2nd International Conference - Water resources and wetlands. 11-13 September, 2014 Tulcea (Romania); Available online at http://www.limnology.ro/water2014/proceedings.html
Editors: Petre Gâştescu ; Włodzimierz Marszelewski ; Petre Bretcan; ISSN: 2285-7923; Pages: 321-328;

CHANGES IN THE FREQUENCY AND MAGNITUDE OF FLOODS IN THE BUCEGI MOUNTAINS (ROMANIAN CARPATHIANS)

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Abstract

This paper analyses the magnitude and frequency of floods in Bucegi Mountains (in Romanian Carpathians) in order to highlight their particularities and identify possible trends in flood occurrence. It is focused on the Valea Cerbului River's catchment, a small basin (approx. 26 km^2) situated on the eastern slope of Bucegi Mountains. The importance of this area is given by its economic value (mainly tourism) and by the presence of major communication axes in its lower part. The analysis is carried out for a period of 50 years (1961 – 2010), based on flow data (mean daily and maximum annual discharge) recorded at Buşteni gauging station, on Valea Cerbului River, and using mostly statistical methods (frequency analysis, linear trends analysis based on Mann-Kendall test). The results show that the magnitude of the annual floods has an upward trend, statistically significant, for $\alpha = 0.1$ level of significance. After 1990, there was observed an increase in the frequency of floods with significant magnitude, as well as an increase in the frequency and magnitude of floods occurred between March – June and September – October. These modifications could be the response of climate changes (manifested, mainly, by the rise in temperatures, by the increased frequency of heavy rainfall events and by the richer precipitation during autumn), but we also notice a relatively cyclic character (approx. 15-20 years) of important flood events. The analysis of floods can be useful at a local scale for improving the related risk mitigation measures.

Keywords: floods magnitude, frequency analysis, linear trends, Valea Cerbului River, Bucegi Mountains.

1 INTRODUCTION

In recent decades, the analysis of changes in the hydroclimatic variability became a general concern for socio-economic and environmental reasons. A significant consideration is given to the extreme phenomena due to their negative consequences both on short and long term. In mountainous regions, the concern for "too much water" on the valleys is more acute, even though the lack of water supply can be a bigger and on long term problem. But as human communities are, in general, preoccupied by the more probable and closer-in-time dangers, the studies and policies for protection against and mitigation of flood effects (on population and material assets) are more frequent. However, the abundance of studies referring to floods are not useless, as each area has its own specific features (in terms of natural, environmental and socio-economic characteristics), so appropriate management methods should be adopted in each case.

This paper aims to analyse, based on historical flow data recorded during 50 years (between 1961 and 2010), the frequency and magnitude of floods in Valea Cerbului Catchment, located in Romanian Carpathians (more precisely, in Bucegi Mountains), an area with a high economic value (mainly touristic and for transport), that confers its vulnerability to floods. Such a study has both a scientific interest and especially a practical one, for a proper local management of flood related risk.

2 STUDY AREA

The study area corresponds to Bucegi Mountains, located, in the eastern extremity of the Southern Carpathians (figure 1). It focused on Valea Cerbului Catchment, extended over only 26 km^2, on the eastern slope of Bucegi Mountains. It is a catchment with a high relief energy (1640 m, between Omu Peak – 2505 m a.s.l. – and the confluence point with Prahova River – 865 m a.s.l.), and a mean altitude of about 1540 m. The main collector (Valea Cerbului River) has a total length of approx. 9.8 km, but only its last 5.6 km have a permanent flow. It has its sources under Omu Peak, at approx. 2125 m a.s.l., and a longitudinal profile with a high mean slope: 132 m/km. In the upper part, the river slope is 198 m/km, while in the lower part the slope falls to 29 m/km. The higher areas of the catchment, developed over calcareous conglomerates, has slopes with gradients between 45° and 80°, favouring the rapid concentration of rainwater and the occurrence of floods (Perju, 2012a,b).

