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Article

A GIS-Based Model for Flood Shelter Locations and Pedestrian Evacuation Scenarios in a Rural Mountain Catchment in Romania

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Abstract: Shelter and evacuation-route planning represents the core of safe and efficient flood management. The methodology detailed in the present study includes an analysis of the suitability of areas for evacuation points, as well as an assessment of the degree of accessibility of those points during evacuation scenarios in small mountainous drainage basins. The analysis is based on water distribution and water-flow increase during the historic 2010 flooding of the Sucevița basin, when the discharge increased in merely 40 min. The proposed model considers the viability of pedestrian evacuation of the local population, as well as the degree of accessibility of nearby evacuation points. Thus, according to the results obtained for the mountain-based locality, 91.68% of the vulnerable population can be evacuated in 30 min, while 8.32% of the inhabitants require up to 54 min to reach an evacuation point. In the case of Marginea, located in a plateau area, the population under analysis can reach one of the evacuation points in approximately 36 min. The present study can support the implementation of non-structural flood management measures and decrease casualties through evacuation optimization.

Keywords: flood hazard; spatial analysis; evacuation; vulnerability; shelter location

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1. Introduction

Globally, natural hazards are expected to increase in frequency and intensity due to climate change, spontaneous urbanization, and population growth in areas prone to extreme phenomena [1,2]. The data from recent studies suggest that floods are the most widespread hydro-meteorological hazard, causing numerous casualties and much damage [3,4].

Flood risk management represents a new approach to the assessment of the vulnerability of communities, incorporating structural and non-structural measures to reduce damage [5]. The flood-protection measures currently in place were based on the assumption of a stationary climate, which was compromised by anthropogenic disturbances from river basins and climate change [6]. Over the past decades, the damage-reduction policies regarding floods have been, in most European Union countries, based on a holistic approach to hazard management. Structural measures have been replaced by non-structural measures (related to insurance, warning and evacuation systems, and recovery measures) due to the relatively low costs involved [7,8].

The management of emergency situations triggered by potentially destructive events involves a series of policies and procedures, grouped into four stages: mitigation, preparedness, response, and recovery [9,10]. Spatial analysis techniques can be used in the management of any stage of the hazard by identifying areas with increased flooding potential [11,12], identifying suitable areas for evacuation points [13], and planning evacuation in case of emergency [14–16].

The development of evacuation plans is a complex process that requires the identification of suitable areas for evacuation, as well as correlating the data sets on which the management of emergency situations triggered by floods is based [17]. Establishing shelter locations is considered a prerequisite in the evacuation planning process. The identification of evacuation shelters for mass evacuation should consider environmental conditions, means of transportation, and access to the facility [13].

When an event with a significant impact on communities occurs, emergency intervention plays a crucial role in responding to and reducing damage. Emergency plans must include the roles and responsibilities of the parties involved, as well as detailed information regarding population evacuation, shelter locations, and the potential impact on infrastructure, information that is often missing [18].

The evacuation of the local population is highly time-sensitive and focuses on moving the inhabitants from hazard-prone areas as quickly as possible and guiding them towards safe and accessible locations [19]. Based on the means of transportation (by car, on foot, by bus) and the type of natural hazard (flood, earthquake, tsunami, etc.), one of two types of evacuation may prove necessary, namely self-evacuation or assisted evacuation [20]. The evacuation of the population can be divided into two categories based on the phenomenon: small-scale evacuation and regional evacuation [21]. Small-scale evacuation is the emergency evacuation of an area that is suddenly and violently affected by a particular hazard, such as in the case of a flash flood. In urban areas, shelters are located in safe areas which facilitate evacuation, such as sports halls, schools, and theatres [13]. In mountainous localities, shelter locations are established based on the suitability of the terrain and local conditions [22], and small-scale evacuations are carried out on foot [23].

Floods pose a significant risk due to their severe consequences. Romania has had at least five catastrophic flooding events over the past decade, the most devastating being in 2008 and 2010 [24]. These flood events were caused by significant levels of rainfall, which generated the recording of discharge values exceeding historical thresholds. These values, correlated with massive deforestation and the decision to build in unsuitable areas prone to flooding [25], have led to casualties and damage unprecedented in Romania [26]. It is, therefore, imperative to devise and apply a model for the evacuation of the population.

In Romania, population evacuation scenarios are found in a small number of plans that are specifically applied to large cities. Several evacuation scenarios have been proposed, and shelter locations for evacuees have been identified, in case of earthquakes, floods, and terrorist attacks in the Romanian capital, Bucharest [27]. Earthquake evacuation models have also been suggested for the city of Iași [28,29]. Nicoară et al. [30,31] have devised plans with evacuation points for various localities of Cluj County.

Multiple criteria evaluation (MCE) is a widely used method in natural hazard mapping analysis and is an emerging approach. Numerous studies have used GIS-based MCE to assess extreme events by analyzing the factors that control or determine how they occur [32,33]. The GIS-MCE technique facilitates geospatial data processing and analyses decision problems [13], making it one of the most valuable methods in land-use planning.

The main objective of the present paper is to assess the spatial distribution of flood shelters and propose evacuation scenarios by identifying optimal routes and travel times to reduce vulnerability in the rural mountain basin. The steps involved are divided as follows: (1) determining the optimal factors to be considered when assessing the suitability of the terrain for evacuation points; (2) identifying potential shelter locations and assessing their spatial distribution in relation to flood risk; (3) proposing an evacuation model based on optimal routes and evacuation timing; and (4) estimating the number of individuals each shelter is designed for and their actual capacity.

For European Union member states, Directive 2007/60/CE establishes public policies aimed at reducing the impact of floods on the development of human communities [34]. A study such as the present one is necessary given that in developing countries, evacuation management plans are not applied at the local level due to a lack of dedicated funds and social education.

The main contribution brought by the present paper is represented by an accessibility evaluation model based on the spatial distribution of shelter locations of the location-allocation type. The proposed model is developed on a micro scale for local administrative units. The identification of evacuation routes and the assessment of shelter locations are imperative for the authorities involved in the management of major hydrological events.

The novelty of this paper is the combination of accessibility assessment methods by integrating spatial distribution of the population concerning the shelter locations, for assessing and reducing vulnerability to natural disasters in rural communities. The contribution of this study is that the proposed approach to selecting evacuation points includes a set of parameters adapted to local conditions. Through the proposed models, it is possible to identify areas requiring emergency intervention.

The relevance of using such a model is to show its applicability since the data used are accessible by the authorities. The model has the possibility to be extended to all settlements with flood vulnerability and can be used as a tool in the development of new plans and strategies.

