applied sciences

Case Report

A Practical Approach on Reducing the Flood Impact: A Case Study from Romania

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Featured Application: This article proposes a solution for reducing and even eliminating flood effects in Prahova County, Romania, by extending the length of a bridge and reducing its embankment.

Abstract: Recently, the frequency and intensity of extreme weather events have increased in many regions worldwide. Among them, floods, whose effects are devastating in many cases, have been recorded in Romania in the last few years. Built to reduce the flooding effects on the communities, structures such as embankments can sometimes accentuate the hazard. This article investigates such a situation and proposes solutions to reduce or even eliminate the flood impact on the community living in the Vărbilău Catchment in Romania. Recorded data series, field observations, GIS techniques, and hydraulic modeling were used to design the hazard maps and perform the 3D representations that illustrate the actual situation (when the small opening of the bridge favors the flooding) and the proposed solutions (extending the bridge opening and shortening the embankment). It is shown that adding seven pillars to the bridge would reduce the flooded surface by more than 1.5 times and the affected buildings' surface by more than 3.5 times compared to the current situation.

Keywords: embankment; risk assessment; modeling; flood

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1. Introduction

Floods are unpredictable hydrological phenomena that can have a devastating impact on communities. They are influenced by various factors such as climate, terrain geomorphology, slope, soil type, vegetation, etc. [1]. Besides these, anthropogenic influences can exacerbate or mitigate the effects of the flood, altering natural water flow. These changes include urbanization, deforestation, and infrastructure (like roads and bridges) [2]. River dams can regulate river discharge, but their failure can have catastrophic downstream effects [3]. For example, The Teton Dam in Idaho, USA, built in 1976, broke in June of the same year at the first filling, causing damages of USD 300 million. The cause of this disaster was internal erosion in the dam [4]. In 2013, 134 bridges were destroyed, and 1035 roads were damaged in Guerrero state in Mexico due to two tropical storms. The economic loss was estimated at over USD one billion. Roads and bridges were crowded, and their structure was damaged. The drainage systems of the highways or railways were also overloaded.

Events such as the Teton Dam failure in Idaho and the destruction of numerous bridges and roads in Guerrero state, Mexico, underscore the urgent need for measures to reduce infrastructure's vulnerability to hydrological phenomena [5].

Embankments situated at a higher level than the floodplains should provide a protective barrier for roads or railways [6]. However, they can act as a river dam when inappropriately positioned, leading to water accumulation. In this respect, most articles discussed the impact of floods on the bridge piers [7–12], others proposed improved hydrodynamic models for the bridge pier flow [13,14], and fewer have investigated the impact of the bridge pier on the flood apparition [15,16].

For example, Szymczak et al. [17] documented the damages along the Ahr Valley railroad line in Germany, particularly focusing on bridges, which are often the weakest points during flood events. The article demonstrates that under significant pressure, an embankment can fail. Other authors [18] indicated the effects of flooding on railway infrastructure. They show that floods can cause significant economic damage and decrease structures' resistance.

A bridge with an insufficiently large opening can further exacerbate the situation, as it hinders the rapid drainage of water during high flows [4]. Despite the topic's importance, only a few articles addressed the following question: How the infrastructure (railway embankments and bridges) favors flooding? This gap in research will be the focus of the present article. Some examples are presented.

Maione et al. [19] analyzed the influence of a highway embankment in the case of a flood from northern Italy when 40 km^2 of land was covered by water. For hydraulic modeling, they used data from the rainfall–runoff model and hydrographic data collected during the flood. Comparisons of the simulation results in the scenarios with and without the highway indicate the structure's hydraulic impact. Ochsner et al. [18] draw attention to the fact that the infrastructure itself is among the factors that can favor the flooding apparition. Lechowska [20] highlighted the impact of building an embankment on land use in a floodplain within a Polish city, contrasting it with a similar city that lacks such a structure. She emphasizes the advantages of the embankment for land use management and its environmental benefits. Assessing the resilience of a rail embankment located in a flat area against a flood with a 200-year return period, Calamak [21] indicated that maintaining railway operations during a flood can influence the safety of the embankment.

Other authors have considered physical-based modeling approaches for producing flood hazard maps. Dazzi et al. [22] highlight the importance of including relevant terrain elements in models that simulate large-scale flooding to determine the dynamics of the events. The main reason is that the digital terrain models do not contain such terrain items. Van Nieuwenhuizen et al. [23] discussed modeling applications' limitations in identifying embankments. They remarked that no automated procedure exists to identify or remove embankments or levees from the DEMs obtained via LiDAR. Manual processing DEM techniques are mainly used, as in their work in HEC-RAS. Urzică et al. [24] presented the methodology of utilizing the hydraulic modeling software in the event of an embankment break, employing data from the Romanian National Water Institute and River Basin Administrations. They showed how water drains through the cracks in the embankment.

Other scientists determined and quantified the hazards' effects based on different scenarios. In their article, Rahadiati et al. [25] analyzed the flooding impact on the houses located at a distance less than 100 m from a river in Indonesia, emphasizing the destruction of buildings, compromising of crops, infrastructure destruction, and the cessation of economic activities in the area. Loschner et al. [26] discussed the risk at a small scale produced by flows that can appear once every 100 and 300 years. Analysis has been carried out in floodplains where the expansion of neighborhoods is expected. Scenarios are analyzed to determine the exposure to floods.

