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Discussions

Results of the post flash-flood disaster investigations in the Transylvanian Depression (Romania) during the last decade (2001–2010)

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Abstract

Flash flood disasters are very rare in the Transylvanian Depression. In the last decades just three events were signalled in the study area, all of them during the last 10 yr. The flash floods occurring in the study area during the last decade had a significant impact on several localities situated at the Transylvanian Depression border. Based on the post flash flood investigation, the present study intends to find out the main characteristics of the flash-floods and the causes that have led to disasters in a region rarely affected by such kind of events. Analyzing the hydrological data, has been seen that the maximum intensity of the flash floods was observed in the upper and middle basins. By comparing the unit peak discharges from the studied region with other specific peak discharges related to the significant flash floods from Romania, it was noticed that the events from the Transylvanian Depression have moderate to low intensity. On the other hand, the results showed that beside high stream power and unexpected character common to flash floods, the inappropriate flood risk management measures increased the dimension of negative effects, leading to tens of life losses and economical damages of tens million dollars.

1 Introduction

Flash floods are one of the most significant natural hazards in Europe, causing serious risk to life and the destruction of buildings and infrastructure (Gaume et al., 2009; Aronica et al., 2012). The potential for flash flood casualties and damages is also increasing in many regions due to the social and economic development bringing pressure on land use (Marchi et al., 2010).

But the flash flood events are poorly understood due to the lack of experimental sites and long-term hydrometeorological data with adequate space-time resolution (Foody et al., 2004; Delrieu et al., 2005; Manus et al., 2009). Such phenomena are difficult to predict accurately, making warning problems. Thus, flash flood forecasting, warning and emergency management are, by their nature, suitable to cope with the characteristics of flash flood risk (Drobot and Parker, 2007; Marchi et al., 2010).

The effective documentation of flash floods requires post-flood survey strategies encompassing accurate radar rainfall estimation, field observations of the hidro-geomorphic processes associated with the flood, indirect reconstruction of peak discharges and interviews of eyewitnesses (Arghiuş, 2008; Marchi et al., 2009). Post-flood surveys appear clearly as a necessity to increase the existing knowledge on such events in order to provide proper methods of analysis and technical solutions for flood prevention and control (Borga et al., 2007; Gaume and Borga, 2008; Rusjan et al., 2009; Roca and Davison, 2010). Flash floods related studies are particularly useful, helping to complete the flash flood event databases (peak discharges, unit peak discharges, damages) which is limited both in Romania and in Europe. A good knowledge about this type of event and about any improvement in its numerical modelling can be also an invaluable aid for forecasting and alert systems (Pastor et al., 2010). On the other hand, if the number of such studies increases, better regional envelope curves for flash floods can be developed more easily and the hazard in risk equation can be more accurately assessed.

1.1 The general context of the study area

The region subjected to study (24 552 km^2), respectively the Transylvanian Depression, is located in the central-north part of Romania, including watercourses that belong to three major basins: Someş, Mureş and Olt (Fig. 1).

The region is bordered by The Carpathians from almost every side, being one of the largest depression in Europe. The depression is divided in two major units. One of them occupies a very large area in the central part of the region (Transylvanian Plateau) and the other, including the so-called “Peri-Transylvanian depressions and hills”, is located at the border.

The altitudes range between 180 m a.s.l. in north-western part and 1080 m a.s.l. in the eastern side (Bicheş Peak). The depression overlaps a relatively short variety of rocks, especially sedimentary rocks like marl, clay, salt and alluvial deposits.

The climate is continental temperate, showing a strong influence of The Westerlies. The mean annual temperature in the region is ~6–9 °C, while mean annual precipitations range between 1000 mm in the extreme eastern side exposed to The Westerlies, and less than 500 mm in the western part that is affected by pseudo-adiabatic processes and foehn-type winds.

The localities network within the studied area includes a number of 391 administrative-territorial units (347 communes and 44 towns). The population belonging to the Transylvanian Depression is about 2.6 million inhabitants, thus results a demographic density of 106 inhabitants km^{-2}. The highest population density is specific to the lower altitude in the major valley corridors and in the border depressions, many inhabitants being located in the flood prone area.

Being mostly a hilly region with relatively low drainage density and large basins with mild slopes, floods belong especially to the slow-onset flood type. Nevertheless, at the border with Carpathians, the basin’s slope gradient becomes steeper, increasing the flash flood risk.

