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# Assessment of Flash Flood Hazard Maps Using Different Threshold Values and Indices Methods

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**Abstract**

This paper presents an integrated approach for preparation of flash flood hazard maps using different threshold values and indices methods. The methods are based on the influence of the main physical-geographical factors on the rainfall-runoff processes.
The approach utilizes the ROFFG threshold runoff values for the small sub-basins configured within the Romanian Flash Flood Guidance System (ROFFG), together with robust runoff coefficient estimates for selected rainfall scenarios. Calculation of Flash Flood Potential employs a dimensionless index based on several geographical factors determined in GIS (raster format at 30 meters cell size) that influence the surface runoff. The index and general rainfall-runoff analysis in representative gauged sub-basins (area < 200 $km^2$) are used for the general validation of the results of the ROFFG threshold runoff method.
The results of the ROFFG method highlight the existence of a high hazard caused by flash floods in 2401 basins, which cover about 61754 $km^2$ (25% of the total area of Romania). The Flash Flood Potential Index (FFPI) method highlights too high and very high values of FFPI in 2805 small basins covering an area of about 80000 $km^2$ (approximately 33% of the total area of Romanian area). Both methods indicate that the highest flash floods hazards occur in the mountain and hilly areas.

**Keywords:** *flash-floods, threshold runoff, hazard maps, small basins, Flash Flood Guidance*

**Rezumat. Evaluarea hărților de hazard la viituri rapide utilizând diferite valori prag si metode bazate pe indici**

Aceasta lucrare prezintă o abordare integrată în vederea pregătiri hărților de hazard pentru viituri rapide utilizând diferite valori prag și metode bazate pe anumiți indici. Metodele sunt bazate pe influența principalilor factori fizico-geografici asupra proceselor ploaie-scurgere. Abordarea utilizează valorile prag ROFFG pentru scurgere stabilite pentru bazinele mici configurate in cadrul sistemului ROFFG, împreună cu un coeficient de scurgere robust, estimate pentru scenarii de precipitații selectate. Calcularea Potențialului de Viituri Rapide implică derivarea unui indice adimensional bazat pe câtiva factori geografici determinați în GIS (format raster – celula de 30m) care influentează scurgerea de suprafață. Indicele și analiza general a scurgerii în sub-bazine reprezentative monitorizate (suprafața < 200 $km^2$) sunt folosite pentru validarea generală a rezultatelor obținute prin metoda valorilor prag din ROFFG.
Rezultatele metodei ROFFG evidențiază existența unui hazard ridicat cauzat de viituri rapide in 2401 bazine, care acoperă aproximativ 61754 $km^2$ (25% din totalul suprafeței României). Metoda FFPI evidențiază valorile mari și foarte mari ale FFPI in 2805 bazine mici ce acoperă o suprafata de aproximativ 80000 $km^2$ (aproximativ 33% din suprafața totală a României). Ambele metode indica faptul ca cele mai expuse areale la hazardul reprezentat de viituri rapide sunt localizate in zonele de deal si de munte.

**Cuvinte-cheie:** *viituri rapide, valori prag ale scurgerii, harti de hazard, bazine mici, Flash Flood Guidance*

## Introduction

Due to the intensification of the high intensity torrential precipitations events in the last years in many countries, and the perspectives of further increase of the frequency of such extreme events as results of the climate changes, the analysis and simulation of the hydrological processes associated with flash floods events remain a major priority for the scientific hydrological community.

Globally, flash floods have the highest mortality rate and the most important damage, taking into account all categories of floods. There is an increasing number of scientific papers that are focused on simulation of hydrological processes associated with flash floods (Dawson and Wilby, 1998; Pilgrim et al., 1998; Wagener et al., 2003; Oudin et al., 2005). Such studies are inevitable for the development of the appropriate measures to mitigate the impacts of flash floods. Frequency of flash floods increased in recent years also in Romania.

Flood mapping is a crucial element of flood risk management in the EU (Directive 2007/60/EC on the assessment and management of flood risks).

