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FLOOD HAZARD ASSESSMENT IN THE JOINT FLOODPLAIN SECTOR OF BAŞEU AND PRUT RIVERS (NE ROMANIA) BY RECONSTRUCTING HISTORICAL FLOOD EVENTS

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Abstract: In the summer of 1969 the Bașeu River (an important tributary of the Prut River in the north-eastern extremity of Romania) recorded historical floods due to heavy rainfalls (about 100 mm/m^2/24h) falling in its hydrographic basin. The maximum flow rate, recorded at Ștefănești gauging station, was 330 m^3/s and associated with a level of 535 cm in the lower floodplain area. The flood event affected the joint floodplain sector of Bașeu and Prut rivers on a width between 2–3 km and, implicitly, five settlements: Stânca, Ștefănești, Bădiuți, Bobulești, Românești. The main objective of this study is to reconstruct the historical flood of 1969 and its effects, as well as to evaluate the flood hazard in case of repeating an event of the same magnitude in the current context and comparing them. Thus, using the HEC-RAS software, we developed two 2D hydraulic scenarios (2D-HS) based on the July 1969 flood hydrograph from the Ștefănești gauging station (on Bașeu River) and Stânca gauging station (on Prut River). In the first 2D hydraulic scenario (2D-HS1) we used the buildings and the land use categories extracted from the topographic maps (1972-1979 edition), while in the second 2D hydraulic scenario (2D-HS2) we used the buildings and the land use categories from the orthophotos (2015 edition). Additionally, we assessed the flood hazard severity for each 2D-HS. The results showed that after the 1969 flood event, the built-up area has narrowed its surface. The constructed area affected by the 1969 flood event was converted to arable land or pasture. In the case of the 2D-HS1 291 buildings were affected and in the case of 2D-HS2 just 234 buildings would be affected. According to flood hazard classification, for both 2D-HS, more than 50% of the affected buildings are located in the first hazard class (with a flood depth <0.5 m). The highest class of flood hazard (flood depth >5 m) corresponds to the Prut River channel and other abandoned meanders of the old course of the Bașeu River.

Keywords: HEC-RAS, RAS-Mapper, 2D hydraulic modeling, flood event reconstruction, common floodplain of Başeu and Prut rivers

1. INTRODUCTION

Flood events affect the north-eastern territory of Romanian once the warm season begins. The sudden melting of snow (end of winter) and the heavy rains (start of spring – middle of summer) can cause catastrophic floods (e.g., 2008 flood event from Siret and Prut River and 2010 flood events from Prut River) (Haidu et al., 2019; Haidu & Strapazan, 2019; Paveluc et al., 2021; Romanescu et al., 2012, 2017, 2018, 2020). The oldest mention of a flood event on Romanian territory dates back to the 13th century, when some devastating hydrological phenomena in the Danube river basin were partially described (Mustățea, 2006). The first mention of a flood event in Moldavian Plain (NE Romania) dates back to the 16th century (1504 AD), when several rivers overflowed from riverbed in the Moldavian region (Mustățea, 2006). However, the main source of information regarding the hydrological risk phenomena (e.g., floods, drought) in north-eastern Romania is represented either by the writings of the chroniclers (e.g., Grigore Ureche, Miron Costin) or by the journals of the great personalities of that time period (e.g., Prince I Apafi). As time passed by, information on negative hydrological events has become more and more accurate, with descriptions of affected areas, material damages, repercussions on the economy and the development of human society or human casualties. Over time, the floods recordings in Moldavian Plain have been numerous. According to national literature analyzed, the most important flood events which affected the north-eastern region of Romania can be identified in: 1932, 1941, 1948, 1959, 1969, 1970, 1991, 2005, 2008, 2010, 2012, 2018 and 2020 (Huţanu et al., 2018; Mustățea, 2006; NARW, 2020). The major historical flood events in north-eastern region of Romania which led to the loss of human lives can be found in Table 1 (Mustățea, 2006; NARW, 2020; Romanescu et al., 2017).

Overall, until the year 2000 in north-eastern Romania they faced two catastrophic floods: 1969 and 1970 flood events. In June–August interval of 1969, Romania was hit by an episode of heavy rains which caused the overflow of most important rivers in the country. More than 100 mm/m^2 rainfall during 24 hours were recorded in the eastern part of Romania and more than 180 mm/m^2 during 24 hours in the western part (Figure 1). Due to this amount of precipitations, historical flow rates were recorded on Motru, Tismana, Bârlad, Buzău, Prut, Jijia, Bahlui, Bașeu River (Huţanu et al., 2020; Mustățea, 2006; Pantazică, 1974). One year later, respectively in May–July interval of 1970, due to the saturated soil from the previous flood event, the melting of snow and the spring rainfall and another episode of heavy rain, the historical flow rate of most rivers in the country were exceeded again (e.g., Vișeu, Iza, Someș, Mureș, Bistrița, Siret, Trotuș, Olt). More than 11 mil. ha agricultural land was affected by floods, more than 2,000 bridges and more than 700 km of-roads were destroyed, 85,000 houses were affected by floods from which 13,000 were destroyed and 215 humans lost their life in the flood event (Chendeș et al., 2015).

The Bașeu River was affected by heavy rains recorded between 09 July and 03 August, 1969. The consequence of these heavy rains was a flash flood which led to the highest flow rate ever recorded at Ștefănești gauging station (Fig. 2, Fig. 3). The flash flood occurred between 12 July and 19 July and it lasted for 192 hours. The flood hydrograph shows that the maximum flow rate recorded at the Havârna gauging station was 140 m^3/s (registered on 13 July) and 330 m^3/s (1% recurrence interval) at the Ștefănești gauging station (registered on 14 July). The flood depth exceeded 1 m on the joint floodplain sector of Bașeu and Prut River on a width between 2–3 km (Mustățea, 2006; Pantazică, 1974).