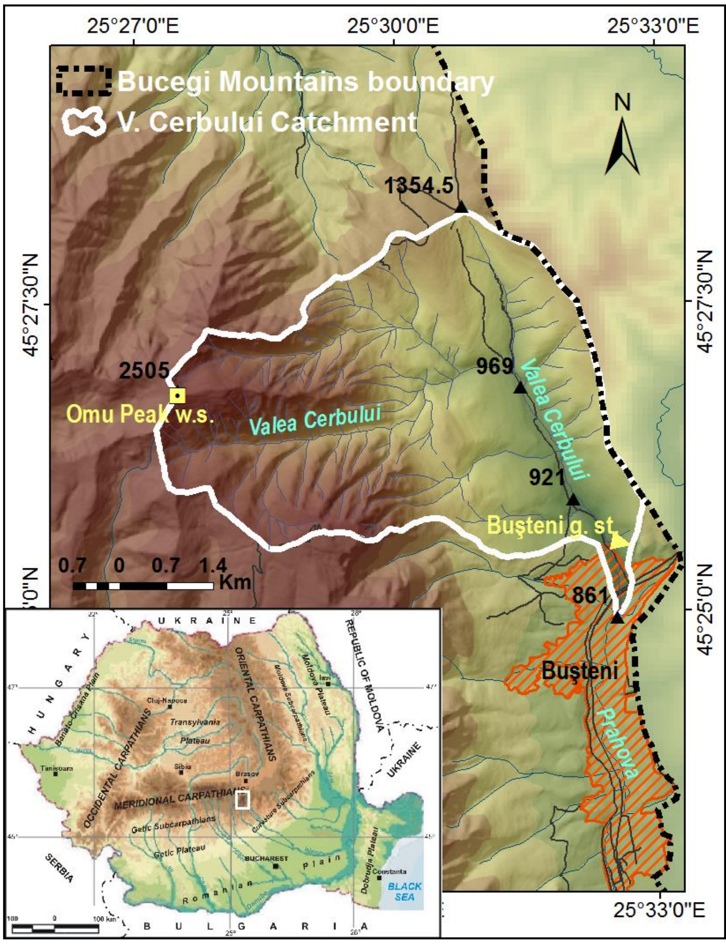

Figure 1. Geographical location of Valea Cerbului River Catchment, and of the weather station (w. s.) and gauging station (g. st.) within the river basin (left). Pictures (right) of elements vulnerable to the floods occurred on Valea Cerbului, in Buşteni City *(*photos: Zaharia*)*

The mean multiannual air temperature increases from approx. 6˚C in the lower part to −2.5˚C at Omu Peak weather station (w.s.), located at 2505 m a.s.l., where the frost lasts in average 260 days per year (A.N.M., 2008). The mean annual precipitation in Valea Cerbului Catchment is 900 – 1030 mm. The richest rainfall is recorded in the period May – August (approx. 100 mm/month) and they often have a torrential character, thus favouring floods. During winter and autumn the precipitation does not exceed 60 mm/month (Perju, 2012a). Being a mountainous basin, the snow layer plays an important role in runoff generation. At Omu Peak w.s. the snow layer has a mean duration of 140 – 220 days/year, with a monthly average thickness up to 70-80 cm, in March – April (A.N.M., 2008).

The mean multiannual discharge of Valea Cerbului River at Buşteni gauging station (for 1961-2010 period) is 0.49 m^3/s, equivalent to a mean specific discharge of 19.1 $l/s/km^2$. The runoff regime is characterised by high flows in summer (38% from the mean multiannual volume), with the maximum in June and July (representing 13% and respectively 15% of the mean multiannual water volume), due to torrential rains specific for this season. Since the snow layer usually persists in summer, these rains contribute to sudden snow melt. The maximum historical flow (62.3 m^3/s) was recorded in June 19th, 2001. An important share of annual water volume is also recorded during spring (30%), when the runoff resulted from liquid precipitation is cumulated with the snowmelt. Low flows are specific for both winter and autumn (13% and respectively 19%) (Perju, 2012a).

3 DATA AND METHODS

The paper is mostly based on hydrological data, namely on annual maximum and mean daily discharge, recorded between 1961 and 2010 at Buşteni gauging station (g.s.), on Valea Cerbului River. The g.s. is situated one kilometre upstream the confluence with Valea Prahovei River, at approx. 896 m a.s.l. (figure 1). The data were provided and validated by the National Institute of Hydrology and Water Management (NIHWM).

The main method used in data processing was the statistical analysis. First, we analysed the frequency and magnitude of annual floods, based on maximum annual discharges (from 1961 – 2010). Their variation was then compared with the 10 years return period discharge (estimated using the Pearson Type III distribution), and with the average of the maximum annual discharges for the analysed period. The inter-annual variation of annual floods' peak discharges was determined using the variation coefficient of maximum annual flows (C_v) and the module coefficient (K_i), computed as ratio between the maximum annual discharges and their average. To identify possible decadal changes in the frequency of floods, we counted the decadal number of important floods (with the peak exceeding the average of the maximum annual discharges), as well as the decadal average, maximum and minimum values of maximum annual discharges.

