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Fast floods on the tributaries of Trotuș river, in the context of current climate change

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Abstract: The paper presents an analysis of the flood formation module in the Trotuș river basin and especially on its tributaries. A special situation was recorded in 2004 when the floods formed on the tributaries presented very high flows, but which did not substantially influence the flow of the main course. The floods produced on the river / stream / torrent type tributaries (example: Asău, Agăș, Goioasa, Iedera) presented flows that exceeded the accepted calculation probabilities. The floods produced were both the effect of torrential rainfall and the configuration of the lower sectors of the riverbeds. The floods produced in 2004 on a series of tributaries of the Trotuș River presented maximum flows that exceeded the calculation probabilities of 0.1% (Agăș - 183 m^3/s, Beheghet - 50.70 m^3/s, Goioasa - 67.10 m^3/s, Iedera - 127 m^3/s). The sudden change of the slope on the lower course of the tributaries determined the deposition of a large volume of alluvium, a situation that reduced the flow section and even blocked it. The result of the corroboration of natural and anthropogenic situations in the propagation of these floods is evidenced by the great destruction produced in a territorial area with numerous human communities and important economic activities.

1. Introduction

Climate change takes place in an environment that interferes with man's activities and nature with the geo-physical characteristics of each area. The phenomenon of global warming has led to an increase in the frequency of extreme weather and hydrological events. In recent decades, there has been a rapid alternation between periods of torrential rainfall, sometimes with hail, which generates disaster floods and periods of heat wave that cause long droughts.

Climate change over the last 30-40 years is felt, in particular, in the annual and in the territory of precipitation and by their zonal intensity. The annual distribution of precipitation significantly influences the formation of maximum flows and implicitly of floods on watercourses (Avram, 2020; Romanescu and Nistor, 2011; Dragomir et al., 2020). Another effect is represented by the high frequency of floods in the last 30 years (Avram et al., 2018). A large part of the floods had disastrous character, a situation that caused significant material damage, but also human losses (Avram, 2020; Tudorache et al., 2020; Luca et al., 2017). Also, the rapid floods contributed to the partial or total degradation of the regularization works performed on the watercourses (Avram et al., 2018; Luca et al., 2019; Romanescu and Nistor, 2011). The influence of climate change on the hydrological regime of watershed is a goal of extensive national and international study (Milly et al., 2005; Marchi et al., 2010).

Due to the climate changes that have occurred in recent decades, the frequency and intensity of hydroclimatic risk phenomena are increasing, and those of hydrological risk have become an extensive object of study at the national level (Avram, 2020; Avram and Luca, 2017; Dragomir et al., 2020) and international (Marchi et al., 2010; Neuhold et al., 2009).

The form of torrential precipitation in small watershed and their consequence represented by the occurrence of flash floods is a field of continuous research in Romania. We can mention the studies conducted by Tudorache et al., (2020) with the analysis of the evolution of maximum flows in the watershed of Casimcea, Olănești and Fernic rivers. Studies conducted by Dragomir et al. (2020) in five small river basins in Romania highlighted the potential for the production of rapid floods. The research carried out by Avram (2020), Avram and Luca (2017) in the watershed of the Trotuș River highlighted the production of rapid floods on the tributaries, which sometimes had a high hydrological risk. At the same time, a series of studies were conducted on the Trotuș River and its tributaries on the formation of floods and their effect on the economic and social environment (Manolache, 2017; Tudorache et al., 2020; Tirnovan et al., 2021).

A series of researches carried out in the Trotuș watershed have highlighted a series of characteristics of the floods formed as a result of torrential rains. The analysis of the floods in the Trotuș watershed between 1990 and 2018 shows that in 2004 a flood occurred on the middle and lower sector, which had an exceptional character, especially on the small tributaries in the Goioasa area (Avram, 2020; Avram et al., 2018). The flows on the main course, although quite high, were not likely to generate floods, but in the case of small tributaries the catastrophic floods that occurred were both the effect of special precipitation concentrated over time, and especially the configuration of the lower sectors of riverbeds. The analysis of this flood allows highlighting the particularly high negative impact on the environment, but especially highlights the numerous damages, which the tributaries in the mountain area can cause through large floods.