Awareness of the hydrological and weather-climate causes of flood and the spatial distribution of these events can reduce the risk and consequences for human society. Therefore, nowadays the historical flood reconstruction represents a great interest due to the implications it has in understanding the manifestation of such events. Multiple studies were conducted in order to reconstruct historical flood events. Hydrological data, documentary data, flood marks on buildings or bridges, sedimentary deposits or botanical evidences

Table 1. The major historical flood events that led to the loss of human lives in the North-Eastern region of Romania

Date	Area/River	Flood manifestation	Human deaths
??-07-1618	Moldavian Plain	River overflow; significant damages	Yes[1]
17-07-1780	Moldavian Plain	River overflow; significant damages	Yes[1]
21-05-1846	Tecuci River	Houses, walls and destroyed fields	Yes[1]
14-06-1985	Bârlad River	River overflow; significant damages	1
19-06-1985	Tutova River	River overflow; significant damages	2
01-06-1897	Jijia river	300 flooded houses; destroyed bridges	2
??-05-1914	Siret river	River overflow; destroyed bridges	4
26-07-1991	Tazlău River	River overflow; significant damages	27
26-07-1991	Butucari River	River overflow; significant damages	10
27-07-1991	Răcăciuni river	River overflow; destroyed bridges	13
28-07-1991	Trotuș River	Dam break; significant damages	35
07-07-2005	Putna River	River overflow; significant damages	9
11-07-2005	Siret River	River overflow; destroyed bridges	9
30-06-2006	Solca River	River overflow; significant damages	11
21-06-2007	Tecucel River	River overflow; significant damages	3
21-06-2010	Jijia River	River overflow; significant damages	7

([1]no information on the number of dead persons was found)

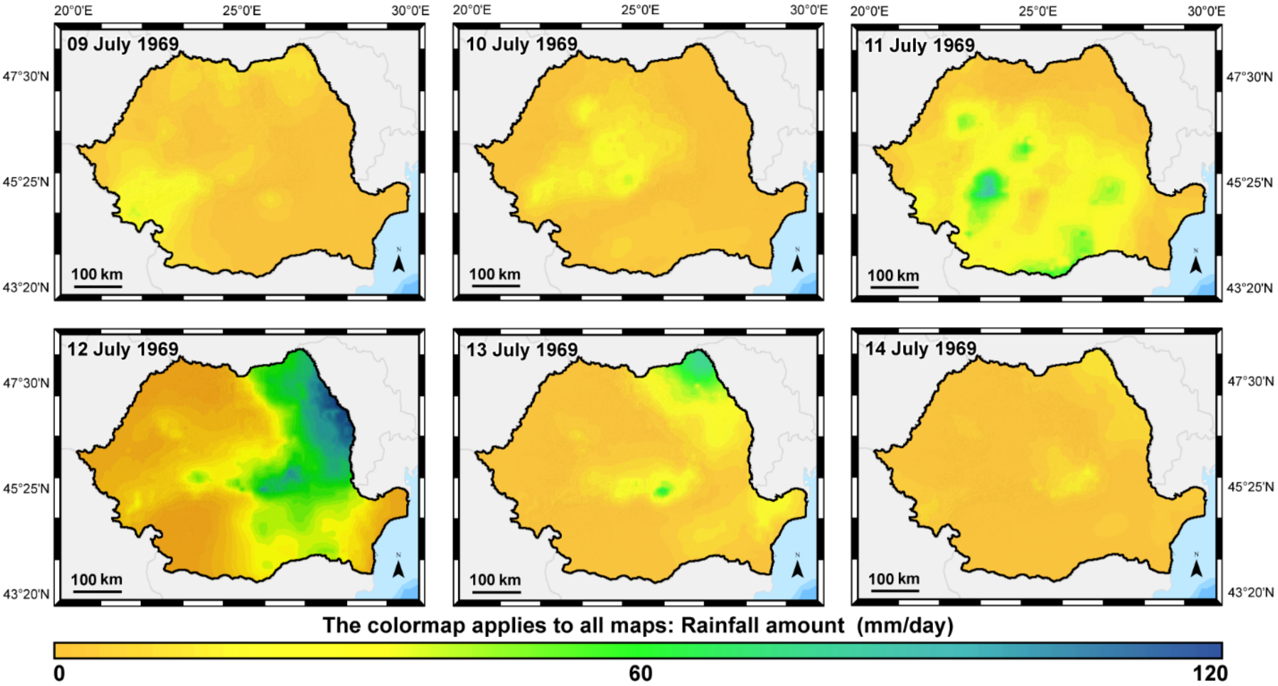

Figure 1. Daily rainfall amount (mm/day) between 09 and 14 July 1969 in Romania. Based on a gridded daily climatic dataset over Romania (Dumitrescu & Bîrsan, 2015)

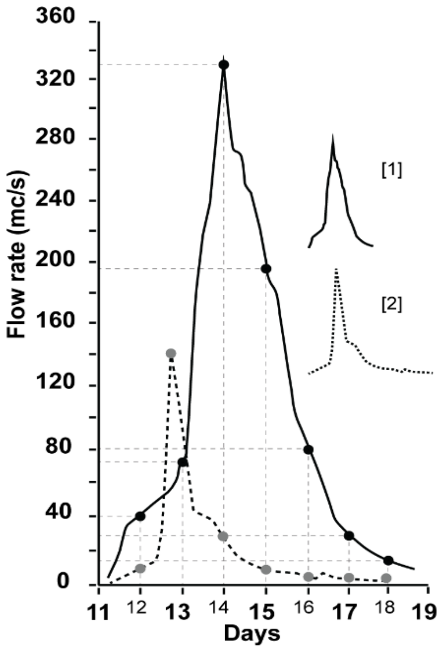

Figure 2. The flood hydrograph of the 1969 flood event recorded at Ştefăneşti gauging station [1] and Havârna gauging station [2] (Pantazică, 1974)

are the main information source for flood reconstruction (Balasch et al., 2010; Barriendos & Rodrigo, 2006; Diakakis, 2013). The reconstruction of historical flood events using modern techniques (e.g., hydraulic and hydrological models) can improve the flood forecasting system (Balasch et al., 2010; Deutsch et al., 2018). Based on historical hydrological data (maximum discharge, maximum water levels, hydrographs of flood events), hydraulic models (e.g., 1D, 2D or coupled 1D/2D) can be used to assess the extent and the water depth of a flood event (Bomers et al., 2019; Brunner, 2014, 2016; Huţanu et al., 2019, 2020; Lea et al., 2019; Liptay et al., 2018; Mihu-Pintilie et al., 2019; Van Leeuwen et al., 2016;).

