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FLOOD VULNERABILITY ASSESSMENT IN THE LOW SECTOR OF SĂRĂȚEL CATCHMENT. CASE STUDY: JOSENI VILLAGE

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Abstract. The studies regarding hydrological risk phenomena hold a great practical importance, as this type of natural hazards produces considerable damages on society. The present paper aims to analyze the occurrence potential of hydrological risk phenomena (floods) in the Sărățel catchment, which is situated in the central south-eastern part of Romania, and the structural vulnerability in a highly exposed village, Joseni. The first part of the paper consisted in calculating and spatially modeling the Flood Potential Index (FPI) in GIS environment, by summing up several key geographical factors favoring catchment floods genesis. Subsequently, the critical areas – with a high potential of flood occurrence (5^{th} class of FPI) – were identified; their highest frequency was observed along the floodplains of the main valleys. Based on these critical areas, the structural vulnerability was assessed by considering the case study of Joseni village, situated in the inferior sector of the Sărățel catchment, which has a high susceptibility to floods. This step required the hydraulic modeling software HEC-RAS 4.1, by means of which the flood-prone area was estimated for Joseni village cross-section of Sărățel River, according to flood peak discharges of different exceedance probabilities (1%, 2%, 5%, 10%). The hydraulic modeling resulted in indicating that ~ 100 dwellings would be affected in case of a 10-year flood (10%), while a discharge with an exceedance probability of 1% (100-year flood) would affect ~ 120 dwellings.

Keywords: Sărățel catchment, flood, vulnerability, HEC-RAS, Joseni, exceedance probabilities.

1. INTRODUCTION

Floods represent one of the most aggressive natural hazards worldwide, as they annually produce numerous damages and human life losses (Jonkman, 2005). The increase in frequency and intensity of these phenomena during the past decades is closely related to current climate changes (Pielke & Downton, 2000; Lasda et al., 2010; Garrelts & Lange, 2011; Klijn et al., 2012).

In Europe, 325 major flooding events have taken place after 1980, of which 200 happened after 2000 (EEA, 2012). The most heavily affected rivers of Europe are: Meuse (in Netherlands), Rhine (in Netherlands, Belgium and Germany), Elbe (in Germany) and Tisza (in Hungary and Romania) (Van der Sande et al., 2003). Consequently, Romania is one of the most massively affected countries in Europe concerning such hydrological risk phenomena (Roo et al., 2007; Constantin-Horia et al., 2009). The most severe floods in the past 40 years affected Romania in 2005 and 2006 (Irimescu et al., 2009); they concerned not only the Danube (Mihnea et al., 2008), but also its main affluent – Siret basin (Romanescu et al., 2011).

Therefore, identifying the areas which are exposed to these natural hazards by means of GIS techniques represent one of the most important measures aimed to prevent and reduce their negative impact on human society. Several researchers proposed a GIS-based, qualitative and non-dimensional index – Flood Potential Index (FPI) (Shaban et al., 2001; Shaban et al., 2006; Kourgialas & Karatzas, 2011), calculated by overlaying several geographical factors playing a key role in water accumulation and stagnation.

In order to perform more detailed analyses, aimed to simulate the size of flood-prone areas for certain river sectors, 1D or 2D hydraulic models are employed (Pezzinga, 2000; Horritt & Bates, 2002; Werner, 2001; Leandro et al., 2009). One of the most widely used model is HEC-RAS 4.1 open-source software, developed by US Army Corps of Engineers and employed in many studies for simulating flood-prone areas in different regions of the world (Devon, 2003; Pappenberger et al., 2005; Yang et al., 2006; Popescu et al., 2008; Rodriguez et al., 2008; Wyrick et al., 2009; Koutroulis & Tsanis, 2010; Stoica & Iancu, 2011; Armaș et al., 2012; Kiesel et al., 2013).

The present paper aims to delimit areas with a high level of susceptibility to flooding in the Sărățel catchment as well as to analyze the flood-prone area (corresponding to discharges with different exceedance probabilities - 1%, 2%, 5% and 10%) for the Sărățel river section that crosses Joseni village. The Joseni area is relevant for the entire basin, as it has a high flooding potential and an increased vulnerability to this hydrological phenomenon.