2. Materials and Methods

The present study proposes an assessment and selection framework for shelter locations designed for mass evacuation, as well as evacuation routes and the length of time involved. It includes an evaluation of the suitability of the terrain for shelter locations using the multiple criteria evaluation (MCE) method, which is an essential tool in decision analysis [13]. Determining shelter locations and their distribution is a precondition in population evacuation management. Instructing the population on evacuation routes may increase the resilience of communities and decrease their vulnerability to hazards [14] since an informed individual can be considered a rescued individual.

2.1. Study Area

The analysis conducted in the present study focuses on the evacuation of the inhabitants of several rural localities in the northeastern part of Romania, within the Sucevița drainage basin, at the contact between mountain and plateau. The favourable conditions deriving from physio-geographical factors have led to various human settlements along the river network and the plateau area of the Sucevița basin (Figure 1). The expansion of anthropic activities in the proximity of rivers has led to damage over time, triggering flood defense works and the necessity for non-structural measures and evacuation plans.

According to the territorial distribution of settlements, there is a dependence on the favourability given by the natural environment, which is a support for their development: slope relief, exposure and orientation of slopes, soils, and large areas covered by forests (58.22%) and the hydrographic network [35].

In order to carry out simulations on the evacuation of the population, two human settlements in the Sucevița river basin were identified due to differences in terms of relief conditions and flood distribution: Sucevița and Marginea. Sucevița, with the related village Voivodeasa is located in a higher area, with a longitudinal distribution of the built area on both sides of the Sucevița river, being limited by slopes, with a total area of 92.3 km^2, but with a built-up area of only 8.32% (7.73 km^2). Marginea village is located in a plateau area, with an extension in the major riverbed of Sucevița at the contact between the mountain-plateau area, with a built-up area of 18.6% of the total surface area.

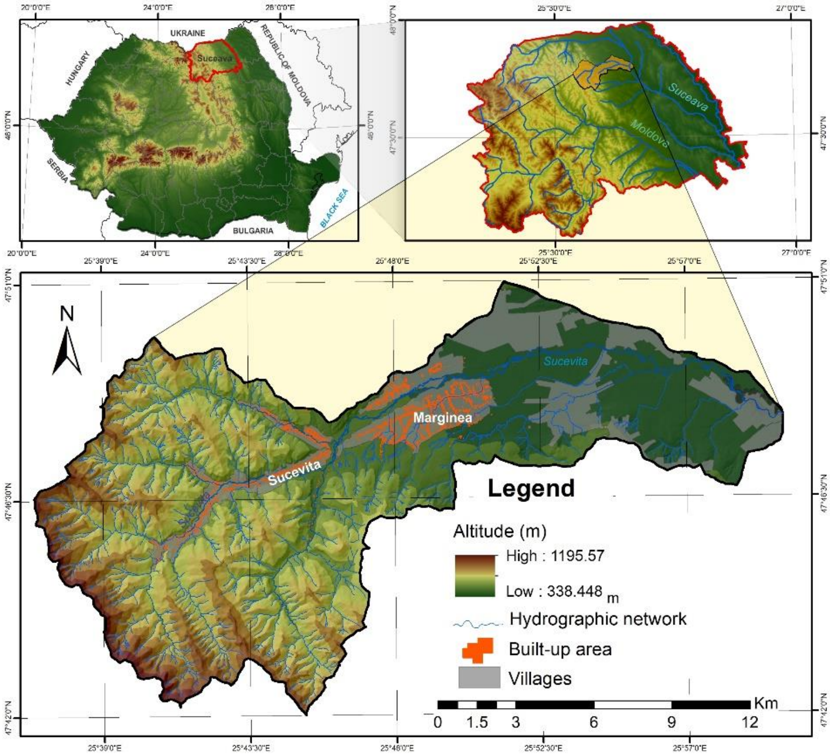

Figure 1. Study area—Sucevița river basin.

2.2. Data Used

In this study, an analysis is carried out on identifying evacuation areas and proposing evacuation scenarios for the population within communities in the mountain-plateau contact area. This analysis considers the spatial assessment of the distribution of flood shelters by applying a methodology based on land suitability.

In the analysis of natural factors, the digital elevation model was used at a spatial resolution of 5 × 5 m per pixel achieved by vectoring 1:5000 topographical plans. Based on the raster obtained, thematic layers related to altitude, slope, and slope orientation were generated. The environmental factor considered in this analysis is the land use extracted from the Copernicus database [36], from the Corine Land Cover set for 2018 (the latest year with available data). The hydrographic network was vectorised on 1:5000 topographic plans and updated on orthophotoplans.

In order to conceive the evacuation scenarios, the vector layers with the road network were used, which were digitised using 2012 orthophotoplans (made available by the National Agency for Cadastre and Real Estate Advertising) in a line layer and classified according to road type.

Scenario simulation was based on the spatial distribution of the 2010 historical flood discharge event, when the duration of the water level rise was 40 min (from 21.40 to 22.00, according to the hydrograph) from a flow of 5.06 m^3/s to 84 m^3/s (Figure 2) [36].

To propose evacuation scenarios for the population, complex databases on the dwellings of the resident population are required. Thus, after vectoring the buildings located near the potential flood areas, field surveys were carried out to collect data on the number of people per dwelling. The presence of buildings and their extensions facilitates the maintenance of flooding at high levels, as it does not allow water to drain over a large area.

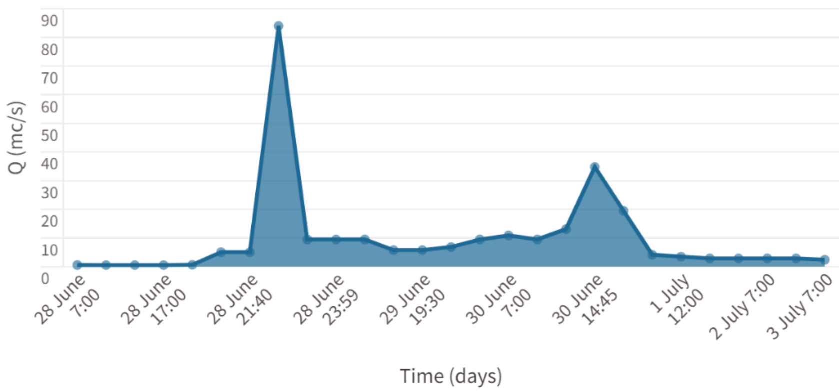

Figure 2. Hydrograph of the 2010 flood event on the Suceviţa river.

