Hrvatski meteorološki časopis – Croatian Meteorological Journal, 48/49, 2013/14, 47–62

Stručni rad
Professional paper

EXTREME HYDROLOGICAL AND METEOROLOGICAL PHENOMENA IN THE MIDDLE BISTRIŢA VALLEY, ROMANIA

Ekstremni hidrološki i meteorološki događaji u dolini Bistriţa, Rumunjska

CLAUDIU GAMAN, LIVIU APOSTOL
Alexandru Ioan Cuza University,
Faculty of Geography and Geology, Iaşi, România,

gaman_claudiu@yahoo.com

Primljeno 16. siječanj 2014., u konačnom obliku 26. rujna 2014.

Abstract: Bistriţa is the river with the longest mountainous sector in Romania, two thirds of its course passing through the Eastern Carpathians. The paper analyzes the most frequent hydrologic and meteorological phenomena with negative consequences from Bistrita valley (extreme temperatures, torrential rainfall, violent storms, winter phenomena etc.), whose frequency has significantly increased during the last decades. Data from meteorological stations and rainfall gauges in the area were used, as well as references considering the factors influencing the occurrence and evolution of risk phenomena. The study also analyzes some of the most important climate and hydrological hazards and risks that have occurred along Bistriţa valley and on some of its tributaries during the last decades, and attempts to establish the peculiar characteristics of the ice jams on Bistriţa and Bistricioara and the causes that have led to the formation in the 1972-1973 winter on Bistriţa of an ice jam considered unique in Romania and even Europe, as well as of solutions to substantially diminish the effects of these phenomena.

Keywords: extreme hydrological and meteorological phenomena, rainfall, floods, ice jams, material losses.

Sažetak: Bistriţa je rijeka u Rumunjskoj koja najduljim dijelom prolazi planinskim sektorom a dvije trećine duljine prolaze istočnim Karpatima. U ovome radu analiziramo najčešće hidrološke i meteorološke pojave i njihove negative posljedice na dolinu Bistrita (ekstremne temperature, obilne kiše, oluje, itd.) čija je učestalost u posljednjih nekoliko dekada signifikantno porasla. Korišteni su podaci s meteoroloških i kišomjernih postaja kao i reference koje razmatraju čimbenike koji utječu na pojavu i razvoj rizika. Rad također analizira neke najvažnije klimatološke i hidrološke katastrofe i njihove rizike koji su se javili u dolini Bistriţa i na neke njihove pritoke tijekom posljednjih dekada i pokušava utvrditi posebne karakteristike zdrobljenog leda u Bistriţa i Bistricioara. Ispituju se uzroci koji su doveli do stvaranja zdrobljenog leda u zimi 1972/73, događaja koji se smatra jedinstvenim u Rumunjskoj ali i u Europi, kao i rješenja kako značajno smanjiti efekte tog fenomena.

Ključne riječi: ekstremni hidrološki i meteorološki događaji, oborine, poplave, zdrobljeni led, materijalni gubici.

1. INTRODUCTION

During 2005-2010, dangerous hydrological and meteorological phenomena have placed second (26.18%) in the emergency situations occurred on the territory of Neamţ county (table 1).

Analyzing some of the concepts and notions of *hazard*, *natural risk and vulnerability* presented in different papers (Smith, 1992; Bălteanu, 1992; Bălteanu and Rădiţa, 2000; Moldovan, 2003; Goţiu and Surdeanu, 2007; Bogdan O. and Marinică I. 2007; Stângă, 2007; Romanescu, 2009 etc.) it is concluded that **nat-**

Table 1. Number and percentage of emergency situations in Neamţ County, during 2005-2010 (Neamţ Emergency Situations Inspectorate)

Tablica 1. Broj i postotak izvanrednih situacija u pokrajini Neamţ rijekom 2005.-2010.

Emergency situations (except SMURD interventions)	2005	2006	2007	2008	2009	2010	Number of cases	Proportion %
Fires	305	368	441	426	488	410	**2438**	50.38
Extrications	1	12	10	26	1	1	**51**	1.05
Personal assistance	24	40	62	91	64	62	**343**	7.09
Environmental protection	2	1	4	12	13	6	**38**	0.79
Other emergency situations (floods, meteorological phenomena, ammunition destruction)	142	94	171	359	248	253	**1267**	26.18
Uncontrolled fires	0	0	23	24	119	52	**218**	4.51
Animal rescue	9	11	17	26	22	25	**110**	2.27
Other interventions	4	7	6	42	101	185	**345**	7.13
Area insurance / surveillance	0	0	0	0	0	29	**29**	0.60
Number of cases	**487**	**533**	**734**	**1006**	**1056**	**1023**	**4839**	100

ural hazard is the likelihood of interaction between man-made, economical, social, political, cultural entities and a dangerous natural phenomenon, whose attributes (location, time, intensity, frequency) cannot be exactly determined. **Natural risk** can be defined as the possibility of human, economic or environmental losses due to a particular natural phenomenon, while **vulnerability** represents the degree of losses (0 - 100%) resulting from the possibility that a phenomenon inflicts casualties and material losses. The vulnerability degree is directly proportional to the level of social and economical development of the respective area.

The analysis of the general climatic conditions from the middle mountainous sector of Bistriţa valley has been conducted based on the studies elaborated at "Stejarul" Pângăraţi (later Piatra Neamţ) Research Station, among them the doctoral thesis of Mihăilescu (2001). The detailed analysis of the hydrological and climate risks and hazards was done based on data recorded at Piatra Neamţ (365 m altitude, ϕ 46º 56', λ 26º 23') and Ceahlău – Toaca (1897 m, ϕ 46º 56', λ 25º 55') stations between 1961 and 2013, as well as from other meteorological stations from the national network, with shorter recording periods: Ceahlău-Sat (552 m, ϕ 47º 02', λ 25º 56') and Ceahlău-Munte (1241 m, ϕ 46º 59', λ 25º 51'). We also used data from stations with temporary activity of 4-9 years established by „Stejaru" Pângăraţi Research Station: Pângăraţi (365 m, ϕ 46º 56', λ 26º 13'), Potoci (525 m), Tunel Potoci, Rugineşti (525 m) and Izvorul Alb (555 m) and rain gauges. To these were added data from hydrometric stations from the study area and its vicinity: Broşteni, Frumosu and Straja on Bistriţa River, Bilbor, Tulgheş and Bistricioara, Izvoru Alb and Tunel Potoci on Izvorul Muntelui dam lake. A part of the data regarding the evolution of the phenomena and the inflicted damage have been obtained during field surveys starting from 2011, as well as during missions of the Neamţ Emergency Situations Inspectorate and voluntary services for the management of such situations.

2. GENERAL CHARACTERIZATION OF THE MAIN CLIMATIC FACTORS THAT INFLUENCE THE OCCURRENCE OF HYDROLOGICAL AND METEOROLOGICAL HAZARDS

The topo-climatic specific of the study area is given by the ***active surface,*** mainly by landforms and the presence of the largest dam lake from the internal rivers of Romania - Izvorul Muntelui. Bistriţa River, having its springs in the Rodnei Mts, in the northern part of the Eastern Carpathians, at an altitude of 1910 m, has a length of 279 km up to its confluence with Siret at Bacău at 138 m altitude (Ujvári, 1972). The river has the longest mountainous (Carpathian) sector of all the Romanian rivers, of 216 km, meaning more than two thirds of its entire length. The analyzed valley sector, included in the central-eastern part of the Central Group of the Eastern Carpathians, is the middle one, delineated upstream by the limit with Suceava County (downstream Broşteni) and downstream by Bicaz (Fig. 1). The study area begins at 122 km from the springs, at a floodplain altitude of Bistriţa of 650 m, and ends at the Izvorul Muntelui dam (with a variable level between 487 m and 512 m and a mean of 500 m), at a distance of 175 km from Bistriţa's springs (Water cadastre atlas from Romania, 1992).