2. STUDY AREA

Sărățel basin is situated in the central south-eastern part of Romania (Fig. 1), representing a first order sub-catchment of Buzău river. The entire study area has 189 km^2 and belongs to the Curvature Sub-Carpathians. The basin's small scale, as well as its shape coefficient of 0.46 (Table 1) increase the risk of flash flood occurrence (Drobot, 2008), favoring subsequent flooding phenomena.

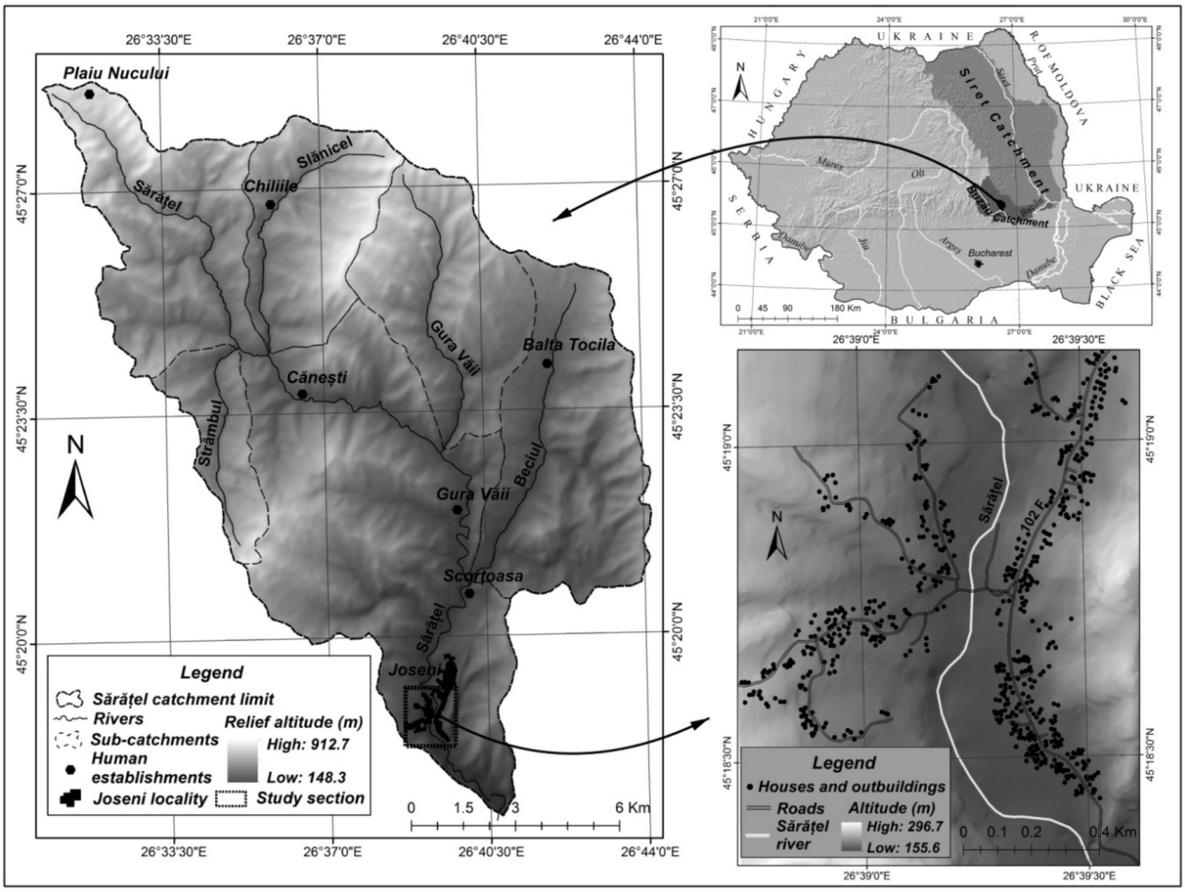

Figure 1. Sărățel basin and Joseni village location in Romania.