The population included in the analysis located in the vulnerable area is 1724 persons from Sucevița village (60.2% of the total population) and 2593 from Marginea village (representing 23.22% of the total population of 11,160 persons). The areas from which the data were taken were selected based on the floodplain boundary and the buffers made on the basis of the hydrographic network. Spatial data on floods that occurred in 2008 and 2010 on Sucevita river tributaries were also integrated into the analysis.

Areas susceptible to flooding were marked as traffic restriction barriers to force a redirect around them [37]. These were established following the stages of fieldwork carried out during the rainfall events of 2008 and 2010 since both localities have a longitudinal distribution of the river's course, and the hydrographic network was affected. These hydrological events are the most representative in terms of recorded water flow (467 m^3/s) and time of water level rise in the study area.

2.3. Methodology

In order to optimise evacuation solutions for people in the event of potentially destructive phenomena, it is necessary to know the evacuation destinations (facilities) and determine the minimum evacuation time, such as the routes (paths) assigned to all destinations.

2.3.1. Suitability of Terrain for Shelter Locations

Evacuation shelters are the most important means of protecting people in flood-prone areas and evacuation planning is a decisive factor in reducing vulnerability and increasing resilience. Shelter location and evacuation route are interdependent [13].

Evacuation areas and population evacuation planning require an efficient and optimal spread and distribution between shelter and population [16]. Thus, in the analysis of flood emergency management, the first step is to identify favourable areas for the location of evacuation shelters. These areas must comply with a series of specific characteristics: small slopes, sunny slopes, positioning near the built-up area, on arable land, or pastures [30].

The suitability of the terrain for the placement of evacuation zones was achieved by including in the analysis six factors that may influence or restrict their positioning. The factors were integrated into the multi-criteria analysis and represented in thematic maps: i. three morphometric factors (elevation, slope, and slope orientation) which were generated from the 1:5000 digital elevation model; ii. one environmental factor (land use) generated from Corine Land Cover 2018; iii. a restrictiveness factor (distance from the built-up area) derived by creating 100, 200, and 300 m buffers from the main hydrographic network; and iv. a proximity factor (distance from the built-up area) obtained by creating buffer zones every 100 m (Figure 3).

For each factor included in the multi-criteria analysis, a thematic raster layer was generated, which was reclassified by assigning weighted scores from 1 to 5 (1 for areas with low favourability and 5 for areas favourable to the location of population evacuation points) (Table 1). The weighted scores were given according to the influence of the factor in the location of evacuation points (favourable or restrictive).

The thematic layers obtained from the weighted score and reclassification were integrated into ArcGis Pro 3.0.0 (Berkeley, California) software by applying the weighted sum function. Using the final layer obtained on the terrain`s natural favourability, favourable evacuation points were established for Marginea and Sucevita villages.

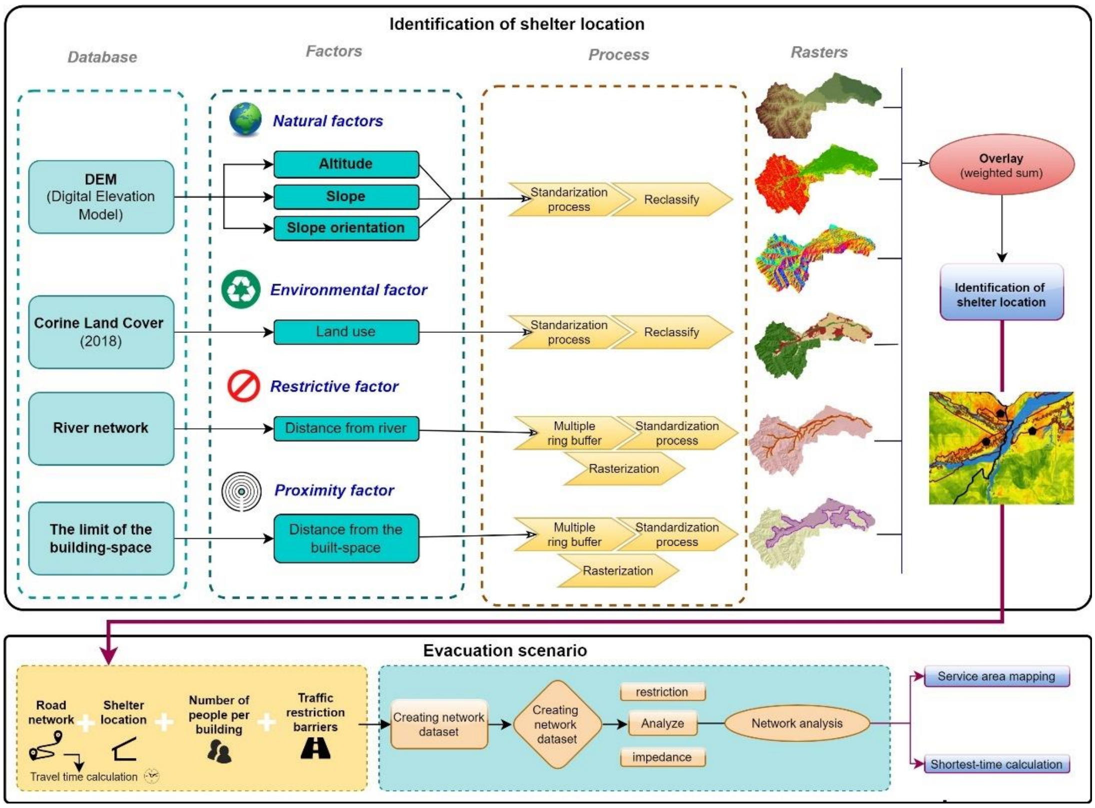

Figure 3. Flowchart.

Table 1. Weight assessment for each factor included in the analysis.