The main objective of this study is to reconstruct the historical flood of 1969 and its effects in the joint floodplain sector of Başeu and Prut River, as well as to evaluate the flood hazard in case of repeating an event of the same magnitude in the current context and comparing them. Thus, using the HEC-RAS software, we developed two 2D hydraulic scenarios (2D-HS) based on the July 1969 flood hydrograph from the Ştefăneşti gauging station (on Başeu River) and Stânca gauging station (on Prut River). In the first 2D hydraulic scenario (2D-HS1) we used the buildings and the land use categories extracted from the topographic maps (1972-1979 edition), while in the second 2D hydraulic scenario (2D-HS2) we used the buildings and the land use categories from the orthophotos (2015 edition). Additionally, we assessed the flood hazard severity for each 2D-HS using the methodology on hazard classification developed by the Japanese Ministry of Land and Transport (MLIT) (Mihu-Pintilie et al., 2019; Quiroga et al., 2016).

2. STUDY AREA

Başeu River is a right-bank tributary of the Prut River, located in north-eastern Romania (Fig. 4a). It springs from a relative elevation of 278 m and it has

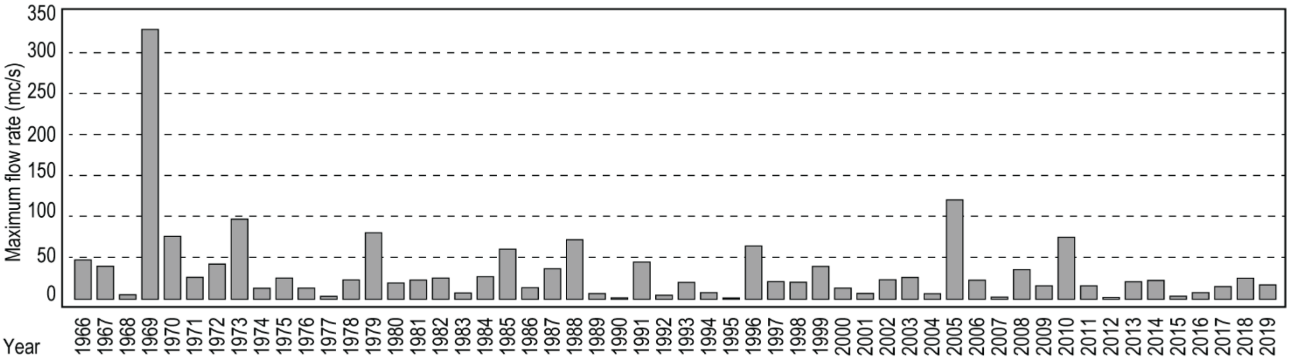

Figure 3. The maximum annual discharge (m^3/s) recorded between 1966 and 2019 at the Ștefănești gauging station

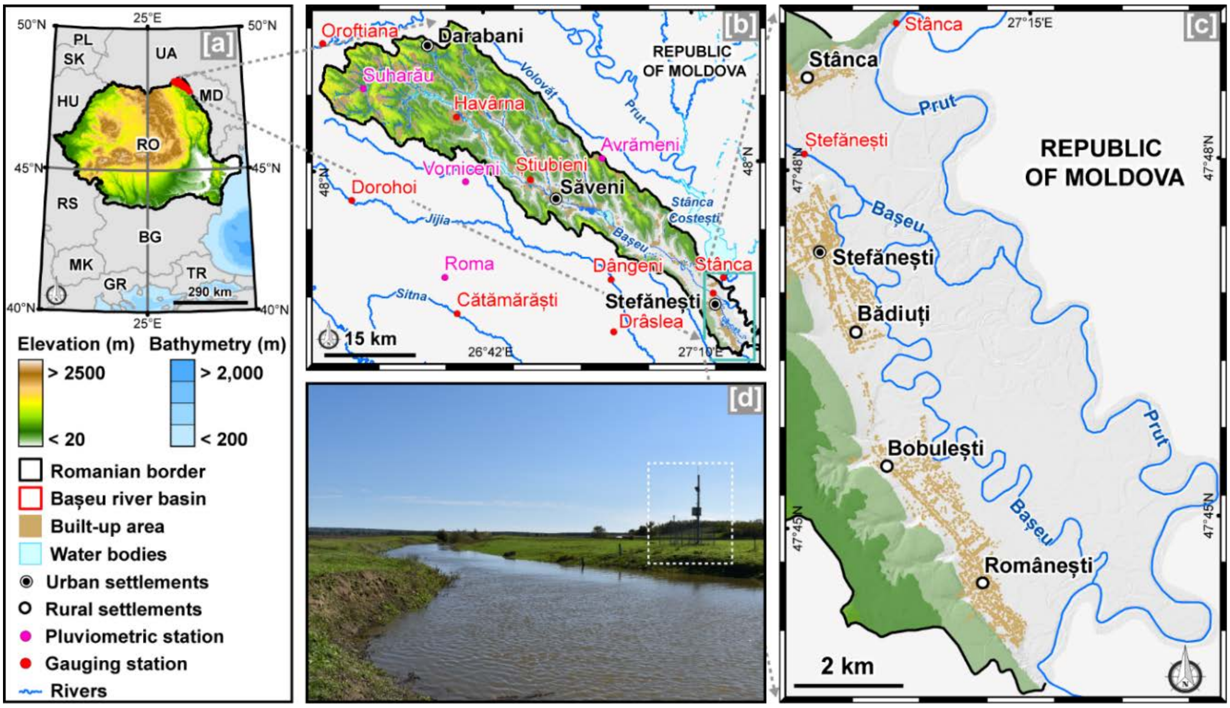

Figure 4. Study area - geographic location into Romania and the Bașeu river basin.

a length of 118 km. Bașeu river basin has a surface of 96,700 ha and a hydrographic network of 1,102 km with an average drainage density of 1.13 km/km^2. Within the Bașeu hydrographic basin are 70 human settlements (67 rural settlements), the northernmost settlement being Darabani city (9,893 inhabitants according to 2011 national census) and the southernmost is Românești village (1,394 inhabitants according to 2011 national census). The flow rate and water levels of Bașeu River are monitored by Ștefănești gauging station which is located in the joint floodplain of Bașeu and Prut River (Fig. 4b) (Pascal et al., 2014).