Table 1. Morphometrical features of the Sărățel River Catchment and its main sub-catchments

River	Sub-catchment						Hydrographic network	
	Area (sq km)	Perimeter (km)	Rc (shape coefficient) $Rc = 4\pi A/P^2$	Altitude (m)			Length (km)	Imed (river slope) (m/km)
				Mean	Max	Min		
Slănicel	21.1	19.7	0.68	538	811	302	8.6	45.7
Gura Văii	26	22.2	0.66	490	811	238	9.3	57
Beciul	34.9	28.96	0.52	348	587	193	10	22.8
Strâmbul	9.78	16.81	0.43	468	760	317	6.4	55
Sărățel	188	72	0.46	415	913	148	34.6	30.2

Among the affluent sub-catchments of Sărățel river, Slănicel and Gura Văii are the most highly exposed to floods and flash floods, as the shape coefficients – of approximately 0.67 (Table 1) – suggest almost circular shapes. The elevation across the basin ranges from 148 m (corresponding to the confluence with Buzău river) to 913 m (recorded at the contact with mountainous area) (Fig. 1).

The slope is a key factor that influences the water runoff and its accumulation in different zones. Sărățel catchment has high slopes (above 15°) on approximately 20% of its total area, thus favoring rapid runoff (Teodor & Mătreață, 2011), which may cause flooding in downstream, low-sloped areas; these areas are located in the northern and eastern areas of the basin. Low slopes, of less than 3º, favor water accumulation and stagnation (Costache & Prăvălie, 2012) and are generally located along floodplains, which represent 4% of the study area.

Land use is another important factor influencing water runoff, particularly due to the forest areas, that have a major role in balancing the hydrological regime (Arghiriade, 1977), as they intercept a great amount of precipitation. Sărățel catchment has a small afforestation coefficient (27%) and is highly susceptible to floods.

At the same time, built areas, covering 2450 ha (13% of the total area), favor flood potential, due to soil waterproofing. As far as the soil is concerned, 78% of the study area is covered by loamy/loamy-clay soils. This fine texture favors water runoff by limiting infiltration.

Joseni village is situated in the inferior sector of Sărățel River (Fig. 1), at 3.5 km from its confluence with Buzău River. The studied section measures 2 km in length, corresponding, on longitudinal profile, to 90% of Joseni village length (Fig. 1). Concerning the vulnerability, 623 buildings and 102F County Road are the main exposed elements. The village was affected by flash floods in 2005, 2007, 2008 and 2010, with massive impacts, consisting in household destruction and damaging the 102F County Road (N.I.H.W.M., 2011).

3. DATA AND METHODS

The present study contains two main steps. In the first step, the spatial variations in flooding potential were determined for the Sărățel basin, by means of Flood Potential Index (FPI). The second step consisted in determining the spatial extent of the flood-prone areas for the Sărățel River, in the cross-section corresponding to Joseni village, for flood peak discharges with exceedance probabilities of 1%, 2%, 5% and 10%, by means of HEC-RAS hydraulic model.

3.1. Determining Flood Potential Index (FPI)

Calculating and spatially modeling the FPI required weighted summing (with GIS techniques) of the following eight geographical factors (Table 2) with an important role in floods genesis: slope, elevation, altitude above channel, drainage density, convergence index, wetness index, runoff depth and lithology (Shaban et al., 2001; Shaban et al., 2006; Pradhan, 2009; Kourgialas & Karatzas, 2011; Costache & Prăvălie, 2012). Except for runoff depth and lithology, the other morphometric features were derived from the DEM (Digital Elevation Model), obtained from SRTM data source.

Table 2. Bonitation and weighting of the flood potential influencing factors

Parameters / weigths	Types/Values				
Slope(°) – 14.9%	>25	15 - 25	7 - 15	3 - 7	< 3
Hipsometry (m) – 11.2%	646.3 - 913.3	514.3 - 646.3	409.3 - 514.3	304.3 - 409.3	148.2 - 304.3
Altitude above channel (m) - 11.8%	> 4	3.1 - 4	2.1 -3	1.1 - 2	0 - 1
Drainage density (km/km^2) – 10.6 %	< 1.4	1.4 - 2.5	2.5 - 3.6	3.6 - 5	> 5
Convergence index – 12.5%	> 0	0 – (1)	(-1) – (-2)	(-2) – (-3)	< -3
Wetness index – 12.5%	2.9 - 6.1	6.1 - 7.6	7.6 - 9.6	9.6 - 13.9	13.9 - 24.6
Runoff (mm)-15.9%	257.2 - 334	334 - 428.1	428.1 - 500.5	500.5 - 541	541 - 626.5
Lithology - 10.6%	Gravels, sands, loess deposits	Marls, clays, lymestones	Sandstones, calcareous shale, conglomerates	Flysch with shale intercalations	Sandstone of Răchitașu
Bonitation score	1	2	3	4	5
FPI (class)	16.8 – 22.8	22.8 – 26.2	26.2 – 30	30 – 35.5	35.5 – 46.3