The aim of the paper is to present the result of studies and research on how floods are formed in a watershed representative of the piedmont and hill areas of Moldova area.

2. Study area and research method

The studies and researches were carried out in the Trotuș River watershed, a component of the large Siret River watershed (Figure 1). Within Romania, the Trotuș river basin occupies a central-eastern position. The Trotuș River is a tributary, on the right side, of the Siret River, and through the surface of 4456 km^2 it is the fourth largest after Bârlad (7220 km^2), Bistrița (7039 km^2) and Buzău (5264 km^2) (Avram, 2020).

The climate in the hydrographic basin of the Trotuș River presents a peculiarity due to the location of the territory in the mountainous (Sub-Eastern Carpathians) and hilly area (Apostol, 2004). The synoptic context that generates torrential precipitation is achieved by the existence of low atmospheric pressure fields in the SE half of Europe, which is in contact with an anticyclone located in NW Europe on the alignment of the Baltic States - east and Poland - central Romania - Greece.

The main tributaries of the Trotuș River (Figure 1) are the following (Ujvari, 1972):

- on the left: Bolovăniș, Tărhăuși, Santu, Cuchiniș, Brusturoasa, Camenca, Agăș, Seaca, Ciungi, Asău, Urmeniș, Plopul, Cucuieți, Vâlcele, Tazlău;
- on the right side: Ciughes, Cotumba, Grohotiș, Sulta, Ciobănuș, Supan, Uz, Dofteana, Slănic, Nicorești, Oituz, Cașin, Gutinaș, Căiuți, Popeni.

On the right side, the tributaries are more numerous, and they drain the higher mountain areas and have a richer flow. They also have larger collection areas. The Tazlău River has a lower flow compared to the other tributaries, although it has a much larger river basin area (1104 km^2).

The research material was composed of hydrological, hydraulic, topographic, geotechnical studies, safety in operation of hydrotechnical and environmental constructions, etc. The detailed researches were carried out in the period 2004 - 2018.