In order to prepare flash flood risk maps it is necessary to delineate and map potentially affected areas and determine the severity of the phenomenon (hazard).

According to *Handbook on good practices for flood mapping in Europe* (EXCIMAP, 2007) several aspects can be highlighted in relation to flash-flood hazard and risk map delineation:

- Flash-flood prone areas can be identified by using meteorological criteria, in terms of rainfall amounts and intensities above a threshold that have impacted the same area in the past;

- Geomorphologic criteria are of primary importance in flash-flood prone areas, since water in most of these rivers does not flow for most of the year;
- Classical 1-D hydraulic modelling for hazard delineation may not be useful in small to medium flash-flood prone areas. Modelling of solid transport is particularly important, since it highly affects the extent of the flood. In order to enable the accuracy of hydrological/hydraulic modelling and produce the final flood hazard map, detailed and accurate digital maps and digital elevation models (DEM) are required;
- General recommended minimum requirements are 10mx10m (possibly 5mx5m) for horizontal and minimum 0.5m for vertical resolution, respectively;
- Risk assessment is of great importance in flash-flood prone areas, because many of them have been highly developed and are thus a highly vulnerable.

## Materials and methods

### *Methodology*

Taking into account all of the above aspects and the need for a Flash Flood Hazard Map at national level, for the entire territory of Romania, we propose the following methodology:

- Use the threshold runoff values from the actual ROFFG operational system configuration;
- Compute the runoff for selected precipitation scenario using the runoff coefficients based on the data from the representative basins in Romania;
- Define and check the flash flood hazard severity classes using information from the existing hydrometric stations in small basins, and Flash Flood Potential Index;
- Estimate the potentially flooded area, taking into consideration the influence of the main physical - geographical factors on the runoff generation processes.

Flash Flood Potential Index is proposed to validate the results of the above approach.

### *The method of identification of flash floods prone basins*

Current operational procedures for elaborating flash flood warnings in Romania are based on information from radar products, stations data, Numerical Weather Prediction (NWP) models, Romanian Flash Flood Guidance System (ROFFG) products, South East Europe Flash-Flood Guidance System (SEEFFG), European Flood Awareness System (EFAS), and other information/indices related with flash-flood potential/susceptibility.

The ROFFG system is component of the Romanian National Hydrological Forecasting and Modeling System. It was developed by the Hydrologic Research Centre (HRC) in San Diego. It was designed to integrate real-time data from various hydro-meteorological sources and evaluate a number of diagnostic indices that are related to occurrence and development of natural flash floods. The ROFFG system uses real-time radar and gauge precipitation data on an hourly basis and other meteorological information (e.g., air temperature and snow information during winter months). It produces flash-floods occurrence diagnostic indices over each of 8851 small basins in Romania (average basin area of approximately 30 square kilometers).

The configuration and use of flash flood guidance systems, is based on the concept of threshold runoff, defined as the amount of effective rainfall of a given duration falling over a watershed that is just enough to cause bankfull conditions at the outlet of the draining stream.

Identification of the basins endangered by flash floods and determination of the class of the hazard was made by comparing the threshold runoff values established within the system ROFFG with the runoff values given by the amount of rainfall with probability of exceeding 1% considered in specialized literature as having the value of 125 mm (Miţă, 1994).

Threshold runoff values were calculated for each of the 8851 river basins according to the methodology proposed by researchers at San Diego Hydrologic Research Centre (Carpenter et al., 1999; Georgakakos, 2006; Ntelekos et al., 2006; Norbiato et al., 2008; Norbiato et al., 2009).

The runoff depth resulting from a given amount of rainfall with probability of exceeding 1%, P = 125 mm (Miţă, 1994) is determined by the formula:

$$R(mm) = P(mm) * \alpha \quad (1)$$

where:

R, P and α = symbols to the equation (1),
R=runoff, P=precipitation, α=runoff coefficient

Runoff coefficient α is determined as function of forestation coefficient, basin slope, and soil type (Miţă, 1994). Runoff coefficients used for representative basins in Romania are given in Table 1, for a precipitation event of 125 mm and previous 5 days API of 40 mm (Miţă and Mătreaţă, 2016).

