Flood risk identification using multicriteria spatial analysis. Case study: Gilort River between Bălcești and Bolbocești.

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Research Article

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Flood risk identification using multicriteria spatial analysis. Case study: Gilort River between Bălcești and Bolbocești.

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Abstract: *Floods are the most widespread hazard globally and have a significant impact on local communities in terms of material and loss of life. Flood risk analysis is a complex process that needs to be addressed both physically and socially. The study provides a method for identifying the risk using Goegraphical Informational Systems techniques. Each indicator taken into account was analyzed, standardized and weighted to obtain the final results. The risk values have been divided into five classes: very low, low, medium, high and very high. The case study was represented by the River Gilort (a tributary to Jiu River), in a hilly area (Getic Sub Carpathians), between Bălcești and Bolbocești). Thus, the last two risk classes listed characterize the localities with the highest population density and which are situated near the river proximity. The results can also be used by the competent local authorities to effectively manage flood risk.*

Keywords: floods, risk, multi-criteria analysis, physical vulnerability, social vulnerability, Gilort, Romania

1. Introduction

Floods are a widely-spread hydrological hazard at global level, with significant economic and social impact on local communities. It is very important to analyze and map flood risks with a view to sustainable territorial planning and the appropriate development of infrastructure.

Such an analysis may have several types of approaches. The first of them uses qualitative analyzes based on expert judgment. Another approach includes quantitative methods based on the numerical relationship between the affected elements and the hazard itself.

The present study is a combination of the two methods and can thus be considered a semi-quantitative analysis. The results of these analyzes are partly subjective and largely based on expert knowledge (Wang, 2011). However, they are used because they are simple analyzes, capable of integrating large sets of data (Zhan et al. 2003; Zhang et al. 2005; Furdada et al. 2008) and have proven to be effective for regional studies (Zhou et al. 2000; he et al. 2004; Tang and Zhu 2005; Dewan et al. 2007). In Romania, the subject of flood risk has been addressed in various studies and from different perspectives (Armaș et al. 2015, Armaș and Avram 2009, Țîncu et al 2020, Arseni et al 2020).

The main purpose of this work is to identify the flood risk in floodplain of the river Gilort, between the localities of Bălcești and Bolbocești, using multi-territorial spatial analysis. This analysis is a useful method to incorporate large spatial data sets and generate an efficient risk estimation. There are many works worldwide on the multi-criteria analysis (Zimmermann and Gutsche 1991; Munda 1995; Belton and Stewart 2002). It was first presented by van Herwijnen (1999), and there are a series of works in which the multi-criteria analysis is applied to identify the flood risk (Tkach and Simonovic 1997; Simonovic and Nirupama 2005; Thinh and Vogel 2006; Rijaaamakers et al. 2008; Wang 2011, Prawiranegara 2014).

2. Study area

The study area is located in southwestern Romania (Fig.1), in the Gorj Sub Carpathians unit. The length of Gilort river in this area, measured on the thalweg, is approximately 5 km.