The runoff depth (average annual depth, expressed in mm) was estimated by means of the Curve Number mathematical model, developed by Soil Conservation Services (SCS-CN). This method, widely used in international literature (Garen & Moore, 2005; Huang et al., 2006; Crăciun et al., 2007; Boudaghpour et al., 2014; Costache, 2014a), estimates the runoff depth corresponding to a certain amount of precipitation.

It is based on the Curve Number associated to an area according to the land cover (data processing from Corine Land Cover, 2006) and the hydrological group of soil (data processing from Soils Map of Romania, 1:200000).

This index (CN) ranges between 0 and 100 and it is inversely proportional to the maximum water retention capacity. The runoff is calculated according to the formula $Q = \frac{(P - 0.2 * S)^2}{P + 0.8 * S}$ (1),

where: - Q – runoff depth in mm;

- P – precipitation amount;

- S – maximum retention capacity in mm ($S = \frac{25400}{CN} - 254$ (2)), where CN – Curve Number.

Spatial modeling of average annual rainfall across the Sărățel river basin was performed by Residual Kriging method (Prudhomme & Reed, 1999; Costache, 2014b), using data collected from 20 meteorological stations (1961 – 2000) situated around the study area (Romanian climate, 2008).

The lithological sub-stratum was derived in vector format from the Geological Map of Romania, 1:200000, and converted into raster format.

Subsequently, the eight resulting factors received bonitation scores from 1 to 5, according to their influence on water stagnation and accumulation (Table 2). As each factor has a different importance in flood potential, they were weighted into the Weight module from Idrisi Selva (Behera et al., 2012). Finally, the 8 factors were summed according to their weights, by means of cartographic algebra, resulting the final Flood Potential Index.

3.2. Determining the flood-prone areas extension

In order to estimate flood-prone areas (for flood peak discharges with different exceedance probabilities) for Sărățel river, in Joseni cross-section, the 1D HEC-RAS 4.1 hydraulic model was used, as well as its extension for ArcGIS 10.1, HEC-GeoRAS 10.1, which relates the hydraulic model to ArcGIS 10.1 software.

The hydraulic modeling included two steps. The first step consisted in defining the elements of the valley, through Hec-GeoRAS 10.1 extension: thalweg line, the two banks and 19 transversal profiles (100 m equidistance) (Fig. 2).