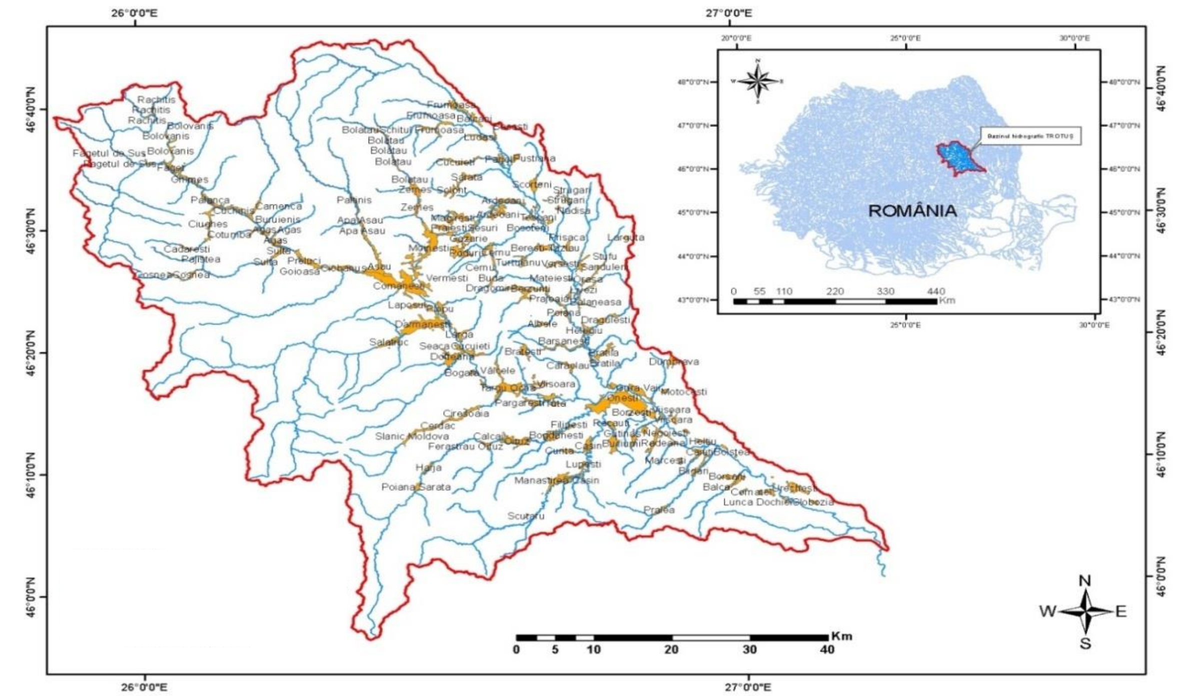


Figure 1. Location of the Trotuș river basin in the Romanian hydrographical network (WBA Siret - Bacau, 2016)

3. Results and discussion

At the end of July 2004, a flood occurred in the middle and lower sector, which was exceptional, especially on the small tributaries in the Goioasa area. The flows on the Trotuș River, although quite high, were not likely to generate floods. The analysis of this flood allows highlighting the particularly high negative impact on the environment, but especially highlights the numerous damages that tributaries in the mountain area can cause through large floods. The core of maximum precipitation was located in the area of Goioasa - Ciobănuș - Asău - Poiana Uzului - Târgu Ocna. The synoptic context that generated these precipitations was determined by the existence of a low atmospheric pressure field in the SE half of Europe in contact with an anticyclone located in NW Europe on the Baltic countries - east, Poland - central Romania-Greece.

At high altitude (5500 m) evolved a cold geopotentially basin, with the subsequent development in our country of low geopotentially nuclei (cut-off), with closed isohypses that played the decisive role. The quantities of precipitation that generated floods, the levels and maximum flows recorded at the hydrometric stations (HS) as well as the values by which the defence quotas were exceeded are presented in detail in Table 1.

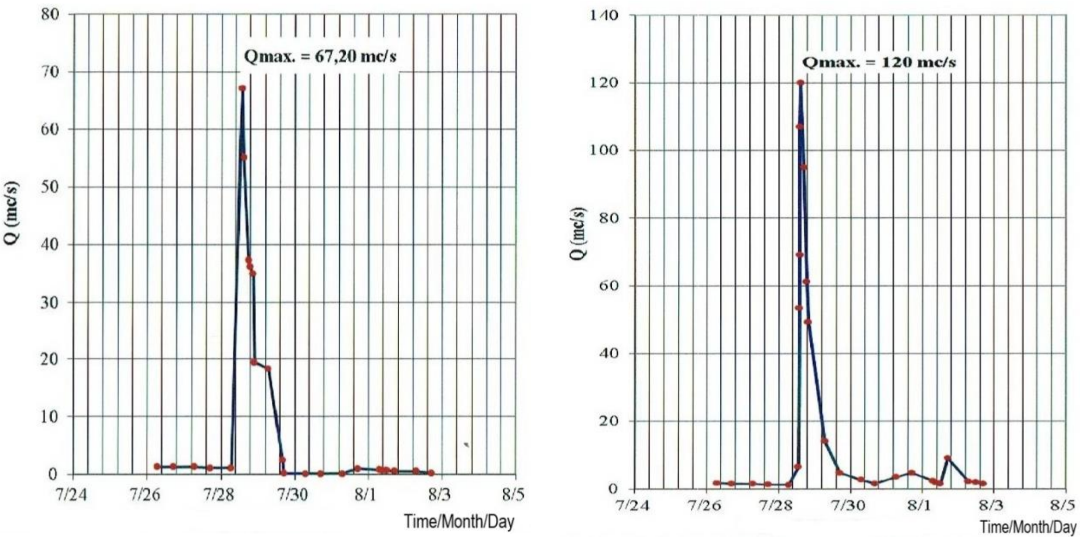
Table 1. Levels and flows registered in July in BH Trotuș, year 2004 (ABA Siret, 2004)