The studied sector has two parts: one upstream the lake, of a 28 km length, and a second one tributary directly to the lake. The Izvorul Muntelui dam lake has a length of 19.1 km at minimum levels and 21.5 km at maximum ones, a maximum width of 1.5, respectively 1.9 km and a surface varying between 16.5 and 29.5 km^2. Bistriţa River has a mean discharge rate of 38.1 m^3/s at Frumosu hydrometric station, upstream the lake, and exits the lake mainly through the adduction tunnel of the Stejaru hydroelectric plant with a mean discharge rate of 50 m^3/s. The main tributary

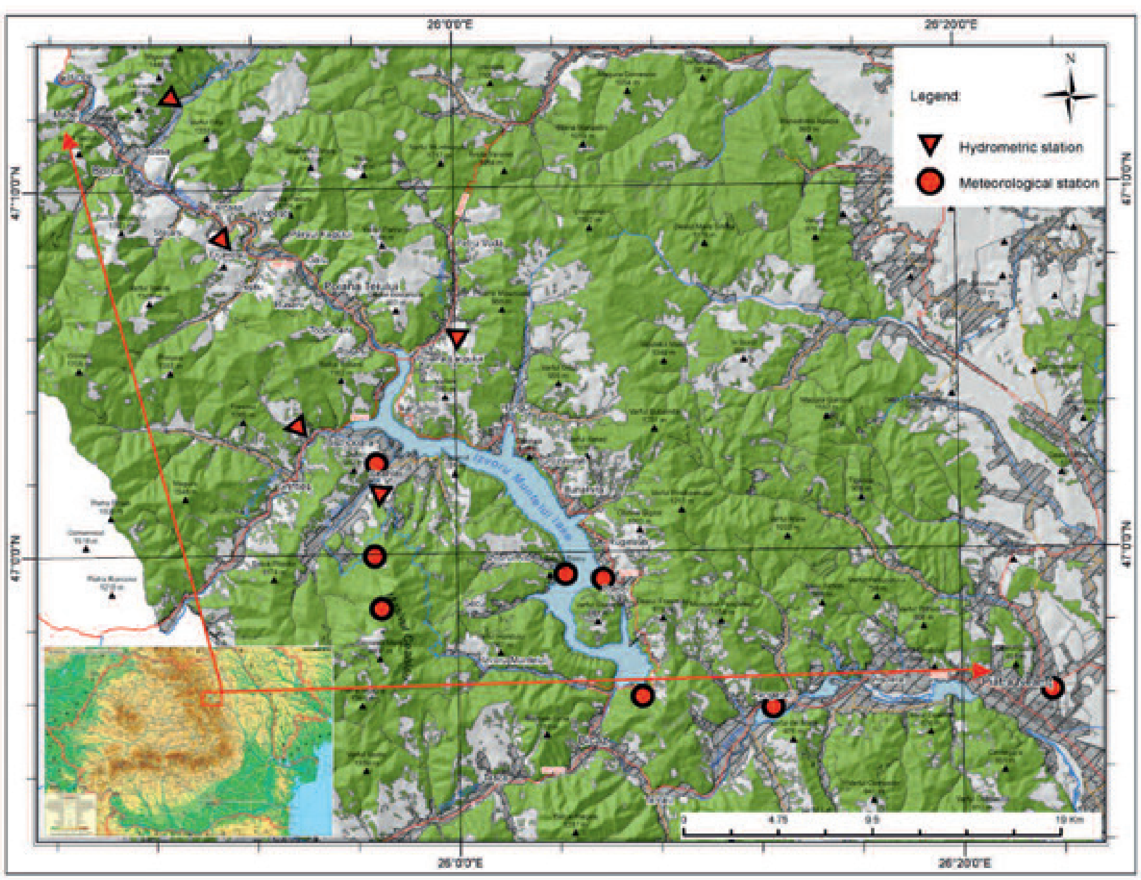

Figure 1. Geographical localization of the study area and stations

Slika 1. Geografski položaj promatranog područja i postaja in the studied area is Bistricioara, with a mean discharge rate at Bistricioara station at of 6.3 m^3/s.

Due to its morphographic, morphometric and genetic characteristics, Bistriţa valley can be considered an evolved one, including a succession of relatively large depressionary basins (Poiana Largului, Hangu - Buhalniţa, Potoci - Izvoru Alb, Pângăra i - Piatra Neamţ) alternating with narrow sectors, determined by the varied lithologic background (metamorphic crystalline rocks and sedimentary Cretaceous and Oligocene flysch) (Donisă, 1968). The minor floodplain presents braided channels and meanders, while in the major floodplain are encountered significant morphographic and morphometric variations, the general tendency being of floodplain widening downstream, from 100-200 m to 2 - 3 km. In the same direction the development of river terraces is higher, mainly for those with relative altitudes of 0.5 – 1.5 m, 2-3 m and 4 - 5 m. The contact with the slopes is made through varied types of proluvial, colluvial and deluvial glacises. Significant changes are registered at the slopes' level, due to the downstream reduction in the altitudes of the mountainous summits which frame the valley. Up to the Izvoru Muntelui-Bicaz reservoir dam the higher altitudes from the crystalline Bistriţa Mts. (Budacu - 1859 m; Grinţieşu - 1758m) and Ceahlau Mts. (Ceahlău - 1907 m) are obvious in comparison to those on the left side of the valley (Tarniţa - 1474 m, Bivolul - 1530 m). As a consequence relief energy also differs among the two valley sides, with values of 800-1000 m on the right and 600-800 m on the left. The right side slopes are shorter and with higher declivities (30-40%), while on the left side they are longer, with declivities of 10-30 %. Their strong fragmentation by the narrow and relatively deep valleys of Bistriţa's tributaries results in a relief fragmentation density of 1.8-4.4 km/km^2, whose main consequence is the different values of global solar radiation according to slopes and aspect. Thus, the climatic role of the slopes is extremely important, determining changes in the physical characteristics of the zonal air masses (Mihăilescu, 2001).

Needleleaf and broadleaf forests cover about 55-58% of the area surface, pastures and hayfields 27-29%, the aquatic surfaces 5% (the reservoir lakes of Topoliceni, Izvoru Muntelui - Bicaz, Pângăraţi, Vaduri, Bâtca Doamnei), the rest of the land being occupied by localities and few arable terrains.

For this geographical position, global solar radiation varies in latitude (decreasing towards north) and altitude (106.5 $kcal/cm^2$ at Piatra Neamţ, 100.4 $kcal/cm^2$ at Pângăraţi, 98.7 $kcal/cm^2$ at Ceahlău - Sat and 99.6 $kcal/cm^2$ at Ceahlău – Toaca, 1961 – 1998 period). The study region is under the influence of atmospheric processes specific to the Eastern Carpathian area, determined by the weather masses of the Azores and Euro-Siberian anticyclones and the Atlantic and Mediterranean cyclones. The mountainous relief essentially influences the local and regional air circulation (Mihăilescu, 2001). On the high summits the wind regime expresses the general atmospheric circulation, dominant being the western one (40-45%). In the lower valley sectors, opened towards the Sub-Carpathians and the tableland unit, the frequency of eastern continental air masses increases.

The general circulation of the air masses is mainly western. The Atlantic cyclones that move towards east through the North-European Plain reach the studied area only with the southern margins of the weather fronts. Important sources of rainfall are the Mediterranean cyclones which tend to retrograde above the Black Sea and induce some of the most intense rainfalls.

3. ASPECTS OF THE MAIN HYDROLOGICAL AND METEOROLOGICAL PHENOMENA GENERATING EMERGENCY SITUATIONS.

The characteristics of the climatic elements from the analyzed valley sector are representative for the *temperate climate of medium and low mountains* from the Eastern Carpathians, moderately cool at lower altitudes and cool at medium ones, with elements of moderately warm climate in the area of Izvoru Muntelui reservoir and warm mountainous climate downstream Pângăraţi - Vaduri lakes (Mihăilescu, 2001).

