocation of major investments for restoration work. The cumulative effect of floods produced at intervals of several years (2001, 2005, 2010, 2012, 2014, 2016 on the Trotuş River) has increased the cost of covering the damage.

The effect of morphological changes in the river bed is immediately reported, or may occur after a longer period of time. The restoration of river regulation and river defence works depends directly on the evolution of hydrological and hydraulic parameters over time.

1. STUDY AREA AND RESEARCH METHODS

The studies and researches were carried out in the hydrographic basin of the Trotus River and its tributaries. The research material was collected from the Siret basin and customized on the Trotuş River basin. The hydrographic basin of the Trotuş River is located in the relief area of the Oriental Carpathians. The Trotuş River crosses the geomorphological units of the Ciuc, Tarcău, Comăneşti and Tazlău - Caşin depressions. The Trotuş River flows into the Siret River downstream of Adjud.

The cadastral code of the Trotuş River is XII-1-69. The streams of the Trotuş River are located in the Ciuc Mountains at an altitude of 1360 m. The Trotuş River is tributary on the right side of Siret, with a surface of 4456 km2, being the fourth largest by Barlad (7220 km^2), Bistrita (7039 km^2) and Buzau (5264 km^2). The main flow direction of the river is north - south. The Trotuş River has a length of 162 km, a mean slope of 8 ‰ and a coefficient of sinuosity of 1.54. The average altitude of the river basin varies from springs to spills within the range 1140 - 734 m.

The tributaries of the Trotuş River on the sector considered in the analysis are (Ujvari I., 1972):

– on the right: Ciugheş, Cotumba, Grohotiş, Suliţa, Ciobănuş, Supan, Uz, Dofteana, Slănic, Nicoreşti, Oituz, Caşin, Gutinas, Căiuţi, Popeni;

– on the left: Bolovăniş, Tarhăuşi, Şanţ, Cuchiniş, Brusturoasa, Camenca, Agăş, Seaca, Ciungi, Asău, Urmeniş, Plopul, Cucuieţi, Vâlcele, Tazlău.

The tributaries on the right are more numerous and have larger hydrographic areas (Uz - 469 km^2, Oituz - 337 km^2 and Caşin - 308 km^2). They drain higher mountain areas and have a richer leak. The most important tributaries on the left are Asaul - 208 km^2 and Tazlăul - 1104 km^2 (Fig.1).

The Trotuş River and the tributaries are monitored by 21 hydrometric stations. They determine parameters of liquid and solid flow (flows, levels, ice, physical and chemical quantities, etc.) over a period of 40-60 years (Table 1). The collected data is processed and converted into water management studies. Hydrological studies are complemented by hydraulic, topographic, geotechnical studies, state of construction and shore defence.

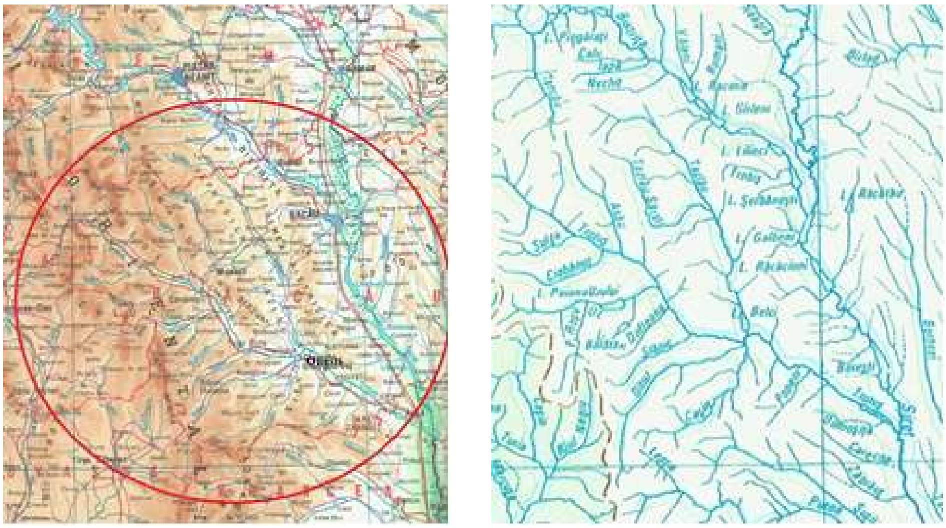


Fig. 1. Location of the study area in the Siret catchments area: a - details of the relief areas in the Eastern Carpathians; b - the hydrographic network characteristic in the study area

The studies and researches for this work are conducted over a period of about 50 years. Several aspects have been developed over a period of 25 years. The theoretical and experimental research was carried out in the following areas:

1. Research of meteorological parameters recorded in the river basin. Parameters analyzed were: daily, decadent, monthly, annual and time division.