2 Methods and data

To include the analysed flash flood events in the natural disasters category, the definitions in the EM-DAT glossary were considered, where a disaster is:

- a situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance;
- an unforeseen and often sudden event that causes great damage, destruction and human suffering (http://www.emdat.be/glossary/9).

For flash flood disaster investigations, several main sets of data, including the meteorological context, the peak discharge parameters, the evolution in time and space of flash floods and the social and economical negative effects have been analyzed.

In order to study the meteorological context, both the data on the rainfall events (rain gauge measurement data and especially the radar image data, provided by the Romanian National Meteorological Administration, RNMA), and the synoptic maps were collected and analyzed. The quantitative precipitation estimation problem is particularly crucial and difficult in the context of flash floods since the causative rain events may develop at very short space and time scales (Tarolli et al., 2012). Hourly radar-raingauge combined estimates are routinely used as an alternative precipitation input for hydrological models (Šálek et al., 2006). The WSR-98D Dopller radar located at Bobohalma that covers the entire study region, generating NEXRAD products like one hour precipitation, three hours precipitation and storm total precipitation. The temporal resolution of the data is 6 min, while the spatial resolution is 1° × 2 km (polar) (http://www.meteoromania.ro/index.php?id=432).

Based on the streamgauge station data, the hydrologic response was examined. Unfortunately, the upstream basins where the most severe flash floods took place are ungauged. There are a number of methods that can be applied to study extreme floods on ungauged watersheds including the so-called “indirect” peak discharge estimates and rainfall–runoff modeling through hydrological models (Gaume et al., 2009; Koutroulis and Tsanis, 2010). Empirical relations must be used with caution and estimates should be made at a minimum of two or three cross-sections for the same river reach to reduce uncertainties (Gaume et al., 2004; Gaume, 2006; Koutroulis and Tsanis, 2010).

Considering the above recommendations, beside the recorded data, results of hydraulic modeling from other related studies were used for supplementing the database.

When the data were poor or missing (e.g. Feernic and Ciunga basins), the post-event surveys was performed. In this situation, the peak discharges were estimated based

on the cross section surveys using the classic hydraulic formula:

$$Q = A \cdot V. \tag{1}$$

where:
Q – peak discharge ($\mathrm{m^3\,s^{-1}}$);
A – cross-sectional wetted areas ($\mathrm{m^2}$);
V – mean flow velocity ($\mathrm{m\,s^{-1}}$).

When no current-meter measurement for the flow velocity (V) was available the Manning–Strickler empirical formula was used:

$$V = n^{-1} R^{0.67} S^{0.50}. \tag{2}$$

where:
n – roughness coefficient;
R – hydraulic radius (m);
S – water surface slope ($\mathrm{m\,m^{-1}}$).

For a proper adjustment and in order to reduce the uncertainty related to the estimation of peak discharges, additional measures were adopted:

- the appropriate cross-sections were chosen;
- additional estimations of the flow velocity (video movies);
- the section has been subdivided into a main channel area and a right and left overbank flow area, and the discharge was calculated separately for each of the sub-areas (Gaume, 2006; Gaume and Borga, 2008);
- interviews addressed to eyewitnesses about the timing of rainfalls and flash floods;
- the comparison with other available investigation data related to studied events.

The analysis of the social effects and direct, tangible damages was based on quantitative data, including the event flood reports of the County Committees for Emergency Situations and County Prefect's Houses. Such investigations require normalization of event loss values (goods and assets values and the cost of repairs/replacements) for changes in inflation (Barredo, 2009; Arghiuş et al., 2011). Thus, using the annual average values of the Implicite Price Deflator, an adjustment of damages cost at the values of goods and services in year 2005 was performed.

3 Results and discussions

Flash flood disasters are very rare in the Transylvanian Depression. Therefore, none of the significant flash-floods that have hit Romania during the second half of the 20th century are to be found in the study region. During the last decade (i.e. 2001–2010 period), the occurrence of such events has increased throughout the country, as the flash floods are listed first in the natural disaster category, in terms of life losses and damages. The study area was also impacted by these events. The three most significant flash floods occurring in the study area during the last decade (Feernic, August 2005, Ilişua, June 2006 and Ciunga, June 2010 events) had a significant impact on many localities from the study area.

3.1 Meteorological context

The meteorological analysis of the flash floods events was focused on the synoptic conditions for heavy, localized rainfall over the study basins and quantitative precipitation estimation.