Factor	Class	Evaluation Rate	Justification
Altitude	<350 m	1	Altitude values between 350 and 650 m have been assigned a rating between 3 and 5, being favourable for the positioning of an evacuation point. The 300 m range is justified by the positioning of the localities within the different relief units.
	350–400	3	
	400–450	5	
	450–500	4	
	500–550	3	
	550–650	3	
	650–750	2	
	750–850	1	
	950–950	1	
	>950 m	1	
Slope (degrees)	<2.5	4	Areas with relatively low slopes are favourable for locating evacuation points, and they were given weighted scores between 4 and 5. Evacuation points are difficult to locate in areas with a higher slope.
	2.5–5	5	
	5–7.5	4	
	7.5–10	3	
	10–12.5	2	

	12.5–15	2	
	>15°	1	
Orientation of slopes	N-NE	1	Weighted scores were given according to the sunshine duration during the day [38]
	E-NE	2	
	E-SE	3	
	S-SE	5	
	S-SW	5	
	W-SW	3	
	W-NW	2	
	N-NW	1	
Land use	Built space	3	Arable land and complex crop areas are considered favourable areas due to the openness and low slope, while the mountain area pastures are considered favourable areas. Forests and watercourses are restrictive for locating evacuation points.
	Arable land + complex crop areas	5	
	Secondary pastures	4	
	Forests	1	
	Watercourses	1	
Distance from the river	<100	1	Flooding areas near the river are a restrictive factor for positioning evacuation points.
	100–200	2	
	200–300	3	
	300–400	4	
	400–500	5	
Distance from built areas	<100	5	Evacuation points must be located near the built-up area to reduce the time and cost of transporting the individuals.
	100–200	4	
	200–300	3	
	300–400	2	
	>500	1	

In order to achieve the layer on the favourability of the land in shelter locations, the following equation was applied:

$$F_{sl} = \sum_{i=1}^{n}(F_i \times Ev_i)$$

where:

Fsl—favourability for shelter locations,
F_i—factors taken into analysis,
Ev_i—evaluation rate for each factor from Table 1.

2.3.2. Pedestrian Evacuation

Disaster management plans aim to organise the safe evacuation of the population from areas likely to be affected by a significant event [39], planning the evacuation process by determining the optimal time and routes that each person can travel from the affected area to the shelter area [40]. Thus, after identifying the areas where evacuation shelters can be located, accessibility within the evacuation scenarios is analysed from two points of view: (i) coverage of the area by evacuation points over time intervals; (ii) identification of the shortest time needed to travel the distance by the population to one of the evacuation points. This tool is helpful to the competent authorities for training the population and accepting the risk to which individuals are exposed by informing and organising how to evacuate, aiming to relieve bottlenecks in crises.

The study area comprises rural communities distributed across the hydrographic network. This type of disposition is observed in most localities in Romania, especially in the mountain area, with a tendency for territorial development in areas with flooding potential that causes an increase in anthropic pressure.

At the base of the model is a network of interconnected lines of nodes (points) represented by the road network. When performing a road network analysis, it is essential to use detailed and accurate data to achieve a representative result [31,41]. In addition, the routes were determined in directions that do not intersect the river network or floodplains.

The road network dataset was developed based on several attributes (such as: (i) road category: national, county, local, operational; (ii) road surface: paved, unpaved; (iii) road sector type: within the built-up area, outside the built-up area; (iv) road section length), which can condition the travel speed of the persons evacuated. Regarding road quality, a high percentage of unpaved roads can be observed (62.2% of the total road network) (Figure 4). This percentage is due to unpaved local roads (39%) and operational roads (both for agricultural and logging purposes).

Figure 4. Quality of the road network in Sucevița and Marginea villages.

Asphalt roads account for only 37.8% of the total, and the highest share corresponds to the national road (DN17A), which crosses both settlements from east to west.

For running the evacuation scenarios, the time travelled on each road segment within the network was calculated according to the distance travelled from the dwelling to the evacuation point (m) and the travel speed (m/min). Thus, in order to perform this type of analysis, it is essential to define an 'impedance' attribute given by the speed of movement and the calculation of the time (in minutes) for the movement of individuals.

To simulate pedestrian traffic, the Network Analyst extension of ArcGis Pro was used. The use of cars or other vehicles is not recommended in case of evacuation, not only because it makes evacuation more difficult and obstructs access routes, but especially because it represents another hazard for pedestrians [14].

To determine the speed of travel, the walking speed of a human was taken into account. A number of authors have addressed this issue in other analyses and proposed models based on different walking speeds. Post et al. [42] performed an assessment of the population's immediate response capacity to tsunamis and assessed the travel speed of the population between 1.7 and 2.8 m/s. Sugimoto [43] and Gonzales-Rinacho [44] classified the population by the speed of movement into a rapid population associated with the adult population, with a travel speed of 1 m/s, and a slow population associated with the elderly, children, and persons with disabilities, with a travel speed of 0.7 m/s.

This study used an average of 1.4 m/s, which is considered a normal adult speed. The same value is used in studies on evacuation and identification of optimal routes in cases of natural hazards [14,45]. The speed of travel may vary depending on the age and motor capacity of each person. The elderly, people with locomotor problems, and children will have a lower travel speed between 0.4 and 1.2 m/s. The maximum speed of 1.6 m/s is in the age category of 20–30 years [46]. In the case of road segments with slopes above 15%, the speed can be reduced to 0.7 m/s [14].

3. Results

Following the multi-criteria analysis, the final raster with the terrain suitability for evacuation point locations was obtained. Thus, evacuation points were established for the two settlements located within the Sucevița basin: Sucevița and Marginea villages.

3.1. Spatial Assessment of Shelter Location

According to Directive 2007/60/EC [47], the Member States of the European Union must propose appropriate measures to reduce flood risk through management plans based on the population`s prevention, protection, and preparedness.

In Romania, each settlement has an obligation to approve a Local Protection Plan against floods, ice, accidents to hydro-technical constructions, and accidental pollution of the hydro-technical system [48] and the analysis of the villages under review shows that they have only one reception center for evacuees, corresponding to the local council headquarters, structures affected by the previous flood events. Based on this argument, in order to improve emergency management, favourable reception areas for evacuated persons were identified, and an analysis was carried out on how to evacuate, and the time needed for this process.

Following this analysis, five evacuation areas of the population were identified and proposed for Sucevița village, one located in the village of Voivodeasa and the other four in the village of Suceviţa. Evacuation points are distributed longitudinally on both sides of the river and tributaries, ensuring the safe evacuation of persons. In the case of the second village, Marginea, five locations were identified, distributed in the area of the commune, ensuring the safe evacuation of the population (Figure 5).