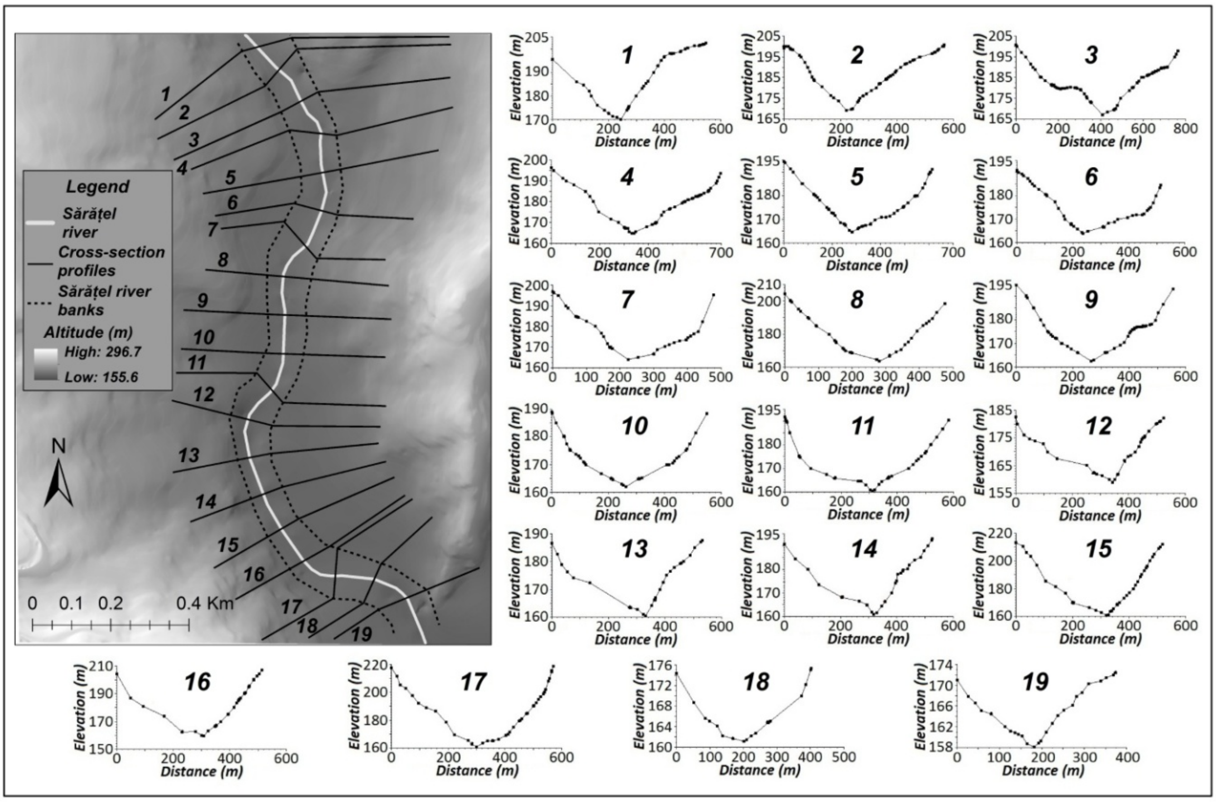

Figure 2. 100 m equidistant cross-sections (plan and vertical view) required for identifying and delimiting flood-prone areas within Joseni village

The valley elements' properties (river sector length, transversal profiles width, the distance between consecutive intersection points between transversal profiles, thalweg line and the two river banks) were also determined by HEC-GeoRAS 10.1 extension. Other elements (river sector end points and transversal profiles elevation), which are essential in hydraulic modeling, were determined from the DEM for Joseni village.

The DEM was generated at 1 m resolution (by ANUDEM interpolation method), based on 5 m equidistance contour lines (topographical map, 1:25000) and 91 elevation points, gathered from the Sărățel river floodplain, by means of a GPS Trimble GeoXH, 2008 Series (10 cm vertical and horizontal accuracy).

Subsequently, the Manning roughness coefficient was computed for each intersection point of the transversal profiles with the river thalweg and with the river banks, using the HEC-GeoRAS 10.1 extension, too. This coefficient generally varies according to land cover; in the present case, within the floodplain, this coefficient is closely related to different factors, such as: the type of sediments composing the river bed, the micro-landforms, the meanders (Dyhouse et al., 2003). The study area recorded a roughness coefficient ranging from 0.035 (for the river thalweg) to 0.05 (for the two banks).

The second step of the hydraulic modeling consisted in simulating the flood-prone areas corresponding to peak discharges with four exceedance probabilities: 143 m³/s – 10%; 192 m³/s – 5%; 270 m³/s – 2%; 340 m³/s – 1% (NIHWM, 2011). This simulation was performed in steady flow, in HEC-RAS 4.1 software. In this case, the water surface profiles calculation is based on one-dimensional energy equation (Knighton, 1998):

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2G} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2G} + h_e \qquad (3),$$

where:

Z_1, Z_2 = elevation of the main channel inverts;

Y_1, Y_2 = water depth at cross-sections;

V_1, V_2 = average velocities (total discharge/total flow area);

a_1, a_2 = velocity weighting coefficients;

g = gravitational acceleration;

h_e = energy head loss.

Finally, the structural elements exposed to floods occurring according to the four probabilities were digitized from Ortorectified Aerial Images (NACREA, 2008) in order to quantify the potential damage.

