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Case Report

Floods Simulation on the Vedea River (Romania) Using Hydraulic Modeling and GIS Software: A Case Study

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Abstract: Extreme hydro-meteorological phenomena have become more frequent in recent years compared to the year 2000 in Europe, including Romania. Flooding occurs from heavy rainfalls favored by natural and anthropogenic factors such as the valley's flat slope or settlements situated near the river. Ţigăneşti and Brânceni villages (from southern Romania) are no exception and have been affected by floods many times. One of these events is that from 2005, when the flow reached 676 m^3/s (a value 80 times higher than the normal flow of the Vedea River) in Brânceni. This paper aims to present a simulation of the flood that occurred during 3–6 July 2005 and its impact on the settlements, roads, and land, using field observation (including some from 2005), GIS software (ArcGIS), software for flood simulations (HEC-RAS—Hydrologic Engineering Center River Analysis System), and flow data from the Romanian National Institute of Hydrology. Simulations were run in HEC-RAS. The obtained flooded areas imported back into GIS (Geographic Information System) were used to determine the area covered by water and the length of affected roads. The surface and number of flooded buildings were calculated using different tools from ArcMap. Results were interpreted, commented on, and compared with data and maps provided by the Romanian Water National Administration. The simulation shows that the villages would be protected from the flood by building a levee along the Vedea River. Significant losses can be prevented, and money can be saved.

Keywords: flood; ArcGIS; simulation; hydraulic modeling; catchment; flow

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1. Introduction

Natural hazards are sources of potential harm and dangers. They include phenomena that significantly impact the natural and human environment, with destructive consequences and high material losses. These include earthquakes, volcanic eruptions, gravitational processes such as landslides, rock falls, or avalanches, and hydrological phenomena such as floods, flash floods, forest fires, desertification, storms, and hurricanes. The hazards' impact can be so severe that the entire inhabited zones are destroyed while relief appearance, vegetation, fauna, and soils are modified. Even if the natural phenomena have a smaller impact, they can still affect the natural environment and inhabited areas. For example, part of the population must be relocated until the phenomena end or, if the impact is too severe, the inhabitants need to be permanently relocated [1].

Central Europe is affected by flooding when high precipitations occur (in May, June, or July) and sometimes when the snow melts very fast in the areas situated close to the mountains (subalpine zones) [2]. Western countries such as the United Kingdom, The Netherlands, France, and Belgium can be affected by heavy rainfalls and storms because of the oceanic influence [3]. Landslides and avalanches can occur in mountainous regions such as the Alps, Carpathians, or the Caucasus due to global warming and human intervention [4]. Summers can be arid in the far eastern parts of Europe. Due to continental influences, drought is frequent. Moreover, the rain quantity is small throughout the year, while the annual thermic amplitude between summer and winter is high. The winters are harsh in countries in eastern and northern Europe due to freezing weather, blizzard, and heavy snowfall. Forest fires can be encountered in Mediterranean areas due to intense heat [3].

Romania is located at the junction between the Mediterranean, continental, and oceanic influences. Thus, different extreme phenomena can occur, such as drought in the southeast, extreme cold, strong winds, and heavy snow in northeastern parts of the country due to continental influences and in eastern parts of Transylvania due to thermic inversions in the mountain depressions [5]. Even if desertification is not highly encountered, it occurs in some small areas in the southwest and southeast. Vegetation fires can appear in the summer due to intense heat, while flooding and flash flooding appear in May, June, and July due to heavy rainfalls or fast snow melting in the spring [4]. The precipitation, lower than in western Europe, is unequally distributed in time and space in Romania. Its volume is sometimes concentrated in one or two months, while in the rest of the year, weeks or months without precipitation are recorded, leading to floods followed by the soil deprivation of water and further erosion and desertification [3].

The impact of such extreme phenomena is so severe sometimes that agricultural production is compromised, houses are destroyed (and people must leave them due to flash floods), or the roads are closed by heavy snow or destroyed by floods [6]. Therefore, identifying the areas with risk is essential to take measures and exclude or at least reduce the human and material losses.

Hydrological phenomena are common in Romania on catchments such as Siret, Timiş, Ialomiţa, or Mureş. Different studies [1,6–9] have been dedicated to flash flood analysis to forecast and avoid their negative impact. Most research focused on atmospheric circulation and aimed at determining the mechanism of the heavy rain apparition. The results give an overview of the negative impact of such phenomena and offer a clear perspective to the authorities based on which they must take measures, such as relocating the inhabitants susceptible to flooding and building river dams or water reservoirs for flow regulation.

This paper aims to evaluate the impact of floods in the study area, considering the terrain slope, land use, shape of the river catchment, riverbed slope, or proximity of inhabited areas. Simulations have been performed using HEC-RAS, and comparisons with the available data have been made. The simulation shows that the villages are protected from flooding by building a levee along the Vedea River. The study must be extended to other regions since it provides information to the authorities. Taking into account their results, emergency institutions must be prepared with human and material resources (vehicles, shelters, food, or drinks) when instant actions are needed [10,11].

2. Study Area and Methodology

2.1. Study Area

The study area—Ţigăneşti and Brânceni villages—is situated in southern Romania, in Teleorman county (Figure 1), 100 km southwest of Bucharest, 10 km south of the county capital, Alexandria [12] situated in Teleorman County, in the catchment of Vedea River. In 2005, the population of Ţigăneşti was over 5000 inhabitants, while Brânceni had a population of 2900 inhabitants [12].

The terrain is relatively flat in the interfluve zones, with valleys that are medium in size downstream for the rivers in Teleorman. Because of steep slopes, narrower meadows, and hilly areas, flash floods can appear, favoring water accumulation downstream in Teleorman [1]. The valleys in Teleorman can be situated at least 20 m below the altitude of the interfluve, thus creating a favorable factor for water accumulation [6]. According to field observation and maps, the catchments of the Vedea River and its tributaries are elongated, with an almost flat riverbed, with a medium width, bordered by slopes with medium inclination. These characteristics, combined with showers lasting for many days, lead to severe flooding [13].

