remote sensing

Article

Methodology for Determining the Nearest Destinations for the Evacuation of People and Equipment from a Disaster Area to a Safe Area

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Abstract: Floods are the most frequent natural disasters in the world. In the system of warning and flood protection of areas at risk of flooding in the event of its occurrence, it seems advisable to initially work out the possibility of evacuating the population, animals, equipment, material values, etc. In this article, a methodology for determining destinations (points of destination) for the evacuation of people and equipment from a predicted flood zone (of a natural disaster) to a safe area is proposed based upon the criterion of the shortest possible distance. In the paper, a scenario is considered that involves the contours of the flood zone boundaries for several variants of the intensity of the probable development of future events (with the aid of geoinformation technologies), and the coordinates of the objects to evacuate are permanent and known in advance. With the known coordinates of the objects and the closest points of the boundary of the predicted flood zone, the shortest distances can be calculated. Based on these calculations, the appropriate destinations for evacuation are determined. The proposed methodology can be used for flood forecasting and flood zone modeling to assess the economic and social risks of their aftereffects and to allow the public, local governments, and other organizations to better understand the potential risks of floods and to identify the measures needed to save lives and avoid damage to and loss of property and equipment. This methodology, in contrast to known approaches, allows the determination of the nearest locations for the evacuation of people and equipment from a flood zone (of a natural disaster) to safe areas, to be determined for several variants, depending on the possible development of future events. The methodology is algorithm-driven and presented in the form of a flowchart and is suitable for use in the appropriate software. The proposed methodology is an introduction to the next stages of research related to the determination of safe places for evacuation of people and their property (equipment) to safe places. This is especially important in case of sudden weather events (flash floods).

Keywords: shortest distance; flood zone; safe area; flood zone boundary; destination

Citation: Korolov, V.; Kurowska, K.; Korolova, O.; Zaiets, Y.; Milkovich, I.; Kryszk, H. Methodology for Determining the Nearest Destinations for the Evacuation of People and Equipment from a Disaster Area to a Safe Area. *Remote Sens.* **2021**, *13*, 2170. https://doi.org/10.3390/rs13112170

Academic Editors: Soheil Sabri, Abbas Rajabifard, Yiqun Chen, Nengcheng Chen and Hao Sheng

Received: 30 March 2021
Accepted: 27 May 2021
Published: 1 June 2021

1. Introduction

Of all the natural hazards in the world, floods are the most common. Surface waters in recent decades have unexpectedly risen in several countries in Europe, North America, Russia, China, Japan, and Asia [1]. Floods continue to pose a major challenge in both developed and developing countries [2], with the most severe consequences for the latter as there are few warning and anti-flood systems in place, and the financial capacity to counteract floods is limited. The rainy season and unexpected rainfall have destroyed technical infrastructure and caused fatalities in countries around the world.

Flash floods are especially dangerous. They are a response to climatic changes and cause massive destruction and losses to farms, human lives, and technical infrastructure [3].

Therefore, it is essential to estimate the sensitivity of an area to flash floods. Humans have no influence on natural events but can prevent and predict their consequences.

The observation of events from the early 20th century to the present day shows the lack of effective systems within countries to cope with natural disasters. Flood hazards can be analyzed from various points of view. Considerable research has been done on urban flood hazards [2,4–6], flash flooding [3,7–9], the impact of climate change on flood hazards [10], the social and economic consequences of floods [11,12], and flood management [13]. Goldberg et al. [1] researched floods due to ice jams and snowmelt. Flood risk can be determined based on the water depth and velocity, while the risk degree is based on the vulnerability of an area [8]. Lin et al. [6] studied the development and prioritization of flood mitigation measures in areas subject to strong urbanization.

The forecasting and modeling of flood zones are conducted to assess the economic and social risk of the effects of floods and raise the awareness of local governments and other organizations concerning flood probability. Various methods for assessing flood hazards have been proposed in the literature. The use of geographic information system (GIS) tools and remote sensing are very popular ways to produce flood hazard and flood risk assessment maps [1,4,14–16]. Flood hazard maps contain information on the predicted inundation area and depth as well as evacuation refuges and routes. These maps aim to quickly evacuate residents safely and efficiently in the event of flooding [2]. Flood assessment maps also show the potential consequences of a flood [17]. The impact of flooding can be reduced through the application of suitable hydrological and hydraulic tools to define flood zones in a specific area [17–19]. Researchers have also proposed the use of a hybrid approach that integrates machine learning and geohydrological models [3,20]. The phenomenon of floods is related to the assumptions of planning and spatial management, which can have a great impact on the system and the subsequent functioning of flood risk management. Flash floods in cities can lead to high levels of water on the streets and roads [15]. By combining flood hazard and flood risk maps with the current and planned urbanization zones, decisions can be made regarding the acceptable level of risk [8].