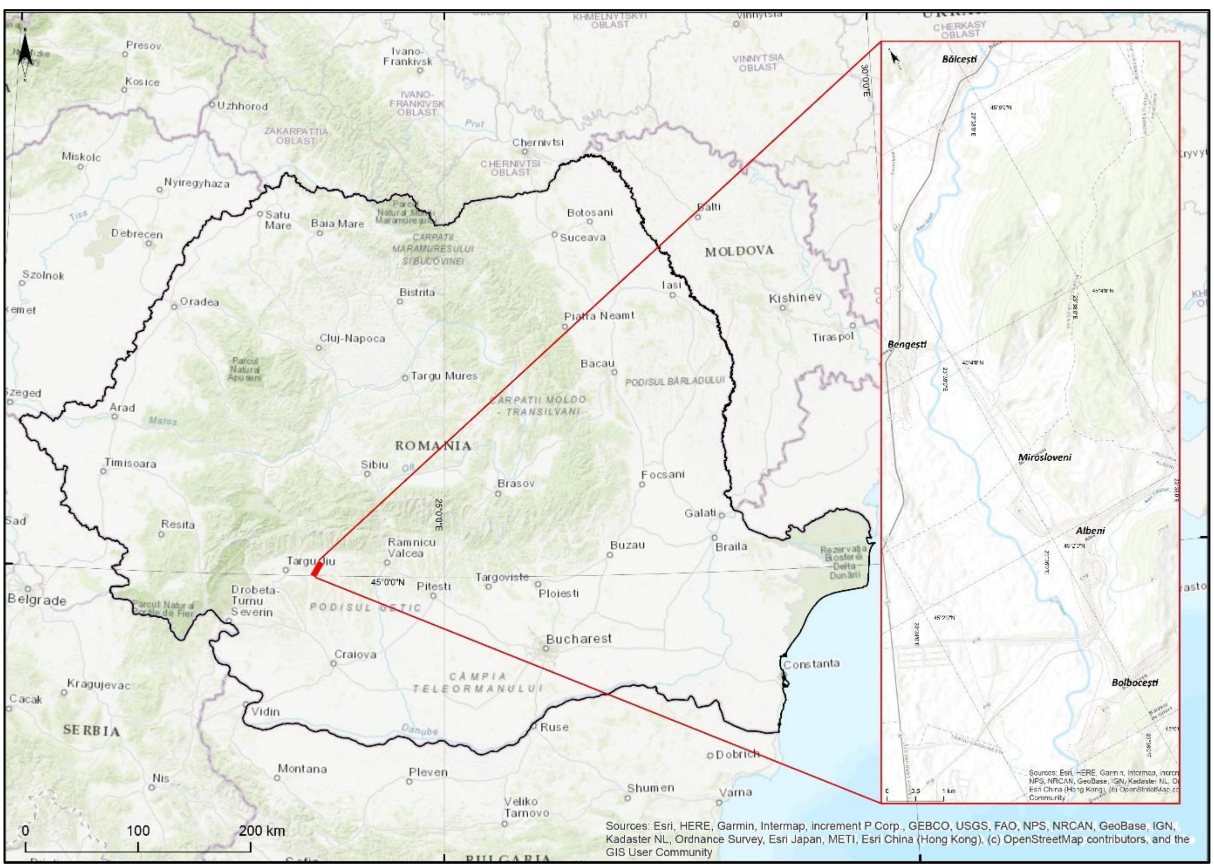


Fig 1 - Location of the study area

The altitude range is between 227 and 503 m. Lower altitudes characterize depression areas and valley corridors, and the higher altitudes characterze hill areas, with the Gorj Subcarpathians being a highly fragmented relief unit. The slope of the terrain varies between 0° (quasi-horizontal surfaces, located mainly in river floodplain, respectively on interfluves) and 45° (specific to the slopes). Geological composition is exclusively made of sedimentary rocks with different characteristics. There are sands, gravels and loessoid deposits (alluvial deposits), as well as marls, clays, gypsum, salt and quartz conglomerates (Ielenicz et al. 2003). From a pedological point of view, there are two distinct groups of soils: specific floodplain soils (alluvial and alluvial prototypes) and soils specific to the topography and geographical position (especially brown argillaceous soils, brown eu-mesobasic soils and rendzine).

The process of gleization on these soils is null or very small (soil map of Romania, 1973). The average flow of the Gilort River in the study area is about 10 m^3/s.

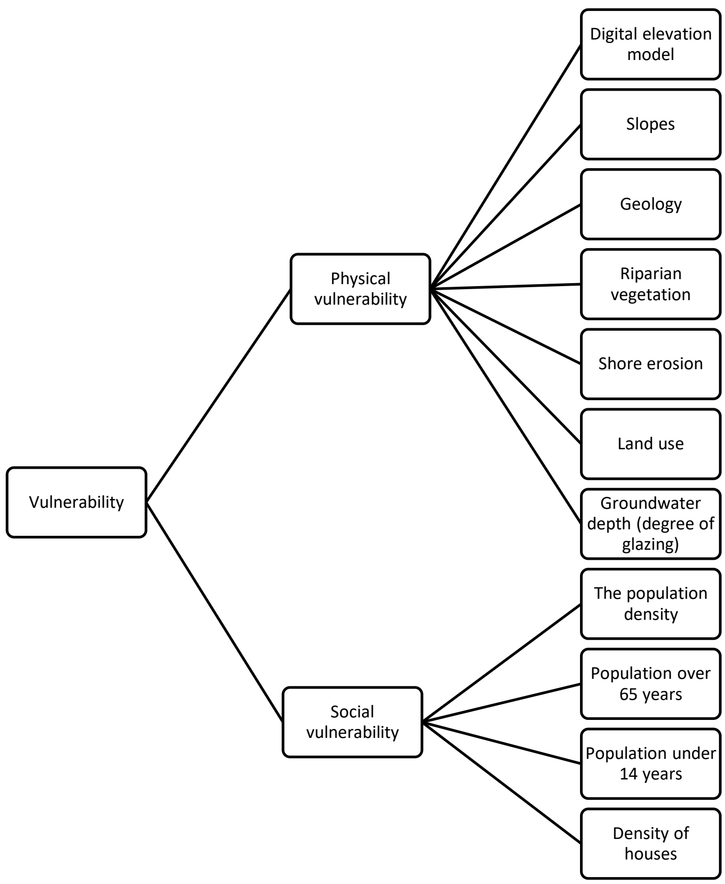
Recent history of the study area has seen a number of floods with different socio-economic implications: Year 2007 – maximum recorded flow rate of 158 mc/s, year 2013 – maximum recorded rate 145.4 mc/s, year 2014 – maximum recorded rate 174 mc/s, year 2016 – maximum recorded rate 118 mc/s, data recorded at the Târgu Cărbunesti Station (downstream of the study area).

Regarding the human component, the localities located in the the study area have a total population of less than 3,000 inhabitants (the maximum value recorded in Bengeşti – 2723 inhabitants). The age groups of interest for the analysis are those under 14 and those over 65 years old. The highest population values for these categories are also recorded in the town of Bengeşti (595 inhabitants over 65 years and 388 inhabitants under 14 years).

3. Methodology

This work is based on multi-criterial analysis, which includes a number of indicators relevant to the determination of flood risk. The general risk calculation formula is *RISK = HAZARD * VULNERABILITY* (Wang 2011), so for the accuracy of the results the two elements must be calculated and analyzed individually. For the type of hazard (flooding with a recurrence period of 10 years), the following data sets were used: The topographic map, scale 1:25000 (1982) for extracting the level curves, making the digital elevation model (DEM, re-interpolated to 5 m) and slope, Romania's geological map 1:200000 (1968), Romania's soil map 1:200000 (1973), statistical data sets obtained from the National Institute of Statistics, the configuration of the intravillan space from the National Agency of Cadastre and Real Estate Advertising, the flood band of the Gilort River obtained from the Jiu Water Basin Administration.