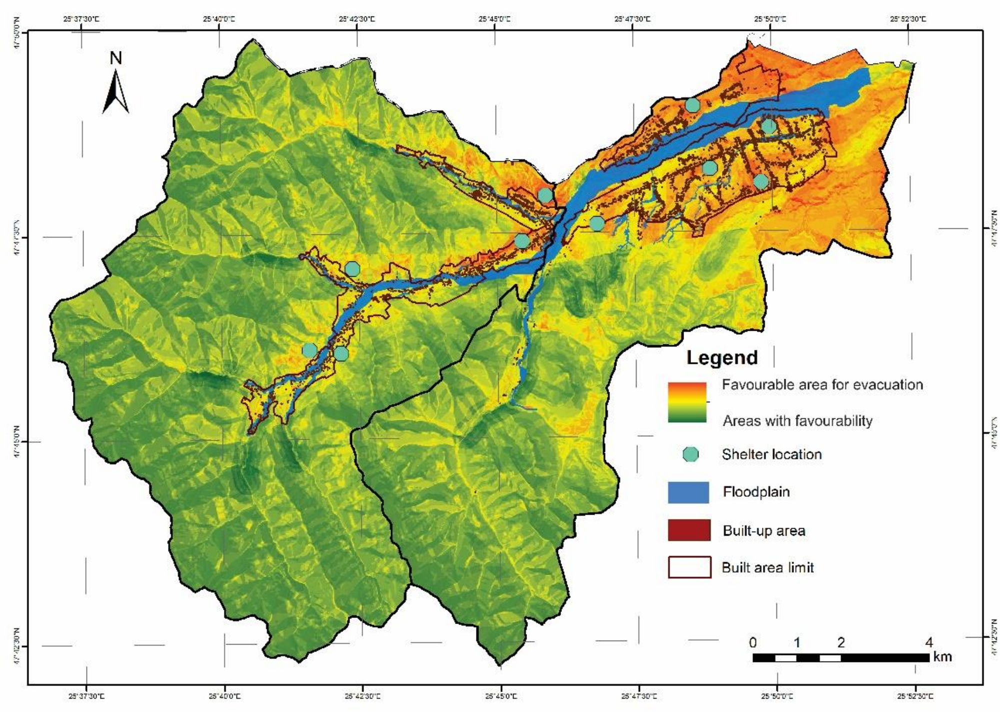

Figure 5. Population evacuation points established according to land favourability.

The spatial distribution of shelters is vital for ensuring access as quickly as possible during the evacuation process because they must be at a reasonable distance from the starting point, be close to the built-up area, and be easily accessible to the population.

3.2. Evacuation Routes Simulations

After determining the distribution of potential flood shelters, the next step is to assess the accessibility of the population to these shelters using spatial modelling.

Based on the results of a previous study on the vulnerability of buildings and the population in this area, where [24] applies a methodology to identify the degree of vulnerability, taking into account several indicators regarding the building material used, the condition of the buildings, and their destination, this paper aimed to calculate the distance and the area served by the evacuation points.

Using the transport network and population data, the time and distance travelled by each pedestrian to the evacuation points were determined, and estimates were made for the capacity of the areas intended to receive the evacuated population.

Network Analyst was used to build the network and run analyses to assess spatial accessibility [49]. To identify areas encompassing all accessible roads for a given facility (shelter location) with a certain impedance (travel speed), a service area analysis was used, which provides information on the distance and evacuation time between households and shelters.

For Sucevița village, located in the mountain area, in terms of facility coverage, it was calculated that 93.13% of the population from the dwellings integrated into this model could be evacuated within 30 min (Figure 6).

As a result of the intersection between the coverage areas with this service and the population analysed, it was identified that 365 persons (21.18%) can be evacuated within 10 min of the activation of the alert and can reach one of the five established points.

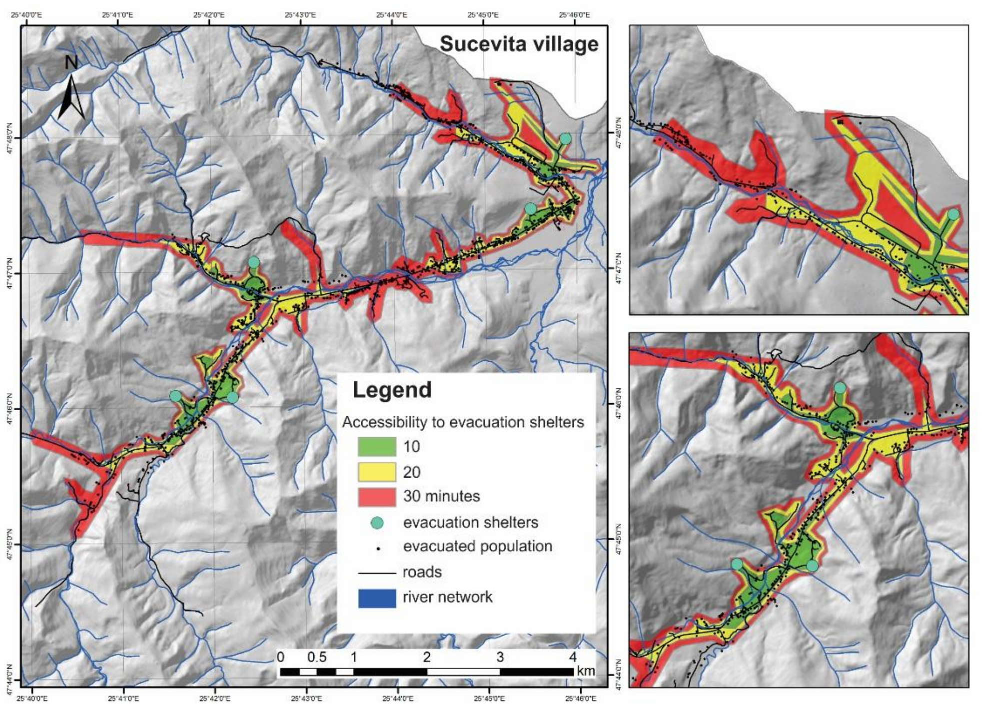

Figure 6. Coverage areas with evacuation service for Sucevița village.

In the next 20 min, 49.30% of the population under review can be evacuated, and by 30 min, another 509 people (29.52%) of 239 dwellings can be evacuated (Figure 7).