There are scientific studies in which subjects have been evacuated from flooded areas [21–27] or other extreme weather events [27,28]. As Zhai and Ikeda [11] emphasized, evacuation is one of the most important issues in reducing the loss of life during disasters. Both the detailed delimitation of flood hazard areas as well as planning of evacuation routes are challenging. As Da Costa et al. [19] emphasized in their research, the main limitations are algorithms and hardware as well as costs, data availability, and incomplete knowledge of how flooding events occur in different areas. The determination of the shortest distance to cover to evacuate people and equipment from a disaster area to a safe area is essential.

The development of geoinformation technologies with digital terrain models has made it possible to significantly automate the process of forecasting and modeling flood zones (natural disasters). Other studies [29,30] have considered methods for calculating the contours of flooding zones using GIS and interactive tools [20,31,32] to create and view maps to determine which objects may be in a flood zone.

However, the problem of finding the shortest distance that must be covered to evacuate people and equipment from a disaster area to a safe area has not yet been considered.

The closest work to the issue under study is the approach proposed by Korolov et al. [33] involving the determination of vehicles from a "shadowing" zone suitable for staff use, although this problem was solved in an analytical form, which significantly complicated the algorithmization. The purpose of the current paper is to find a formalized approach to determine the shortest distance for the evacuation of people and equipment from a disaster area to a safe area. The presented algorithm should ensure calculations for various levels of flooding. It should also be versatile for various configurations of evacuation facility locations relative to the boundaries of "flooded" zones.

2. Materials and Methods

The aim of the article is to present the material regarding a complex problem (method and algorithm for searching potentially suitable evacuation points, method of finding the optimal evacuation route, taking into account the road network, infrastructure, landforms, etc.). This requires its division (decomposition) into subtasks, which need to be solved sequentially (Figure 1). The individual stages of research will be presented in subsequent scientific publications. This article is the first of the intended cycle. The current article contains two stages: a literature review and the possibility to use GIS tools and proposes a method to determine the shortest flood evacuation distance.

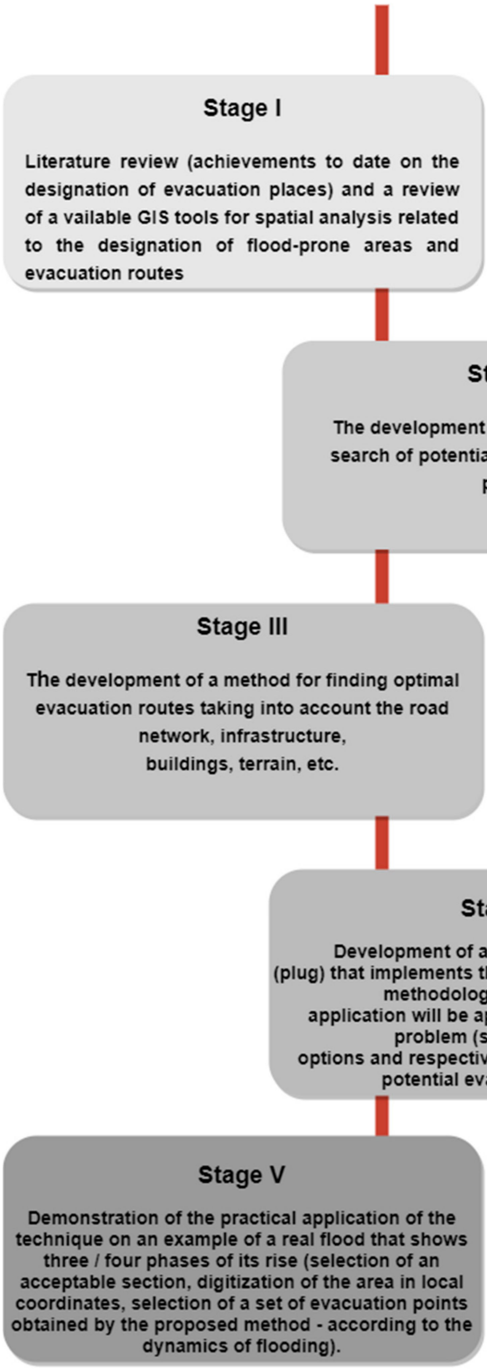


Figure 1. Methodology for finding potentially suitable evacuation points for different levels of flooding.