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**Table 1: Runoff coefficient values, from representative basins**

| $I_b$ (%) | Cp (%) | | | | |
|---|---|---|---|---|---|
| | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 |
| Soils with high infiltration capacity | | | | | |
| 5-10 | 0.44 | 0.42 | 0.40 | 0.38 | 0.36 |
| 10-20 | 0.46 | 0.44 | 0.42 | 0.40 | 0.38 |
| 20-30 | 0.48 | 0.46 | 0.44 | 0.42 | 0.40 |
| 30-40 | 0.50 | 0.48 | 0.46 | 0.44 | 0.42 |
| 40-50 | 0.52 | 0.50 | 0.48 | 0.46 | 0.44 |
| Soils with mean infiltration capacity | | | | | |
| 5-10 | 0.55 | 0.53 | 0.51 | 0.49 | 0.47 |
| 10-20 | 0.57 | 0.55 | 0.53 | 0.51 | 0.49 |
| 20-30 | 0.59 | 0.57 | 0.55 | 0.53 | 0.51 |
| 30-40 | 0.62 | 0.60 | 0.58 | 0.55 | 0.53 |
| 40-50 | 0.64 | 0.62 | 0.60 | 0.57 | 0.55 |
| Soils with low infiltration capacity | | | | | |
| 5-10 | 0.66 | 0.63 | 0.61 | 0.58 | 0.56 |
| 10-20 | 0.69 | 0.66 | 0.63 | 0.60 | 0.57 |
| 20-30 | 0.73 | 0.69 | 0.66 | 0.63 | 0.60 |
| 30-40 | 0.75 | 0.72 | 0.69 | 0.65 | 0.63 |
| 40-50 | 0.78 | 0.75 | 0.72 | 0.68 | 0.65 |

Note: Ib= slope basin; Cp=forestation coefficient.
Source: Miţă and Mătreaţă, 2016

By applying a fuzzy model (Zadeh, 1965) a final grid, with the estimates of maximum runoff coefficient at resolution of 1km is obtained as well. Averaging of maximum runoff coefficients for the 8851 basins of the ROFFG system (Fig. 1) and applying the above formula give runoff estimates from a given amount of rainfall with exceedance probability of 1%.

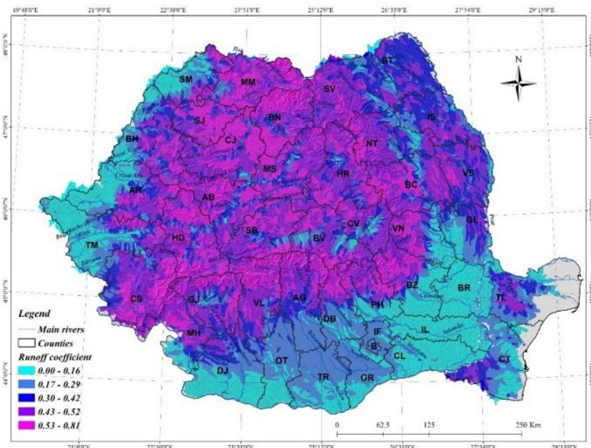


**Fig. 1: Maximum runoff coefficients averaged for the ROFFG sub-basin**

The ratio of this runoff value to runoff thresholds values that may cause the flooding phenomenon at the outlet basins was used to establish three classes of the flash flood hazard: 1 - low, 2 - medium, 3 – high.

