

Study of Susceptibility to Flash Floods in the Vărbilău River Catchment

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Abstract – Identification of areas susceptible to flash floods is essential to establish measures that will help the population in case of a hazard. Therefore, the purpose of the present article is to identify the areas that present a high susceptibility to flash-floods in the Vărbilău catchment. The area, located in the Prahova region, was chosen due to the complexity of the hydrological phenomena. To determine the susceptibility to flash floods, the Flash Flood Susceptibility Index (FFSI) was calculated by integrating ten factors that play an essential role in the flash floods formation. Areas located downstream and in the middle of Vărbilău basin present a low risk, while locations in the northwest (upstream of Luțu Roșu and Scurtești) present a high risk to flash-floods due to steep slope, narrow valleys, solid rocks, and land use.

Keywords – FFSI, flash flood, river catchment, slope, susceptibility

1. INTRODUCTION

Extreme hydrological phenomena are very unpredictable and have a significant impact on human settlements. Their frequency is high due to the climate dynamics, relief, Earth rotation, exposure to the sun, the tilt of the Earth's axis, and human impact. Whether they are in tropical, temperate, or polar areas, the phenomena can be extreme, starting from runoffs on the slope and ending with floods in the lower sector of a river.

Romania is not an exception when it comes to hydrological hazards. Large areas in the Subcarpathians with high population density are affected almost every year due to some factors like slope, heavy rainfall, land use, or lithology [1]. One of the critical phenomena that impact areas in Romania is represented by the flash floods.

Following high precipitations and/or rapid snow melting in a short period, the rivers flow increases very fast, resulting in flash floods that can result in significant losses to the local settlements. Because the phenomenon takes place in a short period, there is a short time for the authorities to evacuate the population and save as much as possible from the households [2].

It is essential to identify the susceptibility to hazards. Thus, the authorities will know what areas are exposed and take measures to defend the residents from hazards.

Many studies regarding the susceptibility to floods, flash-floods, and runoffs at micro and regional levels have been published. Some give a general overview and discuss the phenomena in a broader area [3,4], while others offer a clear perspective on the local areas [5,6].

Different methods to analyze the flash floods have been utilized, some emphasizing the climate component, others considering certain factors that favor the appearance of flash floods.

The purpose of this research is to identify the susceptibility in the study area, taking into consideration the slope, precipitations, land use, slope length factor [7].

2. STUDY AREA

The studied area is the Vărbilău catchment, located entirely in the Prahova region, Romania. Most of its surface is situated in the Prahova Hills (part of the curvature of Subcarpathians), the rest in the mountainous area. The catchment altitude is between 210 meters (at the confluence between Vărbilău and Teleajen) and over 1300 meters upstream. The springs of the Vărbilău main river are Vărsăturile and Clăbucet. The Doftana basin is located west of Vărbilău's catchment, whereas the subbasins of the Teleajen River are situated on its east side. The Vărbilău River has a length of 36 kilometers and flows from north to south into Teleajen River near Dumbrăvești. Its most important tributaries are Slănic, Ștefești, and Bertea.

The relief in the river basin is predominantly hilly, alternating with valleys (Figure 1). Based on the field observations, the riverbeds downstream have a slight slope, thus being prone to floods [8], while the edges of the valleys are steep, favoring the appearance of flash floods. In the river meadow, gravel and sands transported from higher altitudes are found.



Fig.1. Vărbilău riverbed at Poiana Varbilau (left) and Steep slopes in Vărbilău basin (right)

Lithology includes sedimentary formations, like flysch in the north of the catchment, sandstones, clay, gravel, in the remaining area [9].

The climate is temperate continental, locally influenced by the hilly configuration of the relief, with average annual temperatures between 6 and 9 °C, precipitations of 600-900 mm, higher in the north [10]. Local phenomena occur, such as temperature inversion in depressions.

The vegetation consists mainly of deciduous forests due to the hilly relief, while mixed forests (deciduous and coniferous) are present upstream (north). Among the deciduous species are oak (*Quercus robur*), sessile oak (*Quercus petraea*), hornbeam (*Carpinus betulus*), and beech (*Fagus sylvatica*). Based on the field observations, a big part of the area is forested, so the risk of flash floods might be reduced [11]. Still, deforested areas have been identified close to the settlements Vărbilău, Ostrovu and Poiana Vărbilău. There are many houses near the rivers. Areas without forested surfaces (where the risk of flash flood risk is higher) are located between settlements, roads, and rivers (Figure 2).