Ștefănești gauging station has a monitoring period of 54 years (1966–present) (Figure 4d). Another two gauging stations were installed on Bașeu River, Havârna gauging station located in the upper course of Bașeu River with a period of 31 years of monitoring (1969–2000) and Știubieni gauging station, located in the middle course of Bașeu River with a monitoring period of 17 years (1980–2000) (Figure 4b) (Stoleriu et al., 2020; Urzică et al., 2018).

This study was conducted in the joint floodplain sector of Bașeu and Prut River (altitudinal variation between 57.7 – 52.5 m). The river sector for which the hydraulic model was created has a length of 5.7 km, from Ștefănești gauging station (47°48'27" N, 27°11'49" E) to Bașeu–Prut River confluence (47°47'16" N, 27°14'52" E). The joint floodplain sector of Bașeu and Prut River have a length of 13 km and a width between of 2–4 km. Within this sector there are 5 human settlements, four rural settlements (Stânca, Bădiuți, Bobulești and Românești) and one urban settlement (Ștefănești city) and the number of inhabitants is 11,143 (according to 2011 national census) (Fig. 4c).

3. MATERIALS AND METHODS

The methodology used in this study is divided

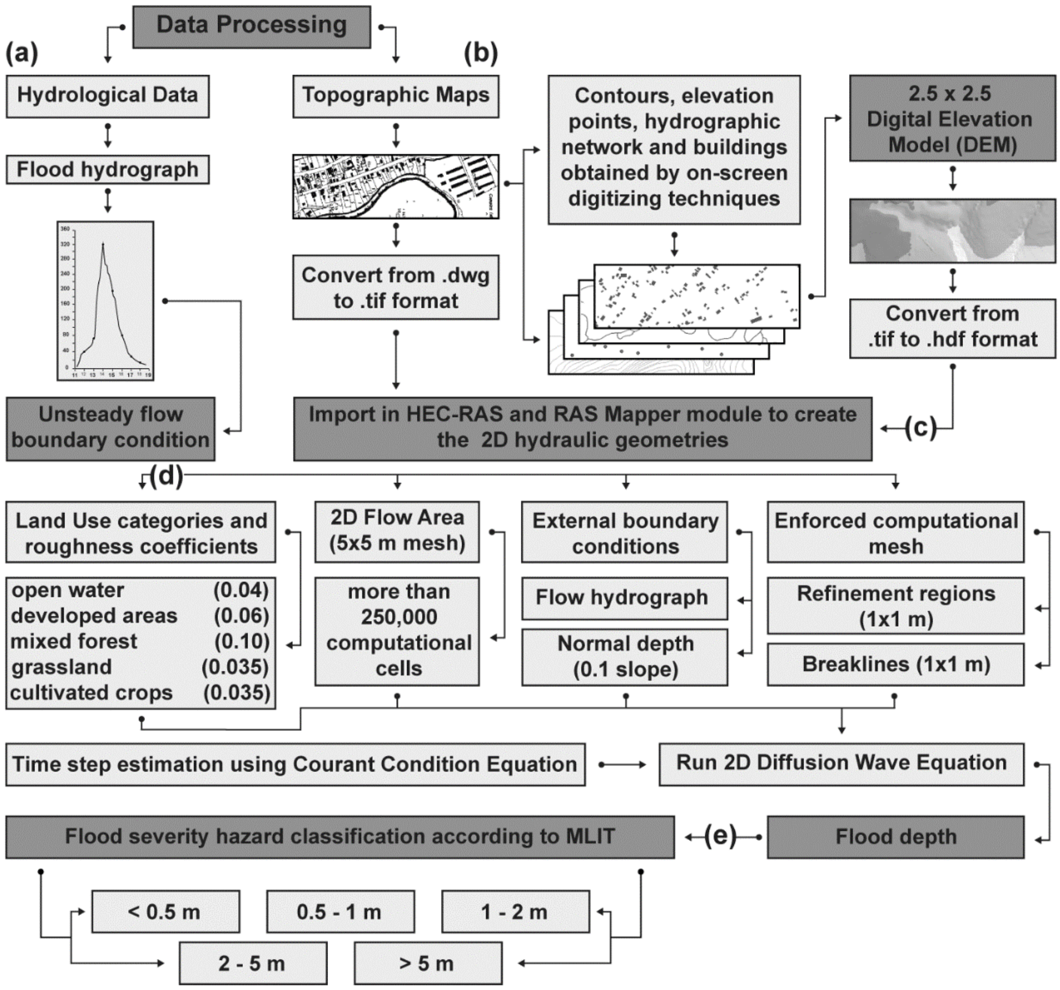

Figure 5. Methodological workflow of the 2D HEC-RAS modeling approach for the joint floodplain of Bașeu and Prut River flood reconstruction: **(a)** literature investigation in order to extract the flood hydrograph of the 1969 flood event on Bașeu River; **(b)** digitizing the topographic maps in order to create a shapefile database to generate a DEM with a spatial resolution of 2.5 m/pixel; **(c)** import the DEM and the topographic maps to create the necessary geometries for the 2D hydraulic model and generate the inundation boundary shapefile and flood depth raster; **(d)** the roughness coefficients used for the 2D-HS **(e)** classify the depth raster according to MLIT to assess the flood hazard severity

in four main steps: (1) obtaining hydrological information about the flood event which took place between 12 July and 19 July, 1969 (Fig. 5a); (2) digitization of contours based on topographic maps (1:5000) and generate a DEM with a spatial resolution of 2.5 m/pixel (Fig. 5b); (3) create the geometries and run the two 2D HEC-RAS hydraulic models (Fig. 5c); (4) create and classify the flood hazard severity raster file according to MLIT methodology for each 2D-HS (Fig. 5d).