2. Research of hydrological parameters registered at hydrographic stations in the river basin. Parameters analyzed were: liquid and solid flows, levels, flood frequency, floods, etc.

3. Investigation of hydraulic parameters on the river section located in the study area. The parameters analyzed were: flows, levels, speeds (averages, maximum and speed distributions) in sections of analysis by river sectors.

4. Research of hydrological risk parameters on the morphology of the river bed on the studied river sector.

5. The effect of hydrological and hydraulic risk parameters on river bed and river basin constructions.

6. Primary data was processed using statistical, hydrological, hydraulic computation programs, shore stability, flood propagation, etc. applicable to the case study.

2. RESULTS AND DISCUSSIONS

The research used climatic data taken from the meteorological stations located in the Trotuş River Basin. The meteorological data were taken over the variables required by the research field (5 - 65 years). The analysis carried out [for the 65year period revealed the fluctuation of the study data for different periods of time. The data has been processed and transposed graphically during the research period (Avram, 2016). A special analysis was made regarding the variation of the annual rainfall from 2000 to 2015 at the Tg, Ocna hydrometric station in the Trotuş hydrografic basin (Fig. 2).

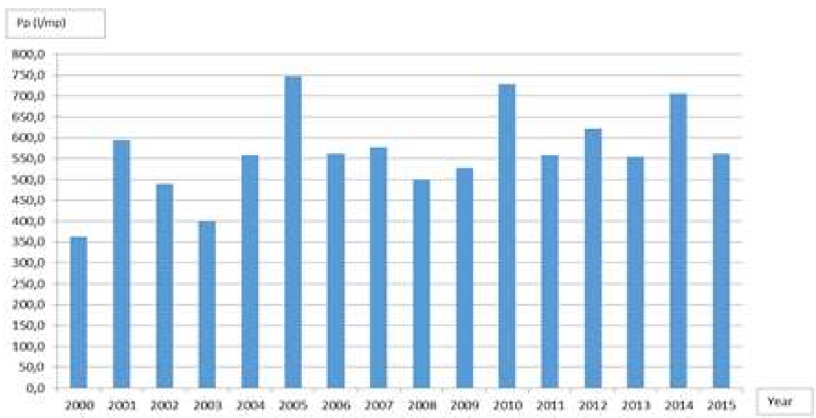


Fig. 2 The variation graph of the annual precipitation in the period 2000 - 2015

The precipitation analysis highlighted a series of positive or negative variations, but there is no clear trend towards growth or diminution. Against the background of global warming in recent years, there is no trend towards the evolution of rainfall. The analysis performed over two long time periods (1950-1983 and 1984-2015) shows that the frequency of exceeding the multi-annual mean value was higher (20 cases) in the first period than in the second period (11 cases).

Fig. 3. Hydrometric stations network in the Trotuş river basin (ABA Bacau)

Hydrological data were collected from hydrometric stations located in characteristic sections on the Trotuş River and its tributaries (Table 1, Fig. 3). A special analysis was carried out for data from the hydroclimatic risk periods, where variable periods of time (10 - 65 years) were considered. The analysis considered the average, maximum and minimum multiannual flows between 1950 and 2016 (Avram, 2016). The Trotuş River and its affluents analyzed the variation in the average annual flows versus the multiannual average and the frequency of overflows with the required calculation probability.