The vulnerability of the area to this type of hazard must be treated in a dual perspective: the physical vulnerability of the area (the way in which the shape of the relief and the natural elements are affected) and the social vulnerability (the degree of damage to the population and socio-economic activities). In order to summarize the concept of vulnerability, the following schema has been achieved.



Vulnerability concept - synthesis elements (after Wang, with modifications)

The contorus extracted from the Romanian topographic map (1:25000), re-interpolated at 5 m., were used to make the digital elevation model. The lower the altitude, the greater the vulnerability of the terrain as the possibility of flooding is higher at lower altitudes. The digital elevation model was used to calculate the slope gradient. The lower the slope (measured in degrees), the lower the flash flood movement speed, which means that the water stagnates for a long period of time, increasing the vulnerability of the area. Geology elements are important in terms of the degree of compaction of the rock, in the sense that the greater the porosity of the rock, the faster water can flow into it, leading to a decrease in the vulnerability of the territory. The riparian vegetation patches present natural barriers to the propagation of the flood wave. Bank erosion, or the Bank Erosion Hazard Index (BEHI), is an indicator that provides information on the bank potential for erosion according to their specific morphometric and geological characteristics. This indicator was considered necessary because, the higher the BEHI, the more the banks are at risk of "breaking" in the event of a flash-flood. This would create the possibility of the flood spreading radially. This indicator has been calculated in the field. Land use, although essentially an indicator created by man-made intervention, is treated as a physical element. This indicator shows maximum vulnerability within the perimeter of built spaces. The degree of gleization has been taken into account in conjunction with the depth at which the groundwater is found. Thus, the higher the degree of gleization the more the groundwater is near the surface, so the saturation level is higher and therefore decreases the soil retention capacity, increasing the vulnerability of the terrain.

Social vulnerability refers to the population of the affected area, expressed in terms of population density. Social vulnerability increases in proportion to population density values. Populations over 65 years and under 14 years respectively are the most vulnerable social groups due to age, health problems and reduced mobility (over 65 years) or inability to raise awareness of the danger (under 14 years). The density of houses can be seen in the light of the potential material damage that can occur as a result of hazard occurence.

For input data, being both text and numeric, values were required to be assigned and normalized. The attribution of values was made on the basis of the impact the indicator has on the analysis (cost or benefit) and the normalization of data was done using the formula:

$$N\_score = \frac{score - lowest\ score}{highest\ score - lowest\ score}$$

Given that the indicators do not have an equal impact on vulnerability of any type, weighting was required. This was done by using the ILWIS 3.4 software, with the Spatial Multi-criteria analysis tool where a multicriteria graph was created that includes all the above-mentioned indicators.

Weighting was performed by the Pairwise type, where the indicators were compared in pairs, and depending on the result, the program automatically generated weights. These are as follows:

- ***Physical vulnerability**: DEM 0.33, slopes 0.22, bank erosion 0.05, land use 0.19, geology 0.04, riparian vegetation 0.13, soils 0.04;*
- ***Social vulnerability**: population density 0.32, population under 14 years 0.22, population over 65 years 0.38, density of houses 0.08*

After the two indicators were calculated, they were combined, using equal weights, to achieve the total vulnerability of the area. It was added to the hazard (the Gilort flood band) using equal weights, and the risk of flooding was obtained.

The flood band in a vector format represents the spatial distribution of floods with a 10-year recovery period.

The resulting flood risk values range from 0 to 1, thus divided into 5 equal classes (very low, low, medium, high and very high), using a range of 0.2.

The methodology for identifying the physical, social and total vulnerability as well as the risk of flooding in the study area was based on multiplication of raster datasets and processing the statistical values generated.

4. Results and discussions

Physical vulnerability

For the calculation of the physical vulnerability of the study area in the event of a flood, the parameters mentioned above (DEM, slope, bank erosion, land use, geology, riparian vegetation, soils) have been processed, the input data has been normalized and the entire database has been rasterized (Fig.2)