The geometries necessary (e.g., contours, point elevation, riverbed position) to create the DEM, were extracted from topographic maps with a scale of 1:5000. The mapping of the 1:5000 topographic maps was carried out between 1972-1979 by the Institute of Geodesy, Photogrammetry, Cartography and Territorial Organization (IGPCTO). The topographic maps offer a relatively detailed perspective about the extension of the inhabited area, the local morphology and the land use categories from the 1969 period. Based on these maps, the contour lines (2.5 m equidistance), riverbed, river banks, irrigation channel, altitudinal points were digitized. Considering the fact that no major changes were recorded in the local geomorphology of the common floodplain of Bașeu and Prut rivers, the obtained DEM was used for both 2D-HS. However, to acquire a better accuracy of each hydraulic model, the buildings and the attachment buildings were digitized, rasterized and integrated in the final DEM. For the DEM used in 2D-HS1, the buildings and the attachment buildings extracted from the 1972-1979 topographic maps were used, and for the DEM used in 2D-HS2, the buildings and the attachment buildings extracted from the 2015 orthophotos were used.

For the two 2D-HS, the HEC-RAS software (v. 5.0.7.) was used. HEC-RAS software has the possibility of running 1D or 2D hydraulic models with a steady or unsteady flow, or 1D/2D coupled hydraulic models. Beginning with HEC-RAS 5.0.7. version and HEC-RAS 6.0. (beta version), the RAS Mapper module allows to create the geometries (riverbed, bank lines, flow paths, cross sections, storage areas, 2D flow areas, breaklines, refinement regions, lateral structures) of the hydraulic model within the HEC-RAS software (Brunner, 2014, 2016, 2020). With this new update, the HEC-RAS software became an independent hydraulic and hydrological software without the need of GIS software to create the necessary geometries.

Therefore, for each 2D-HS, the joint floodplain sector of Bașeu and Prut River was used as 2D flow area for the hydraulic model and a mesh with a computational point spacing of 5 m was generated. A computational mesh of more than 250,000 cells was obtained. Two external BC lines were drawn outside the 2D area as external boundary condition and for each one a hydrograph was set as unsteady flow boundary condition for Bașeu and Prut River. The energy slope of the riverbed (normal depth) of each river was set as boundary condition. For a better computational mesh (cell densifying), we used breaklines for local roads, along the banks of the main channel, levees or other natural barriers. Also, a refinement region was set for each built-up area. The enforced breaklines and refinement regions had a cell size of 1 m. Another important step was to introduce the Manning's roughness coefficients according to the land use categories (Fig. 5d). In order to create the land cover layer, the 1972-1979 topographic maps (2D-HS1) and 2015 orthophotos (2D-HS2) were imported in RAS Mapper module. According to the 1972-1979 topographic maps (2D-HS1) and 2015 orthophotos (2D-HS2) we identify 5 land use categories: open water, developed areas, mixed forest, grassland, cultivated crops. For each land use category, a polygon was created and a roughness coefficient was set (Brunner, 2020). To achieve a higher model stability, the hydraulic model was run with the 2D Diffusion Wave equation (Equation 1) & (Equation 2) and the computational time was estimated with Courant Condition equation (Equation 3) (Brunner, 2014, 2016, 2020; Cîmpianu & Mihu-Pintilie, 2018; Mihu-Pintilie et al., 2019, Urzică et al., 2021).

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)=-\frac{n^2pg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial \zeta}{\partial x}+pf+\frac{\partial}{\rho\partial x}(h\tau_{xx})+\frac{\partial}{\rho\partial y}(h\tau_{xy}) \quad (1)$$

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)=-\frac{n^2qg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial \zeta}{\partial y}+qf+\frac{\partial}{\rho\partial y}(h\tau_{yy})+\frac{\partial}{\rho\partial x}(h\tau_{xy}) \quad (2)$$

Where h is the water depth (m), p and q are the specific flow in the x and y directions (m^2s^{-1}), ζ is the surface elevation (m), g is the acceleration due to gravity (ms^{-2}), n is the Manning resistance, ρ is the water density (kg m^{-3}), τ_{xx}, τ_{yy}, and τ_{xy} are the components of the effective shear stress and f is the Coriolis (s^{-1}). When the diffusive wave is selected, the inertial terms of the momentum equations are neglected (Equations (2) and (3)).

$$\mathrm{C}=\frac{V_w\Delta T}{\Delta X}\leq 1;\quad \Delta T=\frac{\Delta x}{V_w};\quad V_w=\frac{dQ}{dA} \quad (3)$$

Where C is the Courant number, ΔT is the time step (seconds), Δx is the distance step in meters (average two-dimensional cell size), V_w is the flood wave speed (m/s), dQ is the change in discharge over a short time interval ($Q_2 - Q_1$), dA is the change in cross section area over a short time interval ($A_2 - A_1$).

Table 2. Flood hazard classification based on flood depth according to the MLIT methodology (Mihu-Pintilie et al., 2019; Quiroga et al., 2016)

Flood hazard	Flood depth (m)	Hazard classes	Hazard description
H1	< 0.5	Very low	Flood does not pose hazard to people and on-foot evacuation is not difficult
H2	0.5–1	Low	Flood water poses hazard for infants and on-foot evacuation of adults becomes difficult
H3	1–2	Medium	Flood depth can drown people; people may be safe inside their homes
H4	2–5	High	People are exposed to flood hazard even inside their homes
H5	> 5	Extreme	Built-up structures like homes may get covered by the flood

In order to assess the flood hazard severity for the five settlements within the joint floodplain sector of Bașeu and Prut River based on the 2D HEC-RAS hydraulic model and RAS mapper module, we computed the flood depth raster for each 2D-HS. For the hazard classification we used the MLIT methodology which consists in five hazard severity classes: H1–Very low (flood depth < 0.5 m), H2–Low (flood depth between 0.5–1 m), H3–Medium (flood depth between 1–2 m), H4–High (flood depth between 2–5 m), and H5–Extreme (flood depth > 5m). (Table 2) (Mihu-Pintilie et al., 2019; Quiroga et al., 2016).