Secondly, we carried on an in-depth analysis, based on the processing of the mean daily discharge for the same period. The ordinary flood events were identified considering a threshold (Q_{th}) that was established as three times the average multiannual discharge (Q_{avg}), a method used for flood definition (Réméniéras, 1999): Q_{th}-= Q_{avg} x 3 = 0.49 m^3/s x 3 =1.47 m^3/s. Two consecutive daily discharges exceeding the Q_{th} were counted as a single flood event. The floods thus defined helped at counting them by year and decade, in order to identify possible changes in their frequency.

From the mean daily discharges, we selected the maximum value of each month, based on which we determined the extremes (minimum and maximum) and the average for each decade, at monthly and seasonal time scale, to reveal the inter-decadal high flow variability. The average of maximum annually values of the mean daily discharges for the entire period (1961 – 2010) – 4.62 m^3/s – was set as threshold for selecting the major floods, to analyse their frequency.

The significance of linear trends was determined using the Excel template developed on the basis of Mann-Kendall test and Sen's slope method (Salmi et al., 2002).

For cartographic representations and spatial analysis, we used GIS tools, namely ArcMap of ESRI ArcGIS, version 10.1.

4 RESULTS

In accordance with chapter 3, the results are structured in two parts: i) first, the annual floods are analysed, based on maximum annual discharges; ii) the second section focuses on the processing of mean daily discharge.

4.1. Frequency and magnitude of annual floods

The annual floods correspond to the highest discharges recorded during a year (Réméniéras, 1999). Due to the climatic conditions of the Valea Cerbului Basin, almost two thirds (61.5%) of the annual floods occurred during summer (figure 2 left), as a consequence of the torrential rains specific for this season. August has the highest flood frequency (23.1% of cases), followed by June and July (with 19.2% each) (figure 2 right). In winter, the low air temperatures and the presence of the snow layer cause a low frequency of floods (less than 4% of annual floods).

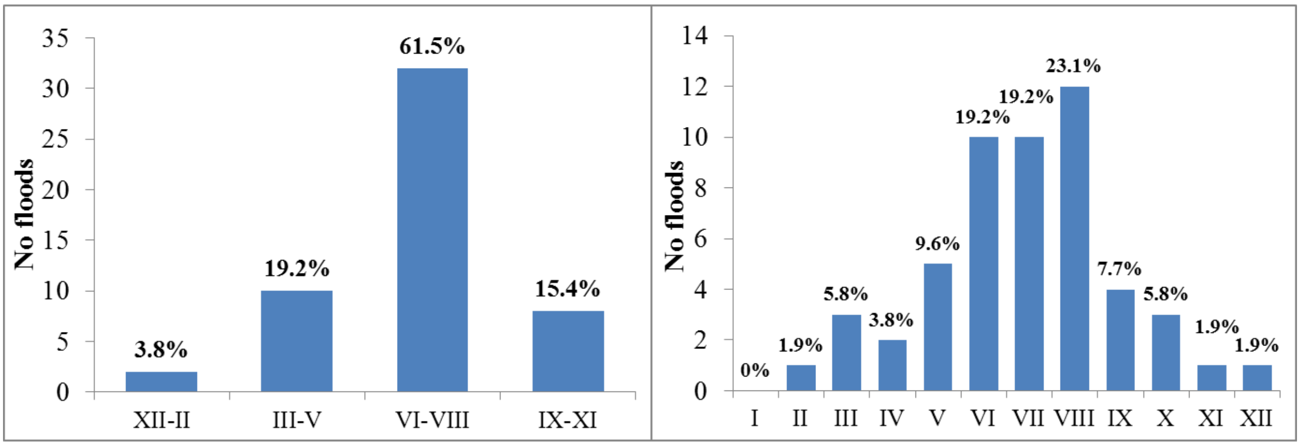

Figure 2. Seasonal (left) and monthly (right) frequency of annual floods recorded on Valea Cerbului River at Bușteni, between 1961 - 2010