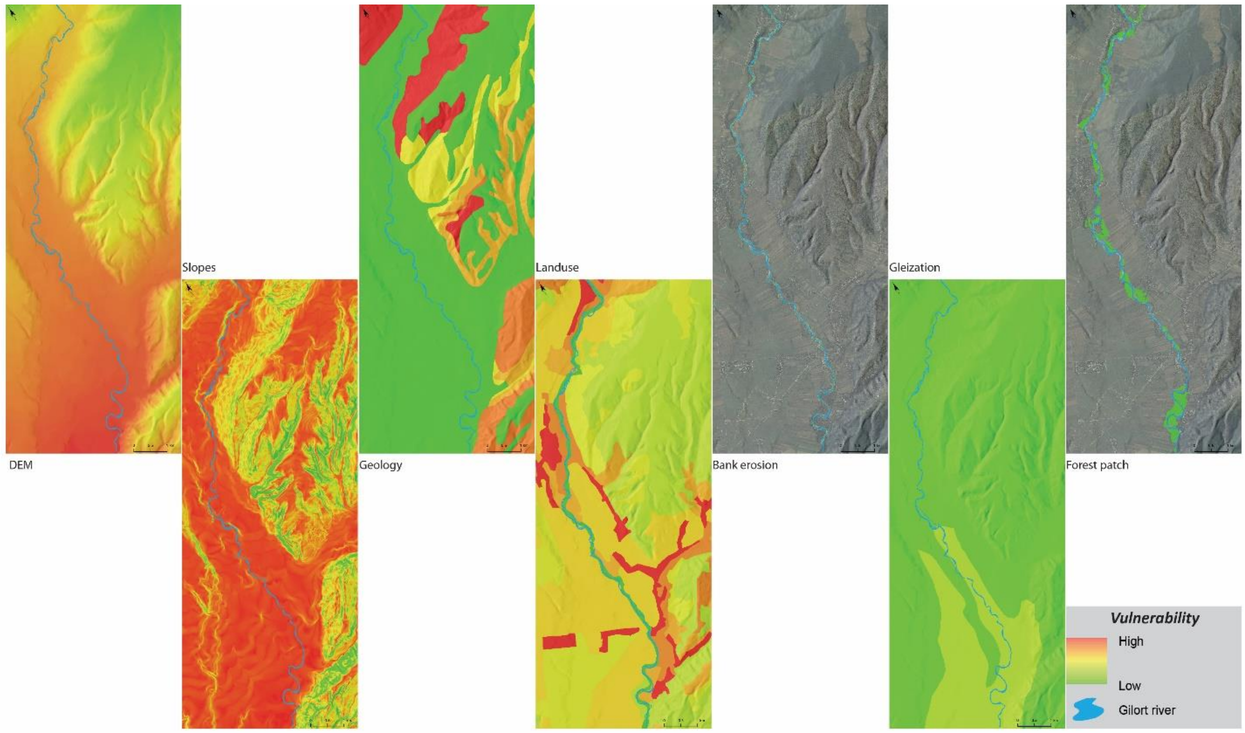


Fig.2 - Database, normalized and rasterized

For the DEM, high and very high vulnerabilities have been identified in the floodplain areas (which represents most of the study area and have the highest potential for the flood wave to spread) and along the watercourses, permanent or temporary, where the altitude of the terrain is reduced. Low and very low vulnerability has been identified on the interfluves in the eastern half of the study region where altitudes are above 400m.

Looking at the slopes, it is noted that the flat or quasi-horizontal surfaces (slopes below 5°), which characterize the valley corridors, have high and very high vulnerability, while high slopes are less vulnerable to flooding. The land use has medium, high and very high vulnerability in the proximity of the river, for two reasons: the concentration in this area of the localities and the population (the municipalities of Bălcești, Bengesti, Albeni, Mirosloveni, Bolbocesti) and most of the land along the river is exploited from an agricultural point of view, thus, the economic impact of a flood would be high (the above mentioned localities have a agricultural profile, so that land degradation or set-aside would affect the local economy). In the geological composition, sands and gravel (alluvial deposits) predominate (Ielenicz et al. 2003), with distribution along minor channel and floodplain. They offer the area a low vulnerability, as they are non-cohesive rocks , which allow water to be quickly infiltrated into the groundwater. The intensity of the gleization process is very low in the study area, so the vulnerability of the region from this point of view is also low.

The physical vulnerability of the area has been achieved through the multiplication of rasters. The result is shown in Fig.3.

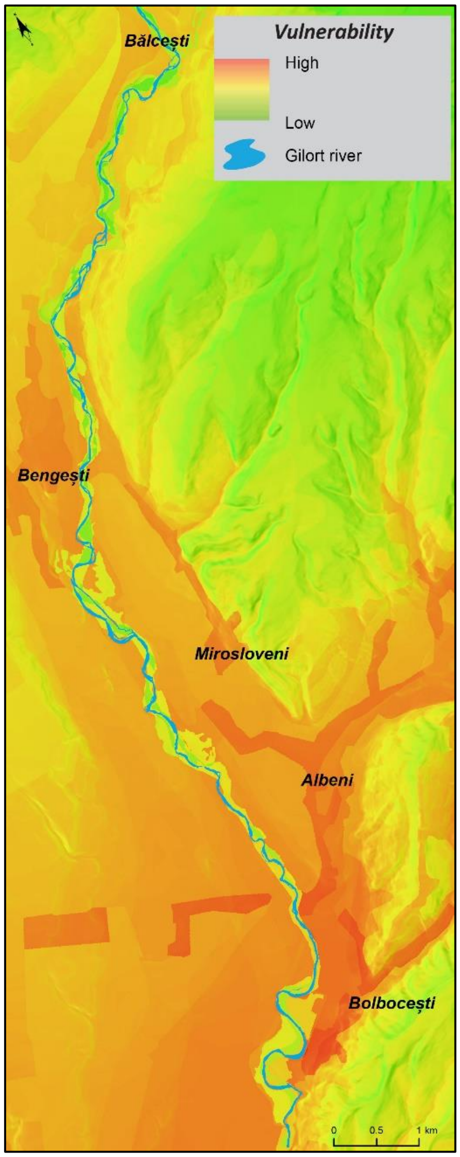


Fig.3 - Physical vulnerability of the study area

Thus, it turned out that the highest physical vulnerability is present in the area of the floodplain, where settlements exist, or where agricultural land predominates, which are the main factors affected in the event of floods. Vulnerability decreases in the eastern part of the study area. It should be noted that the physical vulnerability of the area is lower in the minor riverbed and in its immediate proximity, as there is a relatively uniform distribution of the riparian vegetation patches along the river course. By extracting the area data, a percentage distribution of vulnerability has been achieved (divided into 5 classes – "very low" class did not register values) (Table 1, Fig.4).