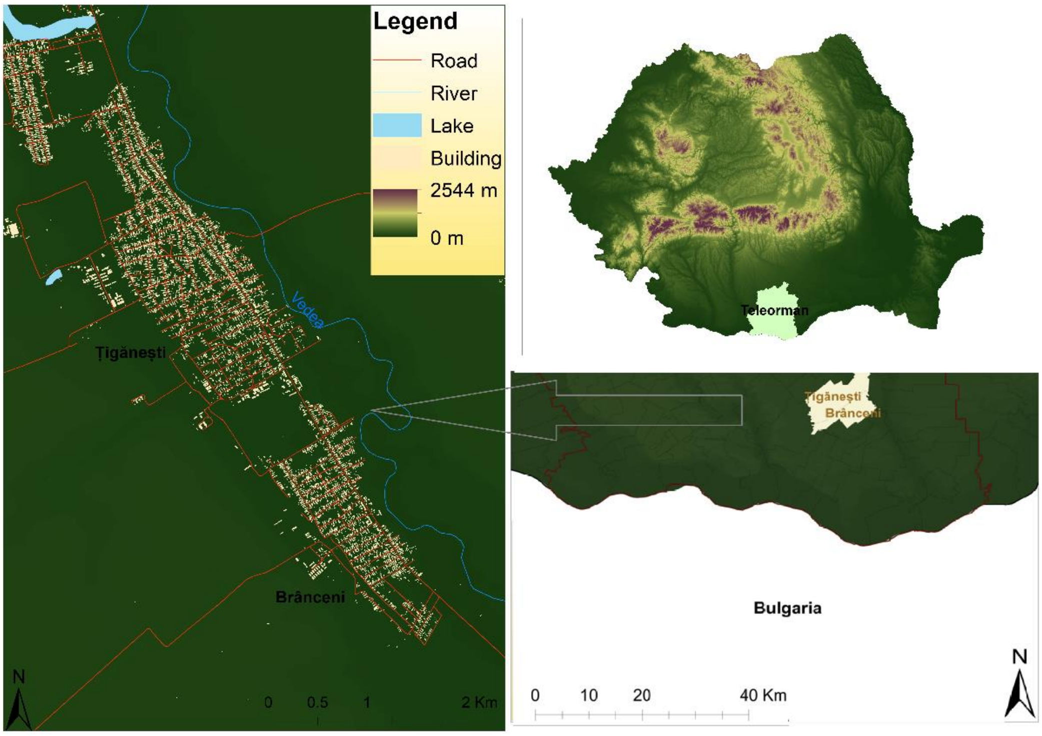


Figure 1. Location of Ţigăneşti and Brânceni.

The last significant flood on the Vedea River happened in 2014, but the most important one in recent times took place in July 2005, with a severe impact on Ţigăneşti and Brânceni villages. In the 1990s, floods occurred annually, with minor consequences on settlements but affecting the agricultural terrains. The flood analyzed in the present research occurred during 3–6 July 2005, affecting a significant number of buildings, roads, and terrains, and the first author was present there when it took place.

Ţigăneşti and Brânceni villages are situated at an altitude of about 35–37 m, close to the Vedea River. The slopes bordering the valleys can climb to altitudes higher than 60 m. The climate is temperate continental (transition influences) with cold winters (average of −3 degrees Celsius in January) and warm summers (average of 22 degrees Celsius in July), high-temperature amplitudes (over 25 degrees between January and July) with precipitations between 500 and 600 $mm/m^2/year$, important quantities falling in May, June, and July [14].

Meadow vegetation (close to Vedea), patches of deciduous forests, and steppe are found in the analyzed zone. Most of the former steppe and forest were replaced with agricultural terrains, settlements, and roads [14]. The absence of extensive forests on the slopes can increase the chances of water runoff into the river [13]. Meadow and chernozem soils are specific to Ţigăneşti and Brânceni. Flooding apparition is favored if the infiltration capacity is exceeded and the soils are saturated with water [15].

2.2. Methodology

The present research is based on field observations, personal observations from the flood that occurred in 2005, and hydrological data from the National Institute of Hydrology. GIS (Geographic Information Software) computing and HEC-RAS 6.2 2D version simulation have been used to evaluate the flood impact on the settlements, land, and roads in the two villages. To process data for HEC-RAS in ArcMap, the HEC-GeoRAS extension of ArcGIS was installed.

The GIS software used to process the data is ArcMap (ArcGIS) from ESRI. GIS database [16] was imported into ArcMap to obtain maps of the terrain, settlements, river, and roads [17], while HEC-RAS was used to simulate floods [18].

The following databases were used: Digital Terrain Model (DTM) of Romania at 30 m, road network, buildings, rivers, and territorial administrative units (TAUs). The coordinate system used was Stereo 1970 (31700).

First, it was necessary to process the large data mentioned above to obtain the information necessary for the simulation in the two villages. The shape of the Vedea valley containing the two villages was obtained by extracting the TAUs and cutting polygons. For example, in ArcGIS, the TAUs or buildings are polygon shapefiles, while rivers are polylines. Moreover, points are equivalent to points of interest [19].

The DTM of the inhabited areas and surroundings of Ţigăneşti and Brânceni was obtained using "Raster Clip" from Raster Processing (Data Management Tools).

A raster image file is a rectangular array of regularly sampled values, known as pixels. In GIS, a raster can be converted into a shapefile.

To create a more realistic appearance, "Hillshade" was applied from the Raster Surface extension of the 3D Analyst Tools alongside an increase of contrast in the display properties of the newly obtained raster layer. Then, transparency was set up for the raster layer obtained from DTM and the "Hillshade" raster layer. The two were overlayed, obtaining maps such as those in Figure 2. The roads and buildings were added after using "Clip" from Geoprocessing.