Under conditions of varying disaster intensity (e.g., flooding), the zone boundary will create its own configuration. A geographic information system (GIS) can be used to model this methodology [34–37]. In stage III, a computer program was developed in the MATLAB environment to illustrate the algorithm.

It is assumed that the location of the boundary line of a specified zone in the form of an array of points with coordinates x_i, y_i can be determined by using GIS.

To calculate the object A-distance to the safety zone, it is necessary to define the line that bounds the natural disaster zone and forms the transition line to the safe area.

The line bounding the natural disaster zone can be modeled (see Figure 1), for example, as a jogged line, whose sides join the vertices x_i, y_i that can be N in amount (N—number of coordinate pairs (x_i, y_i) (i= 1, . . . , N)) and whose array can be obtained from GIS. The set of these points is denoted by GIS.

Let us define the function $x = f(y)$, whose plot is the jogged line, i.e.,

$$x = f(y) = \begin{cases} \frac{x-x_1}{x_2-x_1} = \frac{y-y_1}{y_2-y_1}, x_1 < x < x_2, y_1 < y < y_2 \\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \\ \frac{x-x_{N-1}}{x_N-x_{N-1}} = \frac{y-y_{N-1}}{y_N-y_{N-1}}, x_{N-1} < x < x_N, y_{N-1} < y < y_N \end{cases}, \quad (1)$$

where $x_1 < x < x_N$; $y_1 < y < y_N$.

In Figure 2, we can observe the typical location of people (equipment) A (x_A, y_A), that are in the natural disaster zone and require evacuation.

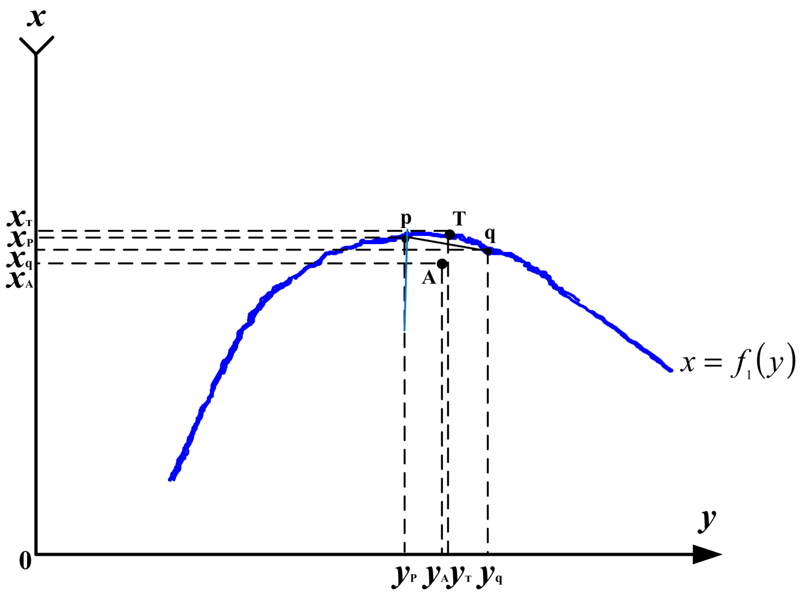


Figure 2. Typical configuration of the natural disaster zone boundary.

3. Results and Discussion

3.1. Literature Review and the Use of GIS Tools for the Delineation of Flood Risk Areas

Evacuation to safe places from an inundated zone is a complex interdisciplinary problem that requires its division (decomposition) into subtasks, which in turn need to be tackled sequentially, namely:

– Identification of potentially suitable evacuation points for different levels of inundation;
– Determination of optimal evacuation routes, taking into account the infrastructure and road network and if these are lacking, taking into account the terrain and the patency of the area;

– Determination of the required number of units and types of equipment to evacuate populations, animals, equipment, material values, etc.;
– Organization of psychological, medical, and humanitarian assistance to victims, etc.