### *Method based on Flash-Flood Potential Index derived at national scale*

The values of Flash-Flood Potential Index (FFPI) were computed for the entire Romanian territory, by taking into account the six geographical factors that influence the surface runoff (Smith, 2003; Teodor and Mătreaţă, 2010; Zaharia et al., 2012; Prăvălie and Costache, 2014): slope, profile curvature, hydrological soil group, lithology, convergence index, drainage network and land use/cover. Influence scores were assigned to each class or factor category (Table 2). The FFPI values were calculated on a grid base representation, using the following equation for each grid cell:

$$FFPI = \frac{S + Lc + Pc + HSG + Li + Ic}{6} \quad (2)$$

where:

FFPI = Flash-Flood Potential Index; S = slope; Lc = land use; Cp = profile curvature; HSG = hydrological soil group; Ic – convergence index.

The curvature profile reveals areas with negative values where runoff is accelerated and areas with positive values where runoff is decelerated. Hydrographic network convergence index highlights through negative values valley areas, while through positive values, the interfluves.

**Table 2: Influence scores of FFPI factors**

| Parameters | Types/values | | | | |
|---|---|---|---|---|---|
| Slope (°) | < 3 | 3 – 7 | 7- 15 | 15– 25 | >25 |
| Land use | Forests, Lakes | Shrubs, Orchards | Agricultural areas, vineyards | Natural grasslands | Built areas, Bare rocks, Rivers |
| Profile curvature | | | 0.9 – 1.4 | 0 – 0.9 | -2 – 0 |
| Hydrological soil group | | A | B | C | D |
| Lithology | Gravels, Sand, Loess | Marne, Clay, Limestone, Casts | Sandstone, Calcareous sandstone, Tuffs | Conglomerates, Massive sandstones, Shyts, Crystaline dolomites | Schists, Volcanic rocks, Hard sandstone |
| Convergence index | 0 - 100 | -1 – 0 | (-2) – (-1) | (-3) – (-2) | (-100) – (-3) |
| Influence scores | 1 | 2 | 3 | 4 | 5 |

## Results and discussions

Map of the flash flood hazard is shown in Fig. 2. Low hazard was calculated for 2894 basins. These basins are located mainly in the lowlands plains and cover the area of 75128 km$^2$. Average hazard was calculated for 3668 basins with total area of 94240 km$^2$, which are distributed uniformly over the entire country.

Catchments characterized by a high hazard to flash flooding are located mainly in the mountainous area, in the Transylvanian Depression and in the Moldavian Plateau. They are also located in Dobrogea area and in the Mehedinţi Plateau.

The number of these basins reaches 2401 and they cover an area of about 61754 km$^2$.