Table 1 weight of ranges with different physical vulnerability classes

Physical vulnerability	Area	Percentage (%)
Low	0.06	0.09
Medium	23.53	32.93
High	43.37	60.69
Very high	4.50	6.29

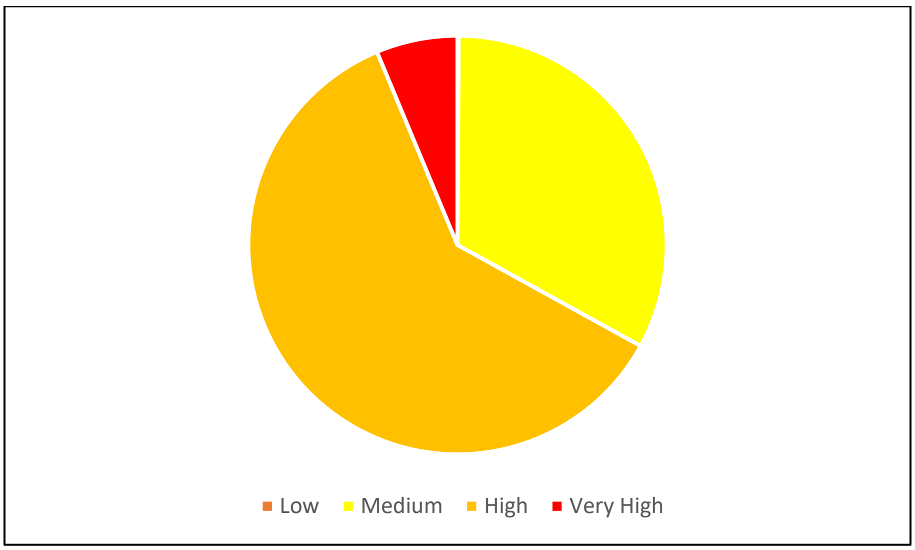


Fig.4 - Distribution of physical vulnerability by class

Social vulnerability

The parameters were used to calculate social vulnerability in the event of a flood (population density, population under 14, population over 65 years, density of houses) have been processed, the input data has been normalized and the entire database has been rasterized (Fig.5). The statistical data used in the analysis are given in Table 2.

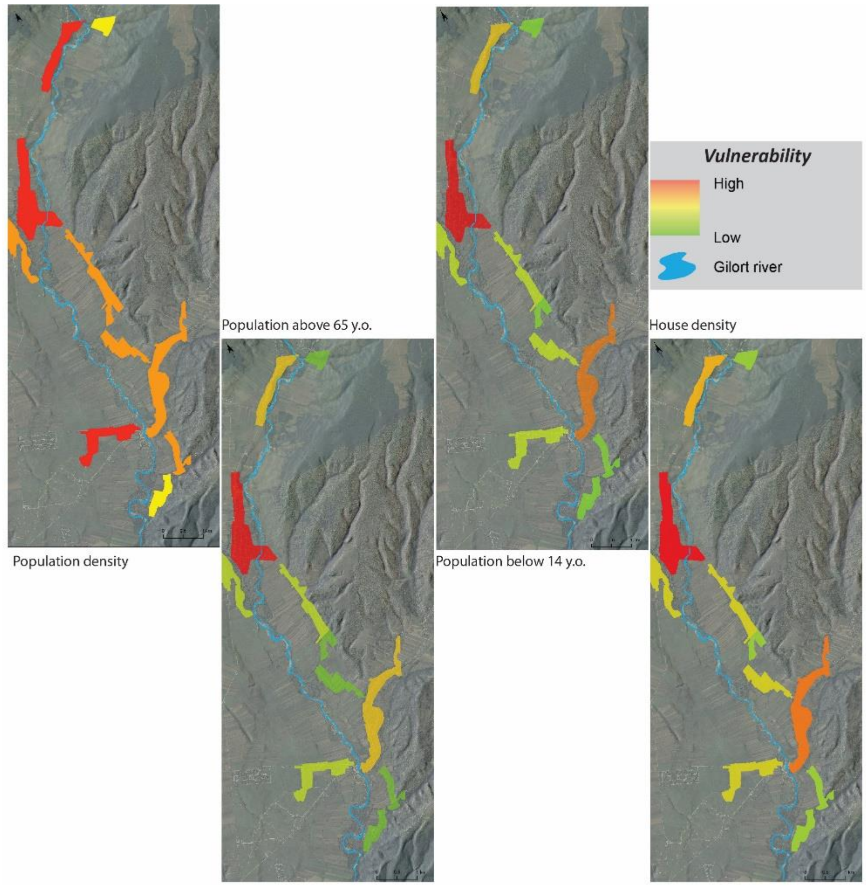


Fig. 5 - Database, normalized and rasterized

For all the parameters considered, the highest values are recorded in the Bengesti town, which is also the most important settlement in the study area. It is followed by Albeni town, as well as values of population and importance in the area.

Table 2 - Population statistics (source: INS, 2020)

	Albeni	Bengești	Bălcesti	Mirosloveni	Bolbocești
Total population	2009	2723	805	588	211
Population under 14 yo	288	388	115	84	30
Population above 65 yo	333	596	176	97	35
No. of houses	502	681	147	147	53
House density (house/sq.km)	282.67	340.91	189.73	284.61	200.78

The social vulnerability of the region is shown in the Fig. 6 thus, the highest values of social vulnerability are recorded in the two mentioned localities. Average vulnerability is recorded in the village of Bălcești (located in the north of the study region). The area not including permanent settlements has been considered to have zero social vulnerability.

