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ASSESSMENT OF BUILDING INFRASTRUCTURE VULNERABILITY TO FLASH-FLOODS IN PĂNĂTĂU RIVER BASIN, ROMANIA

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Abstract: Due to the increase of the frequency and severity of hydrik risk phenomena, applying GIS techniques for spatial analysis became indispensable for the identification of the most vulnerable areas to floods and flash-floods. In this study, a proper methodology was used to estimate built areas vulnerability to flash-floods within Pănătău river basin, which is located in a very exposed area. Thus, the buildings vulnerability index (BVI) was defined and calculated by including the following components: the Flash Flood Potential Index (FFPI) and the buildings density within the built-up area (D). The calculation of BVI was based on multiplying the standardized values of these two components. The results highlighted a high and very high vulnerability to flash-floods, on almost 13% of the total area. According to the spatial distribution of BVI values, within each village, the most vulnerable surfaces are located in Pănătău and Sibiciul de Jos, which is also attested by data from the National Romanian Water Administration. On the other side, Lacu cu Anini village is the less vulnerable.

Key words: Pănătău, FFPI, Building density, BVI, flash-flood vulnerability,

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INTRODUCTION

Hydrological risk phenomena, such as floods and flash-floods, caused by surface runoff on slopes, increased in terms of frequency both at global and national level. The increase of the frequency and severity of these phenomena is strongly related to global climate changes and land use changes (Villarini et al., 2010; Costache and Fontanine, 2013; Prăvălie and Costache, 2013). These phenomena occur mainly in river basins with high slopes and reduced surfaces, causing floods, and consequently, material damage and human life loss (Sorocovschi, 2002, 2003).

In this regard, studying these phenomena occurrence and identifying the vulnerable areas is very important. Lately, using GIS techniques to create hydrologic models with an increased accuracy has become indispensable for research in the field of hydrology (Costache, 2014; Herman, 2009, 2010). These methods are being used in international studies by several researchers (Sui and Maggio, 1999; Al-Sabhan et al., 2003; Connor and Hiroki, 2005; Billa et al., 2011) and also in Romania studies (Minea, 2013; Costache et al., 2014).

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The aim of the study is the assessment of buildings vulnerability to flash-flood phenomena within Pănătău river basin, by using GIS techniques. The final results were obtained by computing a dimensionless index which integrates the susceptibility to flash-flood (Flash-Flood Potential Index) and the buildings density values.

STUDY AREA

Pănătău river basin is located in the central south-eastern part of Romania, being a left tributarry to Buzău River (figure 1). It is located in the Curvature Subcarpathian, one of the most exposed areas to torrential phenomena.