The long time observations showed that the most significant flash floods in Romania are specific to the warm season when, beside frontal precipitations, intense convective processes are developed. In this season, the heavy rainfall events typically occur downstream of a significant cyclone aloft, often exhibiting "cut-off" cyclone nucleuses

(Arghiuş, 2008; Stăncălie et al., 2010) (Fig. 2). The same situation was observed in the studied areas. In this context the height cold nucleuses maintain the cyclonic activity at ground level and increase the atmospheric instability in the lower and middle troposphere, leading to the rapid and massive condensation processes and to short-lived heavy rainfalls (Arghiuş and Maloş, 2009). The situation at the sea level shows a distribution of the baric systems that include a field of high atmospheric pressure (The Azores High) developed from south-western to central Europe, and a Mediterranean cyclone in the south-western part of Romania. In these conditions, the ground-level air circulation is predominantly southern.

The above mentioned circumstances led to heavy rainfalls in the study basins. As in other situations, extreme rainfall events that triggered the analyzed flash floods are not only characterized by quite huge precipitation rates, but also by a quasistationary behavior (Anquetin et al., 2009). In the studied watersheds the heavy rainfalls had ranging durations, from 1.5–2 h in Ciunga basin to 8–9 h in Ilişua basin (Table 1).

The precipitation reconstruction based on radar images showed maximum rainfall rates varying from 102 $\mathrm{mm\,h^{-1}}$ (Feernic basin) to 76 $\mathrm{mm\,h^{-1}}$ (Ciunga basin) (Fig. 3), while the total storm event recorded values that reached up to 175 mm in the eastern side of the Feernic basin, 160 mm in the north-east of the Ilişua basin and 90 mm in the southern part of the Ciunga basin.

The highest amount of precipitation fell in the upper and middle basin areas, overlapping the stepper terrains. The maximum rain rate was recorded at the end of the afternoon and the beginning of the evening, when the convective potential usually shows the highest values.

In all case studies light precipitations and heavy rainfall had saturated soils previously to flash flood events. Thus, three weeks before the events the amounts of precipitations were between 28–53 mm in Ilisua watershed and 100–200 mm in Feernic basin.

3.2 Analysis of flash floods

Extreme rainfall falling on saturated soil, especially in the upper part of the basins, resulted in severe flooding in the Feernic, Ilişua and Ciunga watersheds (Fig. 4). The main characteristics related to the selected basins are listed in Table 2. Streamgauge station data and observations from post-event surveys, combined with hydraulic modeling from another related studies, were used to examine hydrologic response to the storm.

Unfortunately, just two streamgauge stations are located in the study basins (Feernic river – Şimoneşti streamgauge station; Ilişua river – Cristeştii Ciceului streamgauge station), both being located near by the mouth of the rivers. The flash floods recorded at these two streamgauge stations are shown in the Fig. 5.

Analysing the hydrographs, a sudden peak rising can be observed that indicates features related to flash floods. Along with the heavy rain rates in the upper basins, the sudden rise of the peak discharges was influenced by the failure of a series of temporary wooden debris dams which were formed in narrow valley sections. Four important dams were reported in Ilişua watershed and one in Feernic river basin. Another study in the Feernic basin confirms the above mentions. Thus, the recorded discharge values at Şimoneşti streamgauge station show a sudden peak rising, while the simulated hydrograph in the same section follow a milder curve. As the author has observed the impulsivity of the registered hydrograph could depend from the blockage-release effect due to wood and solid material passing through narrow cross sections, while this dynamic is not considered by the model (Sangati, 2009).

Based on flood marks, has been found that the maximum water level ranged from 5.0 m (Lupeni village – Feernic event) to 4.8 m (Târlişua village – Ilişua event) and 4.0 m (Uioara de Jos village – Ciunga event) (Fig. 6).

To enable the comparison of flood intensities on the different watersheds the unit peak discharges are calculated (Table 3). Analysing the data, it can be seen that the maximum intensity of the flash floods was observed in the upper and middle basins

where the unit peak discharges showed the highest values. These observations are in accordance with the radar rainfall data.

Along the Ilişua river, which presents a broad floodplain downstream to Târlişua village, a peak attenuation was observed.

By comparing the unit peak discharges from the studied region with other specific peak discharges related to the significant flash floods from Romania, it was noticed that the flash flood events from the Transylvanian Depression have moderate to low intensity (Fig. 7). Nevertheless, in some areas from this region even low-intensity flash floods can trigger disasters considering that the floodplains are generally associated with high demographic density.