Table 1 The hydrometric monitoring network in the Trotuş catchment area (A.B.A. Siret, 2016)

Nr. crt.	Hidrometric Station	Area. HB F (km^2)	Av. Alt. H_m (m)	Q_{av} (m^3/s)	Q_{max} (m^3/s)	$Q_{max, p,}$ (m^3/s)			
						1%	2%	5%	10
1	Lunca de Sus	88	1140	0,805	23,2	210	165	113	77,5
2	Ghimeș-Făget	381	1116	3,65	127	500	410	300	220
3	Goioasa	781	1052	6,59	353[1]	750	625	460	340
4	Tg. Ocna	2091	924	17,5	1490[2]	1200	1025	795	625
5	Onești	2836	830	25,1	2294[3]	1620	1390	1075	840
6	Vrânceni	4092	734	35,0	2845[4]	2345	2095	1580	1255

The analysis of the multi-annual average flow per seasons showed the following results:

– minimum flow occurs in winter and autumn; The value of the winter flow represents 8.7 - 11.6% of the annual volume and the autumn 12 - 15.5%; The two periods accumulate over 1/5 of the annual flow;

– maximum flow occurs in spring and summer; The value of the spring flow represents 39.9 - 49.3% of the annual volume and the summer one 27.1 - 34.7% of the annual volume.

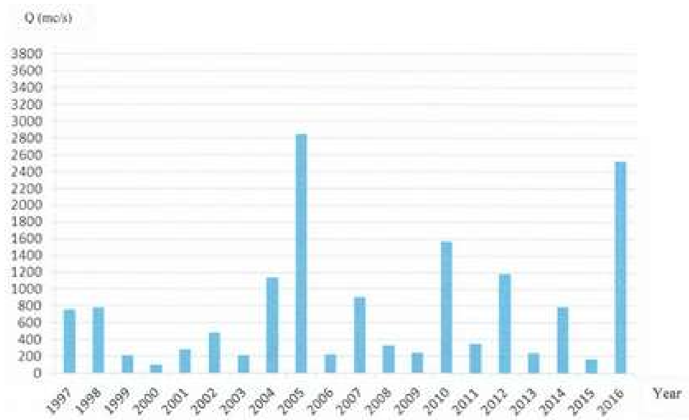


Fig. 4. The variation in the maximum annual flows from 1997 - 2016 at H.S. Vranceni

In the first five months of 2016, there were abnormal phenomena in the thermal regime, precipitation and flow in the studied area. In February, there was a period of excessive heating, which determined the development and evolution of vegetation. Then 1-2 months of intense cooling continued, causing damage to vegetation development. The second half of April and May was a period of thermal and pluviometric oscillations that influenced the drainage of water in the river basin. It should be mentioned that most of Moldova (the northern half) was affected by drought.

It should be noted that the strong torrential rains in this area occur in the synoptic context of retrograde circulating air masses. The effect of these rainfalls can be catastrophic for some river basin areas. The masses of air entering the western Black Sea basin where they are loaded with much humidity on their way to the East are absorbed by the high atmospheric pressure in the Russian Plain, first to the N-E, then to the N and the N-V. With the rise on the higher reliefs in the Moldavian Plateau and Subcarpathians and on the first mountainous chains of the

Oriental Carpathians, cooling, condensation and formation of precipitation occur. These precipitations sometimes exceed 100 l/m^2 in 24h. This event happened in June 2016 (a similar phenomenon occurred in the summer of 2005).

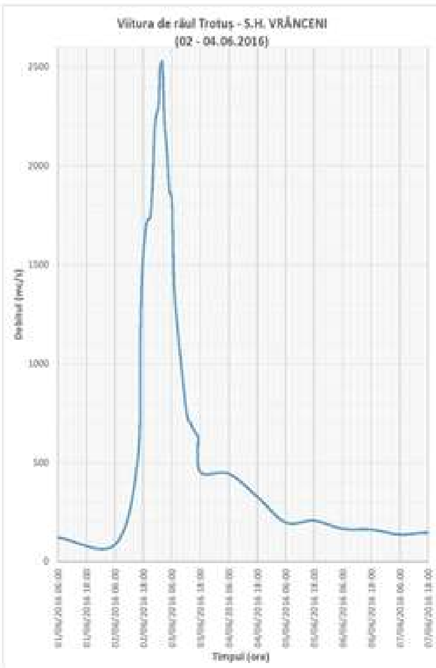
Table 2. Parameters of the floods formed by watercourses in H.B. Trotuş during the period02.06-04.06.2016 (A.B.A. Siret, 2016)