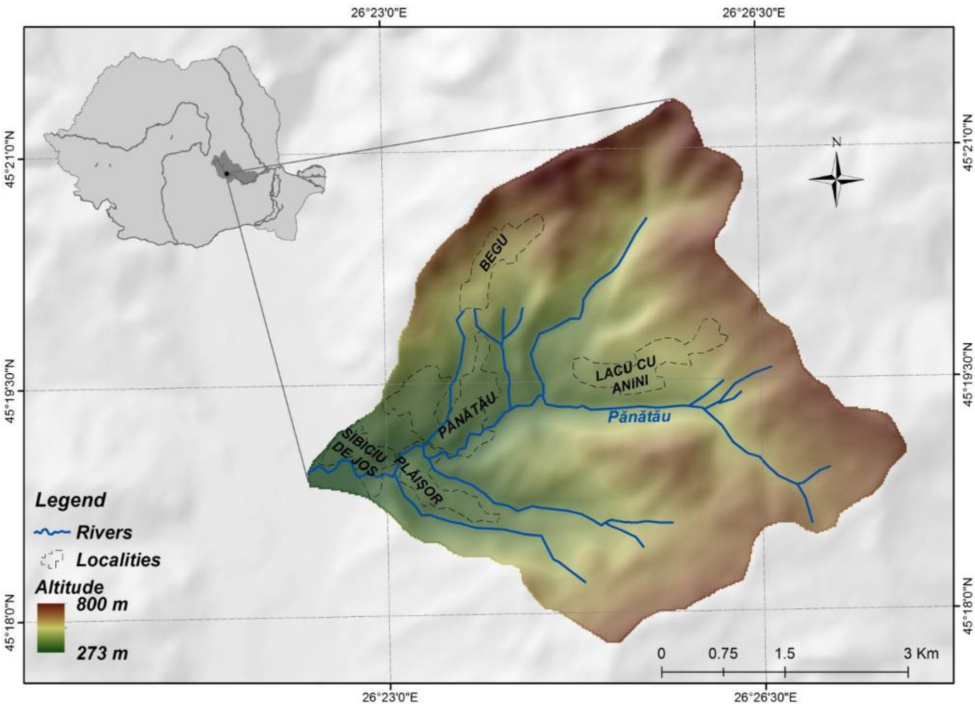

Figure 1. Study area location

The river basin surface is of almost 25 km^2, being a small river basin with high risk for flash-floods. Its circularity index (R_C) equal with 0,66 indicates the tendency to a circular form. Thereby, the time of concentration in the main collector is very low and is an additional factor in flash-flood intensification. The circularity index (R_C) was computed by the following formula: $Rc = \frac{4\pi * F}{P^2}$ (1), where Rc – the circularity ratio of the river basin, F – river basin surface, P – river basin perimeter. In terms of quantity, the time of concentration in the closed section of a river basin can be calculated by the following equation:

$$T_c = \frac{Tlag}{0.6} \quad (2),$$

in which:

$$Tlag = \frac{(L*3.28*10^3)^{0.8}*(\frac{1000}{CN_{aw}}-9)^{0.7}}{1900*Y^{0.5}} \quad (3),$$

$$CN_{aw} = \frac{\sum_{i=1}^{n}(CNi * Ai)}{\sum_{i=1}^{n} Ai} \quad (4),$$

where:

Tlag – lag time of the basin, L- maximum hydraulic length, CNaw – average weighted Curve Number, CNi = the curve number for each land use-soil group polygon, Ai = the area for each land use-soil group polygon, n = the number of land use-soil polygons in each drainage basin, Y – average slope in the river basin (%). In Pănătău river basin, lag time is 106,8 minutes. The length of the main collector from Pănătău river basin is almost 8 km.

The altitudes of the study area range between 273 m, where Pănătău River flows into Buzău River, and 800 on the water divide (figure 1). The high amplitude of the altitude values, recorded on a reduced surface, explains the slopes exceeding 15° on more than 15 % of the total area, which are prone to surface runoff.

Forest vegetation has a major role in controlling the hydrologic balance of the river basin, causing a considerable decrease of the discharge with different excedence probability. In the study area, forest coverage records approximately 45%, covering 11 km^2 of the study area (Corine Land Cover, 2006).

Soils indirectly influence surface runoff due to their properties, especially in which regards their texture. Soil texture regulates the hydraulic conductivity. According to this property, soils were grouped in four hydrologic categories: A, B, C, D. In the study area, the hydrologic C soil group occurs on 18,2 km^2 , respectively 75% of the total area. The C class soils are made of 20-40% clay and more than 50% 92 sand and have a saturated 93 hydraulic conductivity between 1 and 10 µm/s. Within the study area, built areas record a 2.7 km^2 surface (Orthophotomaps, 2008). The average buildings density, considering houses and other extensions, is of 4,3 houses/ha.

DATA AND METHODS

The study is based on the following work flow:

1. Calculation and spatial modelling of the flash-flood potential;
2. Calculation of buildings density within the villages in the study area;
3. Assessment of buildings vulnerability to surface runoff, by computing a specific index due the obtained results from the previous working steps.

1. Calculation and spatial modelling of the flash-flood potential

In order to highlight the surfaces with high vulnerability to surface runoff, the FFPI was computed and spatially modelled. It was obtained by integrating seven geographical factors which influence surface runoff, in GIS environment.

The morphometrical factors derived from the Digital Terrain Model, at a 5 m cell size, obtained by 5 m equidistance contours interpolation, are: slope, profile curvature, L-S factor, hydrographical network convergence index and slope aspect. Slope (figure 2.a) is one of the most important factors, due to its direct influence on surface runoff (Prăvălie & Costache, 2014). The profile curvature (figure 2.b) highlitghs the areas with accelerated surface runoff, corresponding to negative values *„and the ones with decelerated otuflow of the water on slopes”* (Blaga, 2012). L-S factor (figure 2.f.) was obtained using GIS techniques, by applying the formula proposed by Wischmeier and Smith (1978):

$$LS = \left(\frac{\lambda}{22.13}\right)^{t} * (65.4\sin^2\beta + 4.56\sin\beta + 0.0654) \quad (5)$$

where:

λ – is the horizontal projection of slope legth (m);

t - is the constant dependent on the value of slope and

β - is the slope angle (degree).