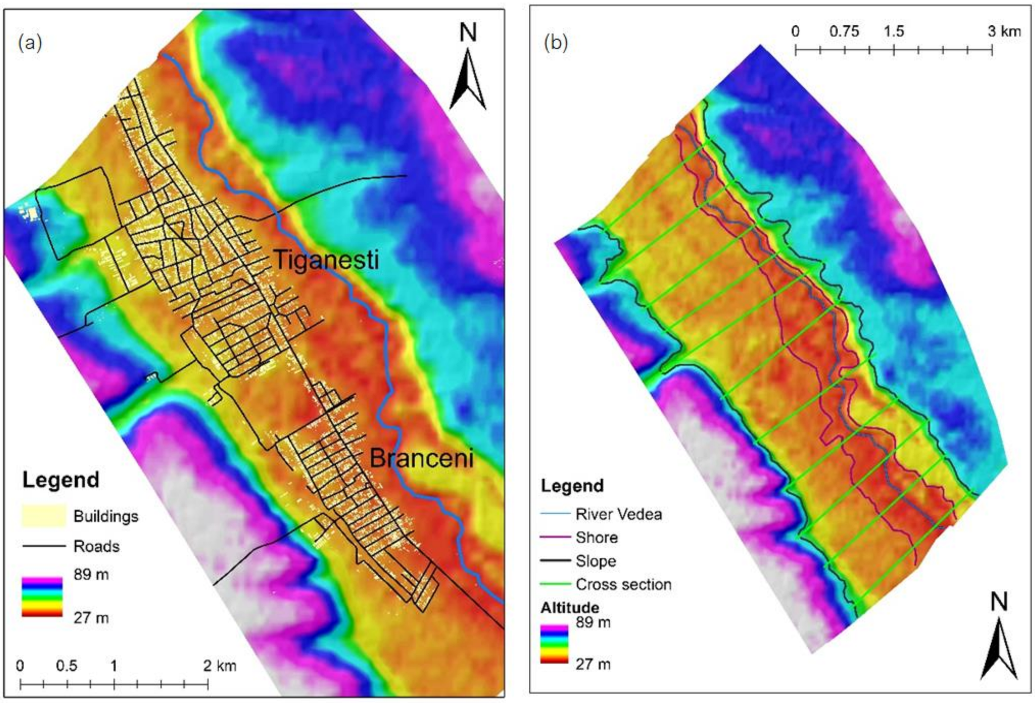


Figure 2. (**a**) DTM of Ţigăneşti and Brânceni; (**b**) RAS layers, including 11 cross-sections.

The next step was to activate the HEC-GeoRAS option and prepare the terrain for flood simulations in HEC-RAS. The RAS layers were manually created, such as stream centerline (or thalweg, the lowest point of a river), bank lines (shore), flow paths (slope), and cross-sections lines (transversal lines from an interfluve or hill to another where the depth of the flood can be observed after stimulation in HEC-RAS) [20].

In Figure 2b, the four elements necessary for flood simulation can be seen. After processing, data were exported for further processing in HEC-RAS.

From HEC-RAS, the obtained data in ArcGIS were added. Before running the simulation, several actions are required. In the "Steady Flow Data" under Edit, the flow value in cubic meters/second (m^3/s) was added, while in the Boundary Conditions, the "Critical Depth" was set up. In the present situation, the river selected for analysis is Vedea [18].

In "Geometric Data in Tables", the "Manning's *n* or *k* values" tab is accessed to set up the roughness coefficient (*n*). Therefore, it is essential to specify the correct values. An increase of *n* will cause a decrease in the water flow velocity across a surface [21]. High values mean an increased favorability to water accumulation. Table 1 contains the values of *n* for each cross-section. The value *n*#1 represents the coefficient for the left bank, *n*#2 for the main channel, and *n*#3 for the right bank. The values for the main channel are smaller because it is smoother (based on field observations the surface is earth channel, weedy, $n = 0.03$), while the banks are rougher (pasture, agricultural land, $n = 0.035$). The numbers in Table 1 are based on a list of roughness coefficient values for different surfaces [21].

Table 1. Manning's roughness coefficient for the Vedea River.

River Station (Equivalent to Cross-Section)	*n*#1	*n*#2	*n*#3
1	0.035	0.03	0.035
2	0.035	0.03	0.035
3	0.035	0.03	0.035
4	0.035	0.03	0.035
5	0.035	0.03	0.035
6	0.035	0.03	0.035
7	0.035	0.03	0.035
8	0.035	0.03	0.035
9	0.035	0.03	0.035
10	0.035	0.03	0.035
11	0.035	0.03	0.035

Manning's equation, used in HEC-RAS for steady flows gives the flow rate as a function of the channel velocity, flow area, and channel slope [21].

$$Q = VA = (1/n)AR^{2/3}\sqrt{S} \tag{1}$$

where:

Q = Flow rate (m^3/s)
V = Velocity (m/s)
A = Flow area (m^2)
n = Manning's roughness coefficient—setup by the HEC-RAS user (Table 1)
R = Hydraulic radius, (m)
S = Channel slope, (m/m)

After setting the variables, the simulation can be run by accessing the "Steady Flow Analysis". After processing, the level of flooding for each cross-section and the flooded surface can be observed [22].

According to the documentation from HEC-RAS, the energy Equation (2) is used for the profile calculations:

$$Z_2 + Y_2 + a_2 V_2^2/(2g) = Z_1 + Y_1 + a_1 V_1^2/(2g) + h_e \tag{2}$$

where:

$Z_1,\ Z_2$—elevation of the main channel inverts (m)
$Y_1,\ Y_2$—depth of water at cross-sections (m)
$V_1,\ V_2$—average velocities (total discharge/total flow area) (m/s^2)
$a_1,\ a_2$—velocity weighting coefficients
g—gravitational acceleration (m/s^2)
h_e—energy head loss (m)

HEC-RAS simulates floods based on the information specified by the user and mentioned above in the methodology: stream centerline, bank lines, flow paths, cross-sections, digital terrain model, roughness coefficient, flow value (example: 676 m^3/s), and specifying the information under "steady flow data" as critical depth [22].