The biggest floods occurred in 2001 and 1988, when the flood peaks exceeded five times the average of maximum annual discharges: Ki = 5.4 in 2001 and Ki = 4.7 in 1988 (figure 3). The great inter-annual variability of the maximum annual discharges is reflected in the variation coefficient which has a relatively high value: $C_v = 0.98$. The linear trend indicates a growth of the magnitude of annual floods at 0.1 level of significance (α = 0.1). The maximum discharge with the return period of 10 years ($Q_{max\ 10\%} = 23.7\ m^3/s$) was exceeded three times – in July 1988, August 1999 and June 2001, which indicates a relatively low frequency of very large floods. Therefore, to select the floods with a somewhat significant magnitude, we considered as a threshold the average of the maximum annual discharges (11.5 m^3/s). The number of annual floods greater than this threshold, was 17 (approximately a third of the total of 50 annual floods) and we notice an important increase in the last two decades, from 2 floods in 1961 – 1970, to 5 in 1991 – 2000 and 4 in 2001 – 2010 (figure 4).

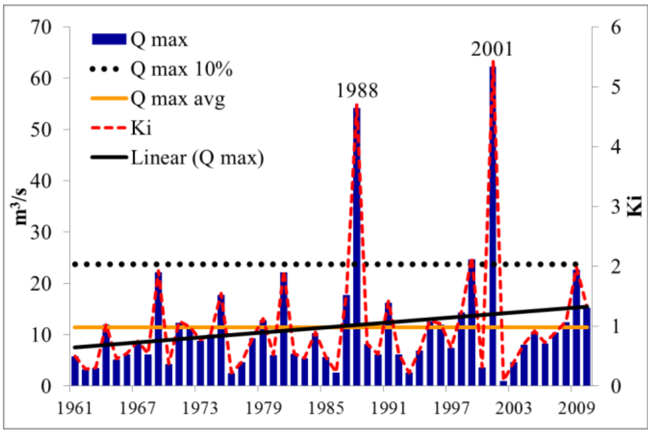

Figure 3. Valea Cerbului River at Buşteni: annual peak flood (Qmax) compared with the average of maximum annual discharge (Qmax avg) and 10 years return period discharge (Qmax10%); the linear trend of maximum annual discharge (Qmax) and the module coefficient (Ki)

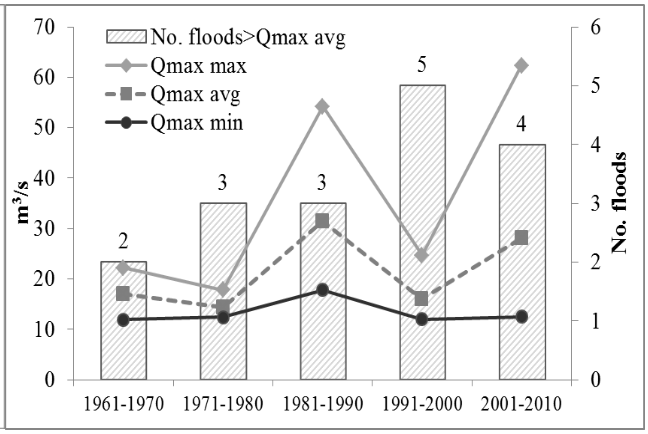

Figure 4. Valea Cerbului River at Buşteni: the maximum (Qmax max), average (Qmax avg) and minimum (Qmax min) decadal values of maximum annual discharges (left axis) and decadal frequency (right axis) of annual floods exceeding the average of the maximum annual discharges

The magnitude of the annual floods does not entirely match with their decadal frequency: it has a quite large variability from a decade to another, especially regarding the maximum and average values of the maximum annual discharges (figure 4). The highest flood peaks are recorded between 1981 – 1990 (54.2 m^3/s) and 2001 – 2010 (62.3 m^3/s), while between 1991 and 2000 the maximum was of 24.7 m^3/s. The minimum values are very close to the average (11-12 m^3/s), excepting the decade 1981 – 1990, with a minimum of 17.8 m^3/s. We find that the minimum values suffer a decrease in the last two decades.

4.2. Flood analysis based on mean daily flow processing

The analysis of daily discharges can reveal more accurate information about flood occurrence. An ordinary flood event was defined, as mentioned at chapter 3, by imposing a threshold (Q_{th}): 3 times the mean multiannual discharge. This threshold is considered low enough to take into account all significant floods. Based on it we identified all the floods over a year. Still, with this method we do not have information about the flood parameters (maximum discharge, increasing time, decreasing time, total duration), but only about the flood occurrence (as mentioned, two consecutive daily discharges exceeding the Q_{th} were counted as a single flood event).