Nr. crt.	River	Hydrometric Station	H_{max} (cm)	*p* (%)	*Pp. tot.* l/m^2	*Q* (m^3/s)
1		Goioasa	237	50	108	227
2		Tg. Ocna	382	5-10	48.5	686
3		Onești	455	10	82.9	846
4		**Vrânceni**	525	**1**	58.3	**2525**
5	Valea Rece	Valea Rece	260	15	65.0	79,8
6	Sulța	Sulța	230	25	68.1	56,9
7	Asău	Asău	220	20	71.1	89,0
8	Slănic	Cireșoaia	260	5	61.4	118
9	Dofteana	Dofteana	285	5	64.6	134
10	Cașin	Haloș	300	50	49.1	87,2
11	Tazlău	Tazlău	226	50	93.6	161
12	Tazlău	Scorțeni	350	10	88.2	401
13	Tazlău	**Helegiu**	410	**2**	69.6	**1280**
14	Tazlăul Sărat	**Lucăcești**	360	**3**	85.9	**342**

Flood between June 02-05 June 2016 in H.B. Trotus was formed following the precipitations of 02 and 03 06.2016. On 02.06.2016 there were precipitations with values above 80 l/m^2. Precipitations continued on 03.06.2016 and on the night of 03-04.06.2016, where the peak reached 40 l/m^2. The measured values at the meteorological stations were 108 l/m^2 in Goioasa, 82.9 l/m^2 in Onesti, 68.1 l/m^2 in Sulta, 87.5 l/m^2 in Cremenea, 61.4 l/m^2 in Ciresoaia, 93.6 l/m^2 in Tazlau, 85.9 l/m^2 in Lucăceşti on the Tazlăul Sărat River, etc. (ABA Bacau, 2016). The accumulation of rainfall over the two days is particularly high, leading to flooding mainly in the middle and lower reaches of the Tazlau River and the Trotuş River.

Table 2 shows only the maximum allowances and maximum flows recorded and the total rainfall falls within the observed range. There are numerous overshoots of defence allowances, including threat rates. The analysis of the data results in the delimitation of a large precipitated area with very large flows located in the Tazlău Depression and on the Trotuş corridor downstream of the Tg. Ocna section. The flood flows in this area have shown probabilities of exceeding the calculation values: on the Trotuş River to Tg. Ocna 5-10%, Onesti 10%, and Vrânceni 1%, on the river Tazlăul to Scorţeni 10%, Helegiu 2% and on the Tazlăul Sărat river in Lucăceşti 3%.

The Vrânceni hydrometric station is located downstream of the confluence of the Trotuş River and the Tazlău River. The surface of the Vrânceni hydrometric station is 4092 km^2 and represents 92% of that of the Trotuş hydrographic basin (4456 km^2). For each flood, the hydrograph was drafted at the hydrometric flow measurement station (Avram, 2016). The results of the debit processing at the Vrânceni Hydrometric Station for June 2016 are presented in Fig. 5.



Data	H (cm)	Q (mc/s)	Frec	Obs
01/06/2016 06:00	180	123	16	
02/06/2016 06:00	146	87.08		
02/06/2016 15:40	300	511		= CA
02/06/2016 16:45	396	1142		+46 cm peste CI
02/06/2016 17:30	430	1448		+80 cm peste CI
02/06/2016 19:00	452	1681		+2 cm peste CP
02/06/2016 20:00	457	1734		+7 cm peste CP
02/06/2016 21:00	457	1734		+7 cm peste CP
02/06/2016 22:00	475	1929		+25 cm peste CP
02/06/2016 23:00	500	2220		+50cm peste CP
03/06/2016 00:25	507	2304		+57 cm CP
03/06/2016 01:00	522	2486		+72 cm CP
03/06/2016 02:00	601	2524		+75 CP
03/06/2016 03:00	500	2220		+ 50 CP
03/06/2016 04:00	487	2067		+37 CP
03/06/2016 05:00	470	1872		+20 CM CP
03/06/2016 06:00	467	1840	42.2	+ 75 cm CI
03/06/2016 07:00	425	1399		+75 cm CI
03/06/2016 09:00	392	1109		+42 cm CI
03/06/2016 10:00	378	996.2		+28 cm peste CI
03/06/2016 11:00	362	881		+12 cm CI
03/06/2016 12:30	340	733		+40 cm CA
03/06/2016 14:00	334	697		
03/06/2016 16:00	326	650.6		
03/06/2016 17:00	323	633.8		
03/06/2016 18:00	287	453.8		
04/06/2016 06:00	285	445	8.8	
04/06/2016 18:00	258	329		
05/06/2016 06:00	221	199.8		
05/06/2016 18:00	224	208.2		
06/06/2016 06:00	207	167.3	14.7	
06/06/2016 18:00	205	163.5		
07/06/2016 06:00	191	138.7		
07/06/2016 18:00	196	147.2		
08/06/2016 06:00	179	121.7		
08/06/2016 18:00	183	127.2		
09/06/2016 06:00	170	110		