Average values of social vulnerability have been recorded in the southern part of the village of Mirosloveni and the lowest values have been recorded in the village of Bolbocesti, as a result of the distribution of demographic parameters considered relevant for this analysis.

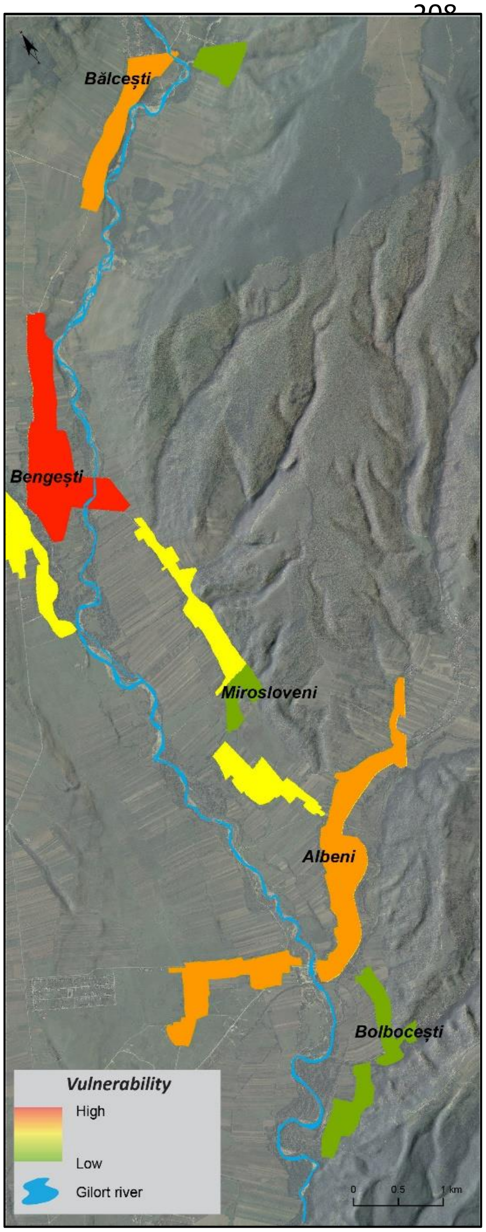


Fig 6 - The social vulnerability of the region

The two types of vulnerability were combined (using equal weights) to achieve the overall vulnerability of the study area (Fig.8). It is noted that the highest values of vulnerability are recorded in the proximity of human settlements, where both types of calculated vulnerabilities are present. The floodplain area have medium vulnerability, while the hill areas with higher altitudes and higher pitch slopes are less vulnerable. The statistical distribution of area distribution data according to the vulnerability of the area is shown in Fig.7. More than 90% of the study area has low and very low vulnerability and the highest values characterize the built spaces.