In Romania, there are different regions where floods frequently occur. Such events are not rare in the Vărbilău catchment discussed in this study. Studies performed for this country mainly addressed the susceptibility to floods in different zones using flood potential indices and artificial intelligence methods [27–30] or the accessibility of different locations in various flooding scenarios [31,32].

While hazard maps were built in the National Flood Management Plan framework to support authorities' informed decisions regarding flood measures preparation, we note that some zones are not covered or are investigated less.

In this context, the novelty of the present study relies on the following:

- Test the hypothesis that the rail embankment is a factor that favors water accumulation in the case of high precipitations or massive snow melt, contributing to flooding apparition. The results cover a gap in the scientific literature that highlights the necessity to investigate bridges' influence on flood events in diverse conditions [15,16];
- Presents the results of simulating floods in Dumbrăvești, situated on the Vărbilău catchment, in the Prahova County (Romania), one of the villages in the river catchment most affected by flooding. Such a study has not been performed until now for this catchment, and the possible loss in the case of flooding with a 100-year return period was not evaluated. This study provides scientific support for authorities to take measures to eliminate or reduce the risk of floods;
- Propose a solution for mitigating the floods' impact. For this aim, the flooding simulation was performed for a 100-year return period, and the results were compared with the case when the embankment was removed and replaced by a bridge;
- Provide an initial evaluation of the economic loss in the three proposed scenarios.

It must be noted that the solutions we propose as water resources scientists are not exhaustive. Road and bridge design engineers must investigate their technical and economic feasibility further. Our goal was to point out an issue that should be solved and provide an analysis that can be successfully applied to other catchments.

2. Study Area and Data Series

2.1. Study Area

Romania is located in the southeastern part of Europe, in a continental temperate climate, and is crossed by the parallel of 45 degrees north. However, different types of climatic influences are favored by the Carpathians' presence (acting as an orographic barrier), the relatively small distance from the Mediterranean, and the opening of the relief to the east [33]. Therefore, diverse influences are noticed: oceanic in the west and center, continental in the east, Pontic in the Black Sea area, sub-Mediterranean in the southwest, Scandinavian-Baltic in the northeast, and transitional in the south. Since the altitudes vary between 0 and 2544 m, climatic stratification also appears [3].

The study area, Dumbrăveşti, is located in the central, southeastern part of Romania, in the central part of Prahova county (Figure 1a), very close to the parallel of 45 degrees northern latitude (Figure 1b), in a transitional climatic zone, specific to the area of low hills (the altitude of Dumbrăveşti is between 229 and 370 m). To the north of the region, not very far, the Carpathians are found, favoring the appearance of a warm wind, the foehn [34].

Precipitation in Dumbrăveşti primarily occurs as showers from May to July, with the potential for floods in spring (March–April) due to snowmelt [3]. The average annual precipitation is 600 $\text{mm}/\text{m}^2/\text{year}$, and the average annual temperature is 10–11 degrees Celsius [35]. The climate and relief, with an elongated valley bordered by hills and the relatively small slope of the riverbed, favor water accumulation during showers [28]. The Vărbilău River, which crosses this zone from north to south, plays a significant role in the area's hydrology. It can bring large amounts of water from upstream, contributing to the risk of flash floods that can turn into floods in the Dumbrăvești area. Sfârleaca village is located on the left bank of the river and Dumbrăveşti on the right.

The vegetation consists of mixed forests (beech and others, especially in hilly areas), part of which is replaced by cultivated fields. Agricultural fields are found in the floodplain area. The forests' absence at low altitudes can also favor floods [29]. The soils are impermeable clay loam, podzolic brown, podzolic, and floodplain clay loam.

The Dumbrăveşti commune is composed of six villages. The residence is in a village with the same name. The analysis also includes the Sfârleanca village, located 1 km east of Dumbrăvesti (Figure 2).