River	HS	Pp. (l/m²)	DO (cm)			C_{max} (cm)	D.C.Ap.	Q_{max} (m³/s)
			AS	FS	DS			
Trotuș	Ghimeș Făget	27.6	150	200	250			
Trotuș	Goioasa	88.4	150	200	300	323	23 DS	358
Trotuș	Tg. Ocna	62.9	200	300	380	396	16 DS	682
Trotuș	Onești	24.5	250	300	400	420	20 DS	869
Trotuș	Vrânceni	15.9	250	300	400	342	42 FS	1136
Sulta	Sulta	77.7	100	200	230	100		41.2
Ciobănuș	Ciobănuș	94.2	100	160	200	200	DS	67.2
Asău	Asău	61.5	150	250	300	220	70 AS	120
Uz	Cremenea	48.2	150	200	250			
Uz	Dărmănești	104	150	200	300	120	under AS	23.0
Dofteana	Dofteana	41.7	140	220	300	270	50 FS	116

Slănic	Cireșoaia	68.7	150	200	250			
Oituz	Ferestrau	46.2	150	200	300	122	-	13.2
Cașin	Halos	54.7	250	350	400	360	10 FS	166
Tazlau	Scorteni	52.0	150	220	280			
Tazlaul Sarat	Lucacesti	25.3	150	250	300	180	30 AS	140

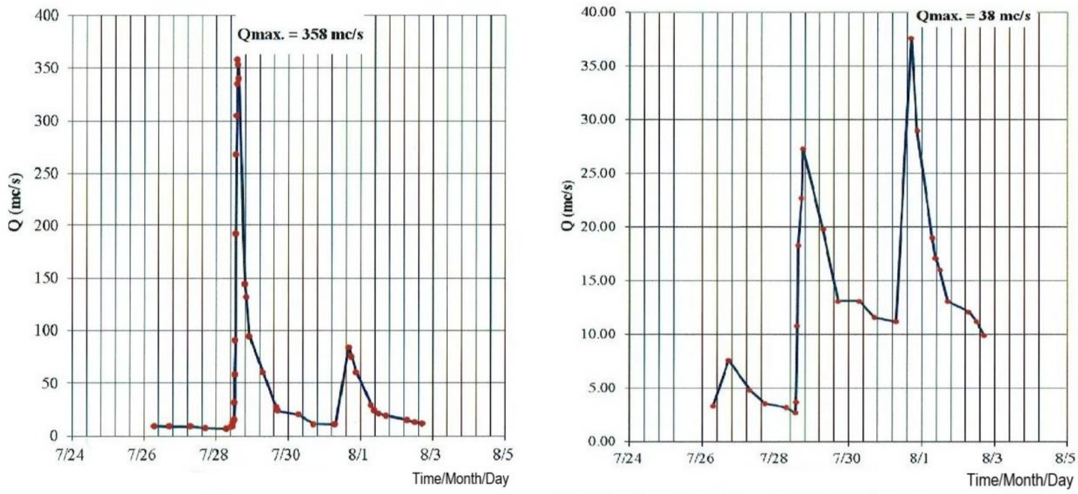
Note: HS - hydrometric stations; P_p – precipitations; DO – defence odds: AS – attention share; FS – flood share; DS – danger share; EDS - exceeding the defence share; S_{max} – maximum flood share; Q_{max} – maximum flow.

From the analysis of the data in table 1, it follows that on the upper course of the Trotuș River (upstream of Goioasa) and in the hydrographic basins of the tributaries Valea Rece, Sulta, Slănic, Oituz, Tazlău, but also on the lower course of the Trotuș River, there were no maximum flows causing significant flooding. The biggest floods occurred on the Trotuș River on the Goioasa-Târgu Ocna on the large tributaries Ciobănuș and Asău (Figure 2 and Figure 3) and especially on several small tributaries from the Goioasa area. The flood hydrograph shows the fast way of flood formation and evolution.



(a) (b)

Figure 2. The flood hydrograph from the period 26.07 - 03.08.2004: a - SH Ciobanus; b – SH Asau (Avram, 2020).



(a) (b)

Figure 3. The flood hydrograph from the period26.07 - 03.08.2004: a - SH Goioasa; b – SH Ghimeș Făget (Avram, 2020).