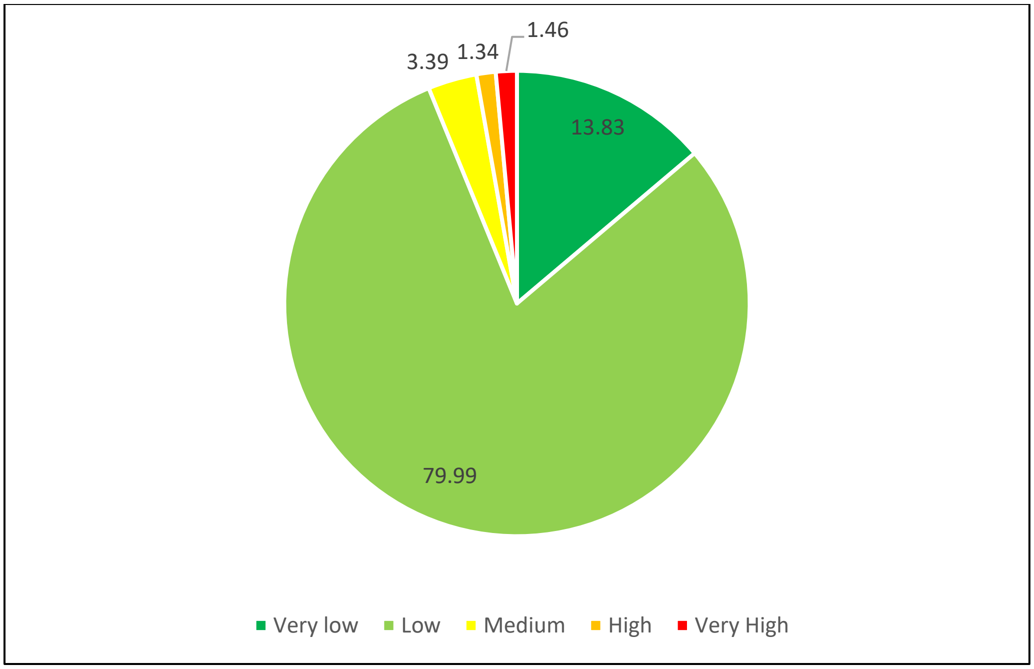


Fig 7 Percentage distribution of total vulnerability

The flood risk distribution (Fig 9) has been based on the risk calculation formula, with the two components: hazard and vulnerability. Thus, the hazard was considered the flood band of the Gilort River. Raster data sets representing hazard and vulnerability were aggregated using equal weights and the result was the spatial distribution of flood risk. 5 risk classes (very low to very high) have been identified in the study area and their spatial and percentage distribution is as follows: very low risk: 63.53 km^2 (88.90%), low risk 3.27 km^2 (4.57%), medium risk 1.23 km^2 (1.72%), high risk 3.37 km^2 (4.71%) and very high risk 0.07 km^2 (0.1%). It is noted that the highest flood risk figures are recorded where the flood band intersects the area of development of the localities (in the case of the Bengești and Albeni), and all conditions for material and human damage are met. The remaining locations in the study area identify medium, low and very low values, with a number of upstream exceptions (Bălcești) where high risk values are present. According to fig 10, over 75% of the existing settlements area has a low and very low risk, 20% medium risk and only 3.29% high and very high risk. High risk values are also identified in the Gilort River floodplain, throughout the flood band.