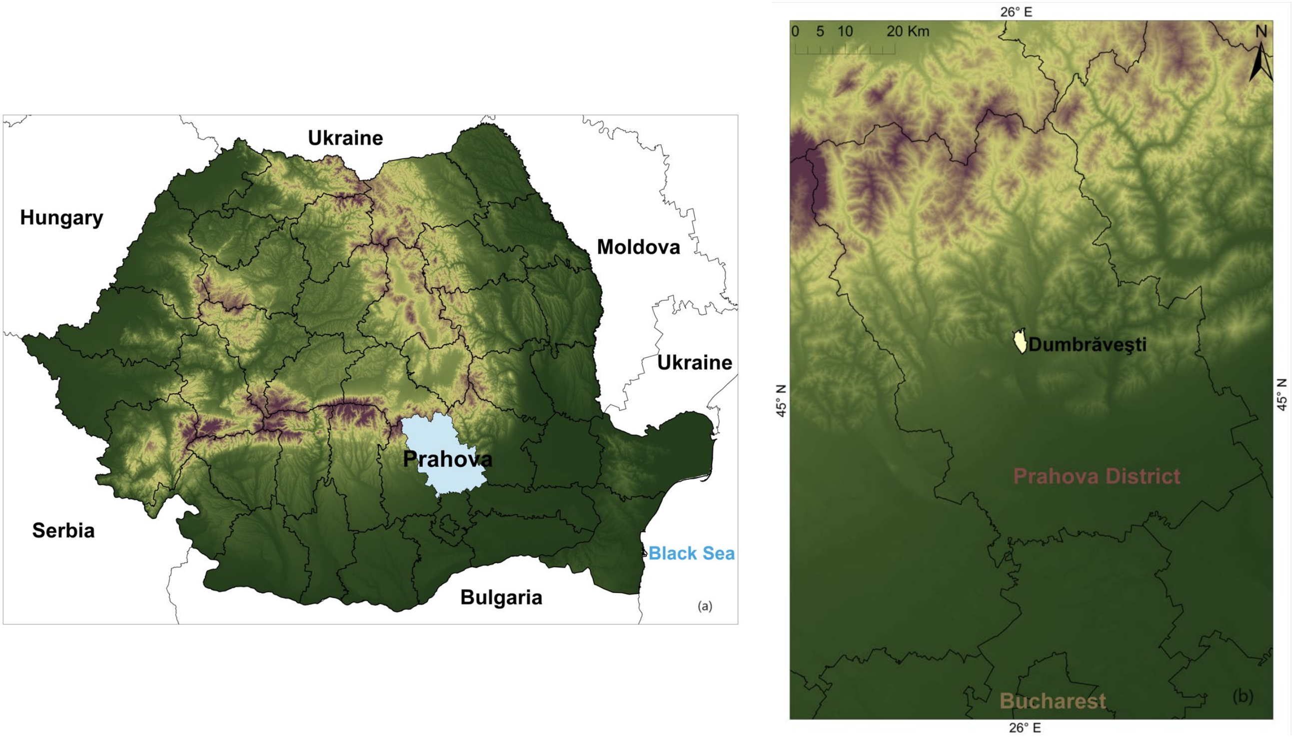

Figure 1. (**a**) Location of Prahova County in Romania; (**b**) location of Dumbrăveşti.

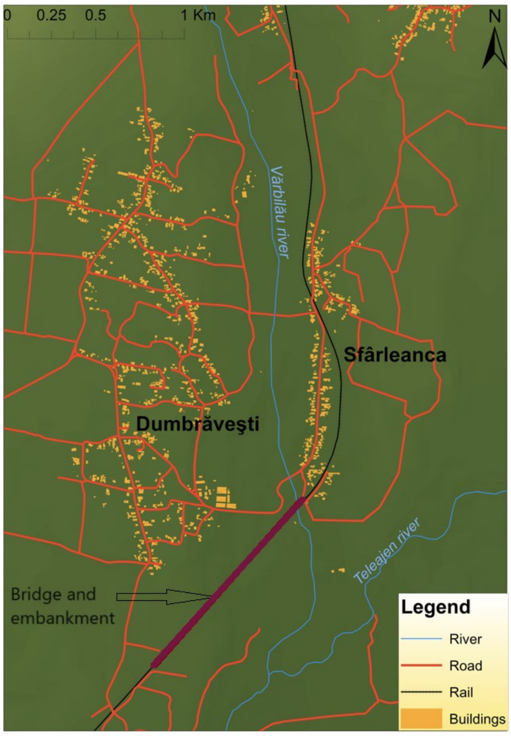

Figure 2. Dumbrăveşti and Sfârleanca villages.

The main road that crosses Dumbrăveşti is County Road 102. Sfârleanca is crossed by communal road 16 [34]. Moreover, part of the terrain analysis was conducted from the road bridge which crosses the Vărbilău River. The bridge is part of a communal road. The Ploieşti-Slănic railway also passes through Dumbrăveşti commune. It crosses the Dumbrăveşti village to the south and Sfârleanca to the south and east.

This railway is the subject of analysis in the present research. It is located on a southwest-northeast embankment, which starts from the right bank of the Vărbilău River (Dumbrăveşti village) and continues with a bridge over the same river. This embankment has a length of 733 m between the bank and the bridge (Figure 3a). The bridge has three pillars and an opening of 100 m (Figure 3b). The railway continues in the Sfârleanca area with another embankment of about 150 m (Figure 4). Then, it changes direction from south to north (but not on an embankment) in the western part of Sfârleanca. The houses in Sfârleanca are located very close to the river, placing them at risk during high-water events.

Figure 3. (**a**) Bridge over Vărbilău and the embankment; (**b**) bridge with three pillars and an opening of 100 m over the Vărbilău River. The blue arrow indicates the flow direction.

Figure 4. Bridge and the second embankment (150 m). The blue arrow indicates the flow direction.

The river flow direction (from north to south), the relatively small opening of the bridge, the embankment direction (from southwest to northeast), and the location of the starting point of the embankment further south compared to the bridge over Vărbilău favor water accumulation and floods when the Vărbilău's flow is extremely high [30].

2.2. Methods

Figure 5 shows the stages of our study, starting from its goal, which is to determine factors that favor flood hazards, then quantifying the damages and providing a solution to reduce their impacts on settlements and terrains [36].