In the literature, several proposals can be found for evacuation from zones of natural disasters. Simonovic et al. [38] proposed a computerized simulation model to capture human behavior during flood emergency evacuation. Their method simulated the acceptance of evacuation orders by the residents of the area under threat, e.g., the number of families, the time of evacuation required to reach safety, and the main set of social and mental factors which determine human behavior during flood evacuation. Matsuo et al. [2] analyzed flood and evacuation simulations for urban flooding to develop an integrated flood evacuation simulator that accounts for the time-space distributions of both flood risk and safe evacuation routes at the community level. Suga et al. [22] analyzed the traversal of flooded areas on foot during flood disaster evacuation. As a result, researchers have proposed safe evacuation strategies for every age group. Bernardini et al. [39] proposed a simulation tool to assess the risk of flood-induced pedestrian evacuation.

A different point of view was presented by Kongsomsaksakul et al. [23]. They proposed a shelter location–allocation model for a flood evacuation model. A location–allocation model and an algorithm were also proposed by Sherali et al. [21], but they also added evacuation planning for hurricanes. The models based on hydrological or hydraulic models proposed to date require a large volume of data; this is a guarantee of achieving an accurate simulation [5]. These models usually do not show places of safe evacuation. Another solution is the flood evacuation timeline model. This methodology is used to assess the flood evacuation capability of proposed large urban development projects on floodplains [25].

There have also been studies in which the authors have also dealt with evacuation in the event of other emergencies. Chen et al. [27] proposed an improved model to quantitatively assess the evacuation vulnerability in urban areas (e.g., when many people congregate in urban areas), including investigating evacuation vulnerability on a spatial-temporal scale.

For inhabited areas and locations of equipment and facilities in flood risk zones, man-made accidents, and natural disasters, it is necessary to conduct preliminary studies (calculations) of evacuation sites to safe areas for people and equipment, depending on the development of the events.

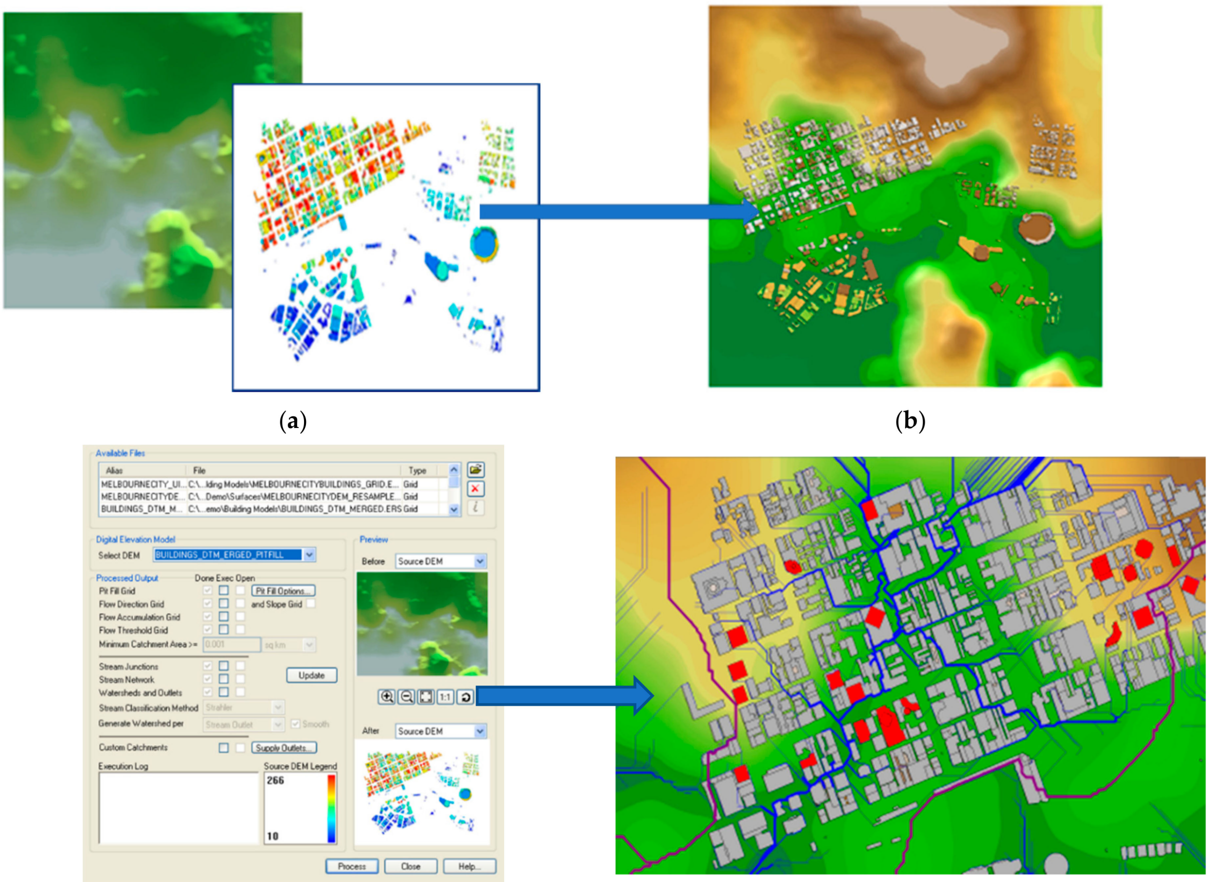
According to Simonovic et al. [38], emergency preparation must be undertaken before a crisis occurs. Conditions in a region affected by a disaster are usually chaotic. Communication is difficult, and command structures may break down because of logistical or communication failures. Human behavior is difficult to control and predict. For this reason, it is very important to find the best solution to this problem. This paper proposes an algorithm to determine the nearest evacuation sites from the flood zone. On the other hand, community-based flood mitigation requires more attention in disaster prevention planning, including the selection of multiple evacuation routes [2].