After obtaining the flooded areas (2D), the accumulated water level for each cross-section can be visualized. In the present research, 11 cross-sections can be accessed [17]. Figure 3 shows the valley shape, the flooded areas, and the water depth for two cross-sections. The user can view the flooded surface by accessing "X-Y-Z perspective plots" from the View tab (Figure 4). The length and depth of the water for the entire valley differ for each cross-section.

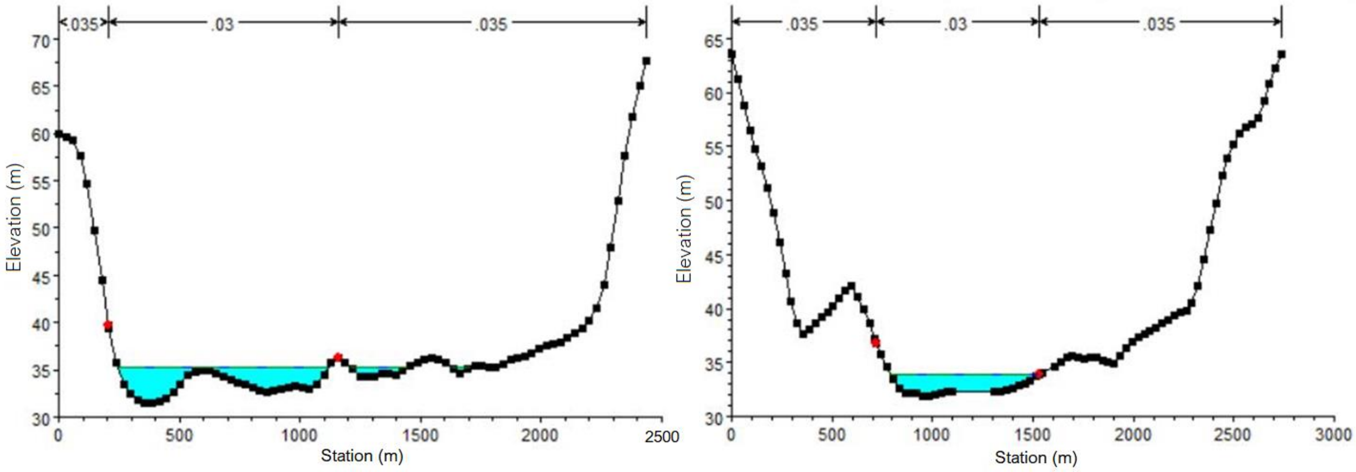


Figure 3. The Valley cross-sections (water volume represented in blue and river banks in red).

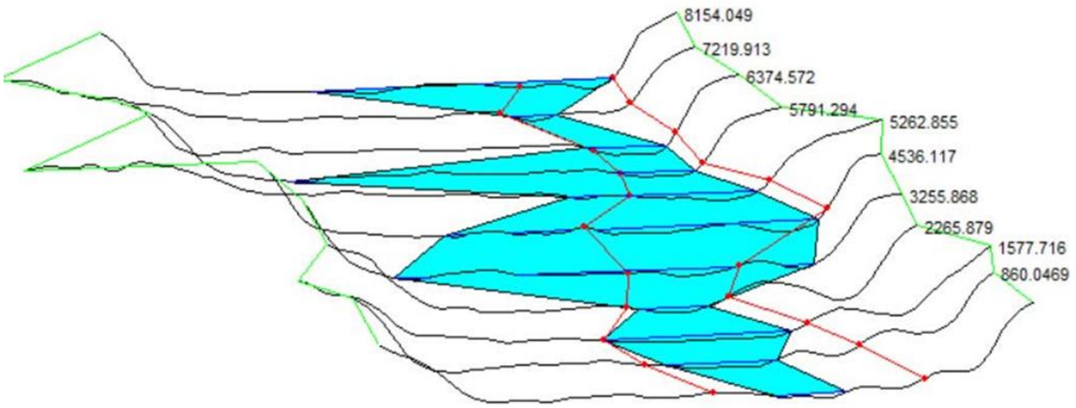


Figure 4. Flooded surface in Ţigăneşti and Brânceni area (the water volume represented in blue).

After verifying the correctness of the obtained data, the flooded area was exported from HEC-RAS as a raster layer using RAS Mapper to be imported into ArcMap. Figure 5 shows a shape of a flooded area. The blue area represents the flooded surface, the green lines the cross sections, while the color palette from green to gray represents altitudes. In ArcMap, the imported raster of the flood was reclassified from multiple values (multiple values come from the depth of the flooded area) into a single value using "Reclassify" from the Raster Reclass extension (3D Analyst Tools). It is essential to have a single value for the raster because, in the following steps, it is easier to quantify the affected buildings and roads and calculate the flooded area.

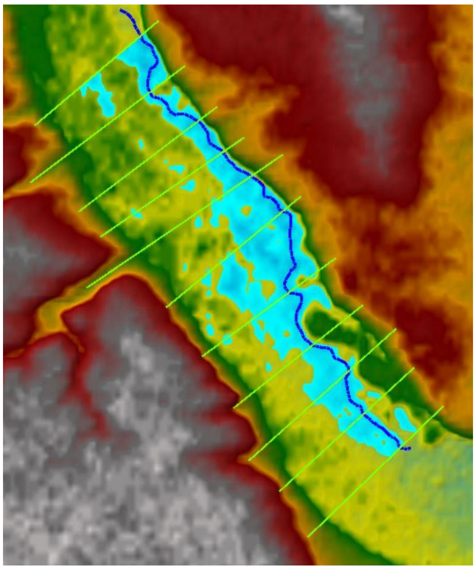


Figure 5. The flooded area visible in RAS Mapper (HEC-RAS).

Further, the raster was converted in GIS into a shapefile using Conversion Tools (from Raster to Polygon shapefile) [23].