This factor represents the relation between slope and its length, its values being directly proportional with the surface runoff potential.

The hydrographical network convergence index (figure 2.c) was obtained in SAGA GIS 2.1.0 differentiates valley areas from interfluves areas. Slope aspect (figure 2.e) indirectly influences surface runoff, due to the influence on torrential precipitation.

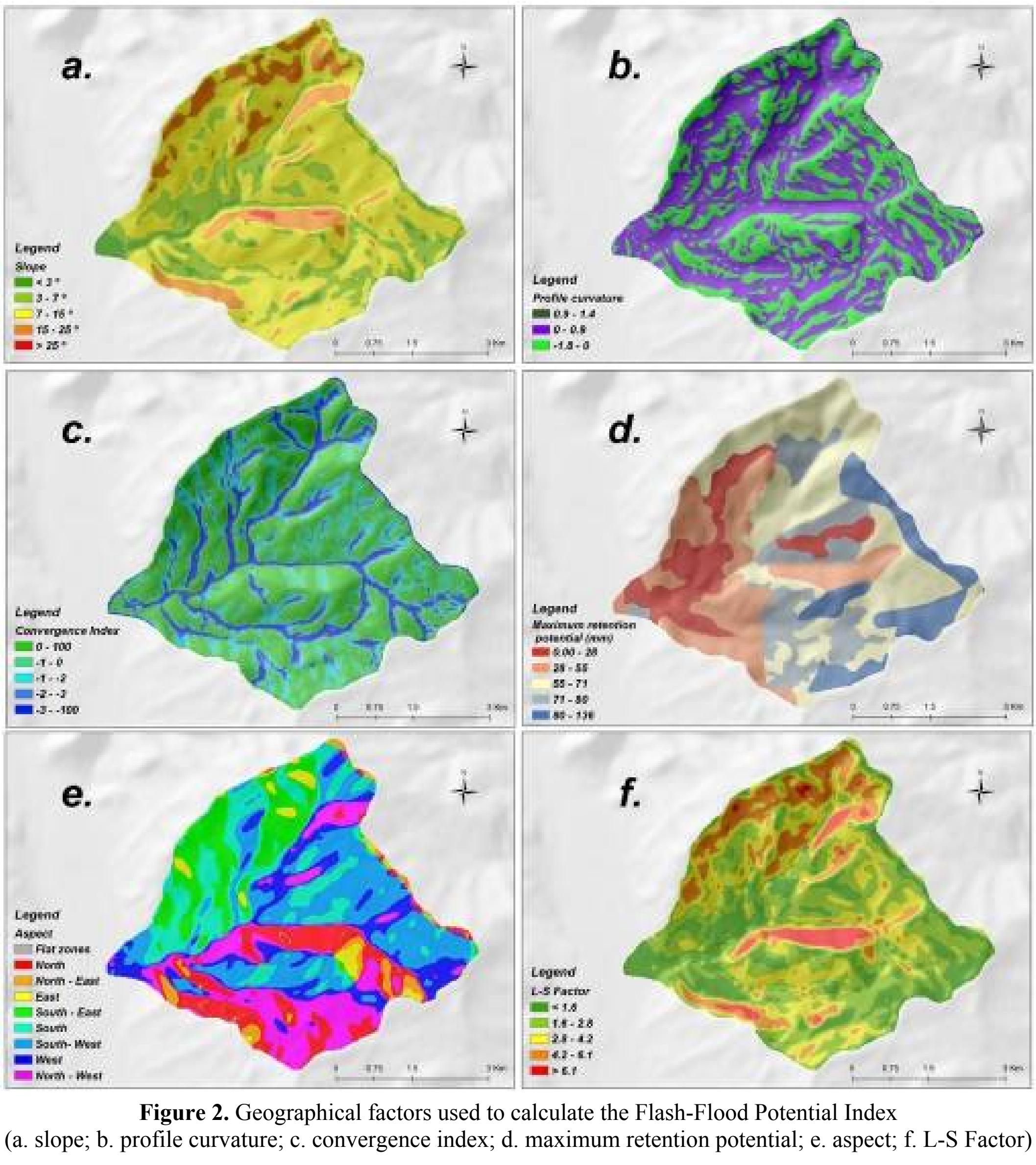

Figure 2. Geographical factors used to calculate the Flash-Flood Potential Index
(a. slope; b. profile curvature; c. convergence index; d. maximum retention potential; e. aspect; f. L-S Factor)

Land use and hydrological soil group were integrated in GIS environment in order to obtain the maximum potential for water retention (mm) by the Curve Number method, using the following formula (Costache, 2014):

$$S = \frac{25400}{CN} - 254 \quad (6),$$

where:

S - Maximum water retention potential;

CN – Curve Number, associated to each intersection between land use and hydrological soil group.

Once the Maximum potential for water retention values obtained (figure 2.d), these were reclassified by assigning values between 1 and 5. The lowest values were assigned score 5, meanwhile 1 score values represent the highest maximum potential for water retention values, which do not influence surface runoff.

The other five factors described above were also grouped in five classes, ranging between 1 and 5, according to their influence on surface run off (table 1). The spatial distribution of the FFPI was obtained by the weighted sum between the reclassified factors (table 1). The weights were given to each factor after using the Weight module in IDRISI Selva software (table 1).

Table 1. The geographical factors and their weights utilized for calculate the FFPI

Parameters	**Types/values**				
Slope (º) – 23%	< 3	3 – 7	7 - 15	15– 25	>25
Maximum retention potential (mm) – 22%	80-136	71 -80	55 - 71	28 - 55	0 - 28