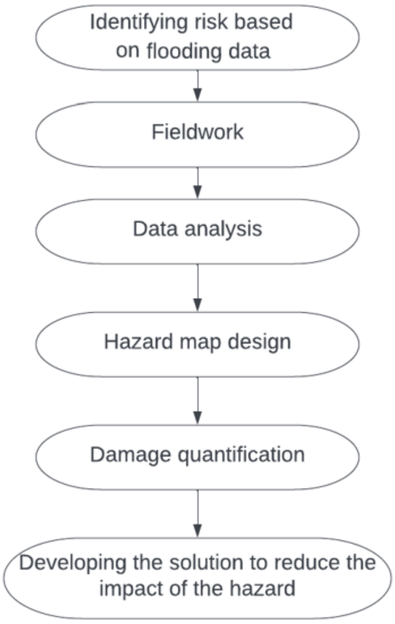

Figure 5. The study flowchart.

First, it was necessary to identify and confirm the risk via field trips and collecting data. Then, this study involved data analysis, developing hazard maps, quantifying damage, and proposing solutions. The fieldwork consisted of identifying the railway embankments, bridge position, number of pillars, and proximity of the buildings to the Vărbilău River, their destination, and the land use. Pictures have been taken to support the research. Available data, such as the floods with an exceedance probability of 1%, the embankment length, and the bridge opening, were analyzed to prepare for the following stages [37].

The flood hazard maps were designed for the following scenarios:

1. The current situation, called Scenario 1, involves the bridge having three pillars, a 100 m opening, and the existing embankments. The bridge is designed to resist floods with an exceedance probability of 1% [38–40];
2. The proposed solution, Scenario 2, involves entirely removing the embankments and replacing them with the railway bridge, resulting in an opening of 280 m. Seven more pillars are added to the existing three. This is the extreme case. The opening length of 280 m is chosen because it is close to the width of the flooded zone upstream of the rail bridge;
3. An intermediary case, called the intermediary scenario, when the opening is widened, resulting in a bridge with an opening of 200 m and seven pillars. This scenario was proposed with the goal of a possible cost reduction but a sufficient enlargement. Therefore, doubling the bridge length is proposed. This solution also supposes building four more pillars. Still, the optimum number of pillars and the exact length of the bridge should be determined to comply with the design norms [38–40], as well as the cost and estimated damages. This analysis will be the object of another analysis, as already mentioned in the Introduction.

All scenarios are applied to the flood with an exceedance probability of 1%. Damage evaluation was performed for each case.

We used GIS data (Digital Terrain Model of Romania or short DEM, shapefiles), data available on the site inundatii.ro and the Romanian Waters National Administration, and data obtained through fieldwork and GIS measurements. The Stereo 1970 (31700) coordinate system was utilized [41]. The resolution of the Digital Terrain Model was 30 m. According to [42,43], a higher resolution implies a better representation of land features compared to a lower resolution that smooths the details. It enables users to have a consistent view of water surfaces and, therefore, can be used to indicate flood-prone zones. Extended descriptions of the methodology, data collecting, and step-by-step computational details are presented in [44].

The software utilized was the Geographic Information System ArcGIS 10.2.2 (ArcMap and ArcScene), the 2D hydraulic modeling software HEC-RAS 6.2, the HEC GeoRAS extension (to export data from ArcMap to HEC-RAS 6.2), and the RAS Mapper extension (employed to export data from HEC-RAS 6.2 to ArcGIS 10.2.2).

Steady flow was used to simulate the flooding. Therefore, the application will show the flooding expansion. Manning's coefficient was introduced based on the terrain. The "*n*" value belonging to Manning's equation was also set in HEC-RAS. Thus, for the thalweg, the correspondent to a gravely, the earth surface was entered, while for both banks, the values for grass and earth terrain were also entered. Levees, the equivalent of embankments, have been added into HEC-RAS to see how the flood band will look with embankments considering different openings: 100 m, 280 m, and 200 m. The flow values have been added to observe the flood bands. The flow paths, banks, channels, and cross-sections necessary for obtaining the flood model have been exported from GIS to HEC-RAS.

The terrain model limitations are represented by the resolution (the higher the resolution, the more precise a simulation is) and the absence of some elements, like vegetation, that can influence the flow direction. Still, the flood band offers an important overview of what buildings and terrains are affected.

The main advantages of the HEC-RAS are the following:

- It is an open-source software [45,46];
- It has the same capabilities as any other software, which is not free of charge [45];
- It has proven its performance in implementing different scenarios worldwide [46];
- It can be used for forecasting [45];
- It is intuitive and easy to learn [46];
- Its internal GIS viewer presents compatibility with other GIS packages [46];
- Is faster when modeling large systems and permits a more precise computation [46].

The main limitations of the HEC-RAS are the following:

- Users may find numerical instability problems during unsteady analyses [45,46];
- The quality of terrain data (in terms of both resolution and accuracy) is essential in creating a detailed and accurate hydraulic model [46];
- In 2D, boundary conditions can only be added at the outer edge of the computation mesh [47];
- Lateral coupling in HEC-RAS 2D is currently a somewhat manual and limited process [46];
- Spatially distributed rainfall cannot be added, and infiltration/evaporation cannot be modeled [47].

ArcMap a component of the ArcGIS suite, was employed to construct flood hazard maps for a 1% exceedance probability for the two scenarios and damage quantification. ArcScene was used to generate 3D maps, and HEC-RAS was utilized to model the flood and incorporate embankments that were absent in the standard Digital Terrain Model [48]. The calibration was carried out by comparing the surface of the flooded zone frominundatii.ro with that obtained by the authors in the first scenario.