In the case of small tributaries, the catastrophic floods that occurred were both the effect of special precipitation concentrated over time, and especially the configuration of the lower sectors of the riverbeds. At the exit from the slope in the Trotuș River meadow, the slopes suddenly decrease and the large quantities of transported alluvium are deposited, greatly reducing the section of the riverbed and sometimes even obstructing it. Under these conditions, manure cones were formed, which created a great instability of the hydrographic network that crosses it. In this way, the most floods occurred in the small river watershed located on the right side of the Trotuș River.

The torrential precipitation produced in 2004 caused significant increases in flow on the right tributaries of the Trotuș River. Significant for this situation is the Agăș brook, which in the Agăș area reached the maximum flow with a probability of 0.1% (Q_{max} = 196 $m^3/s \cong Q_{max\ 0.1\%}$). The flood produced on the Agăș stream affected a large number of houses and outbuildings, agricultural and horticultural crops, pavements and roads.

Given that these lands are the most densely populated, due to the lack of other suitable areas, the damage caused by floods even by small semi-torrential streams is particularly important. Such blockages and obstruction of the lower sectors of the effluent torrents can be very well observed in the surveys taken from the field (Figure 4-6). The maximum flows recorded on these small tributaries in the researched area and the morphometric elements of their river basins are presented in Table 2.

The reconstitution of the maximum flows on these watercourses was realized by specialists from National institute of hydrology and Water Management Bucharest and Siret Water Basin Administration. For some of the sections, reconstitution calculations were performed in two variants depending on the evaluation of the roughness coefficients: 0.067 in the first case and 0.080 in the second.

To assess the probability of overtaking (for comparison), the maximum reconstituted flows from the first variant were taken into account (n = 0.067). Regarding the calculation probabilities (Table 2), from the table above, but also from a long hydrometric experience, it is noted that these values must be updated.

Table 2. Maximum recorded flows and morphometric elements of the basins hydrographical on the tributaries of the Trotuș River (WBA Siret, 2004)

River	F BH (km^2)	H_m (m)	Q_{max} (m^3/s)	$Q_{max, rev}$ (m^3/s)	Q_{max}. p% (current relations)				
					0,1	0,5	1	2	5
Sugura	12.0	1049	47.7	39.8		102	84.0	66.0	40.5
Agăș	16.0	970	195	183	189	134	110		
Seaca	6.34	900	27.1	22.3					
Beheghet	2.19	850	69.8	50.7	38.0	27.0	22.0		
Goioasa	4.75	870	80.5	67.1	55.0	39.0	32.0		
Țiganului	0.75	700	16.8	-	13.0	10.0	7.50		
Iedera	2.75	900	127	-	70.0	50.0	40.0		

Up. Trotuș – upstream Trotuș; Q_{max} – maximum flow recorded; $Q_{max,rev}$ – maximum flow revised; $Q_{max,p\%}$ - maximum flow with probability calculation

Studies carried out in the last 20 years have indicated an increase in the degree of torrential rainfall in the Trotuș river basin (Avram, 2020; Romanescu and Nistor, 2011; Manolache, 2018; Avram et al., 2018). The floods of 2004 in Trotuș River basin caused the death of 3 people and approximately 762 homes and households were destroyed by the floods (Table 3, Figure 4). Also, they were flooded approx. 280 ha of agricultural land, 26 km of roads, 9 economic objectives and 309 bridges. In 2004, about 13.4 km of hydrotechnical works carried out on the Trotuș River were partially or totally destroyed (Figure 4 and Figure 5).

Alluvial deposits in the riverbed were large, with thicknesses of up to 1.50 - 2.0 m, which partially blocked the flow on certain sectors of the main watercourse, but also on tributaries. Alluvial deposits produced changes in the normal flow regime, with influences on the stability of banks and bank defences when crossing urban areas (Figure 4 and Figure 5).