The annual frequency of floods (as defined above) varies greatly: from none (in 1976, 1986 and 2002) to over 10 cases (12, in 1962; 15 in 1966 and 16 in 2010). Although graphically we notice a slight increase of the annual number of floods (figure 5), the Mann-Kendall test shows that statistically it is not significant.

When we group the number of floods by season, some interesting patterns in their decadal variation appear (figure 6). As expected, the lowest frequency is specific in winter and the largest number of floods is recorded in summer, regardless of the decade. But autumn and winter show an increasing frequency of floods, during the last two decades. A greater number of floods in autumn is in accordance with the upward trend of high flows, observed for all rivers in Romania (Bîrsan et al., 2013), fact that correlates, at its turn, with the increase in precipitation amounts for this season (Busuioc et al., 2012). In spring, the frequency of floods depends on the snow depth and on its melting regime; therefore, their decadal frequency shows a strong variability.

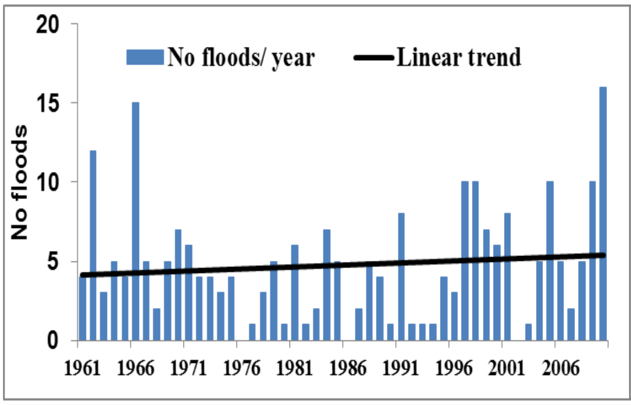

Figure 5. Annual frequency of floods (defined based on daily discharge data) recorded on Valea Cerbului River at Buşteni, and its linear trend (1961 – 2010)

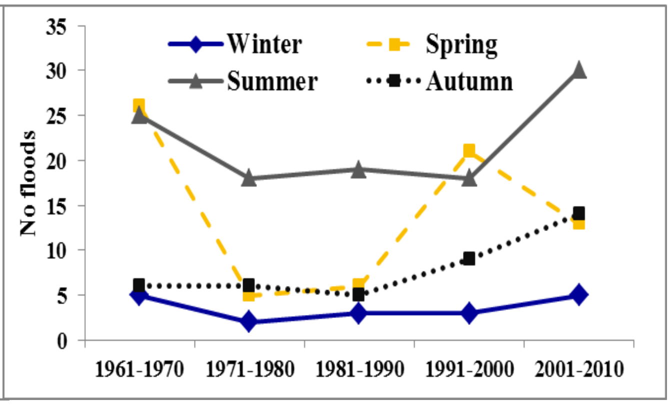

Figure 6. Seasonal flood frequency (flood defined based on daily discharge data) for each decade, on Valea Cerbului River at Buşteni (1961 – 2010)

Regarding the analysis of floods with a greater magnitude, based on mean daily discharges, we selected the maximum values of each month. Their average value was established as the threshold whereupon we identified the annual number of important floods (in terms of magnitude). The decadal analysis of above threshold floods shows a spectacular increase during the last two decades: from 3 cases per decade for 1961 – 1990, to 7, respectively 8 cases per decade between 1991 – 2000 and 2001 – 2010 (figure 7). This fact reveals, as with the case of the annual floods, the upward trend of large floods frequency in the last decades.

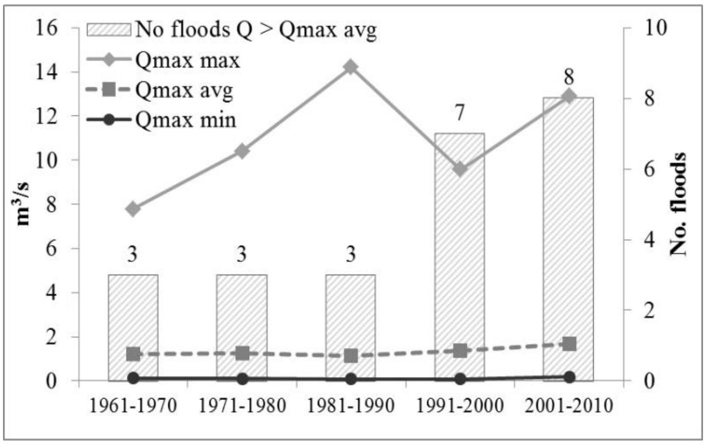

Figure 7. Valea Cerbului River at Buşteni: decadal frequency of floods (monthly number of cases with flows greater than the average of maximum of mean daily discharges), and the maximum (Qmax max), average (Qmax avg) and minimum (Qmax min) of the highest of mean daily discharge