The model was also calibrated by adjusting the roughness coefficient (Manning's coefficient) [49] available in HEC-RAS, considering the terrain features such as floodplains, meadows, rocks, sand, and various soil types.

Sensitivity analysis is utilized to determine the variation of the model's output when varying different parameters [50,51]. Simulations with various flow values were carried out to see how the flood band expands. This way, we could compare the flooded surfaces with a probability of return of 2%, 5%, or 10%.

Comparison of this research and the maps provided by inundation.ro show the following:

- The bridge's opening was considered constant for building the maps available on the site (the same as in our Scenario 1);
- On the website (Scenario 1), the water depth ranges from 2 to 5 m. For example, the thalweg has around 4 to 5 m for a 100-year return period %, almost equivalent to the present study, where the depth for 1% is 4 to 4.5 m;
- Upstream, the flooded surfaces are similar in Scenarios 1 and 2 (Figure 6). Downstream, the two flood bands differ due to different lengths of the embankments.

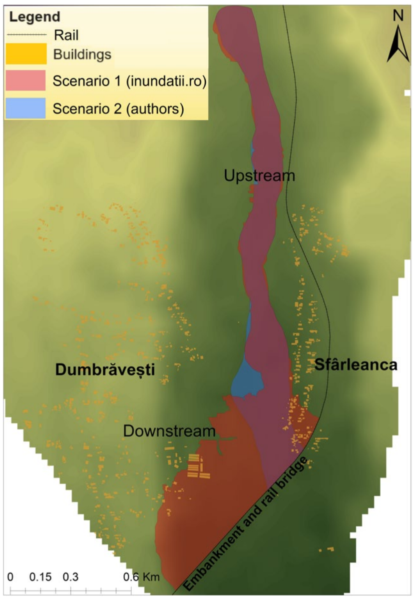

Figure 6. Flooded surfaces in Scenarios 1 and 2.

Besides the two scenarios from Figure 6, for the intermediary case one only short comments will be made in the next chapter.

3. Results and Discussion

Figure 7a contains the flooding simulation in Scenario 1. In this case, the flooded zone is extended especially to the right bank of the Vărbilău River (that flows south towards Dumbrăveşti). This situation is favored by the existence of two embankments that act as a barrier and the small opening of the bridge (only 100 m). Thus, the flow space is reduced in the analyzed case, favoring the flood apparition. Suppose the embankment is shortened and replaced by a bridge with ten pillars (the existing three plus seven new ones for extending the actual length of the bridge). In that case, the situation improves, and the flooded surface is significantly reduced (Figure 7b).

In Scenario 1, there are flooded buildings—houses and annexes—in Dumbrăveşti and Sfârleanca (Figure 8a). In Dumbrăveşti, some greenhouses are also affected [52]. Also, an important surface of agricultural land is covered by water.

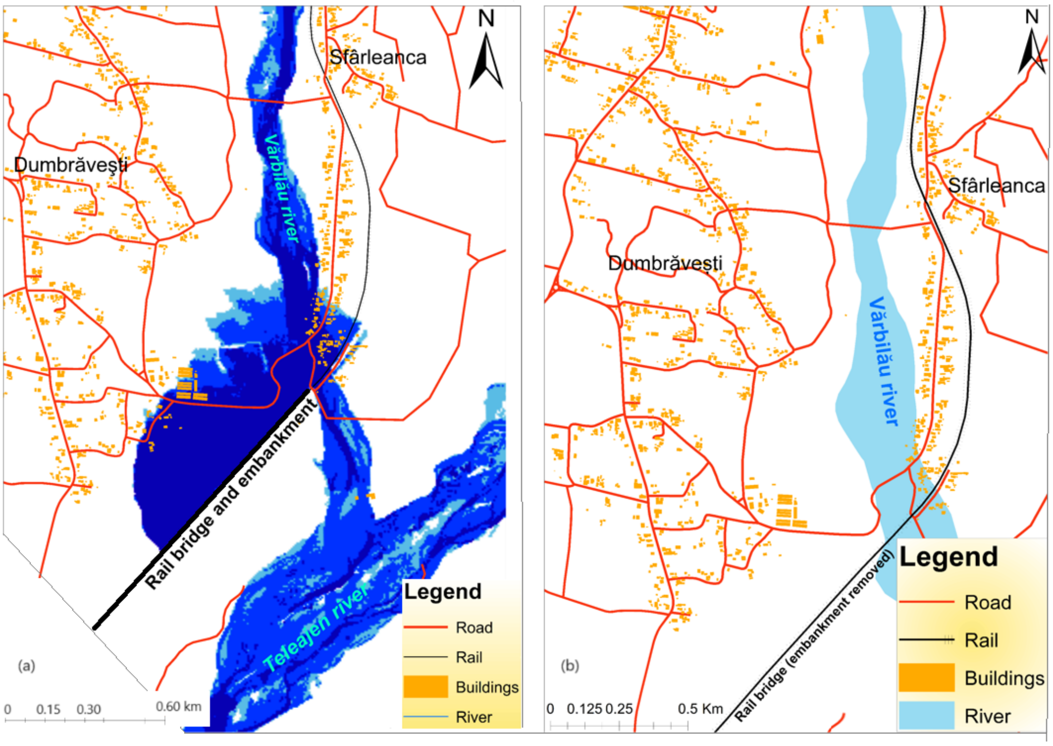

Figure 7. Flooding with 1% probability of exceedance in (**a**) Scenario 1; (**b**) Scenario 2.