4. RESULTS

4.1. Estimating flood potential

The computed Flood Potential Index (FPI) values for the study area range from 16.8 to 46.3 (Fig. 3) and they were grouped into 5 classes (from very low to very high potential).

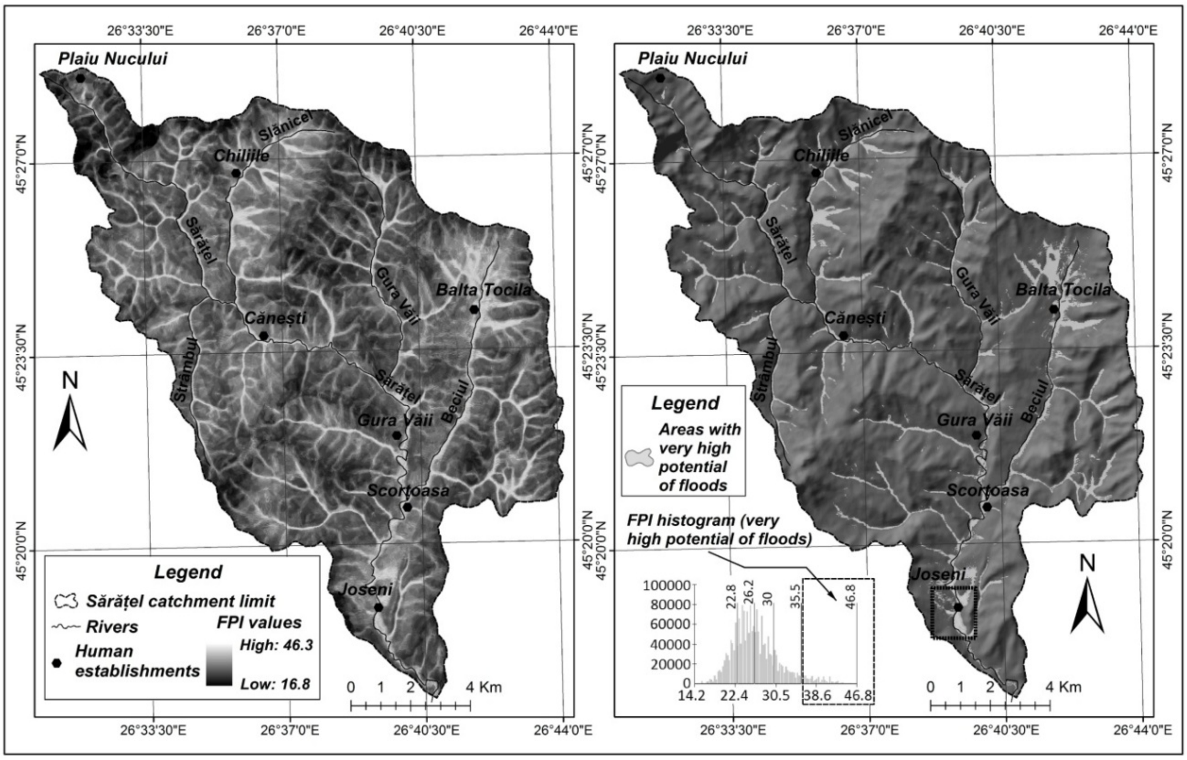

Figure 3. Flood Potential Index (FPI) spatial distribution (left) and 5th high flooding potential class (right)

This values were grouped by means of Natural Breaks method (Simpson & Human, 2008; Jimenez-Peralvarez et al., 2009). The first FPI class contains values from 16.8 to 22.8, covering approximately 18% of the basin, overlapping the interfluve peaks, composed of afforested slopes of more than 15º declivity, where water accumulation and stagnation are not possible (Fig. 3). Low values cover 34% of the basin, ranging from 22.8 to 26.2 (Fig. 3). Areas with a medium flooding potential - between 26.2 and 30 -, have a uniform distribution within the study area, on approximately 28% of the river basin.

FPI values exceeding 30 are specific for areas with high and very high flooding potential (Fig. 3), which have particular features, such as: high channel density and channel convergence, slope below 3º and poor vegetation coverage. These areas are exclusively distributed along the main river valleys, such as the medium and lower course of Sărățel river, including Joseni village (Fig. 3).