3.3 Impact events

Despite the warnings, the preparedness and operational measures were minimal, such that consequences were very severe, with substantial disruption of the local economy and many life losses.

Among the social effects, the most sensitive issue is associated to the losses of human lives. The studied flash floods were responsible for 30 life losses. This value represents 15 % from the total number of casualties caused by floods and flash-floods events in Romania during the 2001–2010 period. Most of them (66 %) were helpless elderly people, more vulnerable to such events.

The analysis of the economic damages was performed based on reports of the County Committees for Emergency Situations and County Prefect's Houses. For the 2005 Feernic event the damages report was available for the entire affected area, including Odorheiu Secuiesc town located outside the Feernic watershed. Counting the direct, tangible damages caused by the analysed flash flood events, the total summed up to 2005 USD 69 574 000 (Table 4). During the 2001–2010 period, the damages represented 1.50 % of the cumulated value of the entire country (2005 USD 69 574 000 as compared to 2005 USD 4.678 billion), whereas the population of the studied areas represents only 0.11 % of the country's total population.

4 Conclusions and lessons learned

The research showed that the most vulnerable areas to flash floods in the study region are the basins from the eastern and northern part which have stepper slopes and small size.

By comparing the unit peak discharges with other specific flash flood peak discharges from Romania, it was noticed that the flash flood events from the study region are rare events and have moderate intensity. Nevertheless, in some areas from this region even moderate- and low-intensity flash floods can trigger disasters.

The high level of damages and many life losses that accompanied the flash floods were influenced by a lot of factors.

The main factor is naturally associated with natural causes. Thus, heavy rainfalls falling on saturated soil, mainly in the upstream stepper basins, led to a rapid concentration of water in the river beds and a sudden rise of the water levels and discharges.

On the other hand, although the demographic density in Ilişua and Feernic basins represents less than a half from the national average population density (see Table 2), the frequent mass-movement processes from the hillslopes and interstream areas and steeper terrain forced the population to occupy the flood plains and alluvial fans, resulting in a high demographic density in the flood prone areas.

The unfavorable background conditions are not the only responsible factors of the significant impact on the local population. Thus, the damages could have been mitigated if the flood risk management measures had been properly adopted.

Unfortunately, in the study region, no important flood control works (embankments, permanent or temporary reservoirs and channelization works) have been done. On the other hand, especially in Ilişua basin, extensive deforestation activities in the steeper terrains were carried out. Such activities have restricted the forest's functions and have generated large amounts of debris wood which were formed instable dams in narrow cross-sections during the events. As in the entire country, another problem is related

to the expanded of the constructed areas and the growth of the building density in the flood prone areas. Normally, in these areas building restrictions should have been applied.

Flash floods affecting localities which belong to Feernic, Ilişua or Ciunga basins were possible even with the implementation of leading technologies that provide nowcasting warnings. Unfortunately, although the meteorological warnings were clearly formulated, The Romanian Flash Flood Guidance (ROFFG) System was not functional yet. In some situations, a lack of proper reaction and responsibility from the local authorities and even the misunderstanding of the warning messages were noticed. Because in most situations the casualties were helpless elderly people, it became urgent and compulsory to develop a plan for the rapid evacuation of these people whenever an emergency situation would occur.

Although in recent years progress has been made in flood risk management by implementing of the National Strategy for Flood Risk Management (2005) and of the Medium and Long Term National Strategy for Flood Risk Management (2010) there are still many issues that must to be solved. Among these, there can be spotted:

- a lack- or no feedback of the educational activities among the population regarding the flood risk;
- a lack of sustainable awareness of the authorities involved in flood risk management and of a specific National Strategy for Flash Flood Risk Management;
- inefficiency of the national insurance system against natural hazards.

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Table 1. Rainfall characteristics for the surveyed basins.

Basins	Total rain at the neareast raingauge stations (mm)	Storm duration (h)	Total basin rain/event (mm)	Highest rain rate shown on radar images ($\text{mm}\,\text{h}^{-1}$)	Periods with highest rain rates (hour intervals)
Feernic	56	5–6	0–175	102	17.00–17.40
Ilişua	60	8–9	15–160	–	16.15–17.15
Ciunga	70	1.5–2	70–90	76	18.15–18.40

Table 2. The main characteristics of the study basins.