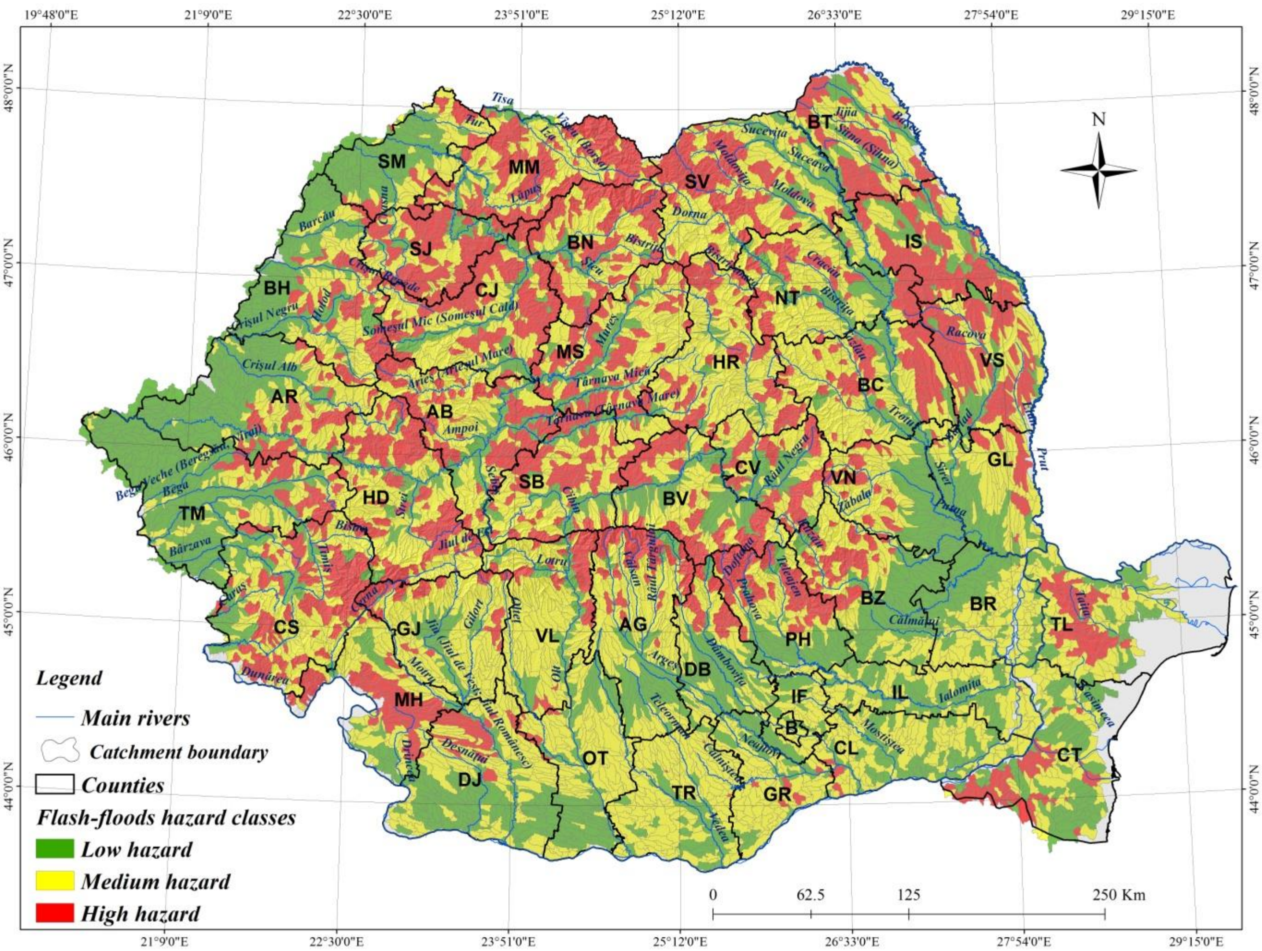


**Fig. 2: Classification of the ROFFG basins according to the flash-floods hazard**

FFPI method proposed as a validation method also indicates the presence of low values of potential to produce flash floods on extensive areas in the Romanian Plain, West Plain and the valleys of the main rivers.

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Calculated Flash Flood Potential Index had values from 1.5 to 5. Basin mean values calculated for the ROFFG basins are shown in Figure 3. 2911 ROFFG basins having small FFPI values cover the area of 70,000 km$^2$. Basins characterized by middle FFPI values (3145 basins) have total area of about 80,000 km$^2$.

In general, they are found in highland and hilly areas. High FFPI values were calculated for 2805 basins with total areas about 80,000 km$^2$. They are generally located in mountainous areas and in the Sub-Carpathian.

Looking to the general results of the two methods, we could conclude that they produce comparable results.