4.2. Flood-prone areas in Joseni village

By performing the HEC-RAS 4.1 model, the flood-prone areas in Joseni village were estimated for peak discharges with different exceedance probabilities: 1%, 2%, 5% and 10% (Fig. 4 a,b,c,d).

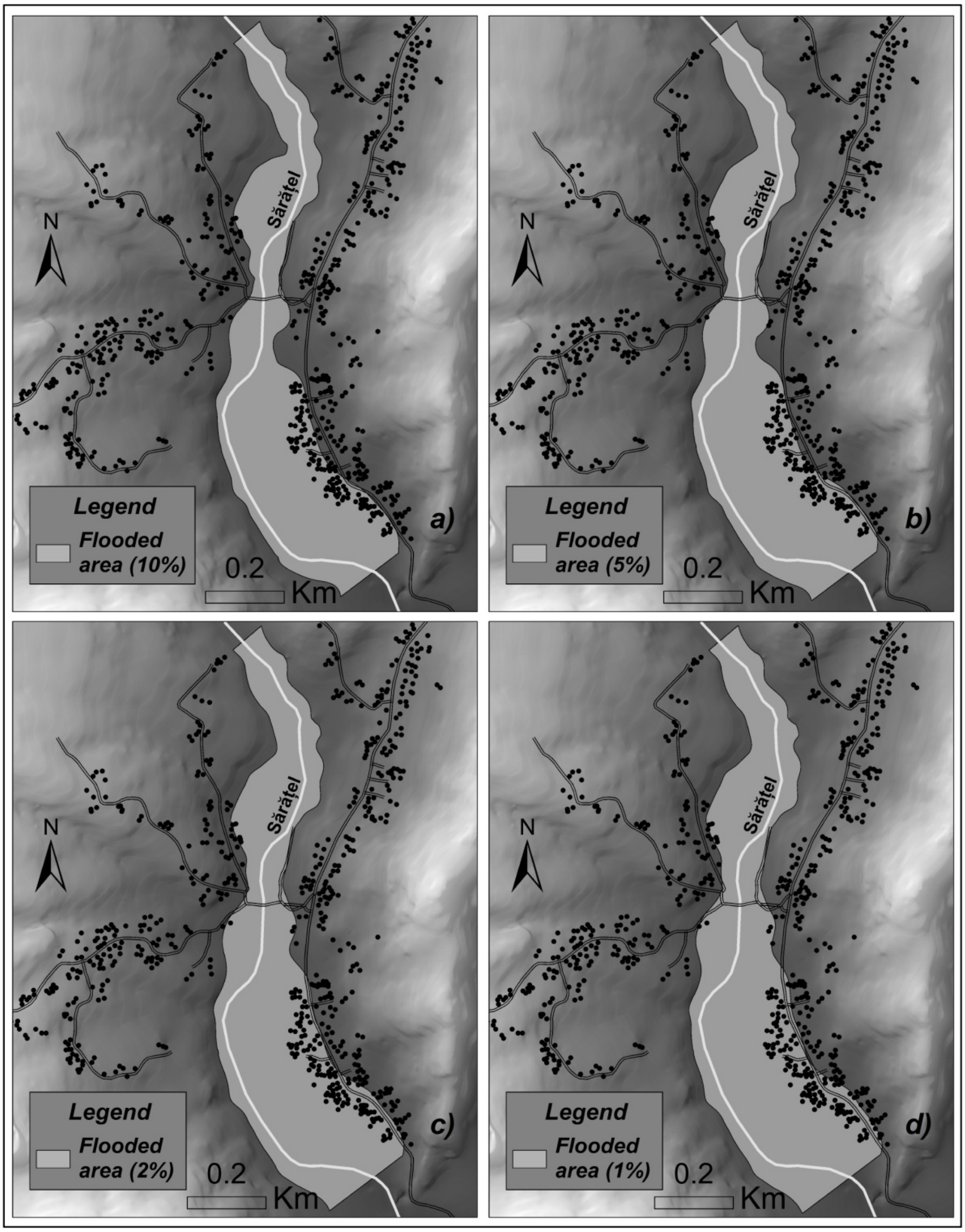

Figure 4. Spatial representation of simulated flooded areas in case of flood peaks with exceedance probabilities of 10% (a), 5% (b), 2% (c) and 1% (d) in Joseni village

In case of a discharge of 143 m³/s - 10% exceedance probability, the flooded area would cover 24 ha, according to 1D hydraulic modeling (Fig. 4a). The damage would reach 103 households from Joseni village, as well as 236 m of roads (100 m belonging to the 102F County Road).