River	Number of stream gauge stations	Length (km)	Channel slope ($\text{m}\,\text{km}^{-1}$)	Average basin slope (%)	Drainage area (km^2)	Mean basin elevation (m a.s.l.)	Afforestation coefficient (%)	Population density (inh. km^{-2})
Ilişua	1	52.0	15.0	21.1	356	516	31.7	36.5
Feernic	1	33.0	16.0	12.9	194	634	20.3	43.8
Ciunga	Ungaged	6.31	27.1	13.0	9.24	365	19.0	134

Table 3. The flash-floods peak disharges and unit peak discharges on the analyzed cross sections.

River	Cross-section location	Drainage area (km^2)	Mean basin elevation (m a.s.l.)	Peak discharge (m^3 s^{-1})	Unit peak discharge (m^3 s^{-1} km^{-2})
Ilisua	Upstream Târlişua[a]	57	–	193	3.39
Ilisua	Downstream Târlişua[b]	160	562	280	1.75
Ilisua	Cristeştii Ciceului station [c]	353	562	212	0.60
Feernic	Lupeni	32.2	841	132	4.10
Feernic	Simoneşti station[c]	145	–	368	2.54
Ciunga	Upstream Uioara de Jos	6.02	420	58	9.63

[a] Hydrate project (http://www.hydrate.tesaf.unipd.it/WareHouse/EuropeanDataCenter/Romania/),
[b] Fetea et al. (2006),
[c] RWNA.

Table 4. The impact of analyzed flash-flood events on socio-economic life.

Flash-flood events	No. of deaths	Damages (Millions Current USD)	GDP Deflator[a]	Damages (Millions 2005 USD)	Per Capita damages (2005 USD)
2005, Feernic basin	16	34.82	1	34.82	769[b]
2006, Ilişua basin	13	37.98	1.106	34.34	2641
2010, Ciunga basin	1	0.629	1.52	0.414	335
Total	30	73.4	–	69.6	–

[a] UNCE, Statistical Database 2000–2010,
[b] including Odorheiu Secuiesc population.

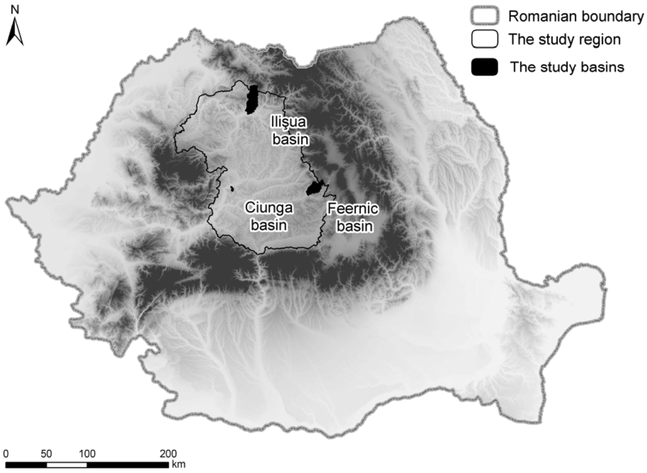

Fig. 1. The location of the study areas.

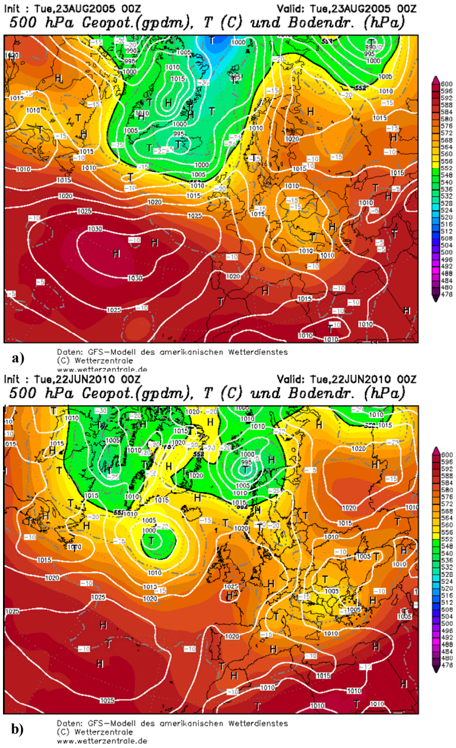

Fig. 2. Sea level pressure (hPa), 500 hPa geopotential height (gpdm) and temperature (°C) on Feernic 2005 **(a)** and Ciunga 2010 **(b)** flash-flood events (http://www.wetterzentrale.de/topkarten/fsavneur.html).