In the analysis of the main climate characteristics have been taken into account, for the

1961- 2013 period, those meteorological phenomena which present a high degree of climatic risk.

Air temperature. The analysis of mean annual and seasonal values in altitude has separated:
- a *warm climate* at altitudes lower than 400 m, with mean annual temperatures of 8-9°C, - 4°C in January and 22-24°C in July;
- a *moderately warm climate* between altitudes of 400-900 m, with a mean annual temperature of 6-8°C, respectively – 4°C in January (with frequent thermal inversions) and 16-19°C in July;
- a *moderately cool climate* between 900-1300 m altitude, with a mean annual value of 4 - 6°C, respectively - 4 – -5.5°C in January and 13 - 16°C in July;
- a *cool climate* between 1300-1700 m, with annual means of 2-4°C, respectively minus 5.5º – minus 7°C in January and 11-13°C in July;
- a *very cool climate* at altitudes over 1700 m, with a mean annual air temperature of 0 - 2°C, minus 7º – minus 9.5°C in January and 9-11°C in July.

Important variations are registered in the monthly or daily temperature regime also. The highest variations of air temperature have been registered, as expected, for the absolute minimum and maximum values, parameter analyzed for the meteorological stations with data for longer periods, for the entire functioning duration, up to 2002 (Piatra Neamţ, 1899-2002, Ceahlău - Sat 1946-1996, Ceahlău - Toaca 1964-2002). The maximum thermal values have been recorded in August, of 39.0°C at Piatra Neamţ (in 1957), 36.5°C at Ceahlău - Sat (in 1946) and of 25°C at Ceahlău - Toaca (in 1987 and 1998). The absolute minimum values have been recorded in January 1942 at Piatra Neamţ in the air masses of the Siberian cold front (as was the situation for all the meteorological stations south and east of the Carpathians) -28.2ºC at Ceahlău-Sat in February 1965 and -30.5ºC in January 1954 at Ceahlău - Toaca. The cold period of the year is favorable for thermal inversions, with significant effects on the freeze-thaw process, especially on the Bistriţa valley upstream Izvorul Muntelui dam lake. In other parts of the river course the lakes mitigate the effects of the phenomenon. The air thermal regime and the water freeze-thaw one are highly different in the microclimatic areas of the reservoirs, mainly in the case of Izvoru Muntelui (mean annual water volume between 351 and 1035 millions cubic meters) (Ujvári, 1972).

Winds. If at higher altitudes wind direction in Romania is subordinated to the general atmospheric circulation, as it can be seen at Ceahlău – Toaca station (the dominant winds being the western ones with 46.9% annually, 50% during summer and 55% in November), at lower altitudes the main circulation is directed along Bistriţa valley, becoming a north-western one. The dominant direction is imposed at the valley level and by the descendant mountain winds (breezes) which occur annually in a daily interval longer than the ascending valley winds from south-east (Mihăilescu, 2001). The system of mountain breezes from Bistriţa valley is the best expressed in Romania. It is also present on tributary valleys, for example at Ceahlău - Sat, where the dominant south-western direction of the descending wind on the Schit brook makes up to 23.0%. At Piatra Neamţ, where the lower mountainous sector of Bistriţa has a west-east direction, the western winds dominate with 22.3%. This relative periodicity of mountain breezes is modified during the year moments when important weather changes occur.

Atmospheric calm periods increase from the valley axis (33.3% at Piatra Neamţ) towards the tributary valleys (51.3% at Ceahlău - Sat), to decrease again on the high summits (14.1% at Ceahlău - Toaca). The highest mean speed values have been recorded at all stations on the maximum frequency direction: western with 4.6 m/s at Piatra Neamţ and 11.0 m/s at Ceahlău – Toaca and south-western with 3.5 m/s at Ceahlău - Sat.

The mean annual wind speed decreases from the valley axis (3.0 m/s at Piatra Neamţ) towards the tributary valleys (1.5 m/s), and then strongly increases on the mountain peaks (9.8 m/s). Here is recorded the highest mean wind speed in Romania, although the Toaca peak from Ceahlău Mts. only reaches 1897 m, in comparison to other meteorological stations in Romania situated at higher altitudes. This situation is explained by the dominant position of the mentioned peak in the middle of the longitudinal Eastern Carpathian chain, perpendicularly on the main wind direction.

During the day, the maximum speed is recorded at 7.00 at Piatra Neamţ, on the background of the strong descending mountain winds; at 13.00 in isolated areas such as Ceahlău-Sat and at 7.00 at Ceahlău-Toaca (11.1 m/s), at a transition between the low areas with maximum speeds at lunch and the higher ones where the maximum speeds occur during the night. Strong winds (speeds over 15 m/s) occur on the lower mountainous Bistriţa valley with a mean frequency of 1.5% at Piatra Neamţ, where the maximum recorded speed has been of 34 m/s. In the sheltered valleys, as is the case of Ceahlău – Sat meteorological station, strong winds are almost inexistent (under 0.1 %), and the maximum speeds are much lower (17 m/s). On the high summits, at Ceahlău – Toaca, strong winds have a frequency of 14.1%, while the winds with speeds over 40 m/s have a mean frequency of 1.5%.

Figure 2. Material losses produced by strong winds during a storm, Piatra Neamţ, 2009

Slika 2. Materijalni gubici nastali jakim vjetrom tijekom oluje, Piatra Neamt, 2009.

Strong winds, even if their occurrence frequency at the level of the inhabited valleys is low, can have a risk potential, inducing material losses (fig. 2).

Rainfalls, important climatic risk factor. The mean annual rainfall quantities have been averaged for the analyzed valley sector (Mihăilescu, 2001) at 605 mm at Piatra Neamţ, 664 mm at Pângăraţi, 708 mm at Tarcău and 675 mm at Ceahlău-Sat, but with important annual and seasonal variations. These low quantities are due to the position in an area affected by föehn from the western slope of the Eastern Carpathians, as well as to the sheltered position of Bistriţa valley, situated almost perpendicularly on the direction of the western moist air masses.

Analyzing the evolution of rainfall quantities in Bistriţa basin at Frumosu station (considered representative for the area upstream Izvoru Muntelui reservoir) for the 2003 - 2013 period, it can be noticed that the multi-annual value is of 652.8 mm, varying between 416 mm in 2011 and 821 mm in 2010 (Fig. 3).

The oldest rainfall measurements on Bistriţa valley point out as memorable years 1912, when at Piatra Neamţ have been recorded 1165 mm, and the droughty year of 1945, with

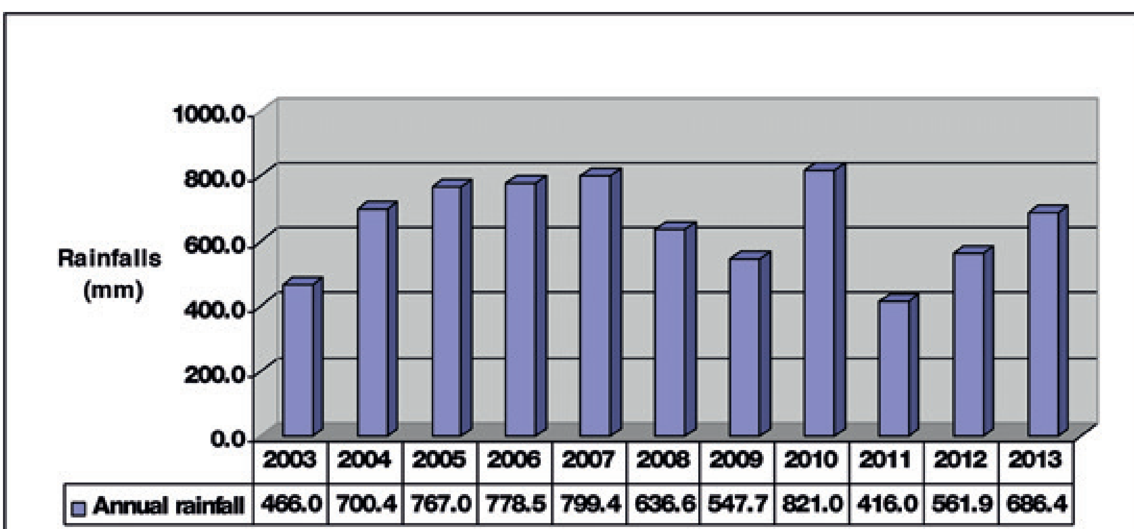

Figure 3. The evolution of annual rainfall quantities in Bistriţa basin – Frumosu station (2003 – 2013)

Slika 3. Godišnji hod oborine u slivu Bistriţa - postaja Frumosa (2003.-2013.)