This problem is important because the number of people living in danger zones systematically increases in relation to the total population growth [40]. From an economic point of view and when operating under time pressure, it is important to identify the most appropriate evacuation route. Alfieri et al. [41] described advances in flood risk mapping and global flood risk models [42].

GIS tools support the acquisition of spatial data from various sources, rapid processing of data, and the release of data in the desired form for multidisciplinary analyses, studies, and forecasts [43]. GIS tools are used to collect, process, update, and release spatial data. They are most useful in the process of acquiring input data from various sources with the involvement of different methods and techniques, ranging from crude field data to fully automated data acquisition systems that do not require human involvement. Data from various sources are processed to generate new information and products [44,45].

The study presents the results of spatial analyses in environmental terms, especially for flood prediction. The main research objective was to evaluate the applicability of GIS tools (data, tools, and multidimensional analyses) to the implementation of delineation of flood risk zones and evacuation routes. The Flood Impact Analysis solution (ArcGIS) and ncom Discover (MapInfo Pro) deliver a set of capabilities that help prepare flood depth and elevation data, define flood impact areas, visualize flooding in 2D and 3D. Accurate evaluation and visualization of the flood impact analysis will depend on several factors, such as availability of flood depth data in the form of the raster, ground elevation data, such as the Digital Terrain Model (DTM) or LiDAR, and features describing the assets to be analyzed such as roads, bridges, and buildings. The MapInfo Professional application (Encom Discover) was used for the spatial analyses of flooded areas (Figures 3 and 4).