4. RESULTS AND DISCUSSION

Based on the 2D HEC-RAS hydraulic model, the inundation boundary and the flood depth were generated from the RAS Mapper module. The inundation boundary layer was used to assess the extent of the affected areas by the flood event which took place in 1969, and the flood depth was used to assess the flood hazard severity.

According to 2D-HS1 results, a surface of 2,278 ha and 291 buildings are flooded (Fig. 7a). Referring to the affected buildings, Bădiuți is the most affected settlement with 36.76% (107 buildings) of the affected buildings. A particular case is given by the existence of high altitudes in the center of Bădiuți settlement, which leads to the protection of a high number of buildings against the flood wave (Figure 7a). The second most affected settlement is Stânca with 29.55% (86 buildings) of the affected buildings. Other affected settlements are Ștefănești with 17.18% (50 buildings) of the affected buildings and Bobulești with 16.49% (48 buildings) of the affected buildings). Due to the topographic position within the joint floodplain sector of Bașeu and Prut River, Româneşti is the only settlement which is not affected by floods (Table 3).

Table 3. Flooded buildings within the joint floodplain sector of Bașeu and Prut River according to 2D-HS1 results

Settlement	No. of affected buildings	(%) of total affected buildings
Stânca	86	29.55
Ştefăneşti	50	17.18
Bădiuţi	107	36.76
Bobuleşti	48	16.49
Româneşti	0	0
Total	291	100

In terms of affected land use categories by floods, the most affected are the cultivated crops with 53.53% (1,273 ha) of the total affected area. This high value is caused by the fact that the joint floodplain sector of Bașeu and Prut River is a predominantly rural area dependent on subsistence farming. Other affected land-use categories are grassland with 18.83% (448 ha) of the affected area, mixed forest with 13.87% (330 ha) of the affected area and open water with 13.12% (312 ha) of the affected area. The least affected category is given by the developed areas with 0.63% (15 ha) of the affected area (Table 4).

Table 4. Flooded land use categories within the joint floodplain sector of Bașeu and Prut River according to 2D-HS1 results

Category	Surface (ha)	Surface %
Open water	312	13.12
Developed areas	15	0.63
Mixed forest	330	13.87
Grassland	448	18.83
Cultivated crops	1,273	53.53
Total	2,378	100

The maximum flood depth is 5.4 m and correspond to the main channel of the Bașeu and Prut River. A flood depth between 0.2–2 m corresponds to the floodplain or abandoned meanders of the old course of the Bașeu River.

According to the flood hazard severity classes (Mihu-Pintilie et al., 2019), more than 40% (968 ha) of the flood extent is located in the H1 class (< 0.5 m), 25.19% (599 ha) is in the H2 class (0.5–1 m), 23% (547 ha) is in the H3 class (1–2 m), 10.81% (257 ha) is in the H4 class (2–5 m) and 0.29% (7 ha) in the H5 class (> 5 m) (Fig. 7a, Table 5).

Table 5. The affected surface and the relative frequency of flood hazard classes within the joint floodplain sector of Bașeu and Prut River according to the flood hazard severity classes according to 2D-HS1 results (Mihu-Pintilie et al., 2019)

Flood hazard classes	Affected surface (ha)	Relative frequency (%)
H1 (Very low)	968	40.71
H2 (Low)	599	25.19
H3 (Medium)	547	23.00
H4 (High)	257	10.81
H5 (Extreme)	7	0.29

Related to the distribution of the total affected buildings on flood hazard severity classes, 85.2% (248 buildings) of the total affected buildings are situated in the H1 class (< 0.5 m) and 17.7% (43 buildings) in the H2 class (0.5–1 m). More than 50% (28 buildings) of the buildings within H2 class (0.5–1 m) are from Bădiuți and Ștefănești settlements (Fig. 7a).

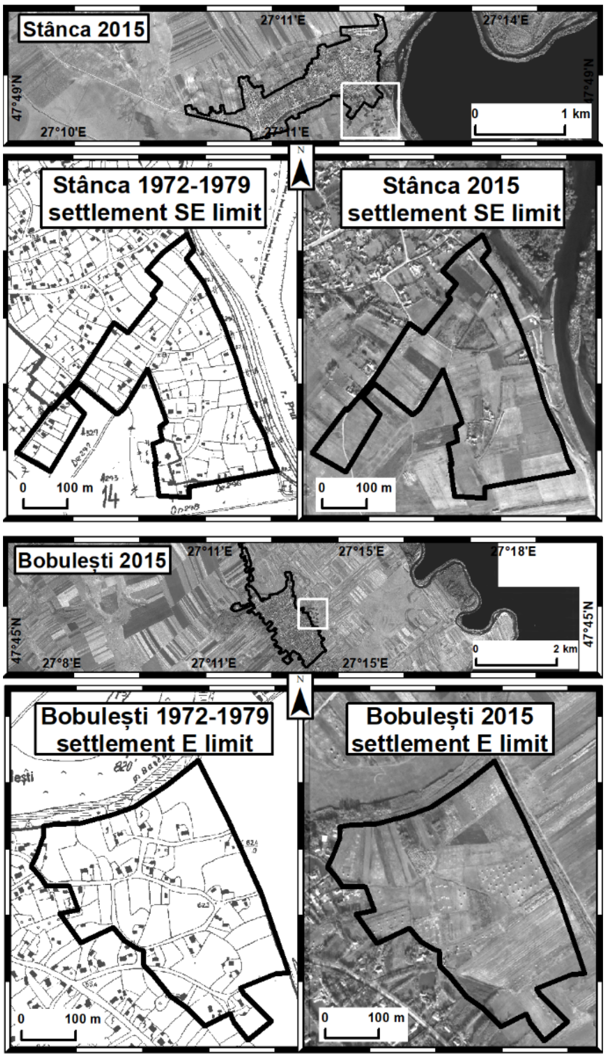

Figure 6. Land cover conversion after the flood event from July 1969 within Stânca and Bobulești settlements

Table 6. Flooded buildings within the joint floodplain sector of Bașeu and Prut River according to 2D-HS2 results.