Table 3 Damage caused by the most significant floods in the Trotuș River basin in 1991, 2004, 2005 and 2018 (WBA SIRET, 2018)

Objective name	1991	2004	2005	2018
Deceased persons (no.)	76	3	5	0
Housing and households affected / destroyed by floods (no.)	2602	25/762	3149/922	91/0
Flooded agricultural land (ha)	11.460	280	5453.5	201
Flooded / destroyed roads (km)	15	26	83.75	23.35/0
Flooded / destroyed bridges (pcs.)	32	309	117	69/3
Flooded economic objectives (no.)	11	9	51	1
Damaged or destroyed hydrotechnical works (km)	5.64	13.4	35.46	12.44

(a) (b)

Figure 4. The effect of the 2004 flood in Agăș commune, Agăș river: a - flooded dwellings; b - important solid transport on the traffic routes in the locality (WBA Siret, 2004).

(a) (b)

Figure 5. The effect of the 2004 flood in the Agăș area through deposits in the riparian area: a - forest material; b - mooring with variable dimensions (WBA Siret, 2004).

The corroboration between the hydroclimatic and the anthropic risks determined catastrophic phenomena in hydrological basin Trotuș, highlighted by the particularly great economic and social damages, including human losses. The permanent presence of hydrological risks in the last 30 years, represented by floods with very high flows (1% - 0.1%), which have often exceeded the calculation probabilities imposed by the norms and standards in force (5% - 1%) require the reconsideration of the sizing and verification values of the flows for the new hydrotechnical constructions, to be realized.

The floods produced in 2004 on the tributaries of the Trotuș River, but also on it determined intense phenomena of erosion of the flow section, and in some areas the riverbed advanced in the riparian area, a situation that determined the breaking of the bridges (Figure 6) and the unveiling of the abutments to the river crossing constructions. The analysis of the maximum flows on the Trotuș river in the period 1990 - 2018 highlights that in 2004 a flood occurred with a flow Q_{max} = 1136 m^3/s registered at SH Vrânceni. Its value is about 40% of the flow recorded, immediately, in 2005 (Q_{max} = 2845 m^3/s) (Avram et al., 2017).

(a) (b)

Figure 6. The effect of the 2004 flood in Asău commune, Asău river: a - general view of the river advance in the riparian area; b - degradation of the bridge over the river (WBA ABA Siret, 2004).

In the period 2014 - 2020, several researches were carried out in small hydrographic basins regarding the effect of floods. Thus, the research carried out in 2016 in the hydrographic basin of the Voroneț River (Luca et al., 2017), a tributary of the Moldova River, highlighted a series of flood characteristics similar to those produced on the Agăș River in 2004 (Avram, 2020). The June 2016 flood on the Voroneț River presented a large volume of alluvium consisting of large stones, gravel and forest material (Figure 7). The alluvium mixture was transported by the flow with a calculation probability of 1% and accentuated the hydrodynamic erosion of the bed and riparian area (Luca et al., 2019).

(a) (b)

Figure 7 Alluvium transport on the Voroneț River during the 2016 flood: a – large stone and gravel on the upper course; b – gravel on the middle course (Luca et al., 2017).

4. Conclusions

The biggest floods in 2004 occurred on the Trotuș River on the Goioasa - sector Târgu Ocna, on the large tributaries Ciobănuș and Asău and especially on several small tributaries from the Goioasa area. The catastrophic floods that occurred were both the effect of special precipitation concentrated over time, and especially the configuration of the lower sectors of the riverbeds.

The analysis of the maximum flows on the Trotuș River highlights the fact that in 2004 a flood occurred with a flow of Q_{max} = 1136 m^3/s registered at SH Vrânceni, its value representing about 40% of the flow recorded, immediately, in 2005 (Q_{max} = 2845 m^3/s) at the same station.

The floods produced in 2004 on the Trotuș River, but especially on its tributaries caused, in addition to the loss of human lives and numerous material damages, by destroying houses and household annexes, bridges, regularization works, and so on. The intensification of the destruction phenomenon was favoured by the massive transport of alluvial material, large boulders and wood material.

The hydroclimatic risks are significantly present in the area occupied by BH Trotuș, the most important being the meteorological risk represented by the torrential precipitations and the hydrological risk represented by the fast floods with very high flows. To these are added the anthropic risk and the natural risk given by the relief by the shape of the river basin, as well as the large slopes of the slopes that determine a short time of concentration of surface runoff and flow in watercourses, especially on small tributaries.