448 mm at Piatra Neamţ and 489 mm at Ceahlău - Sat. During the year, the largest rainfall quantities are recorded in the warm season during May-June (Piatra Neamţ - 103 mm, Pângăraţi - 121 mm, Tarcău 114 mm, Ceahlău - Sat - 124 mm, Rugineşti - 124 mm, Frumosu – 275.3 mm in 2013, Ceahlău Schit - 307 mm in 2010 etc.) and July (188.5 mm at Sabasa in 2010). The lowest quantities are recorded in the cold season, respectively December and January (Piatra Neamţ - 20 mm, Pângăraţi - 21 mm, Tarcău - 23 mm, Ceahlău - Sat - 23 mm). The absolute monthly maximum value measured at Piatra Neamţ was of 413 mm in September 1912 and 312 mm in June 1948, while at Pângăraţi the maximum monthly rainfall have been of 308 mm in May 1971. In comparison, rainfall lacked completely at Piatra Neamţ in March 1934 and December 1910, while at Ceahlău – Sat in April 1948 was measured 1 mm rainfall.

The values of the maximum rainfall quantities in 24 hours have been of 91 mm at Pângăraţi in July 1969; 87.6 mm at Piatra Neamţ in June 1989; 81.9 mm at Ceahlău-Sat in June 1949 and 84.7 mm in June 2010 at Ceahlău - Schit.

Floods, hydrologic risk determined by a climatic one (rainfalls). Floods represent the most frequent natural hazard in Neamţ County. In the studied area they occur frequently on Bistriţa's tributaries (Sabasa, Schit, Hangu). The cause is represented by abundant rainfall determined by accentuated atmospheric instability and the succession of frequent atmospheric fronts.

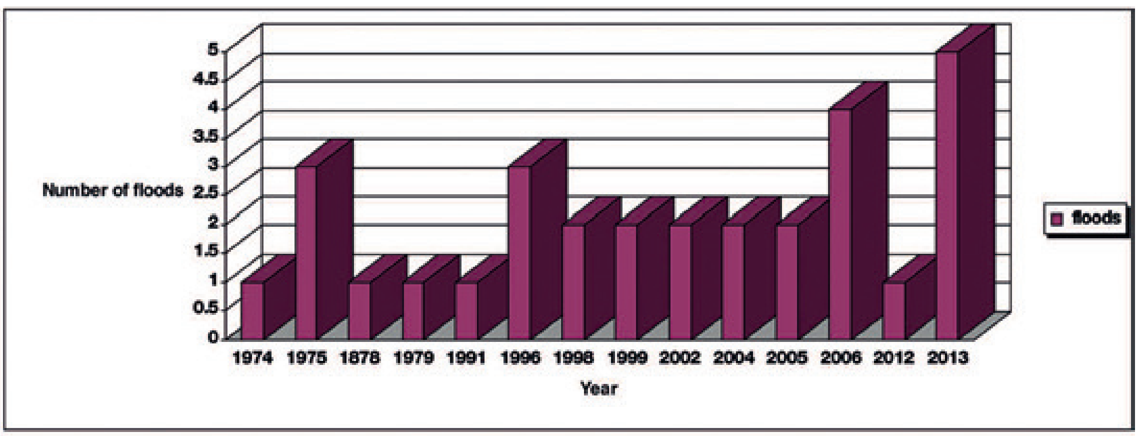

Figure 4. Number of floods during 1974 – 2013 in Hangu Township (Defense plan against floods, ice dams and accidental pollution on water courses from Hangu Township, 2013)

Slika 4. Broj poplava u razdoblju 1974.–2013. u Hangu (Plan obrane od poplava, zdrobljenog leda i incidentnih zagađenja na vodenim površinama u Hangu, 2013.)

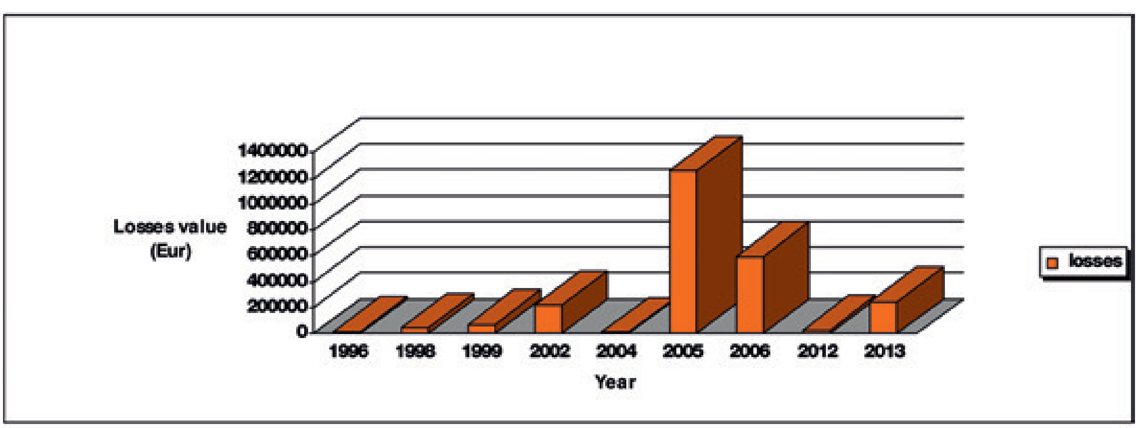

Figure 5. The variation in the losses generated by floods during 1996 – 2013 in Hangu township

Slika 5. Gubici uzrokovani poplavama u razdoblju 1996.–2013. u Hangu

The frequency of flood occurrence and their intensity have increased, mainly due to climatic changes and the reduction in the river transportation capacity due to buildings constructed in the floodplain. This fact can be seen in the graphic showing the variation of floods during 1974 - 2013 in Hangu township (Fig. 4).

Although the number of floods has increased during the analyzed period, after 2005 it was accompanied by a reduction in the losses inflicted. This shows that the structural and non-structural measures taken by local administrative authorities and institutions responsible for the management of emergency situations have been effective (Fig. 5).

Flood intensity has also been amplified due to human influence on environmental elements: deforestation, not managing torrential discharge or drains, the existence of badly projected and constructed works, as well as by buildings constructed in the floodplains. Abundant rainfall have led to important water level increases in some isolated river sectors, the most affected areas being those from the upper basins of Bistriţa, Tarcău, Bicaz, Bistricioara and Hangu.

The year 2005 has represented one of the key moments in what regards flood intensity in the county, as a consequence of the large volume of rainfall. This has been the year when defense levels have been exceeded at 14 of the 30 hydrometric stations that record daily the evolution of water levels from 1970 up to present (tab. 2).