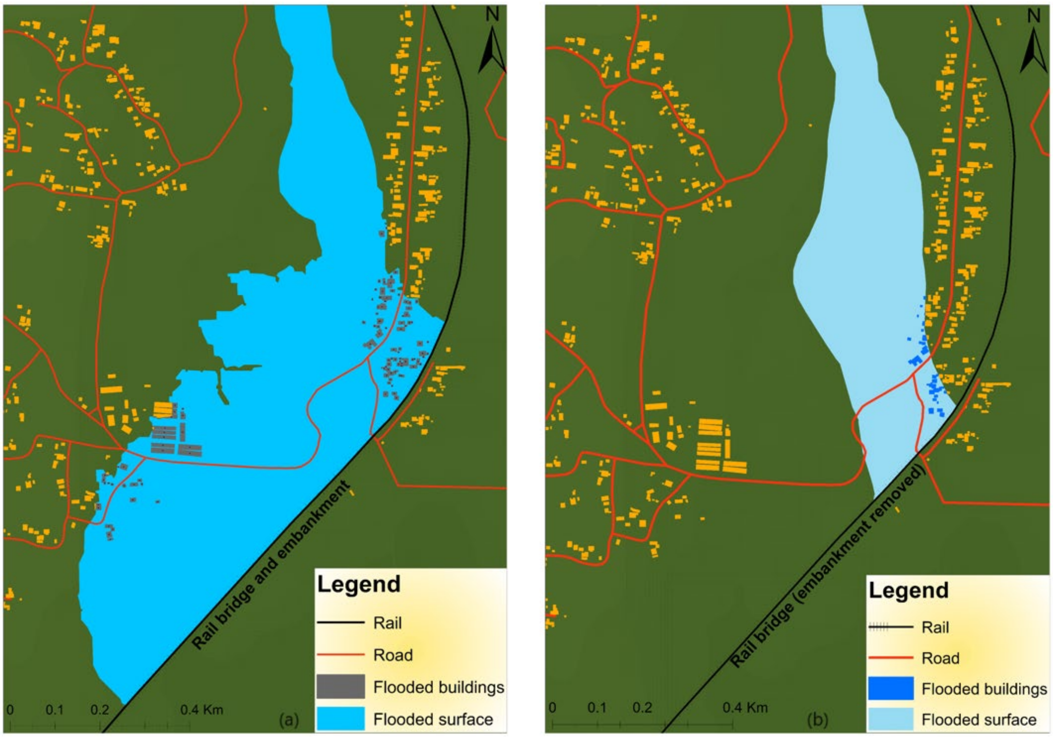

Figure 8. (**a**) Flooded buildings in Scenario 1 and (**b**) Scenario 2 (a bridge with ten pillars).

In Scenario 2, when the bridge is extended, there are no flooded buildings in Dumbrăveşti, whereas in Sfârleanca there are some (Figure 8b), but fewer than in the first situation. In the event of a flood with a probability of exceedance of 1%, Sfârleanca would be isolated because the communal road that connects the locality with Dumbrăveşti is the only access road to the village. Figure 9 shows what happens in the intermediary case.

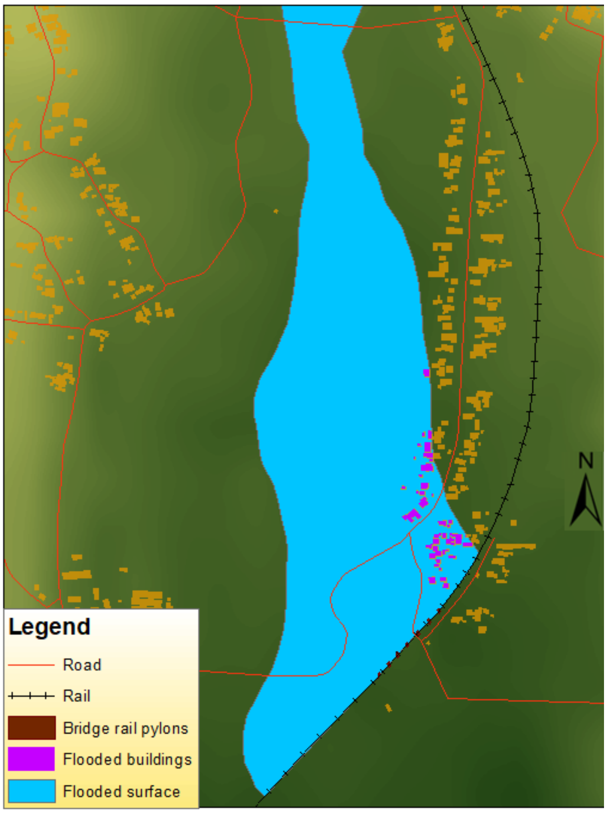

Figure 9. Flooded buildings for the intermediary scenario (a bridge with seven pillars).