References

1. Apostol, L. (2016) *Climate of the Subcarpathians of Moldova*; Edit. University of Suceava: Suceava, Romania (in Romanian).
2. Avram, M. Research on the impact of hydroclimatic risk factors on river regulation works. Thesis. Technical University „Gheorghe Asachi" of Iasi, Romania, 2020.
3. Avram, M.; Luca, M.; Marcoie, N.; Chirica, S. (2018) Studies and research on maximum flows of the Trotus River in 1990 – 2017. *PESD*,*12*(2), 109-119. https://doi.org/10.2478/pesd-2018-0033
4. Avram, M.; Luca, M. (2017) Analysis of phenomena with hydrologic large risk in the hydrographic basin of the Trotuş River. *PESD*, *11*(2), 77-87. https://doi.org/10.1515/pesd-2017-0026
5. Dragomir, A.; Tudorache, A.V.; Costache, R. (2020) Assessment of flash-flood susceptibility in small river basins. *PESD*, *14*(1), 119-130.https://doi.org/10.15551/pesd2020141010
6. Luca, M.; Sion, P.V.; Avram, M.; Chirica, S. (2019) Monitoring of degradation process of the shore defence works in erodible riverbeds. *Pangeea*, *19*, 30-37. https://doi.org/10.29302/Pangeea19.05
7. Luca, M.; Avram, M.; Marcoie, N. (2017) Analysis of the floods effects in june 2016 in the Voronet river hydrographic basin. *The Annals of "Dunarea de Jos" University of Galati, Fascicle IX, Metallurgy and Materials Science*, *2*, 5 - 10.
8. Manolache, (Tudorache) A.V. (2018) The analysis of the flash flood produced during 02-04.06.2016 in the Trotus River basin (Romania). *PESD*, *14*(1), 179 – 187. https://doi.org/10.2478/pesd-2018-0014
9. Marchi, L.; Borga, M.; Peciso, E.; Gaume, E. (2010) Characterization of selected extreme flash floods in Europe and implications for flood risk management. *Journal of Hydrology*, 394(1), 118-133. https://doi.org/10.1016/j.jhydrol.2010.07.017

10. Milly, P.C.D; Dunne, K.A.; Vecchia, A.V. (2005) Global pattern of trends in stream flow and water availability in a changing climate. *Nature*, *438*, 347-350. https://doi.org/10.1038/nature04312

11. Neuhold, C.; Stanzel, P.; Nachtnebel, H.P. (2009) Incorporating river morphological changes to flood risk assessment: uncertainties, methodology and application. *Nat Hazards Earth Syst Sci*, *9*, 789–799.https://doi.org/10.5194/nhess-9-789-2009

12. Romanescu, G.; Nistor, I. (2011) The effect of the July 2005 catastrophic inundations in the Siret River's Lower Watershed, Romania. *Natural Hazards*, *57*(2), 345-368. https://doi.org/10.1007/s11069-010-9617-3

13. Tirnovan, A.; Covaci, O.; Gazda, M.R.; Barsan, N.; Enea, A. (2021) Flood vulnerability reduction. Case study: Tazlau river basin, downstream of its confluence with Tazlău Sărat. *PESD*, *15*(2), 189-198. https://doi.org/10.15551/pesd2021152015

14. Tudorache, A.V.; Mihalcea, A.; Tudorache, G.S. (2020). Trends in variability of maximum water flow in small rivers basins in Romania. *PESD*, *14*(1),186-198. https://doi.org/10.15551/pesd2020141014

15. Ujvari, I. (1972) *Geography of Romania's waters*. Scientific Publishing House: Bucharest, Romania.

16. WBA (Water Basin Administration) Siret - Bacau "Synthesis reports on protection against floods, dangerous hydrometeorological phenomena, accidents at hydrotechnical constructions and accidental pollution in Bacau County, 1991, 2004, 2005, 2010, 2012, 2016, 2018."