During July-August 2005, floods have occurred also on a series of smaller rivers lacking hydro-

Table 2. Flood frequency and value of material losses in July-August 2005 (Synthesis reports regarding flood defense - SGA Neamţ).

Tablica 2. Popis poplava i materijalnih šteta u razdoblju srpanj–kolovoz 2005.

Locality	Flood period	Losses value EUR	Hydro-meteorological data
Ceahlău	11 - 13.07	1311659	Significant large rainfall quantities accompanied by thunders and lightning. At Ceahlău, Schit brook exceeded the attention level (AL) with 10 cm (H= 10 cm, Q= 18.30 cm^3/s), with a maximum on 12.07.2005, at 20.00 when the AL was exceeded by 25 cm (H=25 cm, Q= 29.5 cm^3/s).
Borca		35874	
Poiana Teiului		359641	
Hangu		252017	
Borca	03 - 08.08	16816	During 03-05.08.2005 have been recorded 15.5 l/m^2 at Frumosu, Farcaşa in one hour and 40 minutes, with dense hail (mean diameter 1cm) and 18.4 l/m^2 in 48 hours; 22.2 l/m^2 at Sabasa station, Borca in two and a half hours, with dense hail (mean diameter 2 cm) and 26.8 l/m^2 in 48 hours. During 05-07.08.07.2005 were recorded 7.7 l/m^2 at Frumosu station and 12.2 l/m^2 in 48 ore; 5.2 l/m^2 at Bistricioara station, Ceahlău and 9 l/m^2 in 48 hours.
Farcaşa		941704	
Hangu	17 - 21.08	879596	On extended areas have been recorded significant rainfalls with lightning and wind intensification, the measured quantities being: During 16.08.2005, 07.00 AM - 18.08.2005, 07.00 Am: At Sabasa station on Sabasa brook, Borca – 11.3 l/m^2 in 48 hours; at Poiana Largului station on Bolătău brook – 47.2 l/m^2 in 24 hours / 49.7 l/m^2 in 48 ore; at Frumosu station on Bistriţa – 34.8 l/m^2 in 24 hours / 37.9 l/m^2 in 48 hours. During 18.08.2005, 07.00 AM - 20.08.2005, 07.00 Am at Sabasa station on Sabasa – 8.5 l/m^2 in 24 hours / 64.8 l/m^2 in 48 hours; at Poiana Largului on Bolătău – 2.9 l/m^2 in 24 hours / 78.9 l/m^2 in 48 hours; at Ceahlău on Schitu brook – 8.1 l/m^2 in 24 hours / 73.2 l/m^2 in 48 hours. The levels on all river courses have been rising.

metric stations and on a series of stream flows which have recorded important water quantities coming from the slopes.

The years 2008 and 2010 have been also referential for floods occurring in Neamţ County, due to torrential rainfall during June and July (tab. 3). During the floods from these years, rainfalls have fallen almost daily. Significant periods that have produced floods and torrential discharge have been identified in their regime. In this context all the rainfall quantities fallen have been important for maintaining a high soil humidity, contributing to reduced infiltrations and an effective participation to discharge formation.

In 2013, torrential rainfall from June 6 - 8 (07.06.2013 at Sabasa station on Sabasa – 17.5 l/m^2 between 06.10 - 07.00 hours; Poiana Largului station on Bolătău – 21.2 l/m^2 between 06.10 - 08.25 hours; Frumosu station on Bistriţa – 28.5 l/m^2 between 06.00-09.10; Ceahlău station on Schit – 23.8 l/m^2 between 06.00-09.10 hours) and June 22nd – July 6th (tab. 4) have generated important discharge and level increases on some rivers from Bistriţa basin, producing floods in our study area (fig. 6).

Table 3. Rainfall quantities in 24 hours during 23. - 29.7.2008 and 20.6. – 29.7.2010 (Synthesis reports regarding defense against flooding – S.G.A. Neamț)

Tablica 3. 24-satne količine oborine u razdoblju 23.–29.7.2008. i 20.6.–29.7.2010.

Hydrometric station / gauge	River	Rainfall (l/m^2) in 24 hours per days (7.00 a.m.)							Total quantity for 23 – 29.07.2008
		23.07	24.07	25.07	26.07	27.07	28.07	29.07	
Sabasa	Sabasa	9.4	50.6	26.5	0.5	22.5	25.4	4.2	138.7
Frumosu	Bistrița	8.8	50.0	13.5	2.3	6.8	38.3	0.2	74.9

Hydrometric station / gauge	River	Rainfall (l/m^2) in 24 hours per days (7.00 a.m.)											Total 20.06-01.07. 2010	Mean monthly values (June)
		20-21. 06. 2010	21-22. 06. 2010	22-23. 06. 2010	23-24. 06. 2010	24-25. 06. 2010	25-26. 06. 2010	26-27. 06. 2010	27-28. 06. 2010	28-29. 06. 2010	29-30. 06. 2010	30.06-01.07. 2010		
Bistrița	**Frumosu**	10.30	27.10	50.80	13.90	2.40	4.10	10.40	2.90	14.60	9.20	8.10	153.80	**99.97**
Sabasa	**Sabasa**	15.20	27.30	53.50	5.10	2.10	3.40	14.20	1.10	24.30	14.70	20.50	181.40	**91.73**
Bolătău	**P.oiana Largului**	1.10	27.50	54.90	8.40	1.20	5.50	31.20	1.50	16.50	5.90	12.80	166.50	**91.13**
Schit	**Ceahlău**	5.50	35.50	84.70	30.70	4.10	19.50	43.50	7.40	30.90	11.10	34.10	307.00	**107.75**

Hydrometric station / gauge	River	Rainfall (l/m^2) in 24 hours per days (7.00 a.m.)											Total 02.07-15.07. 2010	Mean monthly values (July)
		02-03. 07. 2010	03-04. 07. 2010	04-05. 07. 2010	05-06. 07. 2010	06-07. 07. 2010	07-08. 07. 2010	10-11. 07. 2010	11-12. 07. 2010	12-13. 07. 2010	13-14. 07. 2010	14-15. 07. 2010		
Sabasa	**Sabasa**	3.2	8.5	4.5	0.5	3.2	2.1	2.2	5.4	1.2	17.6	1.4	49.8	**99.9**
Bolătău	**P. Largului**	0.0	0.0	0.0	0.0	6.3	1.6	8.0	1.4	0.0	23.6	0.7	41.6	**104.7**

Table 4. Rainfall quantities in 24 hours from June 21st – July 6th 2013 (Synthesis report regarding defense against floods – S.G.A. Neamț).

Tablica 4. 24-satne količine oborine u razdoblju 21. lipnja - 6. srpnja 2013.

River	Hydrometric station / gauge	Rainfall (l/m^2) in 24 hours (6.00 a.m.)															Total June 2013	Mean monthly rainfall (June)
		21-22 .06.	22-23. 06.	23-24. 06.	24-25. 06.	25-26. 06.	26-27. 06.	27-28. 06.	28-29. 06.	29-30. 06.	30.06-01.07.	01-02. 07.	02-03. 07.	03-04. 07.	04-05. 07.	05-06. 07.		
Bistrița	Frumosu	28.8	17.7	1.4	19.9	4.2	2.1	12.8	12.1	6.2	0.0	0.0	0.0	0.0	1.1	0.8	275.3	**100.7**
Bistrița	Straja	0.0	40.1	2.0	30.4	23.4	8.7	12.2	5.8	2.1	0.0	0.0	0.0	0.0	2.1	10.4	244.1	**113.3**
Sabasa	Sabasa	43.2	24.8	0.6	14.6	9.1	1.2	12.3	34.2	2.4	0.0	0.0	0.0	0.0	2.1	1.0	343.8	**98.2**
Bolătău	Poiana Largului	1.2	8.1	10.2	27.3	10.2	0.0	14.9	8.8	14.8	0.0	0.0	0.0	0.0	2.4	0.9	266.1	**96.7**