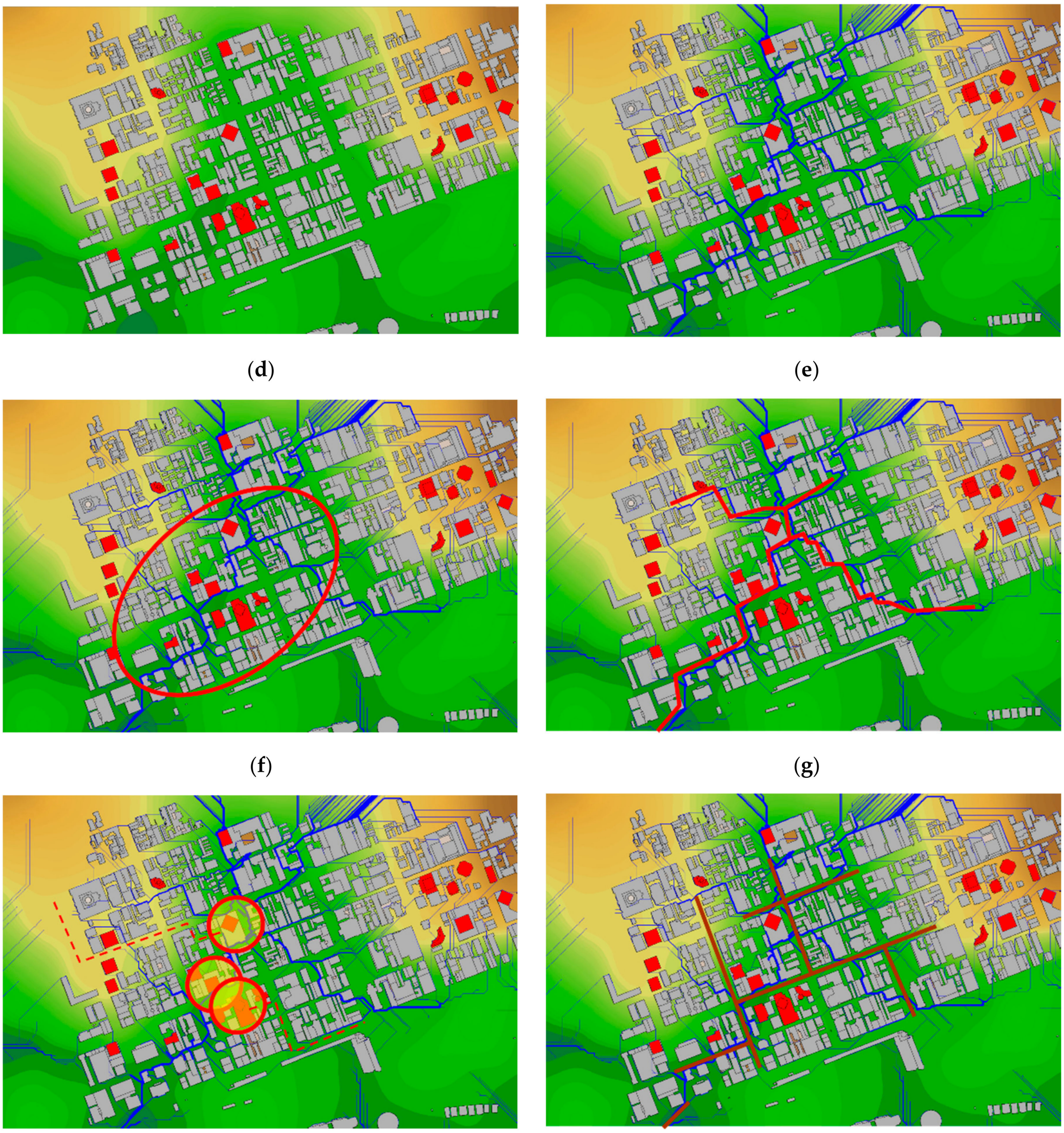
The flood impact area defines the geographical extent for each flood depth scenario. These flood impact areas are the foundation for the analysis of the impact on buildings, roads, or bridges (Figure 3c). The "Analyze roads" task allows flood-affected roads to be analyzed by calculating the flood depth for each road segment for any number of flood levels. The result is a new feature class representing road segments with a depth attribute for each flood scenario (Figure 3g,i). Buildings can be analyzed as well. The tool uses geodatabase of water depths and a specific risk type to calculate the flood depth exposure of each building in the flood impact area. Features can then be symbolized according to the calculated flood exposure attributes, such as flood depth (Figure 3h).



(**a**) (**b**)

(**c**)

Figure 3. *Cont.*



(**d**) (**e**) (**f**) (**g**) (**h**) (**i**)

Figure 3. Modeling the threat of local flooding (Encom MapInfo Discover) 2D model. (**a**) Creation of a numerical terrain model for the flooded area. (**b**) Numerical terrain model for an urbanized area. (**c**) Creation of a flood model. (**d**) Selection of residential buildings in the endangered area. (**e**) Determination of places where water accumulates during flooding. (**f**) Designation of zones particularly threatened by flooding. (**g**) Selection of streets that will be "cut off" during flooding. (**h**) Identification of residential buildings particularly vulnerable to flooding and designation of pathways for access and evacuation during flooding. (**i**) Planned sewerage network, discharging excessive water.

The best way to communicate the impact of a flood scenario is to show how it will affect homes, streets, bridges, and neighborhoods. Visualization of 3D flood levels is more powerful when shown together with other 3D layers, such as 3D buildings, 3D trees, and detailed terrain elevation (Figure 4).

GIS tools streamline the process of developing flooding scenarios to facilitate planning for a flood event. These workflows include preparing the data for analysis, defining the flood impact area and the impact on infrastructure, facilities and buildings, sharing flood impact information, visualizing flood impacts in 3D, and sharing impacts in 3D.