The flooded area would reach 26 ha in case of a peak discharge having 5% exceedance probability - 192 m³/s (Fig. 4b), affecting 111 households and 503 m of the road network, including 275 m of the 102 F County Road.

A discharge of 270 m^3/s (2%) for Sărățel river, recorded along the 19 cross sections, would flood 28 ha (Fig. 4c), damaging 115 households and 824 m of the road network in Joseni village.

Finaly, a 1% probability, corresponding to 340 m^3/s, would affect approximately 30 ha (Fig. 4d); this area includes 122 households and 1050 m of road network in Joseni village.

At the same time, by means of hydraulic modeling in HEC-RAS 4.1, the water surface level from the thalweg line was estimated as well. For instance, a discharge of 340 m^3/s would lead to a 6.3 m water surface level (Fig. 5a) along the profile no.1 (which is situated in the upstream extremity of the study area), while the profile no.19 would record only 3.6 m in water level (Fig. 5b).

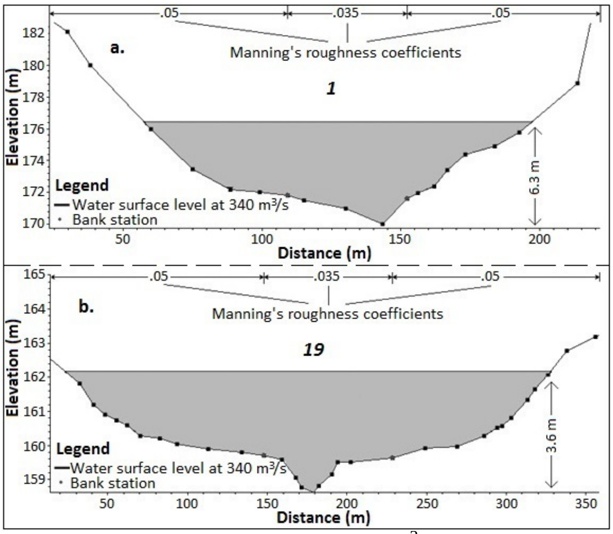

Figure 5. Water surface level at 340 m^3/s discharge value within the profile no. 1 (a) and the profile no. 19 (b)

The flooded area also follows an upstream-downstream gradient; the flood-prone area width reaches 350 m for the profile no. 19, situated downstream and only 140 m for the profile no. 1.

The difference between water depth and lateral extension of the flood-prone areas for the two transversal profiles are due to the Sărățel river valley contour – narrower upstream and wider downstream, where the exposed elements are more vulnerable, as they are frequently situated in the floodplain.

5. CONCLUSIONS

The present study was aimed at highlighting the areas with high flooding potential for the entire Sărățel basin and to subsequently analyze this potential for the critical areas in Joseni village, which is exposed to hydrological risk phenomena. These analyses focused on spatially modeling the flood-prone areas, according to different discharges, with exceedance probabilities of 1%, 2%, 5% and 10%.

This analysis pointed out several important patterns of the flooding phenomena. For example, even though the 340 m^3/s discharge (1%) is 2.5 times higher than the 143 m^3/s discharge (10%), the difference in flood-prone area reaches only 6 ha (30 ha versus 24 ha). This particular feature is explained by the Sărățel river contour of the valley, whose lateral extension is reduced in the study area and is bordered by steep slopes. Nevertheless, a flash flood with a 10 year probability would lead to important damages for Joseni village.

On the other hand, the hydraulic modeling for the four exceedance probabilities could have some limitations. They could be related to the spatial resolution of the digital elevation model used for computing flood-prone areas in the Joseni area. Consequently, an exact assessment of the structural vulnerability for the four scenarios remains difficult to perform.

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