Soil patterns influence infiltration and further percolation in aquifers [11]. In the area of study, clay-alluvial, brown, and cambisols can be found. Clay soils favor the appearance of flash floods on steep slopes and high precipitation because clay texture prevents the rapid infiltration of water. When the soil becomes saturated with water, it also favors the flash floods generation. Acid brown soils can be found in mountainous areas where the altitudes are high.



Fig.2. Houses (left) and roads (right) located very close to the river

3. METHODOLOGY

Field exploration and GIS analysis have been employed for this study.

Field exploration consisted of prospecting areas exposed to floods (houses and roads near rivers), observing the riverbed slopes (if the slope is smooth or steep), the valley configuration, the forest presence, land use, length between the riverbanks. Field observations helped the elaboration of the GIS analysis. For example, in riverbeds with slight slopes and an appreciable distance between the banks, there is a slight possibility of flash floods occurrence, but there is a more considerable chance for floods to take place [10] because water will accumulate in the valley, runoff being slow due to the inclination. On the other hand, flash floods may occur on rivers located in narrow valleys with steep slopes.

To determine the susceptibility to flash floods, the Flash Flood Susceptibility Index (FFSI) was used. FFSI is an improved method of the Flash Flood Potential Index (FFPI) proposed by Smith in 2003 [7] and utilized to identify areas with a high rate of flash-floods. Authors like Zaharia et al. [6], Mătreacă and Mătreacă [12], and Minea [13] improved and adapted this method for Romanian areas exposed to hydrological phenomena [1].

Certain factors are involved in the computation of the FFSI index: lithology, relief inclination (slope), profile curvature of the surfaces from the catchment, the ratio between the width from the left to the right bank and their slope (L-S factor), a factor that causes repetitive torrential rains, precipitations, convergence index, the configuration of sub-basins, soils and land uses in the catchment. This index was adapted in GIS software to integrate each factor and obtain the spatial distribution of FFSI [14].

First, certain factors were obtained in a polygon vector shapefile (lithology, precipitations, soils, configuration of subbasins, land use). Subsequently, their transformation took place in raster format in ArcGIS 10.3. Corine Land Cover 2006 [15] was employed to obtain the terrains' uses, while soil distribution was determined from a pedological map 1:20000 in Stereo 70 projection [16]. For lithological representation, the Romanian Geological Map 1:50000 in Stereo 70 system was employed [17]. To spatialize the precipitations, Romanian Climate, 2008, was utilized. Global Mapper 12 was used for georeferencing and project cartographical support [1].

The other factors have been obtained with the help of Digital Elevation Model (deduction from DTM corresponding to the Vărbilău basin resulted from the isoline and digitized altitude points from the topographical maps, projection Stereo 70). Relief inclination, a factor that causes repetitive torrential rains, and profile curvature of the

surfaces from the catchment have been determined with the help of ArcGIS tools. Configuration of sub-basins was calculated using the equation:

$$Ff = F/L^2, \tag{1}$$

where Ff = sub-basins configuration, F = the basin surface, L = the basin length.

If a river basin is elongated, then there is the possibility of flooding (water stagnates more in wide valleys with reduced slope), especially in the lower sector of the basin, close to the confluence with the collector river. If the catchments are circular, then the water will drain quickly due to the steep slope and narrow valleys causing the appearance of flash floods [11].

LS factor is the ratio between the width from the left to the right bank and the slope. Sin LS is not dimensional, the following index has been computed, using the formula:

$$LS = (m+1) (As/22.13)^m (\sin\beta/0.0896)^n, \tag{2}$$

where LS = the ratio between the width from the left to the right bank and their slope, As = the basin surface, β = the slope gradient (degrees) and $m = 0.4$ and $n = 1.3$ [19].

To elaborate a general index, the mentioned factors have been integrated into the GIS environment, gathering the rasters corresponding to the river basin's spatial distribution. This action was performed in ArcGIS 10.3 using the Raster Calculator from the Spatial Analyst extension. Each factor was separated into five classes depending on how they led to rapid floods (Table 1).