The decadal maximum values of mean daily discharge follows the variations of the annual maximum flows (as shown at 4.1), with the highest value in 1981 – 1990 decade (14.2 m^3/s), a lower discharge for the next decade (9.6 m^3/s) and a growth in 2001 – 2010 (12.9 m^3/s) (figure 7). The decadal values of minimum and average of the maximum of mean daily discharge had a very slight increase over the last two decades.

During the first three decades of the period analysed, a high variation of the extreme parameters (minimum and maximum) of the monthly maximum of mean daily discharge is observed from May to October, with a maximum in July (figure 8). This pattern is changed in the last two decades, when the amplitudes got larger for almost each month (exception being January and February). In 2001 – 2010 we notice the shift of high discharges in spring (March – May) and June. During the last two decades, there was a significant increase of the number of ordinary floods (meaning the floods with the daily discharge above the threshold of three times the mean multiannual discharge): 51 between 1991 – 2000 and 62 between 2001 – 2010, compared to 1971 – 1980 and 1981 – 1990, when there were recorded only 31 and respectively 33 floods (figure 8). Frequent ordinary floods were also recorded during the first decade of the period of analysis (1961 – 1970).

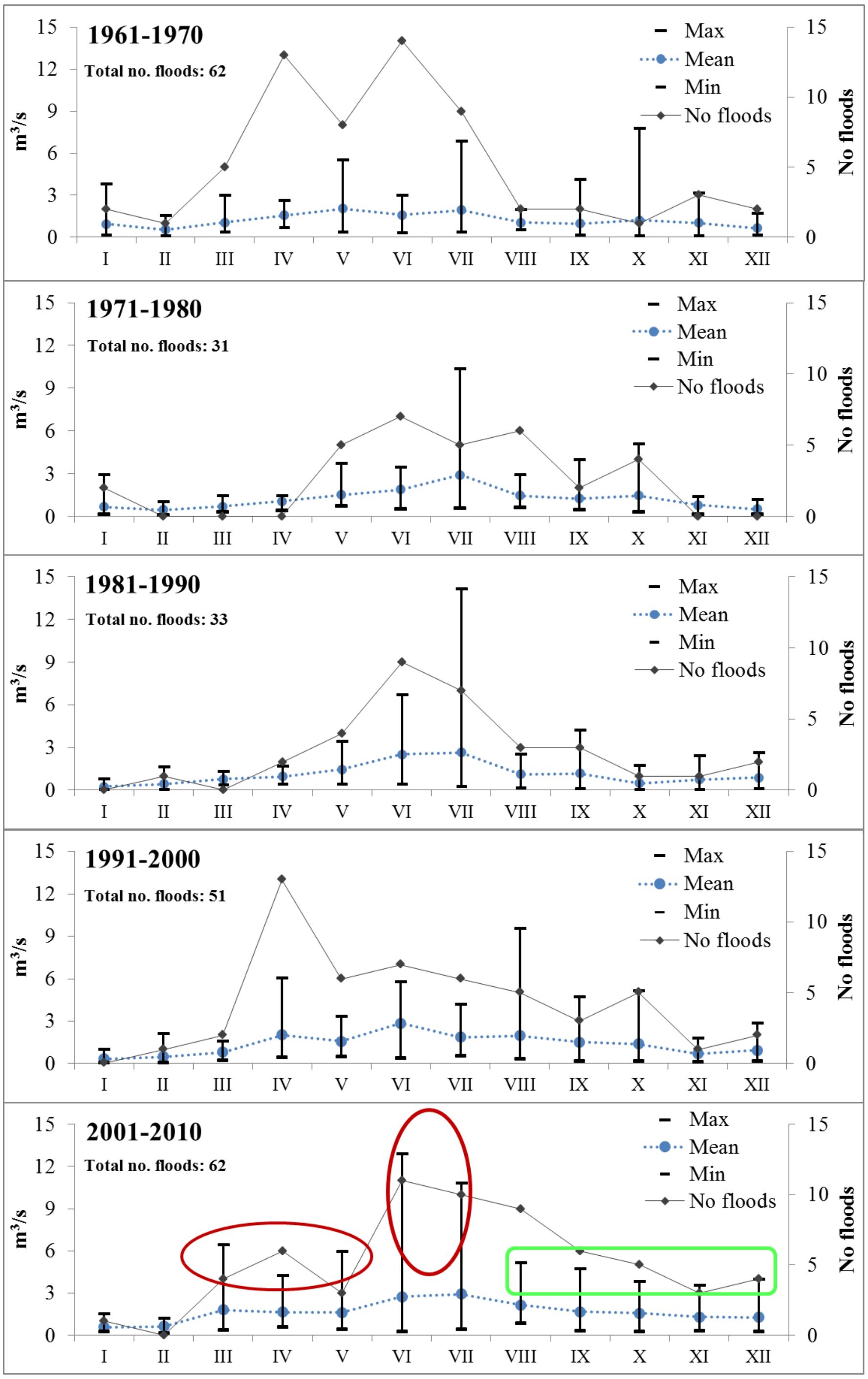

Figure 8. Valea Cerbului River at Buşteni: maximum, average and minimum values of the monthly maximum of mean daily discharge (left axis); decadal frequency (by months) of ordinary floods defined as the daily discharge above the threshold of 3 times the mean multiannual discharge (right axis)

Monthly, we can observe that for the first and for the last two decades there are peaks of high frequency of floods in April and June. The higher flows and the greater flood frequency in the period March – June for the last two decades could be caused by the climate changes identified in the Carpathian area, expressed, mainly, by rising temperatures (Busuioc et al., 2012), having as effect the earlier melting of the snow layer. However, the large number of floods occurred during the decade 1961 – 1970 is similar to that of the last two decades, fact that may show a cycle of 15-20 years in the manifestation of floods. In this sense, in figure 5 we can identify the periods 1961 – 1975 and 1997 – 2010 with frequent floods and the period 1975 – 1996 with fewer floods.

5 CONCLUSIONS AND OUTLOOK