Settlement	No. of affected buildings	(%) of total affected buildings
Stânca	22	9.40
Ștefănești	61	26.07
Bădiuţi	138	58.97
Bobulești	6	2.56
Românești	7	2.99
Total	234	100

According to 2D-HS2 results, a surface of 2,361 ha and 234 buildings are potentially affected by the same flood event recorded in July 1969 (Fig. 7b). The total number of the potentially affected buildings decreased with 19.5% (31 buildings) compared to 2D-HS1 (Table 6). Three of five settlements recorded an increase of the affected buildings. Thereby, the most affected settlement remains the Bădiuţi village with an increase of the number of affected buildings to 138 (58.97% of the affected buildings). The second most affected settlement is Ștefănești with an increase of the number of affected buildings to 61 (26.07% of the affected buildings). Româneşti settlement recorded 2.99% of potentially affected buildings (7 buildings). Stânca and Bobulești are the only settlements where the number of the affected buildings decreased. Therefore, Stânca settlement has 9.40% (22 buildings) of the affected buildings and Bobulești settlement has 2.56% (6 buildings) of the affected buildings (Table 6). These two settlements, after the flood event from July 1969 converted the built-up area located within the joint floodplain sector of Bașeu and Prut river to arable land and grassland. The land cover conversion led to a highly decrease of the number of the potentially affected buildings if a similar flood event occurs (Fig. 6).

Regarding the affected land use categories, the most affected category remains the cultivated crops with 54.33% (1,283 ha) of the total affected area. Other affected land-use categories are grassland with 19.01% (449 ha) of the affected area, mixed forest with 13.97% (330 ha) of the affected area, open water with 12.49% (295 ha) of the affected area. Due to the land cover conversion from Stânca and Bobulești settlements, the affected surface of the developed area decreased to 4 ha (0.17% of the total affected area) (Table 7).

Table 7. Flooded land use categories within the joint floodplain sector of Bașeu and Prut River according to 2D-HS2 results

Category	Surface (ha)	Surface %
Open water	295	12.49
Developed areas	4	0.17
Mixed forest	330	13.97
Grassland	449	19.01
Cultivated crops	1,283	54.33
Total	2,361	100

In the case of 2D-HS2, the maximum flood depth was 5.4 m, similar to the maximum flood depth from 2D-HS1. According to the flood hazard severity classes (Mihu-Pintilie et al., 2019), more than 40% (951 ha) of the flood extent is located in the H1 class (< 0.5 m), 25.37% (599 ha) is in the H2 class (0.5–1m), 23.17% (547 ha) is in the H3 class (1–2 m), 10.89% (257 ha) is in the H4 class (2–5 m) and 0.30% (7 ha) in the H5 class (> 5 m) (Fig. 7b, Table 8).