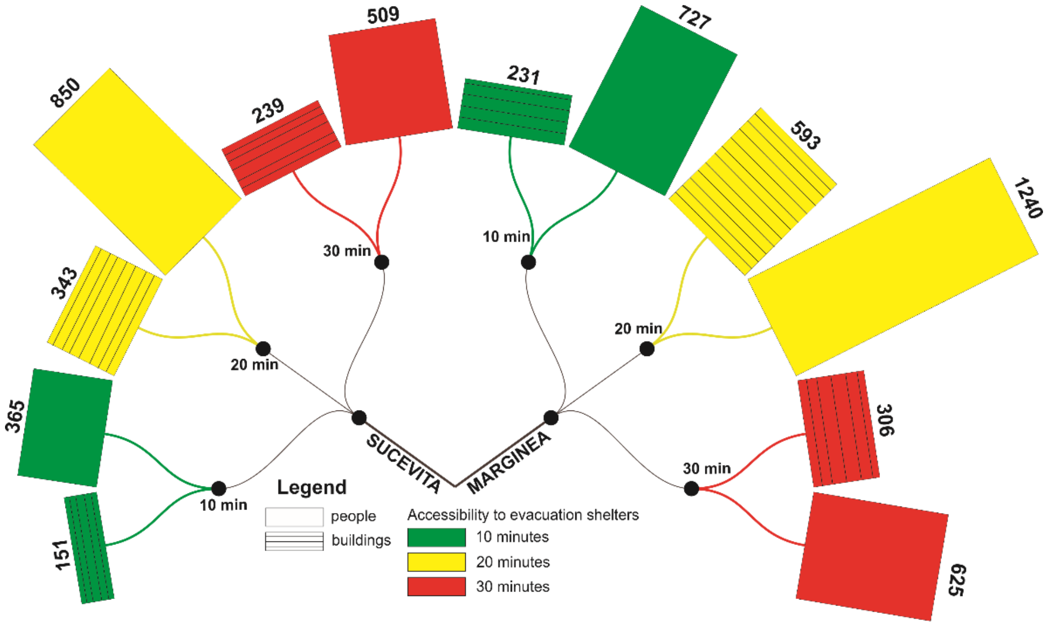

Figure 7. Number of people and dwellings evacuated in 10, 20, and 30 min from the area under review.

For Marginea village, located in a plateau area with an extended distribution of the built-up space given by slopes and low altitudes, the analysis of results regarding the areas of coverage of the evacuation service shows that 727 people (representing 28% of the population integrated into the analysis) can reach one of the five evacuation points in about 10 min after the onset of the state of emergency.

In 20 min, 1240 people (47.83%) of 593 dwellings can be evacuated, and in 30 min, another 625 people (24.13%) of 306 dwellings have the possibility to reach one of the evacuation points (Figure 7 and Figure 8).

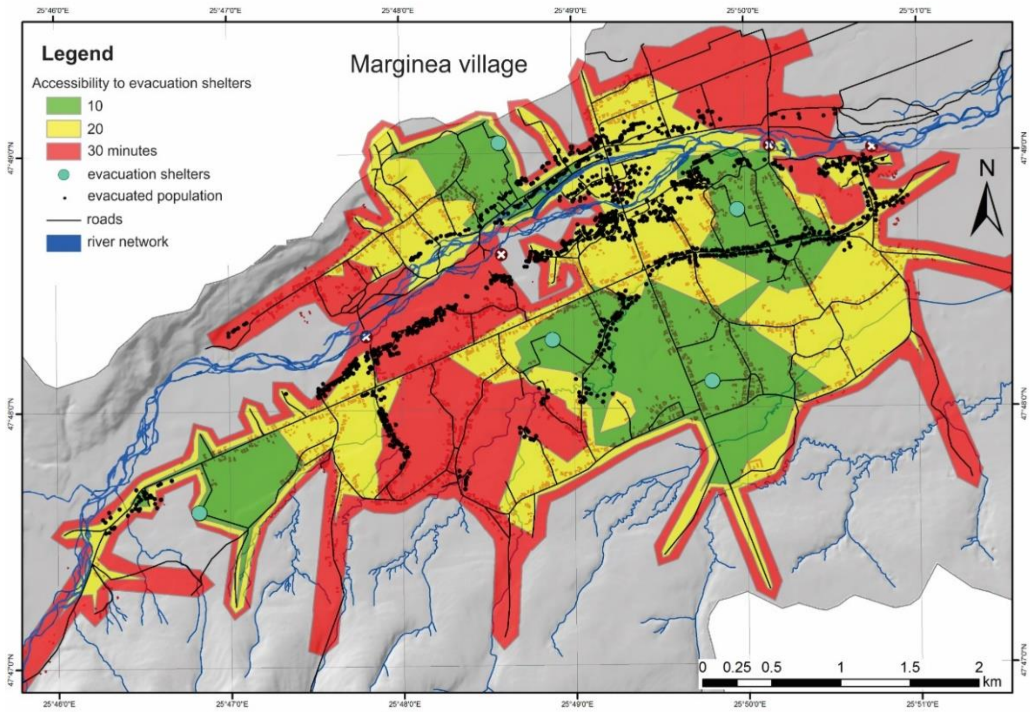

Figure 8. Coverage areas with evacuation service for Marginea village.

The next step in the analysis is to identify optimal pathways to the nearest population evacuation point using the closest facility function. In this type of analysis, evacuation points (facilities), population (incidents), and impedance (travel time of the population from the dwellings to evacuation points, calculated for the movement of pedestrians with an average speed of 5 km/h) were integrated. The results show the optimal evacuation routes from each incident to a facility for each side of the river, determine the accessibility of individuals to evacuation points, and provide information on the number of evacuates for each reception point (Figure 9).

Regarding the accessibility of the population, in Sucevița village, 673 persons (36.39%) are less than 1 km away from an evacuation area, and this distance can be travelled in about 10 min (Table 2).

During the next 5 min after the alert is declared, 393 people from 174 dwellings can be evacuated by crossing an average distance of 1500 m from one of the above shelters. Between 15 and 25 min, another 415 people can be evacuated, who travel a distance of up to 2,500 m. In the next 10 min (25–35 min from the onset of the state of alert), 214 people can reach one of the evacuation points, and 8.32% of the people under review in Sucevița village need up to 54 min to evacuate their dwellings and reach a shelter.