In the first scenario, the maximum water depth is 4.2 m, and the mean depth is 1.24 m. The maximum velocity is 4.45 m/s, and the mean is 2 m/s. It was observed that buildings in Sfârleanca are situated in a zone with a velocity that ranges from 1.52 m/s to 4.45 m/s and a water depth from 1.18 to 2.46 m. The higher values are located towards the south (Figure 10). This means that the respective settlements have a higher exposure to flooding.

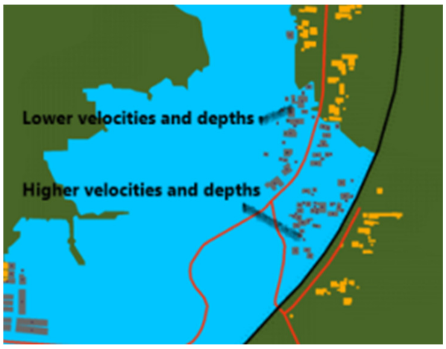

Figure 10. Location of flooded houses in Scenario 1 and distribution of low and high depths and velocities.

Simulations were conducted for a water discharge of 300 m^3 (150 m^3/s) resulting in maximum water depth of 3.69 m (3.11 m), average depths of 1.02 m (0.84 m), a maximum velocity of 3.86 m/s (3.23 m/s), and an average velocity of 1.7 m/s (0.85 m/s).

Table 1 contains the estimated damages. In the first scenario, the number of flooded buildings is 104, much higher than in the second scenario, where only 29 buildings would be flooded [52]. Also, the flooded surface of land would decrease from 0.66 km^2 (the actual case) to only 0.38 km^2 (Scenario 2). More than 10,000 m^2 would be flooded in the current situation, whereas in Scenario 2, the surface is only 1729 m^2.

Table 1. Damage quantification in the case of a flood with an exceedance probability of 1%.

Scenario (450 m^3/s)	1	2	Intermediary
Number of flooded buildings	104	29	46
Surface of flooded buildings (m^2)	10,030	1729	3143
Flooded surface (km^2)	0.66	0.38	0.44
Damages evaluation (EUR)	3,009,000	518,700	942,900

In the intermediary scenario, 46 buildings would be flooded, representing 3143 m^2. The flooded area would be 0.44 km^2. The comparison of the intermediary scenario with the actual one shows that the number of flooded buildings would decrease more than 2.26 times, the surface of the flooded buildings would diminish 3.15 times, and the total flooded surface would be 1.5-times lower in the last case. The situation is much better in the second one compared to the first. Scenario 2 proposes the extension of the bridge to 280 m (ten pillars instead of the existing three) and shortening the embankments to reduce the flooding surface in case of a hazard with a 100-year return period, similar to the findings from [53]. Thus, the active drainage section would increase through a larger opening, and the hazard would diminish significantly.

The evaluation of the economic losses (in EUR) is presented in the last row of Table 1. In the intermediary scenario, the losses are more than 3-times lower than in Scenario 1. In the second scenario, the decrease is 5.5 times with respect to the current situation. The economic benefit of building a bridge with a higher opening must be evaluated after comparing the estimated cost of such a project with the possible loss in the case of a flood.

Figures 11 and 12 represent the 3D maps for Scenarios 1 and 2.

Figure 11. 3D representation of the current situation for a flood with a 100-year return period: (**a**) view from the south of the flooded surface, embankments, existing bridge, and affected buildings-in red; (**b**) view from the north on the 3-pillar bridge.

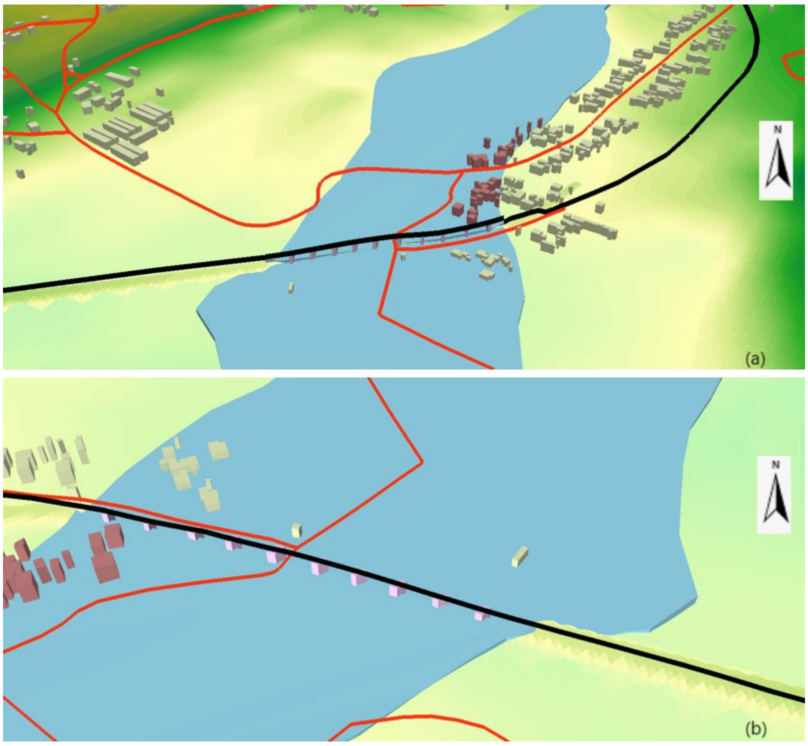

Figure 12. 3D representation of the hypothetical situation for a flood with an exceedance probability of 1%. (**a**) View from the south of the flooded surface, embankments, extended bridge, and affected buildings with red; (**b**) zoom in from the northwest on the 10-pillar bridge.