Table 1. Factors that determine the FFSI in the Vărbilău catchment

Factors	Value/type				
Lithology	sands	marls, clay	sandstones, limestone	gypsum, flysch	shists, conglomerates
Slope (degree)	0-3	3-7	7-15	15-25	>25
Curvature (rad/m)			0.99-1.74	0-0.99	(-2) - 0
LS factor	0-2	2-4	4-6	6-8	>8
Factor for repetitive torrential rains	N, NE	NV, E	Flat areas	SE, V	S, SV
Precipitation (mm/year)		600-700	700-800	800-1000	>1000
Convergence index	>0	0 - (-1)	(-1) - (-2)	(-2) - (-3)	(-3) - (-100)
Configuration of sub-basins	0.09	0.18 - 0.19	0.21-0.3	0.31-0.38	0.42-0.67
Soil	sandy	sandy-loamy	loamy-clayey	loamy-clayey	loamy
Land use	forests	fruit trees, shrubs	arable land	pasture	anthropogenic areas, rocks
Score	1	2	3	4	5

The orthophotomaps [19] overlapped the final FFSI map, thus validating areas more or less exposed to flash floods.

4. RESULTS AND DISCUSSION

The Flash Flood Susceptibility Index obtained using the methodology from the previous section was spatialized as presented in Figure 4.

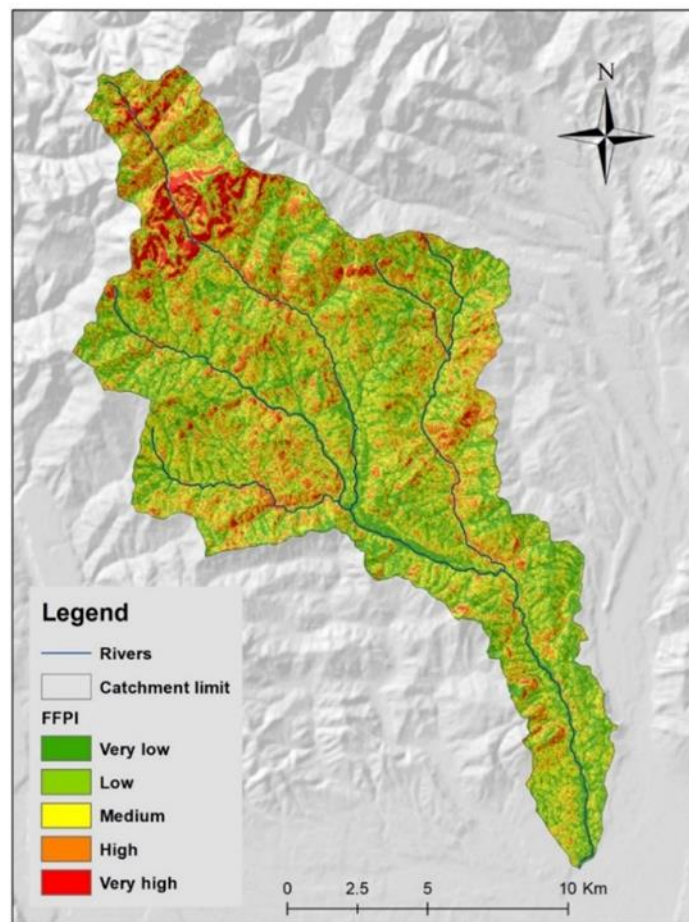


Fig. 4. Spatial distribution of FFSI index in the Vărbilău catchment

From Figure 5, one can see that areas with low and very low susceptibility to flash floods represent almost half of the total surface because of low and almost horizontal slopes in many areas, wide riverbeds, and elongated basins. These zones have a slow runoff. There are areas with an average probability of flash floods (about 30%), especially where the slope is 7-15 degrees, and there are arable lands (hilly areas located very close to houses and rivers). High and very high values of the FFSI index represent almost 24% of the total

area, meaning that almost a quarter of the areas are highly exposed to the flash floods appearance, especially where there exists steep slopes, narrow valleys, exposed land because of the absence of forests, loamy soil or solid rocks (that favor a fast runoff when significant rainfalls occur).