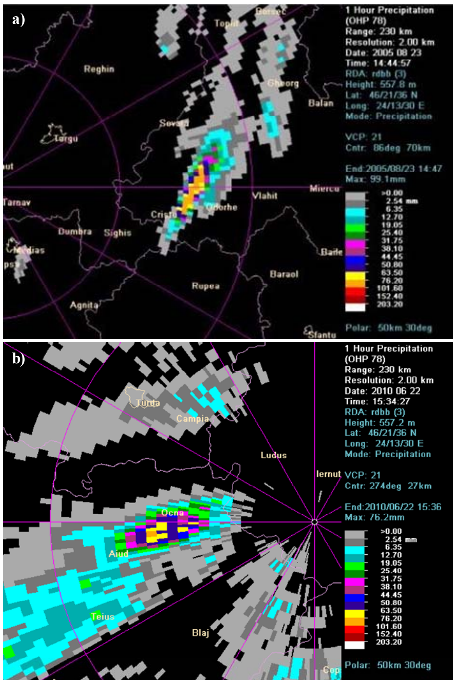

Fig. 3. The estimation of rainfall rates (mm h^{-1}) with the Doppler radar on **(a)** Feernic and **(b)** Ciunga basinal areas (source of radar images: Regional Meteorological Center "Transilvania Nord").

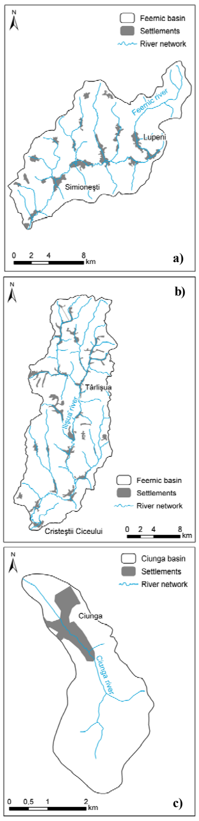

Fig. 4. The studied watershades: **(a)** Feernic basin, **(b)** Ilişua basin and **(c)** Ciunga basin.

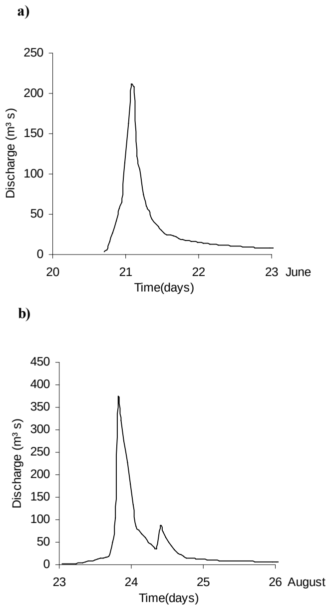

Fig. 5. Flash-flood hydrographs recorded at: **(a)** Cristeştii-Ciceului streamgauge station – June 2006 Ilişua event; **(b)** Şimoneşti streamgauge station – August 2005 Feernic event (source of data: Romanian Waters National Administration, RWNA).

Fig. 6. The flash-floods marks in the affected areas: **(a)** Lupeni village – Feernic basin; **(b)** Uioara de Jos village – Ciunga basin.

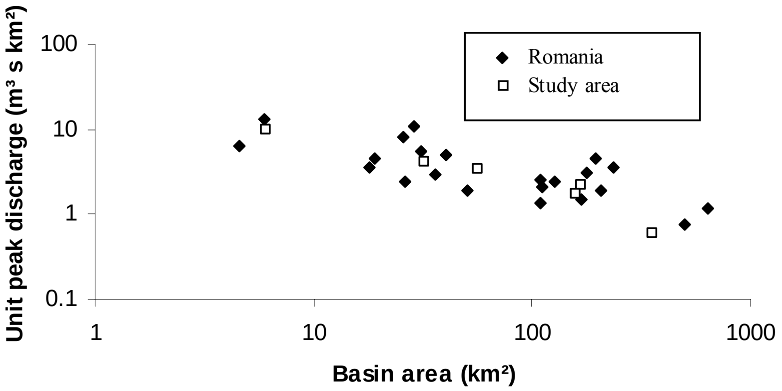

Fig. 7. Relation between basin area and unit peak discharge for the studied events and other significant flash floods in Romania.