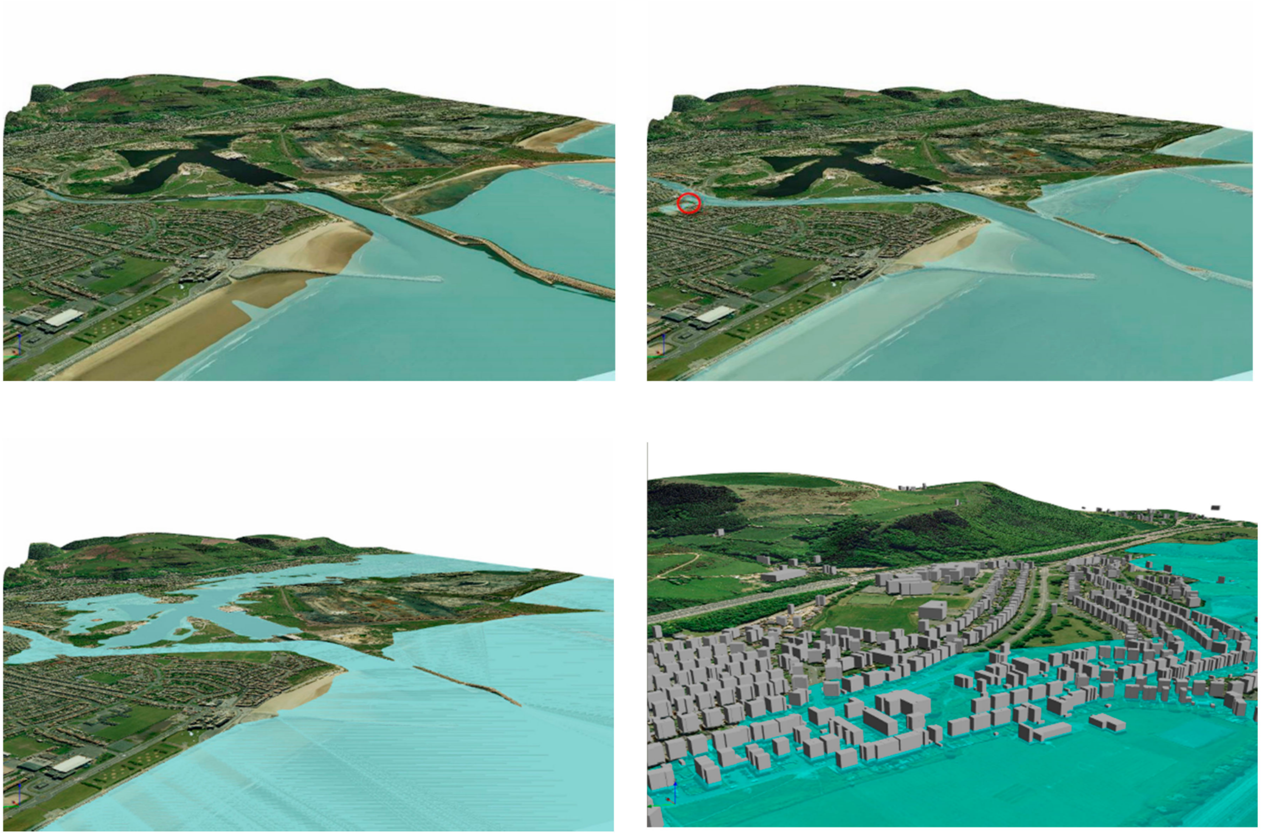


Figure 4. Modeling of local flood risk (Encom MapInfo Discover)—3D model according to flood dynamics.

3.2. The Development of an Algorithm for the Search of Potentially Suitable Evacuation Points

Enumerating the distances from point A to the vertices of the jogged line on either side generates the vertex of the jogged line T (x_T, y_T) which is closest to A (x_A, y_A).

The adjacent vertices of the jogged line P (x_R, y_P), Q (x_Q, y_Q) meet the conditions $AT < AP$ and $AT < AQ$. There are two options for point location A with regard to PT and PQ (see Figures 5 and 6).