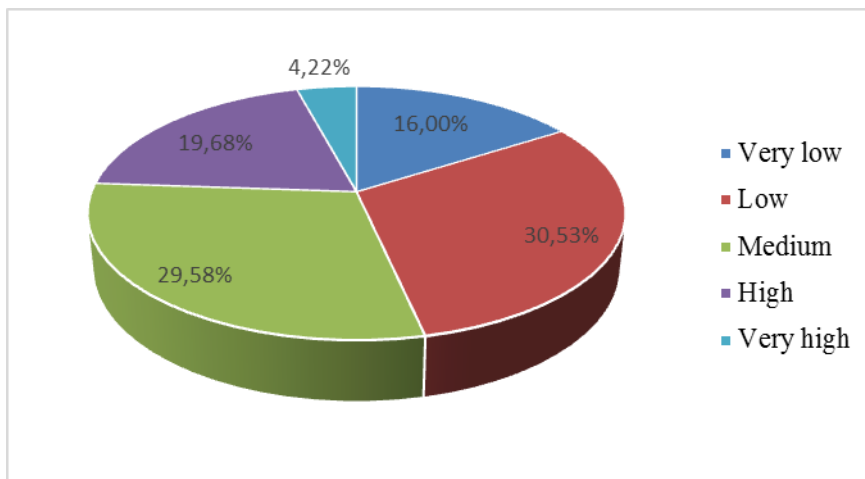


Fig. 5. Percentage distribution of FFSI index

Figure 4 shows the areas exposed to flash floods. The elongated subbasins and wide valleys in the center and south favor an accumulation of water resulting in floods. Flash floods are less likely due to slow runoff caused by a reduced slope and other factors such as broad valleys or soil texture. Therefore, villages less exposed to flash floods are Vărbilău (located at the confluence with Slănic), all villages located south of it to the confluence with Teleajen River, Ostrovu (at the confluence between Vărbilău and Aluniș), Stefești and all communes between Ostrovu and Varbilau. The rivers flowing in these areas collect the water from the flash floods from the upper areas, increasing the flooding risk.

Susceptibility is medium, especially in areas between the rivers and the higher areas of the hills in the central part of the river basin.

Slănic, a town with a population of approximately 6000 inhabitants, the most important settlement in the area, located central east on the river with the same name [20], is partially exposed to flash floods in the upper areas of its administrative territory (southeast of the town) because of the steep slope, the presence of pastures, loamy soil or lithology.

Zones with high susceptibility to flash-floods are located in the northwest of the basin on large areas and in smaller areas in the north, center, and west. This risk is caused by a steep slope, absence of forests, land use (pasture), and basin configuration. Precipitations that are higher up north due to altitude are essential factors in the flash floods formation, especially when torrential. The risk is higher in May and June when high precipitations fall.

Based on Figure 6, areas north of Luțu Roșu and Scurtești are highly exposed to flash floods. The altitudes are high (some over 800 m), steep slopes and narrow valleys are common. Being a mountainous area (Ciucaș Mountains) with solid rocks, precipitations are higher than those from the lower part of the basin. All these factors favor the flash floods apparition. However, the settlements are not affected by flash floods because they are not in

the vicinity of these areas. Still, there is a risk of immediate flooding downstream in Luțu Roșu and Scurtești due to upstream water collection.

In the upper Vărbilău basin, the settlements are far from the Inspectorate for Emergency Situations (ISU), which should intervene by evacuating the population and saving their belongings when hydrological phenomena appear. The main issue is that the flash-floods appear very quickly. In this area, Luțu Roșu and Scurtești, the closest ISU center is at Slănic, 20-23 km away or 30 minutes drive. In extreme situations, when hazards appear, it can be challenging to access the area. The establishment of a new ISU center would shorten the travel time and increase the intervention capacity of the authorities.

The susceptibility of flash floods presented above is a good starting point for analyzing flood susceptibility in Vărbilău basin because flash-floods are a potential source of flood formation downstream.

5. CONCLUSION

Field observations and GIS techniques are essential to perform such a research. By calculating the FFSI in Vărbilău catchment it was possible to determine the susceptibility to flash-floods. Areas in the south and central parts of the basin have a low susceptibility to flash floods, mainly due to a slight slope, presence of forests, elongated river basins, and wide valleys. However, these factors favor the accumulation of water from upstream that can lead to flooding. Areas in the northwest are highly susceptible to flash-floods due to higher precipitations, circular shape of river basins, steep slopes, solid rocks, and land use. Runoff is much faster here in comparison with the other areas. The study can be useful for authorities (ISU) because it shows the areas that are susceptible to flash floods. They can take measures to reduce the impact of extreme hydrological phenomena by creating a new ISU center in the northwest part of the basin that will increase intervention capacity. GIS techniques alongside fields observations used in the present research to determine the susceptibility are applicable for other catchments and can result in other studies, such as flood potential analysis, flash floods being a factor that causes water accumulation downstream.

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