L-S Factor – 15%	< 1.6	1.6 – 2.8	2.8 – 4.2	4.2 – 6.1	> 6.1
Convergence index – 13%	0 - 100	-1 – 0	(-2) – (-1)	(-3) – (-2)	(-100) – (-3)
Profile curvature – 15%			0.9 – 1.4	0 – 0.9	-1.8 – 0
Slope aspect – 12%	N, NE	NW, E	Flat Areas	SE, W	S, SW
Score given	1	2	3	4	5
FFPI (class)	14.5 – 25.8	25.8 – 29.7	29.7 – 34.1	34.1 – 36.6	36.6 – 41.5

Finally, the FFPI was obtained by the formula:

$$FFPI = 2.3 * R + 2.2 * S + 1.5 * L - S + 1.3 * C + 1.5 * P + 1.2 * A \quad (7),$$

where:

R – slope (º)

S – maximum water retention potential (mm)

L-S – L-S Factor

C – convergence index

P – profile curvature

A – aspect

2. Calculation of buildings density within the villages in the study area

In order to obtain the buildings density, the following formula was used:

$$D = \frac{C}{A_{Ha}} (8),$$

where:

C – number of buildings;

A_{Ha} – surfaces (Hectares);

Firstly, buildings were digitized in point shape format, from the ANCPI Ortophomap, 2008 and a grid of polygons with 100 m cell size was computed.

Secondly, the number of buildings within each cell was obtained by the Spatial Join tool from ArcGIS 10,1.

3. Assessment of buildings vulnerability to surface runoff

In order to estimate the buildings vulnerability to flash-floods, the Buildings Vulnerability Index (BVI) was computed by integrating the FFPI and the buildings density, after following several working steps.

To start with, FFPI and buildings density were standardized, so that these range between 0 and 1 and could be integrated in the formula (Salvati & Zitti, 2009):

$$X_{t,i,j} = \frac{X'_{i,j} - X'_{min,j}}{X'_{max,j} - X'_{min,j}} \quad (9),$$

where:

$X_{t,i,j}$ - transformed value for each case;
$X'_{i,j}$ – original value of each case;
$X'_{min,j}$ – minimum value of the variable;
$X'_{max,j}$ – maximum value of the variable.

After applying the formula for the FFPI and the buildings density, each grid cell was assigned an average values of the FFPI between 0 an 1, through Zonal Statistics tool from ArcGIS 10.1.