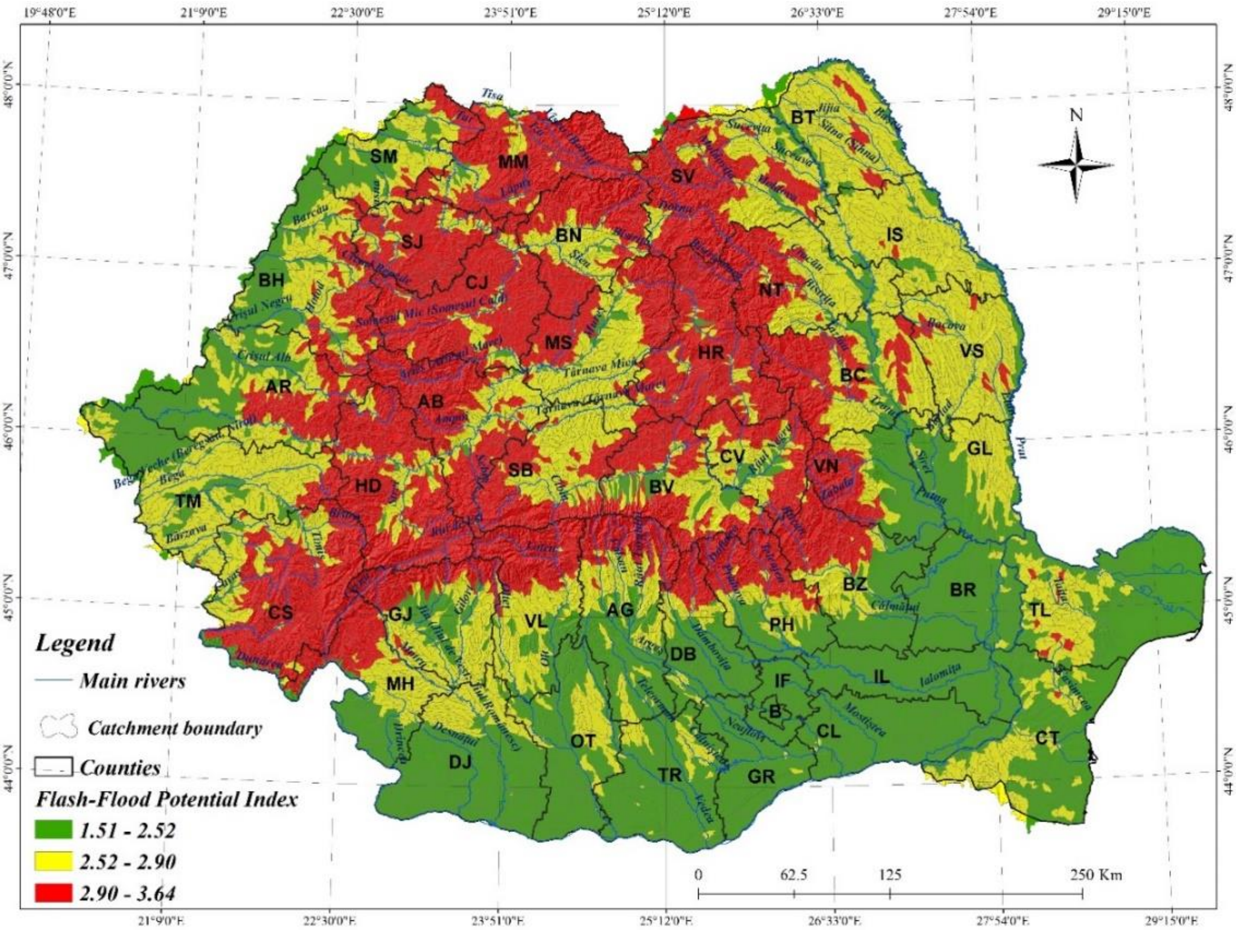


**Fig. 3: The Flash Flood Potential INDEX in the basins**

## Conclusion

We consider that the presented methodology, is a robust approach suitable for the first general assessment of flash flood hazard determination in small basins.

It can be applied for large areas, especially in basins were a Flash Flood Guidance type system is already implemented.

The requested GIS input data are in general available at global scale, but it is recommended to use local relations for a proper estimation of the runoff coefficient. Of course, for local small scale application, it is recommended to apply first a detailed distributed hydrological model, and to use the more general approach for a robust validation.

Further improvement and extension of the results will be conducted as follows:

a) Detailed analysis at the river network cells level will be added, in order to take into account the effect of the upstream areas;
b) Then, a detailed robust distributed modeling will be investigated, using a cellular automata model approach.

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