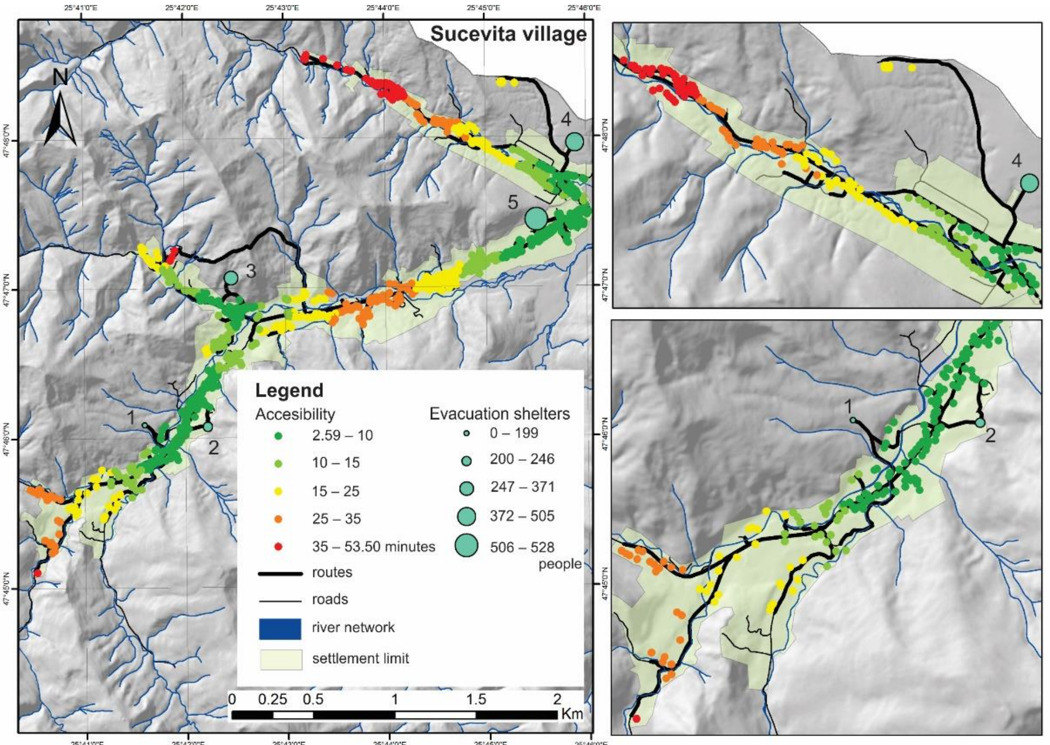

Figure 9. Optimal evacuation routes and accessibility of the population for Sucevița village.

Table 2. Summary table on the time required to travel distances to evacuation areas for Sucevița village.

Time to Travel the Distance (Minutes)	Number of Persons	Dwellings
2.59–10	673	277
10–15	393	174
15–25	415	188
25–35	214	109
35–53.50	154	49

The results also help to estimate the capacities needed for the evacuation reception points and the time needed for people to reach these points (Table 3). Thus, the second point considered is the most favourable regarding distances and time travelled because 246 people can arrive at this shelter (13%) in about 14 min.

Table 3. Capacity of evacuation points in Sucevița village.

Evacuation Zone ID	Persons	Travel Time (Min)
1	199	3.04–34.46
2	246	3.17–14.07
3	371	4.71–29.06
4	528	2.59–29.06
5	505	5.70–53.50

The only evacuation point proposed on the territory of Voivodeasa village (point 4) can accommodate 505 people from 202 dwellings. However, the evacuation of these dwellings can be conducted in about 50 min, being the most difficult point to reach.

Applying this model to the Marginea village, it was determined that in approximately 36 min, the areas at risk could be evacuated (Figure 10). The analysis is based on a network road. The model considered the traffic restriction barriers on the road and pedestrian bridges connecting the right and left sides of the Sucevita river. The population was unable to cross to a point on the opposite side. Thus, in the first 10 min, a population of 585 people reaches the evacuation points. In the next 10 min, another 644 persons are moving to these points. The 588 people who travel up to 2000 m in about 15–20 min to evacuation areas are predominantly located in areas with a high vulnerability (Table 4), and 14% travel the distance in up to 30 min.

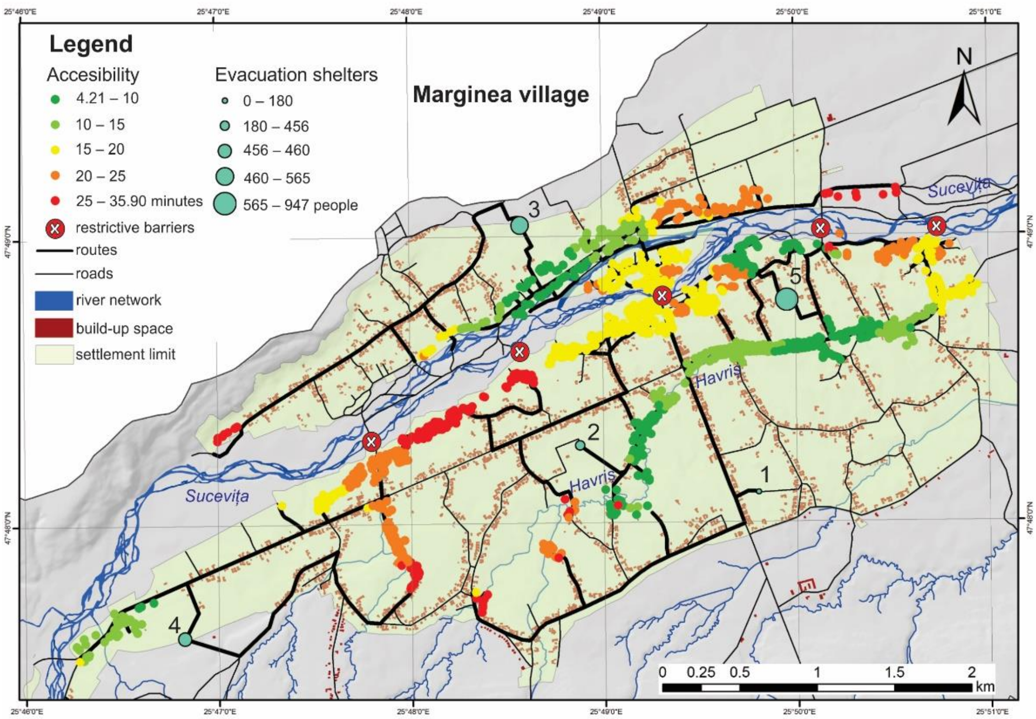

Figure 10. Optimal evacuation routes and accessibility of the population for Marginea village.

Table 4. Summary table on the time required to travel distances to evacuation areas for Marginea village.

Time to Travel the Distance (Minutes)	Number of Persons	Dwellings
4.21–10	585	206
10–15	644	204
15–20	588	316
20–25	415	238
25–35.90	376	174

The analysis of the shelters for evacuees shows that 180 people (6.90% of the analysed population) arrive within 30 min at the first evacuation point located in the southern part of the village, where evacuees arrive from the tributaries of the Sucevita river. The point on the left side of the Sucevița river provides shelter for 460 people (17%) who travel between 5 and 32 min (Table 5) from their homes to evacuation facilities.

Table 5. Capacity of evacuation points in Marginea village.