Once the FFPI values computed at the same spatial unit as the buildings density values, and the two components obtained at the same range values between 0 and 1, these were included in the formula:

$$BVI = FFPI' * D' \quad (10)$$

where:

BVI' –Buildings Vulnerability Index
FFPI' – runoff index values between 0 and 1;
D' – buildings density from the built areas between 0 and 1;

RESULTS

By applying the described methodology in chapter **1**, FFPI values were obtained and spatially modelled for Pănătău river basin (figure 3).

This index values range between 14.5 and 41.5. Its values were grouped in five classes through Natural Breaks method, which is a data classification method *"that seeks to partition data into classes based on natural groups in the data distribution"*.[1]

The first class of values, between 14.5 and 41.5 occurs on almost 19% of the total study area, mainly in the south-eastern part, with high degree of forestation and low slopes. The second class of values, between 25.8 - 29.7, which cover 35% of study area, have a uniform distribution within the river basin. The middle class of values, between 29.7 - 34.1 is more likely distributed as the second class of values, being more obvious in the central and northern parts of the study area. The highest surface runoff potential values exceed 36.6, on almost 10 % of the study area. These values occur on slopes over 15°, with a decreased potential for water retention and high convergence values, as within Pănătău River valley and its major tributaries (figure 3).

The result of the methodology described in chapter **2** consisted of the representation of spatial distribution of the buildings density within Pănătău river basin, obtained by the number of houses related to one hectare. The buildings density ranges between 0 – 30 buildings /hectares (figure 4).

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[1] *http://support.esri.com/other-resources/gis-dictionary/*