For computing the flooded area, a new column was created ("surface") in the attributes of the flooded area polygon shapefile. Using "calculate geometry" in the attribute table, the flooded surface in "km^2" was estimated.

Then, the surface of the total surface of the flooded buildings was computed. First, with the help of "Clip" from Geoprocessing, the affected buildings were obtained based on the flood polygon shapefile [23]. In the attribute table of the affected buildings, the surface of each item can be observed. To calculate the total surface of the buildings in "m^2", "Summary Statistics" from Statistics extension (Analysis Tools) was used. A table under "List by source" (Table of Contents) with the total surface of the buildings was obtained.

When using ArcMap, one can also determine the number of flooded buildings. First, polygons corresponding to each structure were transformed into points using "Feature to Point" from the Features extension (Data Management Tools). Further, the points were summarized using "Spatial Join" from the Overlay extension (Analysis Tools) based on the flooded area polygon shapefile [24]. In the attribute table, under the new column called "Join_Count" of the newly created polygon, one can see the number of affected buildings [24].

The length of the flooded roads can also be calculated in ArcMap. Using "Clip" from the Geoprocessing tab, the flooded roads were obtained based on the flooded area polygon shapefile [25]. In the attribute table, the distance of each flooded road in meters was computed using "calculate geometry" under a newly created column. The next step was to determine the total flooded roads. Using "Summarize Statistics" from the Statistics extension (Analyst Tools), the total length of flooded roads was calculated. The new table is also available under "List by source" (Table of Contents) [25].

The methodology used to calculate the surface of the flooded area can be applied to any flooded area polygon shapefile obtained based on flow values (m^3/s). Of course, the surface of the affected buildings and the length of flooded roads are different depending on the flow values used to calculate them. The flow values used in this study were 200, 400, 676, and 800 m^3/s.

Even though the values in July 2005 did not exceed 676 m^3/s based on the data from the National Institute of Hydrology, it was interesting to see the flooded surface at a bigger value, 800 m^3/s, because after discussing with the villagers that lived for decades in Ţigăneşti and Brânceni, it was learned that larger floods occurred in the 1970s and 1980s.

For Brânceni, the DTM was modified in HEC-RAS by adding a levee to see how it protects the village from flooding at different flow values.

The losses were also calculated based on the Ministry of Environment and national road company data. The model was validated based on the observations from 2005 (similarities in how the flood area appeared in reality and the simulation), the configuration of the Vedea Valley, and values from the National Institute of Hydrology. Moreover, the observations from 2014, when important flow values occurred, showed that the village could be protected even at high values.

In the HEC-RAS simulation, the water level did not exceed the dike of approximately 2 m at flows up to 800 m^3/s. Based on a document from the Romanian Waters, the levee was projected to withstand flows of 813 m^3/s; it is one of the reasons why the value of 800 cubic meters was also chosen in the analysis. A similar situation was observed in 2014 when even though the flow was very high, the water level did not exceed the newly constructed levee (the difference between the water level and the top of the dike was a little over half a meter).

The study limitation comes from the data available from the National Institute of Hydrology that does not include the water depth measured at the hydrometric station, but only the flow rate. Thus, the matching between the simulation and the event on the site had to be done using the above methods.

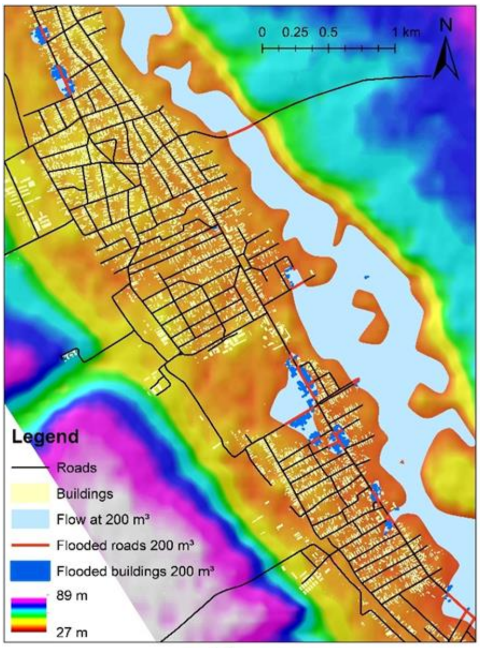
3. Results and Discussion

The flow registered for river Vedea in Ţigăneşti and Brânceni during 3–6 July 2005 was significantly high to affect the two villages. Usually, the river flow is around 8.36 m^3/s. Thus, the flow exceeded more than 80 times when the flood occurred. On the 3 July at noon, river Vedea had a flow of abound 200 m^3/s. The next day, it was at its maximum of 676 m^3/s at 11 a.m. and 12 p.m. On the 6 July at 6 a.m., the flow value decreased to 133 m^3/s. The water depth increased by almost 5 m from the thalweg. The water level reached up to 1–2 m in the inhabited area.

According to Figure 6a, at a flow of 200 m^3/s, most of the areas affected included crops, significant parts of the meadow located in the proximity of the river, pasture areas, but also some roads and houses in the northern and central part of Brânceni and several settlements, roads in the southeastern and northern parts of Ţigăneşti and a bridge in the same village. Because of the impressive quantity of precipitation felt in that period (2005 was the rainiest year in recent times), several ponds formed in the two villages, flooding roads and buildings.