Figure 6. Effects of the hydrological and meteorological phenomena from June 5-8 and 22 – 23.6.2013 in the townships of Borca and Farcașa

Slika 6. Utjecaj hidroloških i meteoroloških pojava u razdoblju 5.–8. lipanj i 22.–23. lipanj 2013. u područjima Borca i Farcașa

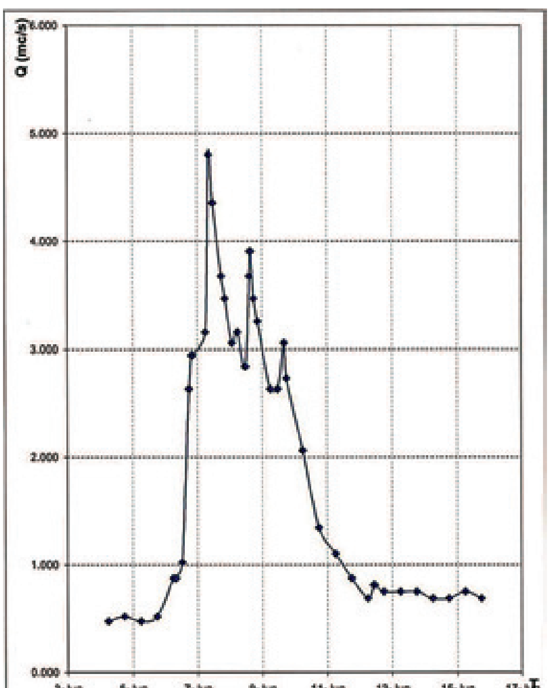

Figure 7. Hydrograph of the flood from June 7th 2013, Schit brook, Ceahlău station

Slika 7. Hidrograf poplave 7. srpnja 2013. godine rječice Schilt, postaja Ceahlău

The torrential discharge regime on the mentioned courses can be seen in the hydrograph of the flood occurred on Schit brook at the Ceahlău hydrometric station (Fig. 7).

Ice jams. Ice jams, complex hydrological and meteorological phenomenon, specific for the cold season and determined by river water freeze-thaw processes, is common for mid-latitude area rivers and is an important risk factor in flood occurrence. On Bistriţa and some of its tributaries the phenomenon is the most frequent and intense in the country.

Ice jams (*zator*, Russian; *embâcle*, French; *eisbarre*, German: *zăpor*, Romanian) is the name given to ice dams that form on rivers during the winter periods. The consequence of ice jams formation is the blockage of river waters that leads to a decrease in water level downstream and sometimes to a sudden increase upstream, where important floods may occur. The destructive effects of ice jams determined Ashton (1986) to consider them the largest hazard of winter phenomena.

According to the moment of occurrence, freeze and thaw ice jams can be distinguished. The freeze ice jams occur during the period of river water freezing from the beginning of the winter phenomenon, and are caused by the accumulation of frazil ice under the ice bridge. Thaw ice jams are caused by the accumulation of ice floes on the river in certain sectors, resulted from the breaking of ice jams due to increases on air temperature. In Bistriţa basin (upstream Izvoru Muntelui – Bicaz reservoir) the phenomenon has a larger frequency in the upper course (Dornelor Depression up to Zugreni) and a lower one in Zugreni – Crucea sector (Ştefănache, 2003, 2007; Surdeanu et al, 2005; Rădoane et al 2009; Giurma and Ştefănache, 2010). In the Crucea – Borca sector these types of ice jams have a lower frequency,

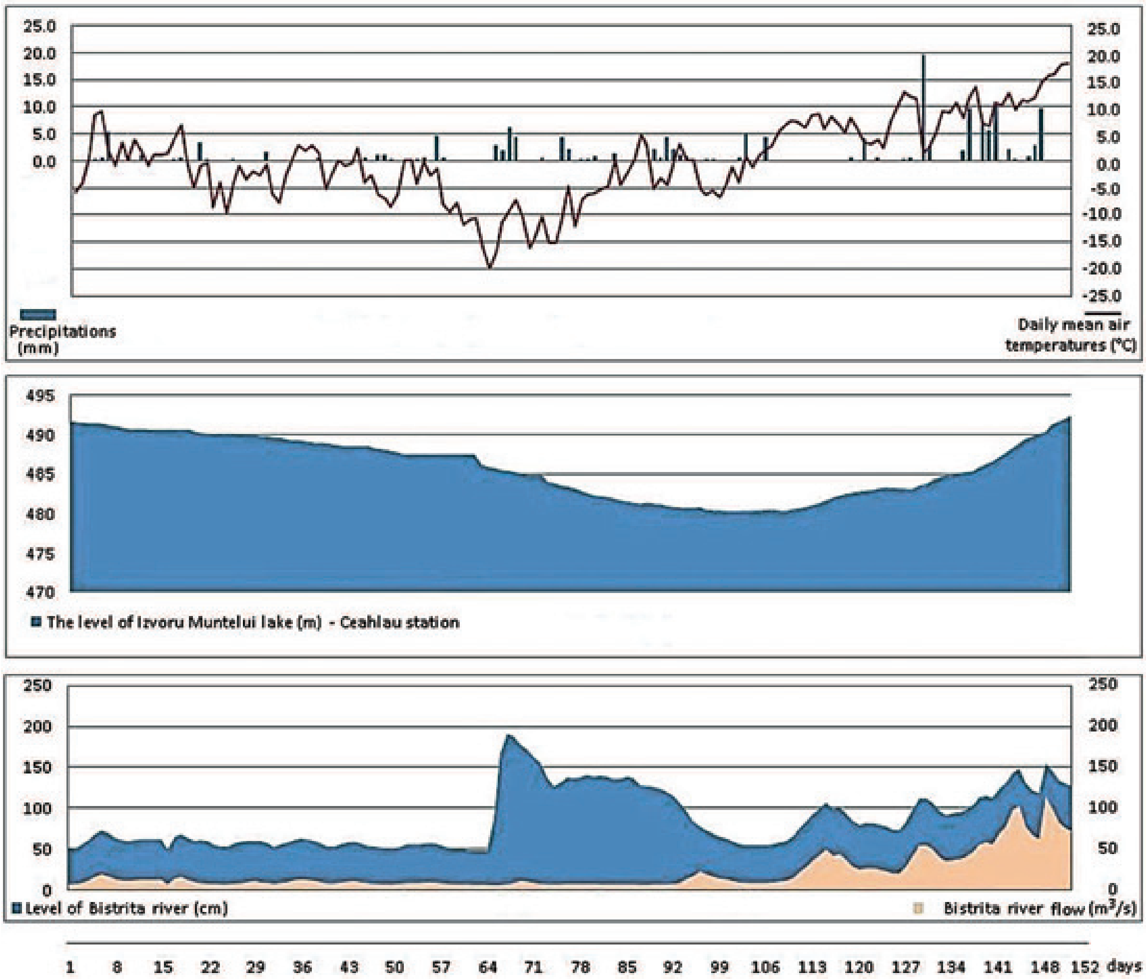

Figure 8. Variation of the hydrological and meteorological factors that have influenced the occurrence of ice dams at Frumosu station on Bistriţa, 1 December 2011 – 30 April 2012

Slika 8. Promjena hidroloških i meteoroloških parametara koji su utjecali na stvaranje zdrobljenog leda na postaji Frumosu na rijeci Bistriţa, 1. prosinac 2011. - 30. travanj 2012.

while downstream Borca they have not been mentioned.

After the emplacement of Izvoru Muntelui – Bicaz reservoir, another type of ice jam occurred downstream Borca, which blocks the floodplain on a 20 km length, for 14 – 35, sometimes even more than 40 days (at Frumosu station on Bistriţa), and which has a annual frequency and sometimes occurs 2 - 3 times per year (Fig. 8, 9).