This paper emphasise some aspects regarding the frequency and magnitude of floods occurred between 1961 – 2010 in a small mountainous basin: Valea Cerbului River Basin (26 km^2), situated on the eastern slope of Bucegi Mountains. The climatic features of the basin impact on the temporal distribution of floods: their highest frequency is met during summer (June – August), due to heavy convective rains, associated, especially in early summer, with the snowmelt (because of high altitudes the snow layer persists until summer months).

Following the statistical analysis, the results show an increase in the frequency of large floods after 1990, while the number of ordinary floods has a slight ascending trend, but statistically not significant. The analysis also shows that in the last two decades (1990 – 2010) the magnitude of high flows and their frequency have an upward trend between March and June, as well as in September and October. Since the flow regime of the Valea Cerbului River is quasi-natural, the modifications identified in the manifestation of floods are the reflex of climate changes that affected the Romanian Carpathians area. Thus, the increase in frequency and amplitude of spring and early summer floods can be attributed to the climate warming, considered unequivocal in the last decades (IPCC, 2007), and causing earlier snow melt from the high mountainous areas; in autumn, an increase of precipitation was identified for the whole Romanian space (Busuioc et al., 2012). The general upward trend in large flood frequency can be also correlated with the increasing number of heavy and extreme rainfall events (above 50 mm and, respectively, above 100 mm of precipitation recorded in 24 hours) identified in Romania for the period 1980 – 2009 (Ştefãnescu et al., 2013). Even though some of the trends are clear, we have to consider the cyclic character of the hydro-climatic phenomena, because relatively high frequencies of floods were also recorded for the period 1961 – 1975.

The high slope and the small surface of the Valea Cerbului Catchment determine the rapidity of floods and their great destructive force, thus being a major risk, especially for the lower part of the basin (with a high vulnerability to floods). Therefore, knowing the specific features and trends of floods has a practical interest for the adoption of appropriate measures of prevention and protection, in order to mitigate the risk associated. In the future, we intend to estimate the possible future changes in flood frequency and magnitude using flow modelling and different climatic scenarios. In this regard, some preliminary results were already obtained (Perju et al., 2013 a and b).

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