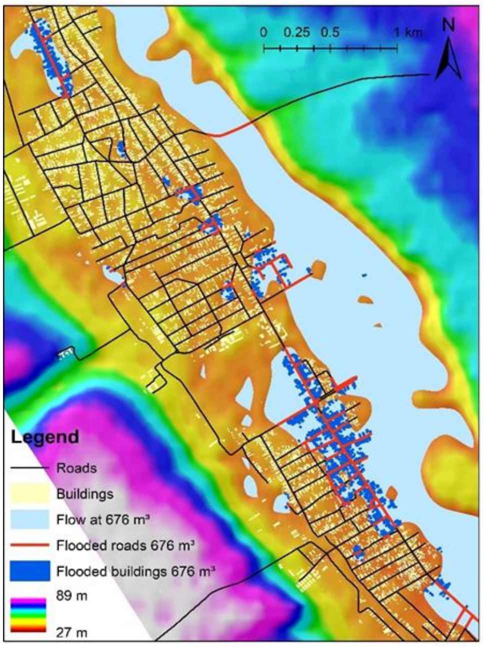
Figure 6b shows that at a flow of 400 m^3/s, the flooded area increased compared to that for 200 m^3/s, covering important surfaces with houses and roads in Brânceni (the northern and central parts and smaller numbers in the south). Ţigăneşti was less affected by comparison with Brânceni. Agricultural terrains and pastures were flooded as well.

When the highest flow rate of 676 m^3/s was recorded, according to Figure 7a, the areas affected were significant parts of Brânceni (north, center, and south). By comparison, a smaller surface Ţigăneşti was affected (in the north and southeast). The flooded area was higher compared to that at 400 m^3/s. Ponds that flood houses and roads were also formed. In Brânceni, the access (National Road 51) to Alexandria (in the north) and Zimnicea was cut because of the flooding, making the authorities' intervention difficult. The bridge affected in Ţigăneşti had only local importance, connecting the village with the pasture land located in the east.



(a) (b)

Figure 6. Flooding at (**a**) 200 m^3/s, (**b**) 400 m^3/s.



(a) (b)

Figure 7. Flooding at (**a**) 676 m^3/s, (**b**) 800 m^3/s.

Even though the flow rate of 800 m^3/s is hypothetical, it was probably recorded in the 1970s when bigger floods occurred. A larger surface was affected compared to the one at 676 m^3/s. One-third of the settlements and roads in Brânceni is entirely covered by water, according to Figure 7b.

The most critical factors that favored the settlements' flooding are their location near the river, the terrain elevation [26], very high precipitations that lasted for days, almost flat terrain in the river valley, the elongated shape of the catchment, absence of large forested areas, and precarious hydro-technical works. The water depth in the villages exceeded in some parts 1.5 m. Figures 6 and 7 show that Brânceni was more affected because the settlements are located at a lower elevation compared to Ţigăneşti.

According to Figure 8, in Branceni, almost the entire section of the main road was flooded. The village supply of goods was affected for a couple of days, while the electricity was stopped for four days. The village was accessible only by large 4 × 4 vehicles through its edge from the interfluve (hill).

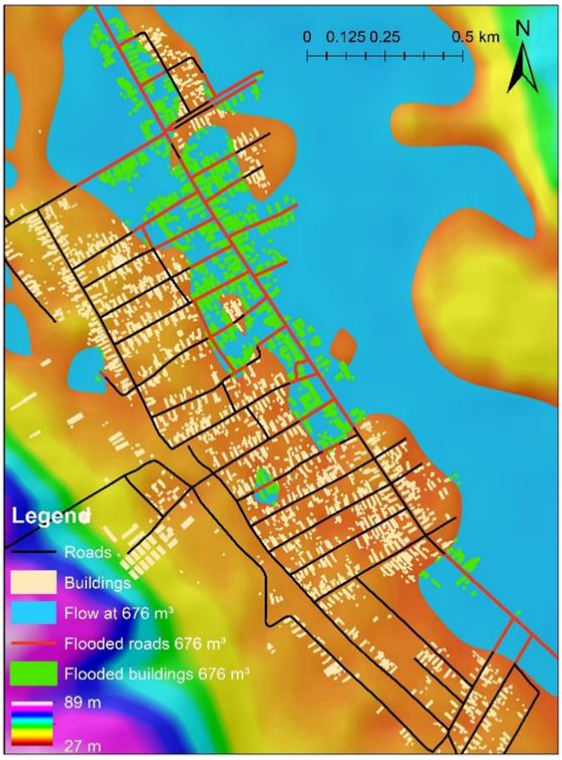


Figure 8. Flooded areas in Brânceni at 676 m^3/s.

The village hall, school, kindergarten, church, monastery, dispensary, police station, and several shops were completely flooded. Here, the water levels exceeded 1 m. After the flooding, one house was destroyed, the structure of several settlements was affected, animals drowned, household crops were compromised that year, and water from the fountains was no longer safe to drink. In addition, after the waters' withdrawal, areas covered with dirt and waste remained.

Figure 9 contains photos from that period. The left one presents a flooded house on a lateral street. The second shows National Road 51 covered by water, while the third is from the center of Brânceni.

Figure 9. Photos from the 2005 flooding in Brânceni.

Table 2 contains the estimated loss by flooding in the four scenarios. At 200 m^3/s, the flooded area was 2.7 km^2, and 306 buildings were affected, representing 23,314 m^2 (3.39% of the total surface of the buildings). The length of the flooded roads was 3212 m (4.84% of the total length of the roads).

Table 2. List of values for flooded areas, buildings, and roads at different flow values.

Flow Rate	200 m^3/s	400 m^3/s	676 m^3/s	800 m^3/s	Damages
Flooded area (km^2)	2.7	3.46	4.16	4.45	Total surface of buildings (m^2)
Number of flooded buildings	306	674	1117	1380	687,718
Surface of flooded buildings (m^2)	23,314	52,278	99,693	108,469	Total length of roads (m)
Length of flooded roads (m)	3212	6483	10,287	12,125	66,238

At 400 m^3/s, the flooded surface was 3.46 km^2 and 674 buildings were affected, representing 52,278 m^2 (7.6% of the buildings' surface). The distance of the flooded roads was 6483 m (9.78% of the total length of the roads).

At a flow of 676 m^3/s, the flooded area was 4.16 km^2, and 1117 buildings were flooded, representing 14.49% of the buildings' total surface. The length of the flooded roads was 15.53% of the total length of the roads.