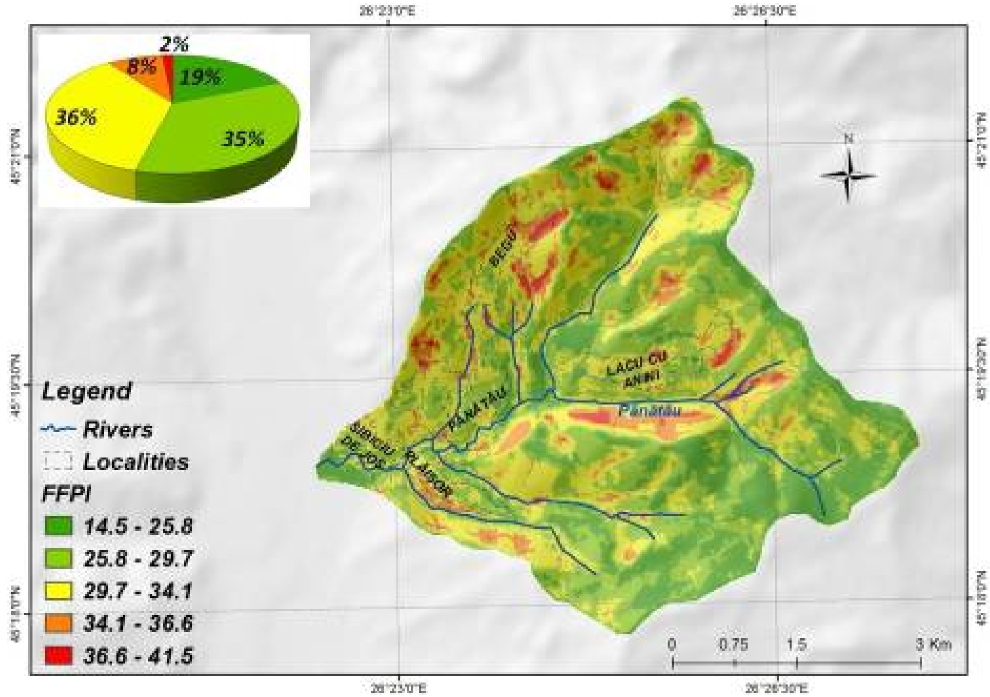

Figure 3. The FFPI values within Pănătău river basin

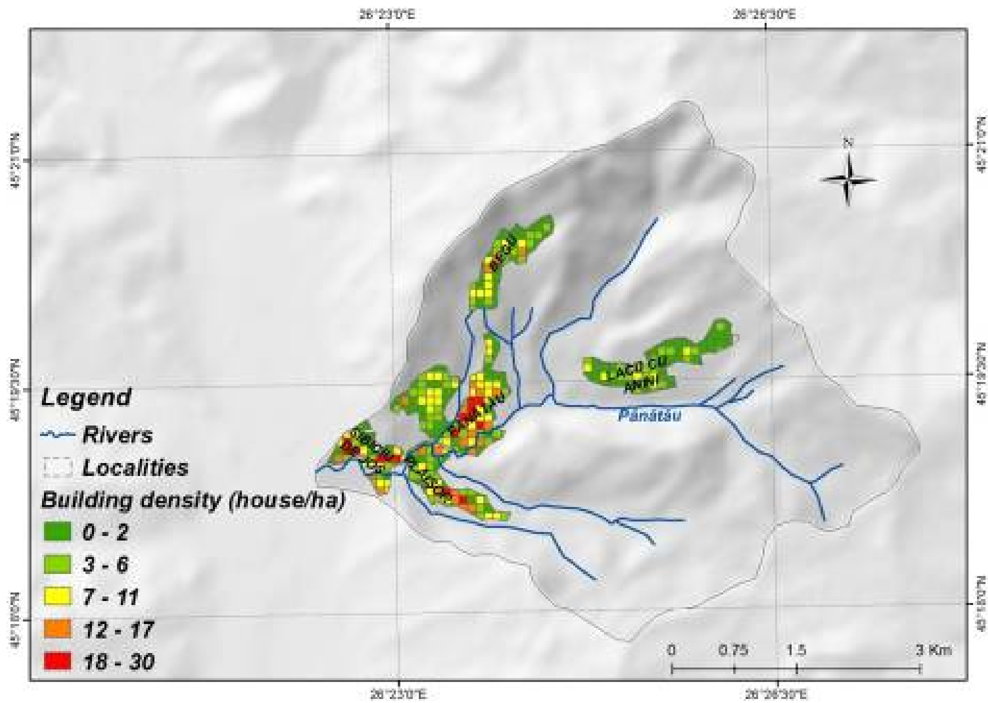

Figure 4. Buildings density in Pănătău river basin

The highest density values are recorded within the lower river basin areas, placed near its closed section. Here, buildings density exceeds 18 houses / hectare. The most representative villages with high buildings density are Pănătău, Plăişor and Sibiciul de Jos.

According to the methodology described in chapter **3** for the calculation of BVI (Buildings Vulnerability Index), the standardization of the FFPI and Buildings Density was necessary (figure. 5 c., d.), as also the computation of the FFPI values at the same spatial unit like Buildings Density.

Once these values standardize, the equation **(10)** cloud be used to obtain de BVI for the built area within the villages in Pănătău river basin. These values were related to one hectare cell size, obtaining values between 0 and 0.58, which were grouped in five classes by Natural Breaks method in ArcGIS 10.1.

Within a total surface of 391 hectares of the BVI, low values between 0 and 0.1 occur on 71% (figure 6). These values sum almost 276 ha and are representative for areas with low buildings density and surface runoff values. According to BVI values distribution within the river basin (figure 7), 90% of the values between 0 and 0.1 are assigned to Lacu cu Anini village (figure 7.a), which the less vulnerable to flash-floods. Also, 65% of the lowest BVI are recorded in Begu village.