The graphics show the existence if ice jams during 04.02 - 10.03.2012 (36 days). The ice jam formed as the level of Bistriţa at Frumosu section rose up to 191cm on February 2nd, temperatures have been below 0ºC, the discharge constant and the level of the Izvoru Muntelui reservoir below 490 m (Gaman, 2013). On February 5th at 07 hours, the hydrologic situation on Bistriţa upstream Izvoru Muntelui was the following:

- between Poiana Largului viaduct up to 200 m downstream Ruseni bridge, the river presented ice jams with thicknesses of 0.2-2.5 m, on 6.8 km;
- from Săvineşti bridge up to 0.4 km upstream Frumosu bridge, the river had ice agglomerations (frazil ice and snow) with thicknesses of 0.2-1.0 m alternating with free water areas of 1-3 m width, on 30 - 35% of the sector length;
- with temperatures at Frumosu station of -10.5°C, frazil ice came from upstream on 40% of the water surface.

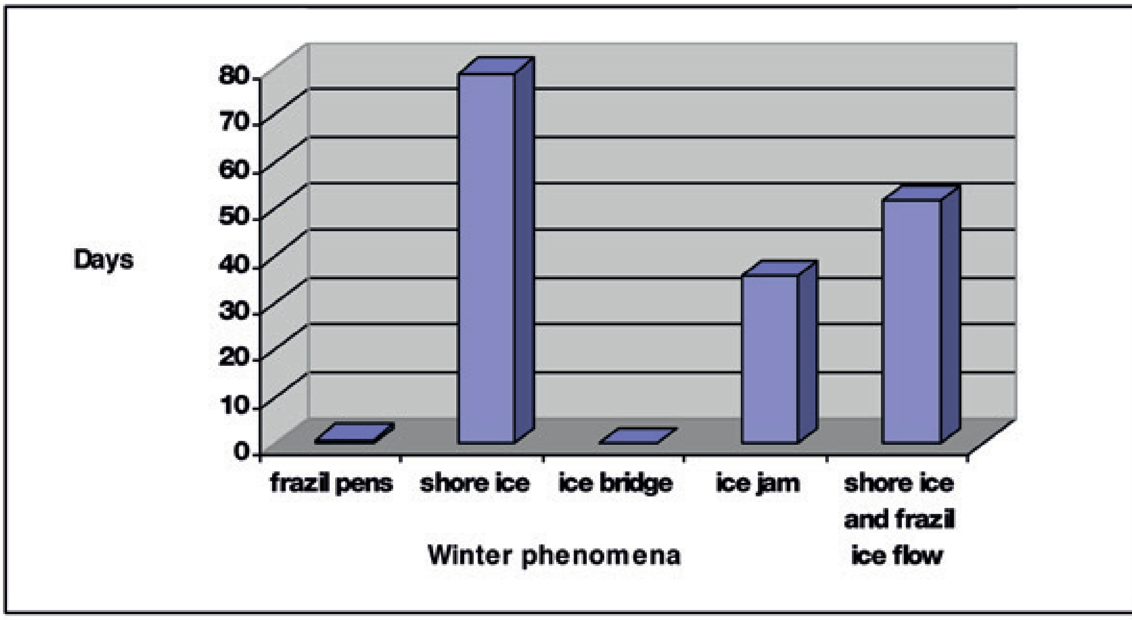

Figure 9. Quantitative evolution of winter phenomena on Bistriţa at Frumosu section in the 2011 – 2012 winter

Slika 9. Zimski fenomeni u predjelu Bistrita na postaji Frumosu, zima 2011/2012

Figure 10a. Ice jams on Bistriţa in 2009

Slika 10a. Zdrobljeni led na rijeci Bistriţa u 2009. godini

Figure 10b. Modified course of Bistriţa on the bottom of the Izvoru Muntelui – Bicaz reservoir after the clogging of the old floodplain, 2012

Slika 10b. Promjena toka rijeke Bistriţa na dnu rezervoara Izvoru Muntelui – Bicaz nakon začepljenja zbog prijašnje poplave, 2012

This type of ice jam has been signaled first by Ciaglic et. al (1975). The authors mention that the phenomenon has two phases: the first submerged phase when the ice floe brought by the river enters under the ice bridge on a certain distance. The blocking of the river section is done by the deposition of the ice floe on the bottom of the old floodplain and not by "sticking" to the lower base of the ice bridge (as it is usual on rivers), from where it extends slowly in the floodplain, sometimes filling it and overflowing (Fig. 10 a, b).

The authors consider the phenomenon to be human-influenced, because the flows of ice floes and packs have occurred in the area long ago before the creation of the Izvoru Muntelui reservoir. At the same time the phenomenon is also considered atypical, because the ice floes agglomerations occur in the absence of an ice bridge (Rădoane et al, 2009).

To avoid losses, Ştefănache (2007) and Giurma and Ştefănache (2010) propose as solution the careful monitoring of the phenomenon. Ciaglic (2008, 2009) considers that for substantially diminishing the effects of ice jams there the causes need to be addressed, respectively the ice floes that manifest almost continuously during the winter along the whole river sector between the confluence with Crucea and Bistriţa's entrance into the reservoir. He proposes two solutions:

1. diminishing the formation of ice needles and as a consequence of bottom ice that generated the ice floes;
2. at the beginning of the cold season, when the first winter phenomena occur on the river, and on the reservoir ice bridges of up to 15 cm occupy a small surface at the bottom of the lake, a free water channel should be maintained, whose side should be wider than the river's underwater floodplain and which should follow the old river course. Thus the ice floes would flow towards the reservoir area lacking ice bridge, where it would dissipate and melt into the mass of water due to the temperatures of 4-5^{o}C.

The idea of diminishing the ice floes has occurred during the research conducted in the extremely cold winter of 1963 – 1964 on Bistricioara, right side tributary of Bistriţa close to the reservoir entrance.

Although the climatic, geological and morphological conditions were identical, the river basin being smaller, in its upper part (upstream the confluence with Azod brook), the ice bridge with thicknesses of 35 - 40 cm covered, with very small exceptions, the entire river surface. Downstream the ice bridge suddenly disappeared, even if air temperature was the same. The conducted measurements led to the conclusion that the phenomenon is caused by the nature of the hydraulic relationships established between the river and the underground waters (Ciaglic, 1965; Ciaglic and Vornicu, 1973). This phenomenon has also been observed during our field research in March 2012, when water temperature measurements were conducted in different areas (Fig. 11).

Figure 11. Ice bridges on Bistricioara downstream Azod brook and on Azod brook at the confluence with Bistricioara, 2012

Slika 11. Ledeni mostovi na Bistricioara nizvodno od potoka Azod i na ušću potoka Azod u rijeku Bistricioara, 2012. godina

Re-conducting research after the damages inflicted by ice jams in 2003, the conclusion was that besides the hydraulic exchange relations, latent heat liberated during the disintegration reactions of radioactive elements from the underground participated to the phenomenon. The areas where ice jams don't occur or are weakly manifested are those where uranium deposits exist (the exploitation from Leşu Ursului on Bistriţa, Bradu and Putna Întunecoasă on Bistricioara).

Taking into account the fact that the effect of the attenuation in the intensity of ice formations on Bistricioara is very strong (up to disappearance) due to the high water losses through infiltration (> 40 %) in the Capul Corbului area and that then it reappears in the left bank upstream the confluence with Azod brook at Sângeroasa – Tulgheş, we might conclude that the same effect might be obtained on Bistriţa.

In this respect Ciaglic V. (2008 and 2009) propose that in the many points that Bistriţa has water losses (areas identified together with Ciaglic in the field in the winters of 2011–2012 and 2012-2013) small transversal submerged rapids, with heights of 40–50 cm, to be built. Along these would occur a level increase upstream, increasing the discharge lost through infiltration, which on Bistriţa is smaller than on Bistricioara. The effect would be a substantial increase in the temperature of waters downstream, where the underground waters would come back to the river, diminishing the occurrence of ice needles, bottom river ice and ice floes.