Evacuation Point	Persons	Travel Time (Min)
1	180	11–30
2	456	4.2–35.9
3	460	5–32
4	565	7–34
5	947	4–27.58

The evacuation area from the eastern part of the commune is located between the Sucevița river and the Havriș stream and provides a shelter for 947 people from 356 dwellings. Small distances from the evacuation point reduce the travel time of persons, and the area may be evacuated within 28 min. Of the total population surveyed, only 0.6% needed more than 30 min to travel to one of the five evacuation points. In Marginea, the population can be evacuated in about 36 min. Thus, the methodology regarding the favourability of the evacuation points and their spatialisation is validated due to the fact that the evacuation process falls within the mentioned time limit—40 min (related to the streamflow increase time during the 2010 flood events).

The results show that the spatial distribution of evacuated reception areas is well organised because in a short time, the persons evacuated can reach one of the proposed points in case of an organised action. For the application of such an evacuation scenario, the population of this village must be informed and integrated into preparatory actions and attend practical simulation exercises intended to change the attitude and behaviour of the population. Vulnerability in these situations is inversely proportional to the population's reaction to danger.

Modernisation and restructuring of emergency services by training the staff of responsible institutions with minimal knowledge of spatial data modelling could lead to efficient management and a reduction of possible damage [38].

4. Discussion

The pre-planning of shelters and evacuation routes is the basis for efficient management through optimisation. Decision-making in case of evacuation of the population upon the occurrence of a potentially destructive phenomenon requires several types of data, including potential evacuation locations, the determination of areas susceptible to flooding, and emergency services to facilitate the main functions of shelters (providing safe areas where the population is protected and allowing authorities to evacuate safely) [50].

Rural communities are complex when it comes to the potential risk of flooding due to the high population density located in exposed areas, various land use patterns, economic activities, and unsuitable land use. In this context, the current society relies on different flood risk management plans, which require a new approach to risk assessment through structural, non-structural, and emergency preparedness measures to mitigate the damage caused [51,52].

Approaches based on the use of GIS techniques have been widely adopted to provide decision-making support in flood analysis and mapping and in preparing damage mitigation models [53,54].

This study aims to develop a methodology to assess the accessibility of evacuation points concerning the population in vulnerable areas. Shelters should be located in such a way as to reduce evacuation times and, at the same time, be away from vulnerable areas. The methodology identified potential areas for receiving evacuees and their capacity, proposing routes and assessing evacuation times.

The results of the study may support non-structural measures taken by the competent authorities in the field of natural disasters by mapping the areas where evacuee reception areas can be located and establishing the accessibility of these locations through calculation of the distance and time necessary for evacuation by using spatial techniques.

The analysis and results show that the proposed method can be used to assess the spatial distribution of evacuation points and provide a statistical estimate of the capacity of the proposed shelters, the people evacuated, and the time required for this process. Therefore, the shortest routes were identified, and the use of GIS software can increase awareness among the population and authorities of the locations and their accessibility.

Emergency evacuation planning for natural hazards requires a detailed database, the lack of which makes it difficult to develop spatial plans, especially in developing countries [55]. One of the specific problems in these countries in terms of emergency management consists of the lack of social education among the population in terms of natural disaster response. This attitude stems from the lack of exercises associated with emergencies, which are generally scriptural and less factual in Romania.

This makes it difficult to implement such a system by building explicit spatial models for emergency preparedness and including them in evacuation strategies. The results can provide some valuable managerial insights for the stakeholders working in shelter planning and evacuation [20].

Vulnerability involves the way human society reacts to a disaster. Thus, for the functionality of these models, a stage of preparation and training of the population is necessary, aimed at establishing new perceptions and attitudes. However, the most significant influence on perception stems from the experiences of each individual, and after the events of 2008 and 2010 the population in the villages under review would be more receptive to the application of these models.

This study can be included in emergency management plans as a pilot study for small catchments. The model used can constitute an essential chapter in population evacuation plans and can be applied to human settlements in river basins developed under relief conditions. Since the study is focused on a rural area in Romania, the evacuation points are not associated with standard units for receiving the evacuated population (schools, theatres, town halls, sports facilities) because they are all often located in areas susceptible to flooding.

Several limitations were also identified in this analysis. The lack of a digital format of the database needed to carry out evacuation plans has led to a transposition of data from the statistics of public institutions, which is a time-consuming, costly approach and can sometimes lead to interpretation errors. There is also a lack of real-time information on extreme hydro-climatic events and improvement of the warning system. However, this situation is not only specific to Romania. It has also been observed in countries with much broader and more efficient monitoring and warning systems, as happened in Germany during the 2021 flood events [56,57]. Another possible limitation can reside in the fact that the study only concerned flood analysis, because the area was affected by this phenomenon in recent decades, without taking into account other potentially destructive natural events (landslides, earthquakes). In terms of simulation scenarios, the limitations are that no scenarios were run for the elderly, people with locomotor problems, or children, as well as differences in travel speed on a higher slope. Another important aspect is that the distribution of the population needs to be periodically updated concerning the mode of occurrence of extreme hydrological events. However, in the case of the latter, conditionalities are different and require model adaptations.

This study can form the basis for developing specific methodologies to assess the distribution of shelter locations in which other associated limiting factors induced by floods are included and integrated into the assessment matrix.

5. Conclusions

Assessing the spatial distribution of evacuation sites in relation to flood risk and proposing scenarios for evacuation of the population in a developing country, where resources for implementing non-structural measures are minimal, are considered essential tools in crisis management.

In order to manage the flood risk, scenarios have been developed for the evacuation of the population from a river basin located in the eastern part of the Romanian Carpathians, in the Suceviţa river basin. The analysis was carried out at the level of two territorial administrative units, Suceviţa and Marginea, where a notable historical flooding event led to the conduction of this study. In order to develop population evacuation scenarios, the areas favourable for the location of evacuation points were first identified. The favourability was established by carrying out a multi-criteria analysis of natural, environmental, restrictive, and proximity factors integrated into the GIS environment.

The results show that theoretically, 91.67% of the population vulnerable to flooding in Suceviţa would travel the distance from their houses to one of the evacuation points in about 35 min. Moreover, 8.32% of the population needs a longer time (up to 54 min) to reach one of the points due to the relief conditions in that mountain area. In Marginea, due to the small distances between dwelling and evacuation areas, as well as the low slope relief, the population under review can be evacuated in about 35 min. In terms of distances travelled and accessibility of the population to these evacuation areas, approximately 58% of the population under review, i.e., 47%, can be evacuated within 20 min in Suceviţa and Marginea villages.

Digitising the model using spatial analysis techniques and making scenarios by identifying the time needed to evacuate certain areas can be important tools in the management activities to achieve an organised and safe evacuation of the population. The study has an applicative character, and the results obtained can be essential tools for authorities in managing floods and integrating them into management plans.

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