Regarding the hypothetical flow of 800 m^3/s, the flooded surface would be 4.45 km^2, and 1380 buildings and 12.125 km would be affected.

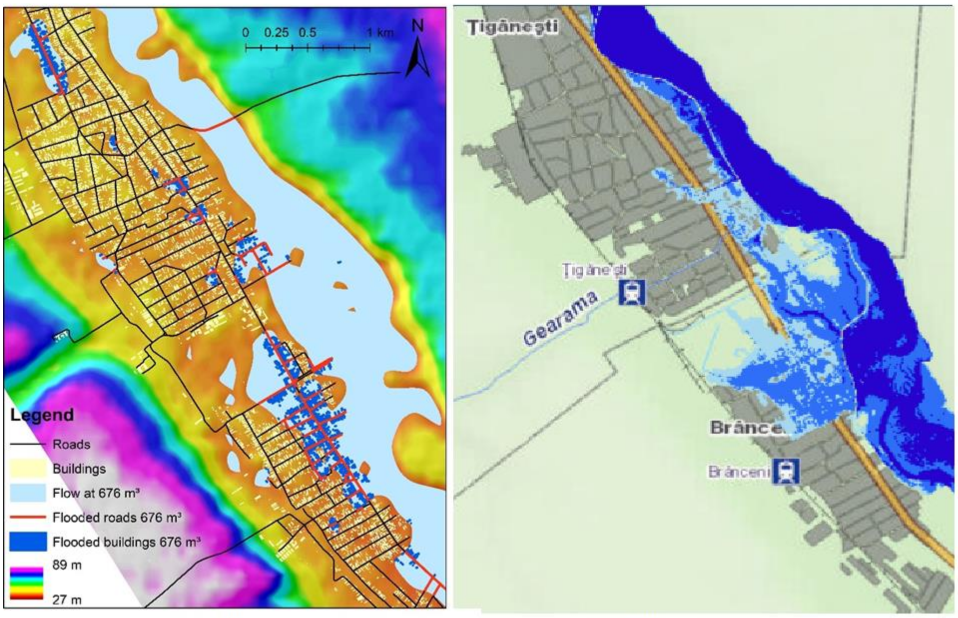
Table 3 contains the estimated flood losses at a flow of 676 m^3/s in both villages. The building unit value is a national estimation from the Ministry of Environment from 2005. The current value from 2022 was calculated by multiplying the 2005 value with the annual inflation from 2006 to 2022. The cost for the complete reconstruction of one kilometer of the national road that crosses the villages in the flat area, such as the one studied in this article, comes from the contracts of the national road company (CNAIR). The unit value loss in the case of buildings is 14,959 lei, while the total loss is more than 3 million euros. In the case of the national road, the unit value (1 km) is 12,223,600 lei, while the estimated loss is more than 8 million euros if the road should be rebuilt. Thus, the losses can be very high.

Table 3. Estimated losses in Romanian currency (lei) and euros for year 2022.

Infrastrucure Elements	Number of Houses/km	Unit Value (RON)	Estimated Losses (RON)	Estimated Losses (Euros)
Houses	1117	14,959	16,709,203	3,389,433
Length of national roads (km)	3.306 km	12,223,600	40,411,221.6	8,197,704

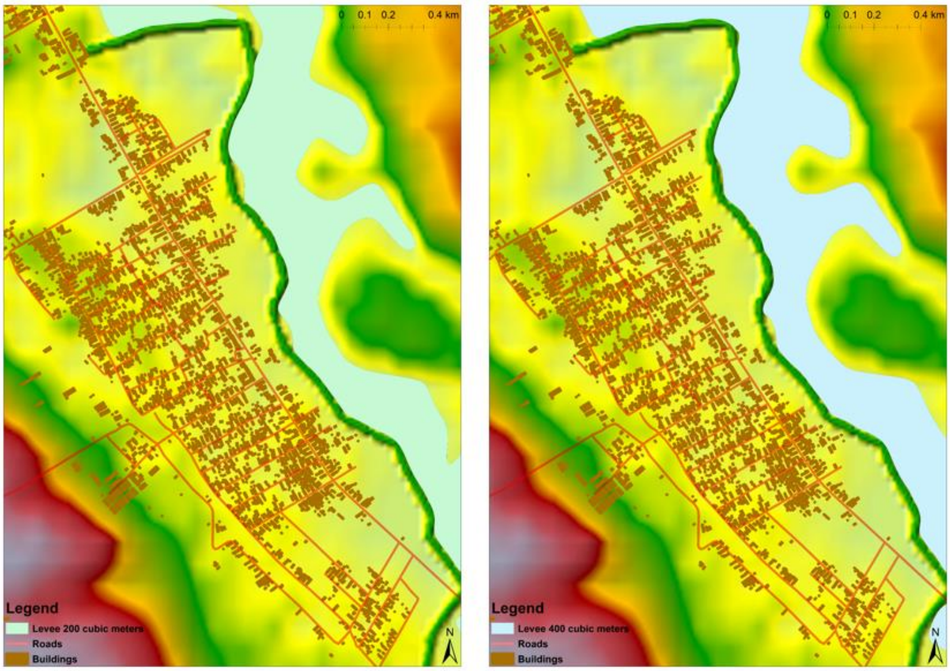
In 2005, the flood impact was very high, comparable with a hydrological phenomenon with a probability of 1%. Figure 10a is the result of our simulation—the flood at 676 m^3/s—while Figure 10b is the map obtained from the National Administration Romanian Water, showing the flood with a probability of 1% in the same zone [27,28]. One can find in the two images similarities regarding the flooded surfaces. For example, the most affected zones are the northern part of Brânceni and the pasture areas between Ţigăneşti and Brânceni. Moreover, in both representations, Ţigăneşti village was less affected.