Fig. 5. The flood shelter of June 2016 R. Trotuş, H.S. Vrânceni

The floods produced in June 2016 in the Trotuş River hydrografic basin have caused major damage to the economic and social environment, as well as human losses. The June 2016 flood has partially and total degraded housing, social and economic construction, agricultural crops and orchards, forest land, road transport infrastructure (national and local roads), railways, bridges, etc. (Figure 6, 7 and 8). A comparative summary of the damage is presented in Table 5. The degradations were multiple and important on all the tributaries of the Trotuş River (Avram, 2016, ABA Siret, 2016).

Hydrotechnical works were strongly affected by the 2016 floods in the Trotuş catchment area, where approximately 35.46 km of partially and totally degraded works were centralized (ABA Siret, 2016).

Fig. 6. General view of a landslide, the Caşin River, with the degradation of the road (Avram M., 2016)

Fig. 7. The degradation of the riparian area on the Flooding Casin River in June 2016 (Avram M., 2016)

Table 3. Comparative analysis of main damages caused by floods in Trotuş Hydrographic Basin (A.B.A. SIRET, 1991-2016, Avram M., 2017)

Nr. crt.	Object name	2005	2016
1	Impaired or destroyed hydrotechnical works (km)	35.46 out of which 28.61 in the area considered	318.14 in Bacău County
2	Dwellings and households affected / destroyed by floods (no)	3149/922	376/64
3	Agricultural land flooded (ha)	5453,5	1337
4	Flooded / destroyed roads (km)	83,75	355
5	Flooded/destroyed bridges (pieces)	117	180
7	Flooded economic targets (no.)	51	4
8	Dead people (no.)	5	1

The analysis carried out in the Trotuş River Basin on varying intervals has revealed a number of hydroclimatic risk factors. These include:

– precipitation concentrated in high volume over short intervals (2 to 4 days);

– torrential rainfall had a high frequency over short intervals (in the same month or in consecutive months);

– the current riverbed (minor and major) has a low transport capacity for floods with high flows;

– the current riverbed is morphologically modified, with the formation of sedimentation and erosion zones, influencing the flood transit capacity;

– increasing transport of biological material in the bed (branches, wood waste, trees, etc.), which causes the blocking of the river bed section in the bridges area;

– uncontrolled deforestation that has intensified rainfall-drainage and water-streaming in rivers;

– the continuous degradation of the flow regulating works on the non-permanent (torrential) alluvial basins in the hydrographic basin, which causes the tributary flow to be increased in the main bed;

– modification of drainage coefficients in the river basin due to anthropogenic intervention.

a b

Fig. 8. Erosion of the Trotuş River in June 2016: a - erosion in the area of dwellings; b - the erosion of the county road (Avram M., 2016)

Conclusions

1. In the last 25 years, Trotuş hydrographic basin has experienced disastrous hydrological phenomena, which have significantly influenced the morphology of the rivers with negative influences on the riparian environment.

2. During the period 2000-2016, a series of floods with high flow rates but also with high frequency at short intervals occurred in the Trotuş basin, which morphologically altered the bed and degraded the shore settlement and defence work.

3. The floods produced in June 2016 on the Trotuş River and its tributaries recorded debits with probabilities of 1.0 ... 5.0 %, which generated destructive phenomena on the riverbed and the riparian.

4. The flood with a probability of calculation of 1.0% and a value of 2542 m^3/s produced in June 2016 on the Trotuş River presented one of the highest flows recorded at SH Vrânceni.

5. The climatic and mainly hydrological situations produced in the Trout River basin over the past 27 years can be characterized as hydroclimatic risk phenomena through their destructive influence on the riverbed and riparian riverbed.

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