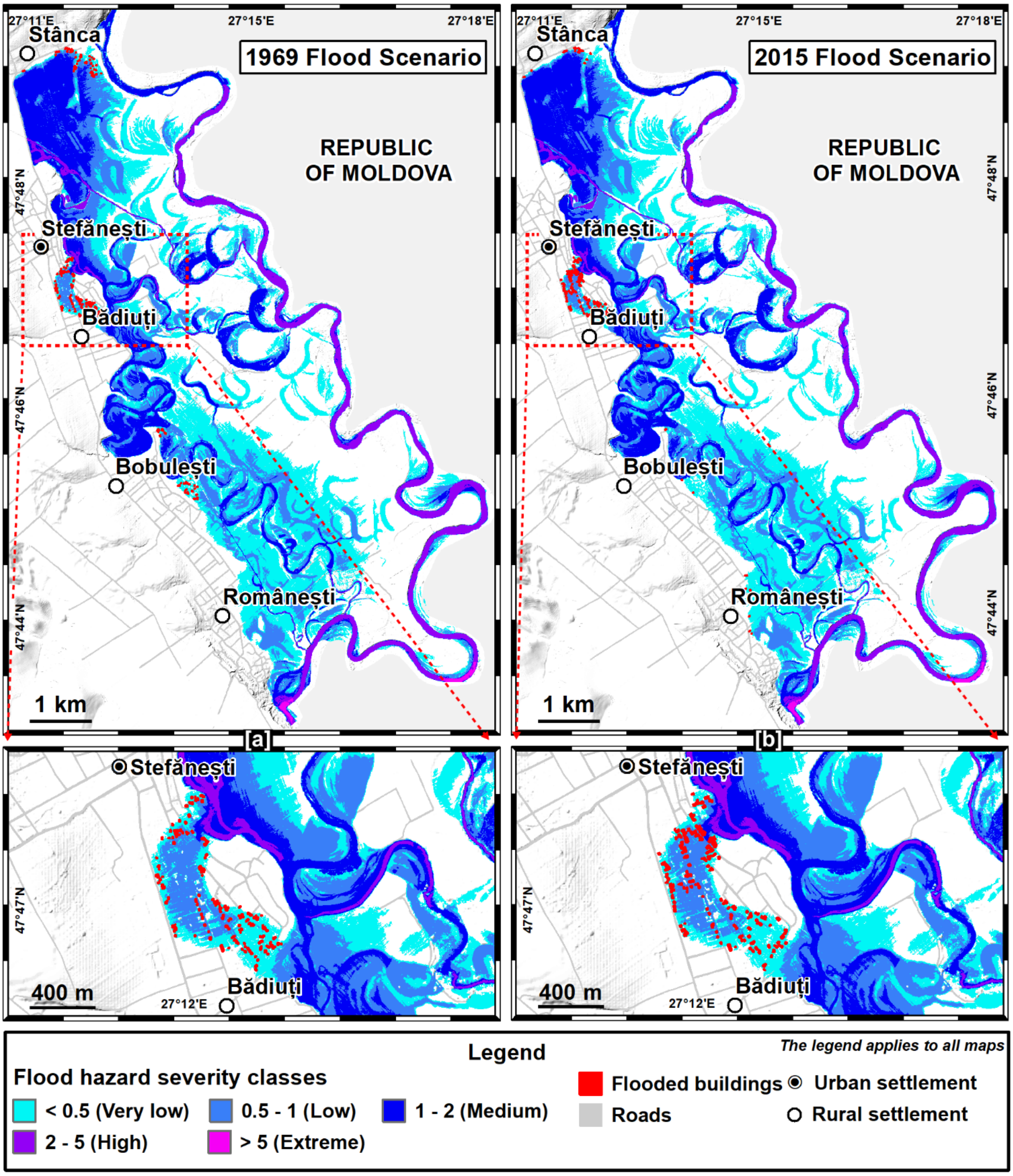

Figure 7. 2D hydraulic scenario (2D-HS) of (**a**) 1969 flood scenario and (**b**) 2015 flood scenario maps based on the flood depth classification according to the MLIT methodology (Mihu-Pintilie et al., 2019; Quiroga et al., 2016)

Related to the distribution of the total affected buildings on flood hazard severity classes, 72.51% (165 buildings) of the total affected buildings are situated in the H1 class (< 0.5 m) and 29.48% (69 buildings) in the H2 class (0.5–1 m). The affected buildings within H2 class (0.5–1 m) are from Bădiuți and Ștefănești settlements (Fig. 7b).

Floods cannot be prevented, but the devastating effects can be mitigated. Diminishing the effects of floods can also be achieved by studying historical flood events and their spatial manifestation. The information offered by a historical flood event (e.g., flood extent, flood intensity, affected buildings) are relevant and need to be taken into consideration by local authorities in the moment when the expansion of the built-up area along the river is discussed. A best example is given by Stânca and Bobulești settlements where, after the 1969 flood event, the buildings and the attachment buildings that were located in the floodable floodplain of Bașeu and

Prut rivers, were removed. Being aware of the consequences of the 1969 flood event and due to the land cover conversion, a smaller number of buildings are potentially affected by a similar flood event.

Table 8. The affected surface and the relative frequency of flood hazard classes within the joint floodplain sector of Bașeu and Prut River according to the flood hazard severity classes according to 2D-HS2 results (Mihu-Pintilie et al., 2019)

Flood hazard classes	Affected surface (ha)	Relative frequency (%)
H1 (Very low)	951	40.28
H2 (Low)	599	25.37
H3 (Medium)	547	23.17
H4 (High)	257	10.89
H5 (Extreme)	7	0.30

In the case of Ștefănești and Bădiuți settlements, the continuous development of the villages without taking into consideration the devastating effects of the 1969 flood event, increased the number of buildings and attachment buildings that are potentially affected by a similar flood event. In order to reduce the number of the affected buildings by the floods, a levee with a maximum length of 350 m and a height of 2 m can be built in the south-east of Ștefănești settlement, alongside of Bașeu River. This levee will prevent the overflow of the Bașeu River and will protected the buildings and the attachment buildings within the Ștefănești and Bădiuți settlements.

The use of a 2D hydraulic model, creating the necessary geometries and the training data is time consuming, but final results can offer a better understanding of how a historical flood event affected a human community 50 years ago and how a similar phenomenon will affect the human community in the present.

5. CONCLUSIONS

In this study, based on a 2D hydraulic HEC-RAS model the flood event which took place between 12 July and 19 July, 1969, within the joint floodplain sector of Bașeu and Prut River was reconstructed. Based on the same flow hydrograph two 2D-HS were created (2D-HS1 and 2D-HS2). The differences between the two hydraulic models were: (1) the buildings and the attachment buildings which were integrated in the DEM, and (2) the roughness coefficient. For the first hydraulic model the buildings and the attachment buildings and the roughness coefficient were extracted from 1972-1979 topographic maps. For the second hydraulic model, those variables were extracted from 2015 orthophotos. In order to create the two 2D hydraulic models, the hydrological data recorded (flow hydrograph) on the Ștefănești gauging station (Bașeu River) and Stânca gauging station (Prut River) and a DEM with a spatial resolution of 2.5 m were used. Due to the fact that no major topographical changes were recorded in the joint floodplain of Bașeu and Prut rivers, the same initial DEM was used.

According to 2D-HS1 results, 2,378 ha of the joint floodplain of Bașeu and Prut River and 291 buildings were affected by the flood wave. Regarding the land-use categories, the results have shown that extensive cultivated crops (1,273 ha), grassland (448 ha), mixed forest (330 ha), open water (312 ha) and developed areas (15 ha) have been affected by floods. Based on MLIT methodology for flood hazard severity assessment, 968 ha were located within H1 class, 599 ha were located within H2 class, 547 ha were located within H3 class, 257 ha were located within H4 class and 7 ha were located within H5 class. From the affected buildings, 248 buildings were located within H1 class and 43 buildings were located within H2 class.

According to 2D-HS2 results, 2,361 ha of the joint floodplain of Bașeu and Prut River and 234 buildings were affected by the flood wave. The results have shown that cultivated crops (1,283 ha), grassland (449 ha), mixed forest (330 ha), open water (295 ha) and developed areas (4 ha) have been affected by floods. Based on MLIT methodology for flood hazard severity assessment, 951 ha were located within H1 class, 599 ha were located within H2 class, 547 ha were located within H3 class, 257 ha were located within H4 class and 7 ha were located within H5 class. From the affected buildings, 165 buildings were located within H1 class and 69 buildings were located within H2 class. Compared to 2D-HS1, the number of the affected buildings and attachment buildings has decreased with 19.5%.

The new capabilities of RAS Mapper module allowed to create all the necessary geometries (2D flow areas, breaklines, refinement regions) for the hydraulic model within the HEC-RAS software. The hydraulic and hydrological modeling can ensure an overview of historical flood events and the possibility to understand the natural and anthropogenic factors which lead to the formation of such events.

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