The most important floods occurred due to ice jams and other favorable factors (the existence of bridges that reduce the dimensions of the floodplain, unfinished waterworks, irrational extension into the floodplain of households), with human casualties and important

Table 5. Characteristics of the ice jams determined floods from 24.12.1995 and 1.1.2003

Tablica 5. Karakteristike zdrobljenog leda u poplavama 24.12.1995. i 1.1.2003.

Flood date	River length with ice jams (Km)	Ice thicknes s (m)	Maximum rainfall in the basin (l/m^2)	Human casualties	Dead animals	Losses EUR
24.12.1995	21	5-7	38,1	-	-	137220
01.01.2003	21	5-7	13,4	3	845	347533

material losses, have occurred on December 24th 1995 and January 1st 2003. The comparative data of the two floods are presented in table 5.

For the study area, climate risks may also be considered the heavy snows and blizzards which block the traffic on the DN15 national road in the Bicaz – Potoci sector, hails and thunder storms and long droughts which may produce fires in households or forests (0.25 ha in Bicaz Forestry Fund on August 12th 2013), fogs and avalanches (Ceahlău Mts.).

4. CONCLUSIONS

Hydrological and meteorological risk phenomena that have occurred during the last 15 years in the middle Bistriţa valley have strongly affected the human settlements, defense structures, infrastructure, agricultural terrains etc. The causes that influence the occurrence of these hazards are natural and anthropic.

To prevent floods due to heavy rainfall and winter ice dams on the Bistriţa valley (especially upstream Izvoru Muntelui reservoir) and an efficient risk management are needed the following measures:

- *structural measures*: a corresponding management of floodplains, slope forestation and mitigating soil erosion, conducting works to correct torrential organisms, continuing works needed to energetically manage Bistriţa river, re-dimensioning bridges (Romanescu, 2005);
- building transversal submerged rapids in certain points where Bistrita river has water losses, so as to diminish the occurrence of ice needles, bottom river ice or ice floes;
- *non-structural measures*: education through mass-media for preventing and alleviating extreme phenomena, improving means of alerting population, improving means of synoptic surveillance of regions vulnerable to risks so as to prevent population, strengthening legislation and administrative measures to ensure an efficient activity of all organisms involved and of population in case of disasters, creating concrete plans of managing natural risks, involving non-governmental and ecological organizations and people in mitigation activities of extreme natural phenomena (strategies of managing meteo-climatic risks, according to the conferences from Rio, 1992 and Yokohama, 1994).

REFERENCES

Ashton, G. D., 1986: River and Lake Ice Engineering. Waterres Publications. Littleton. Co. USA.

Balteanu, D., 1992: Natural Hazards in Romania. R. R. Geogr. Bucureşti.

Bălteanu, D., Alexe, R., 2001: Hazarde naturale şi antropogene. Edit. Corint. Bucureşti.

Bogdan, O., Marinica, I., 2007: Hazarde climatice din zona temperată, geneză şi vulnerabilitate cu aplicaţii în România. Editura Lucian Blaga. Sibiu.

Ciaglic, V., 1965: Evoluţia fenomenului de îngheţ pe râul pe râul Bistricioara, în iarna 1963 – 1964. Rev. Hidrotehnica, nr. 10:2.

Ciaglic, V., Rudnic, I., Timofte, V., Vornicu, P., 1975: Contribuţii la cunoaşterea fenomenului de colmatare a lacului de acumulare Izvoru Muntelui. IMH. Studii de hidrologie. XLIV. 235-261.

Ciaglic, V., Vornicu, P., 1973: Observaţii asupra schimbului de apă dintre râul Bistricioara şi stratul acvifer freatic din albia majoră. Studii de hidrogeologie, INMH Bucureşti.

Ciaglic, V., 2008: Soluţii pentru eliminarea gheţurilor de pe valea Bistriţei. Monitorul de Neamţ. 02 februarie.

Ciaglic, V., 2009: Metodă brevetată de natură pentru înlăturarea zăporului de pe Bistriţa, România Liberă. 02 martie.

Donisa, I., 1968: Geomorfologia văii Bistriţei. Editura Academiei. Bucureşti.

Gaman, C., 2013: Hazarde hidrologice generatoare de situaţii de urgenţă, în sectorul montan mijlociu al văii Bistriţei. Seminarul Geografic Internaţional ,,Dimitrie Cantemir”. Ediţia a XXXIII-a. Univ. Al. I. Cuza, Iaşi.

Gaman C., Apostol. L, (2013), Climate and hydrological risks in the middle Bistriţa valley, Romania, Conference Challenges in meteorology 3: “Extreme Weather and impact on society”, Zagreb,Croaţia.

Gotiu, D., Surdeanu, V., 2007: Noţiuni fundamentale în studiul hazardelor natural. Edit. Presa Universitară Clujeană. Cluj - Napoca.

Grecu, F., 2003: Hazarde şi riscuri natural. Edit. Universitară. Bucureşti.

Giurma, I., Ştefanache, D., 2010: Fenomene de iarnă pe râul Bistriţa între hazard şi vulnerabilitate. Lucr. Conf. jubiliare INHGA. Univ. Tehn. „Gh. Asachi". Iaşi.

Mihailescu, F. I., 2001: Studiu climatic şi microclimatic al văii râului Bistriţa în sectorul montan, cu lacuri de acumulare. Edit. Ex. Ponto. Constanţa.

Moldovan, F., 2003: Fenomene climatice de risc. Edit. Echinocţiu. Cluj - Napoca.

Radoane, M., Ciaglic, V., Radoane, N., 2009: Hydropower impact on the ice jam formation on the upper Bistriţa River, Romania. Cold Regions Science and Technology Journal. 60:3

Romanescu, G., 2005: Riscul inundaţiilor în amonte de lacul Izvoru Muntelui şi efectul imediat asupra trăsăturilor geomorfologice ale albiei. Riscuri şi catastrophe. IV. 2. Cluj - Napoca.

Romanescu, G., 2009: Evaluarea riscurilor hidrologice. Editura Terra Nostra. Iaşi.

Smith, H.K., 1992: Environmental Hazards – Assessing Risk and Reducing Disaster. London. New York. Routledge.

Stanga, I.C., 2007: Riscuri naturale, noţiuni şi concept. Editura Universităţii Alexandru Ioan Cuza. Iaşi

Surdeanu, V., Berindean, N., Olariu, P., 2005: Factori naturali şi antropici care determină formarea zăpoarelor în bazinul superior al râului Bistriţa. Riscuri şi catastrophe. IV. 2. Cluj - Napoca.

Ştefanache, D., 2003: Consideraţii asupra fenomenelor extreme pe râul Bistriţa în perioada de iarnă. Seminarul geografic "D. Cantemir". Univ. Al. I. Cuza. Iaşi.

Ştefanache, D., 2007: Riscuri hidrologice privind evoluţia fenomenelor de iarnă pe râul Bistriţa. Conf. internaţ. „Monitorizarea dezastrelor şi poluării. Univ. Tehn. „Gh. Asachi". Iaşi.

Ujvari I. (1972), *Geografia apelor Romîniei,* Edit. Ştiinţifică, Bucureşti.

*** 1992: Summary of the United Nations Conference on Environment and Development (UNCED), The Rio Earth Summit, Brazil.

*** (1992), *Atlasul cadastrului apelor din România – partea a I-a, Date morfohidrografice* asupra reţelei hidrografice de suprafaţă, Ministerul Mediului, Bucureşti.

*** 1994: Guidelines for Natural Disaster Prevention, Preparedness and Mitigation, World Conference on Natural Disaster Reduction, Yokohama. Japan.