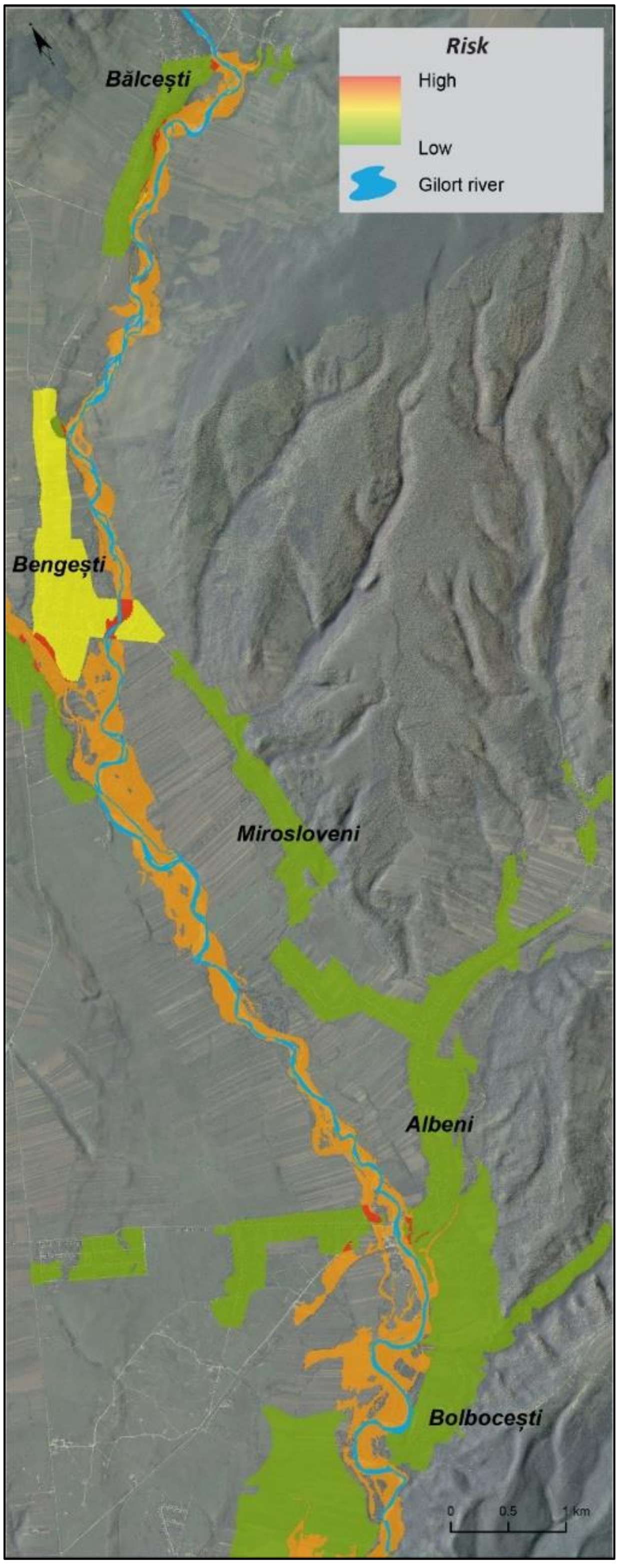


Fig. 8 Total vulnerability in the study area

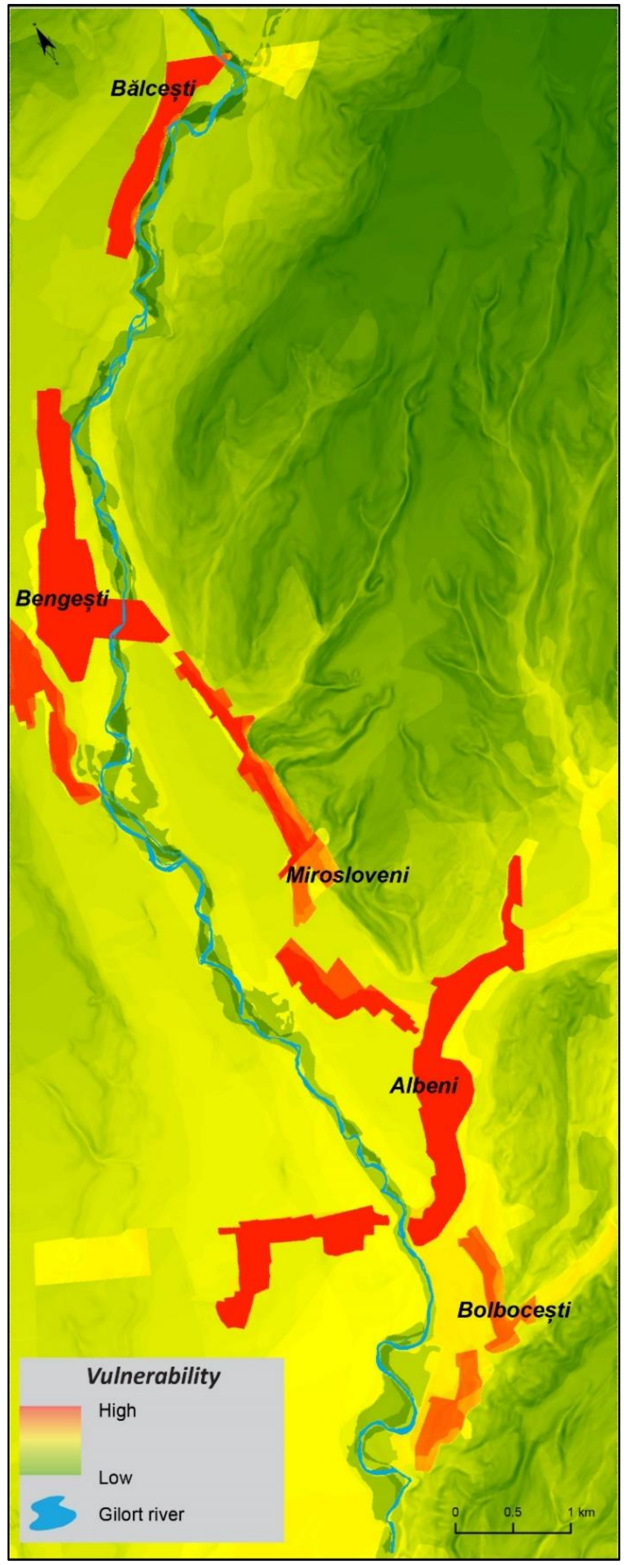


Fig 9 - Risk of flooding in the study area

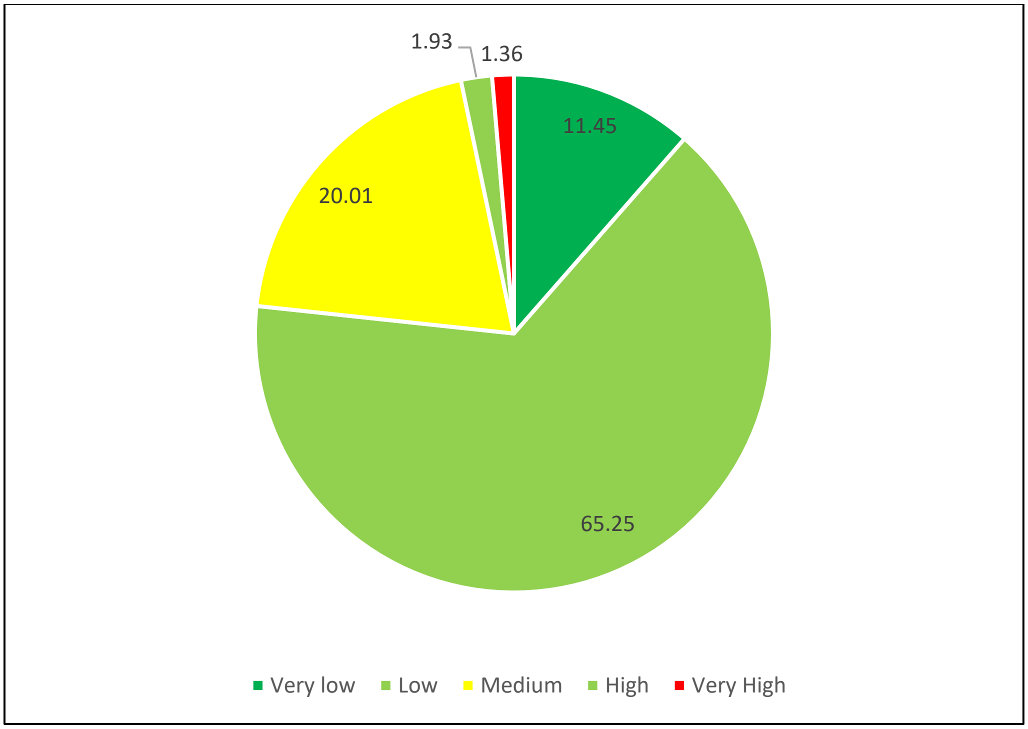


Fig 10 - The percentage distribution of risk data within the localities

5. Conclusions

Flooding is a hydrological hazard with a significant impact on population, constructions and economic activities. Identifying the hazard is not sufficient and the economic impact of the hazard must be taken into account. Such analysis may be carried out using GIS techniques, taking into account also elements of physical and social vulnerability. For the study area, the risk of flooding is high where the flood band intersects the built area, the most affected localities being Bengesti and Albeni.

The limitations of the study relate in particular to the accuracy of the data available at the time. Such analysis may be used as a decision-making tool for risk management and may be extended to all types of natural hazard.

The study can continue with the development of effective flood risk management measures based on the results achieved.

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Competing Interests.

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Author Contributions.

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