An aspect that deserves to be discussed in the flood risk evaluation is the influence of different factors on the flood's apparition and propagation. In this article, we did not consider all of them (like climate, vegetation, lithology, slope, soil type, land use, profile curvature, etc.). Each factor and its relative importance with respect to the others responsible for such a hazard must be assessed after a rigorous study of the catchment characteristics. Such research was performed for the Vărbilău basin considering the slope, curvature, lithology, direction of the repetitive torrential rains, directions of the flat zones, precipitation, convergence index, configuration of sub-basins, soil, and land use [29]. Based on the simulated floods, the susceptibility in the region has also been studied after computing a flood potential index (FPI). We also [31] proposed an extended FPI calculated based on 12 themes (slope, aspect, hypsometry, convergence index, drainage density, topographic wetness index, profile curvature, catchment shape index, precipitation, soil, lithology, and land use) for evaluating the flood impact in the same zone. A weight was attached to each thematic layer using a multicriteria selection procedure and the resulting flood map was cross-validated using the maps available at inundatii.ro (including the flood zones—simulated for a return period of 100 years). The findings from [29,31] indicated a highly susceptible area to flooding, Dumbrăvești. Still, the impact of the embankment built in Sfârleanca (on the Vărbilău River) on the flood hazard was never assessed.

Given that a certain problem can be approached in different ways and there is no 'best method', the present research proposed a solution for a practical problem, filling a gap in the knowledge related to the study zone. The results of this study confirm the findings of Maione et al. [19], showing the significant impact of the embankment's existence on the flooding apparition. It is in agreement with the research of Ochsner et al. [18] that emphasized the necessity of careful analysis before building the railway infrastructure such that it does not contribute to producing disasters. Contrary to Leckowska's conclusions [20] that presented the benefit of the embankments' existence, one may remark the negative impact of the bridge and embankment on the research zone due to its inappropriate design. Moreover, our results are in concordance with those of Szymczak et al. [17], showing that the bridge of Dumbrăveşti can represent a vulnerability point if the embankment is broken during a flooding event, which could have catastrophic effects on the population downstream.

This research shows the importance of considering elements like embankments and levees in models for accurately simulating and forecasting catastrophic hydrological events, as it was also remarked by Calamak [21].

To expand this research, an index can be developed taking into account the existing index FPI [29,31] and also creating a new value based on the flood surface, depth, velocity, proximity from the flooded area, and road accessibility for emergency units. This can show the exposure of buildings to flooding and how vulnerable they are.

4. Conclusions

This study analyzed the risk of flooding in the Dumbrăveşti area located on the Vărbilău River catchment (Romania). It addresses the following question: Does the rail embankment built in the Sfârleanca village favor the flood apparition? To answer this question, we built flood hazard maps for three scenarios, using the capabilities of ArcGIS 10.2.2, HEC-RAS 6.2, HEC GeoRAS, and the RAS Mapper extension.

Since the investigation provided an affirmative answer, we suggested possible solutions to reduce the flood impact on the life and economic activity of the population in the Vărbilău catchment. This study's results agree with those of other scientists, who show that anthropic constructions can favor the apparition and propagation of hazards.

Here are the main findings of the research.

- Simulation of the flooding apparition with an exceedance probability of 1% indicates that the study is affected by floods in the actual conditions of the presence of a bridge over the Vărbilău River with an opening of 100 m and a rail embankment;
- Simulation with the same return period (100 years) in two scenarios (Scenario 2 and the intermediary one) indicates that enlarging the bridge opening will result in a significant diminishing of the hazard effects;
- In Scenario 2 (a bridge with 10 pillars and an opening of 280 m), the number of flooded buildings would be about 3.8-times lower, the surface of flooded buildings would be 5.80-times lower, and the flooded land surface would be about 1.73-times lower than in Scenario 1 (actual situation);
- In the intermediary scenario (a bridge with seven pillars and an opening of 200 m), the number of flooded buildings and their affected surface are 2.26 and 3.15 times lower, respectively;
- In monetary terms, the damages will be 5.5 (3.19)-times lower in Scenario 1 (intermediary scenario) than in the actual situation;
- Enlarging the bridge opening and shortening the embankment will significantly reduce the surfaces and buildings affected in the case of a flood with a 100-year return period. Still, the opening of the bridge and the optimal number of pillars to be built must be determined by the structural engineers and bridge designers, taking into account not only the technical feasibility but also the economic efficiency that must be deeper investigated in the future.

From a practical viewpoint, the same methodology can be applied to other watersheds with the same characteristics, such as shape (elongated), vegetation, and geographic characteristics. This investigation also fills a gap in the knowledge related to the flooding extent in the Vărbilău basin not covered by other research and that can be used by the authorities for preparing action plans in the case of flood or even to eliminate the risk.

It was shown that the bridge opening influences the extent of the flooded surfaces (the higher the opening, the lower the impact on the structure is), but further research will attempt to build a mathematical model, which describes the correlation between the surface of the flooded zone (as an explained variable) on some physical and geographical factors that characterize the study area and the water flow characteristics.

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