After 2005, a tall river levee of around two meters was built in Brânceni to defend the village from flooding. The levee proved to be useful in 2014 when the water level of the Vedea River augmented again due to heavy rainfall [29]. In the simulation from Figure 11 at (a) 200 and (b) 400 m^3/s the village is not flooded because the levee protects it. This applies also to the higher flows of 676 and 800 m^3/s (Figure 12).



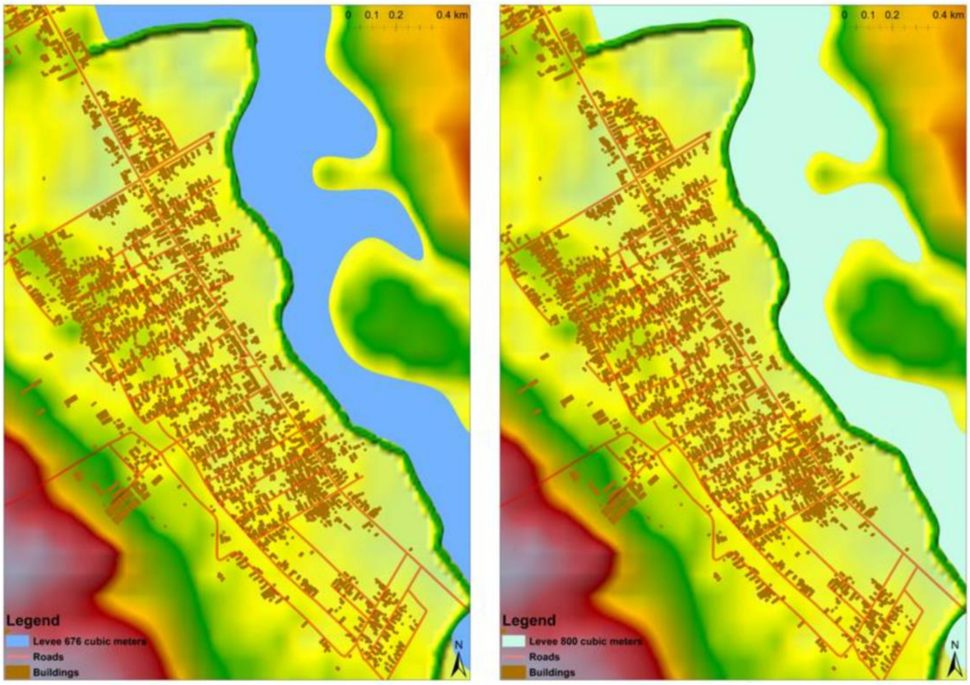
(a) (b)

Figure 10. (**a**) Flood at 676 m^3/s and (**b**) flood with a probability of 1% (image from 2014, RoWater) [27].



(a) (b)

Figure 11. Flooding simulation (**a**) 200 m^3/s, (**b**) 400 m^3/s after building the levee.



(a) (b)

Figure 12. Flooding at (**a**) 676 m^3/s, (**b**) 800 m^3/s after building the levee.

Based on the information from the European climate change website (climate.ec.europa.eu), the cost for lower river levees is 3 million euros/km. The combined distance of the dikes in Brânceni and Ţigăneşti is 7 km. Thus, the implementation cost is 21 million euros. Because the levee prevents floods, the potential loss becomes, in this case, a benefit (avoid the houses and roads losses). The benefit-cost is 11.58 million euros if the flood occurs only once. In the past 30 years, there have been two major floods (2005 and 2014) and other small ones. It is hard to determine the difference between the implementation and benefit for 100 years, for example. However, if the flow of 676 m^3/s occurred twice in 100 years, then the benefit would be 11.52 million euros multiplied by 2 (a total of 23.16 million euros). Therefore, it is worth building levees in this area because the difference between implementation and benefit is $23.16 - 21 = 2.16$ million euros.

4. Conclusions

In this paper, we presented of case study on the floods of the Vedea River, Romania. The location was selected because it is prone to flooding when large quantities of precipitations fall due to the elongated catchment shape, the location of the settlements close to the Vedea River, and the almost horizontal slope of the valley.

At the beginning of July 2005, the maximum recorded value of the flow registered was 676 m^3/s (80 times higher than the average flow), affecting 1117 houses, administrative buildings, 12.287 km of roads, crops, and pasture areas, especially in the northern and central parts of the Brânceni village. The water level exceeded 1 m in the central area of Brânceni. Ţigăneşti village was less affected. The flooding that occurred in July 2005 brought attention from the national media. The emergency authorities used special 4 × 4 vehicles, inflatable boats, and water pumps. The intervention was difficult, especially in Brânceni, because the paved road was completely covered with water, and the access from the two cities, Alexandria and Zimnicea, was cut off.

Extreme flooding phenomena are hard to predict. They frequently occur in May, June, and July, or spring (after heavy winters, when the snow melts rapidly due to the abrupt temperature change). The region of Ţigăneşti and Brânceni is no exception.

The simulation of the flood impact was performed at flow rates of 200, 400, 676 m^3/s, and 800 m^3/s, indicating an increase in the number of the flooded buildings from 306 to

1380, of the surface of flooded buildings from 23,314 m^2 to 108,469 m^2, and the number of kilometers of flooded roads from 3.212 to 12.125, in the worst case (800 m^3/s) compared to the best one (200 m^3/s). Losses were very high at a flow of 676 m^3/s (11.58 million euros) before the levee construction.

The situation of the two villages improved after the flooding in 2005 since, in Brânceni, a high and solid levee was built on the right bank, while in Ţigăneşti, protection works against floods with a probability of occurrence of 5% were carried out [28]. The new levee in Brânceni protects the village from floods even at flow values of 800 m3/s, as results from the performed simulation.

Similar studies will be carried out for other zones where flooding is expected and will be publicly available to provide the authorities with solid documentation for making decisions for population protection.

This paper is unique for the Brânceni and Ţigăneşti villages quantifying the flooded roads and buildings (including building surface). It determined the flooded areas at different flow values, the potential losses, and the economic loss. It also showed the usefulness of the levee. So far, no such research has been carried out for the discussed area.

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