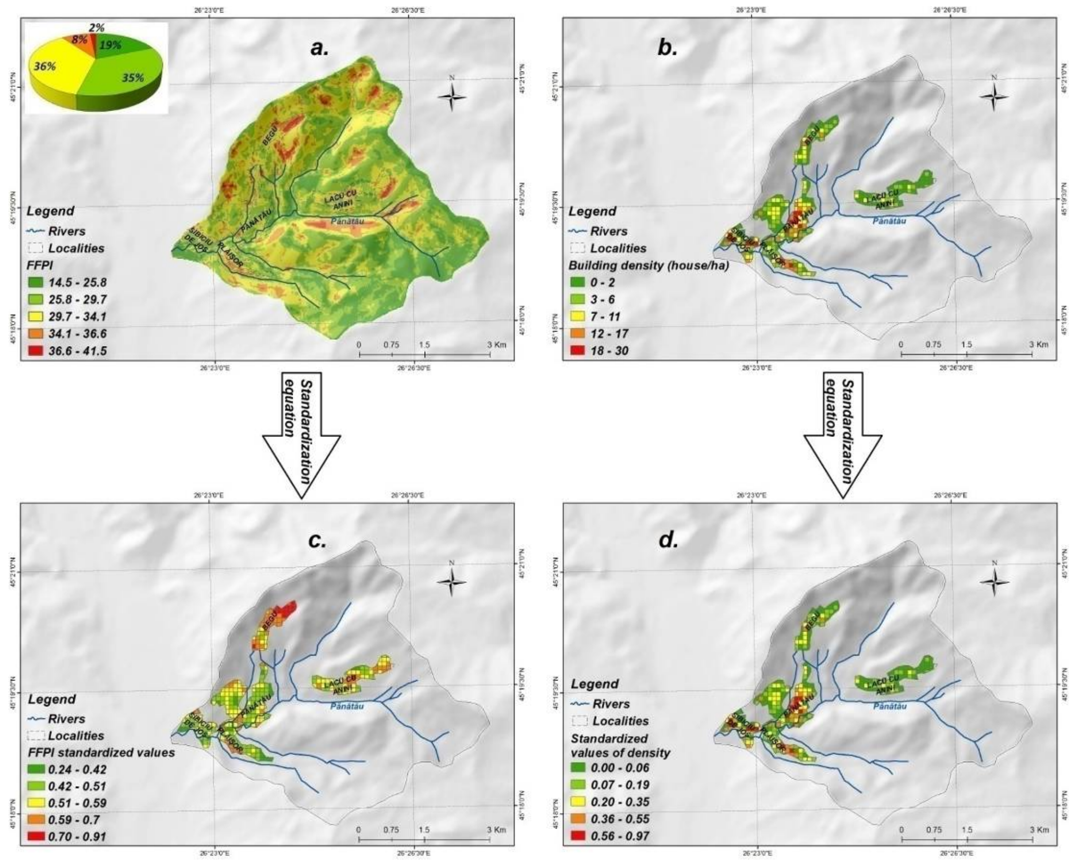

Figure 5. Standardized values (c., d.) of FFPI (a.) and buildings density (b.)

The moderate values of BVI, between 0.11 – 0.17 occur on all the villages within the study area, corresponding to areas with medium vulnerability to flash-floods. Generally, moderate BVI occur on approximately 16% of the study area (figure 6). A similar weight value is recorded within 4 of the 5 villages of the study area. Only for Lacu cu Anini, the BVI values weight is 9.6%.

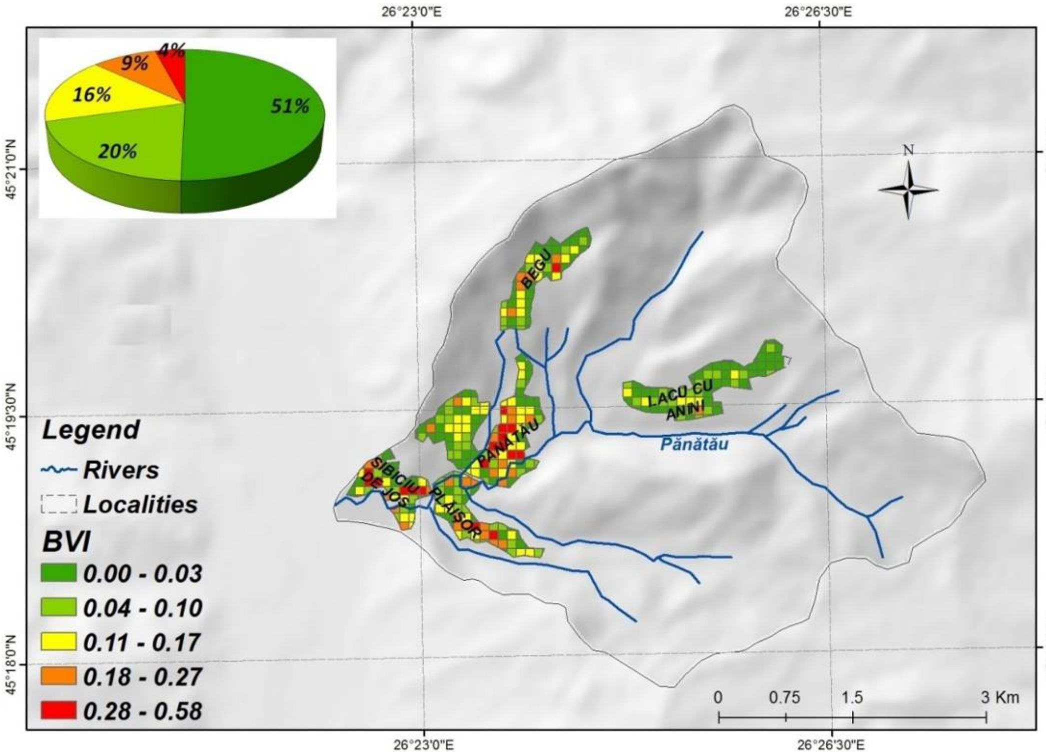

Figure 6. The distribution of BVI values within Pănătău river basin

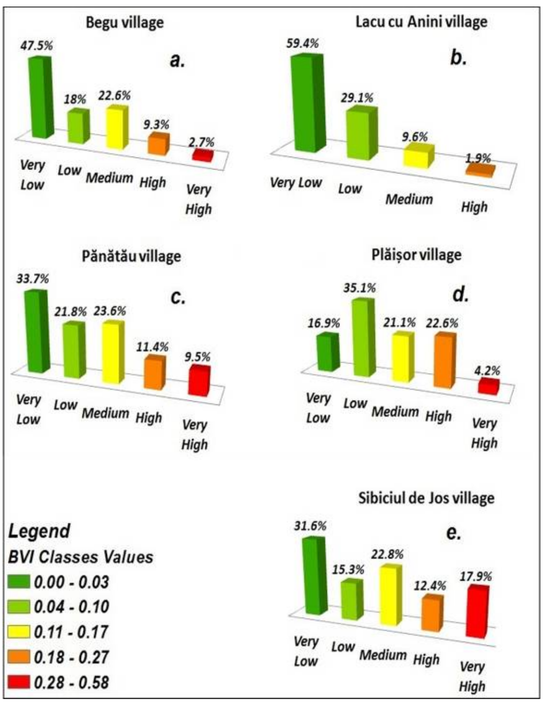

Figure 7. The distribution of the BVI Classes within the villages of Pănătău river basin (a.Begu; b.Lacu cu Anini; c.Pănătău; d.Plăișor; e.Sibiciul de Jos)

BVI values between 0.18 – 0.27, corresponding to the fourth class of values, occur on almost 9% of the total area (figure 6), mostly in Plăişor village, where over 22% of its built surface is highly vulnerable to surface runoff. In Begu, Pănătău and Sibiciul de Jos, these class of values records values between 9.3% and 12.4%.

On the opposite, Lacu cu Anini, only 1.9% of Lacu cu Anini village is highly prone to surface runoff (figure 7.b). Also, in Lacu cu Anini village, the fifth class of values of the BVI is absent.

Concerning the spatial distribution of the highest BVI values, Sibiciul de Jos village is the most remarkable, where 18% of its built surface is highly exposed to surface runoff (figure 7.e).

Another remarkable village in terms of the weight of the BVI fifth class of values is Pănătău, where BVI fifth class of values occurs on 9.5% of its total surface (figure 7.c).

CONCLUSIONS

The methodology used for estimating the built areas vulnerability to flash-floods considers two important components: a. the degree of exposure to hazard - represented by the FFPI; b. the elements of risk assessment - represented by the buildings density. Thereby, the results have an increased accuracy, being more appropriate to the field reality. The results are enforced by the National Administration Romanian Water data from River basin management plans for protection against floods. According to these documents, the most vulnerable areas to floods and floods from Pănătău river basin are found in Sibiciul de Jos village, from which 17 buildings could be highly endangered by flash-floods. Therefore, economical damage would be considerable.

The high degree of the buildings vulnerability to flash-floods in Sibiciul de Jos and Pănătău villages is also explained by their positioning within an area with increased hydrological convergence values, in the lower sector of the river basin, where the river flows into the main collector.

In order to perform more detailed analysis of the building vulnerability to floods caused by flash-floods, research is currently oriented to hydraulic modeling methods, on river sectors precisely bounded and to the assessment of the economical loss by flash-floods.

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