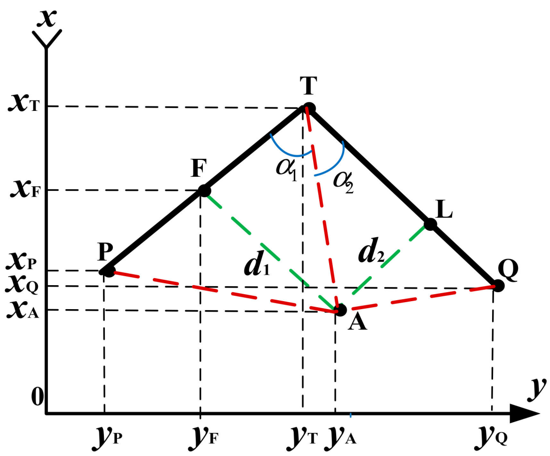


Figure 5. Upward-convex option of flood zone boundary.

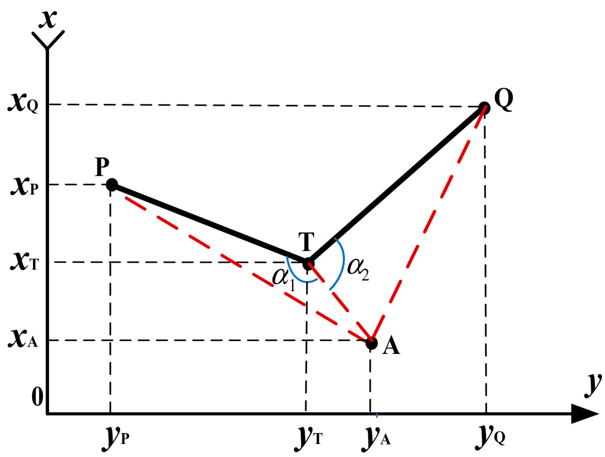


Figure 6. Downward-convex option of flood zone boundary.

To determine the implemented location, we find the values of the angles α_1 and α_2. To do this, we write the scalar products of the vectors $(\overline{PT} \cdot \overline{AT})$ and $(\overline{AT} \cdot \overline{TQ})$. Note that the coordinates of the points $P(x_P, y_P)$, $T(x_T, y_T)$, $A(x_A, y_A)$ and $Q(x_Q, y_Q)$ are known to us.

Based on the definition of the scalar product of two vectors [46], we obtain the following:

$$(\overline{TP} \cdot \overline{TA}) = |\overline{TP}| \cdot |\overline{TA}| \cdot \cos\alpha_1 = \sqrt{(x_P - x_T)^2 + (y_P - y_T)^2} \cdot \sqrt{(x_T - x_P)^2 + (y_T - y_A)^2} \cos\alpha_1, \tag{2}$$

$$(\overline{TA} \cdot \overline{TQ}) = |\overline{TA}| \cdot |\overline{TQ}| \cdot \cos\alpha_2 = \sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2} \cdot \sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2} \cos\alpha_2. \tag{3}$$

On the other hand, the same scalar products in coordinates can be written as follows:

$$(\overline{TP} \cdot \overline{TA}) = (x_P - x_T)(x_A - x_T) + (y_P - y_T)(y_A - y_T), \tag{4}$$

$$(\overline{TA} \cdot \overline{TQ}) = (x_A - x_T)(x_Q - x_T) + (y_A - y_T)(y_Q - y_T). \tag{5}$$

From comparisons (2) and (4), we obtain

$$cos\alpha_1 = \frac{(x_P - x_T)(x_A - x_T) + (y_P - y_T)(y_A - y_T)}{\sqrt{(x_P - x_T)^2 + (y_P - y_T)^2} \cdot \sqrt{(x_T - x_A)^2 + (y_T - y_A)^2}},$$

$$\alpha_1 = arccos\frac{(x_P - x_T)(x_A - x_T) + (y_P - y_T)(y_A - y_T)}{\sqrt{(x_P - x_T)^2 + (y_P - y_T)^2} \cdot \sqrt{(x_T - x_A)^2 + (y_T - y_A)^2}}, \tag{6}$$

Similar to (3) and (5), we obtain

$$cos\alpha_2 = \frac{(x_A - x_T)(x_A - x_T) + (y_A - y_T)(y_Q - y_T)}{\sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2} \cdot \sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2}}.$$

$$\alpha_2 = arccos\frac{(x_A - x_T)(x_Q - x_T) + (y_A - y_T)(y_Q - y_T)}{\sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2} \cdot \sqrt{(x_Q - x_T)^2 + (y_Q - y_T)^2}}. \tag{7}$$

If $\alpha_1 + \alpha_2 \geq \pi$, then the option presented in Figure 3 is realized.

In this case, point T $(x_T,\ y_T)$ should be considered as a destination for object A evacuation. This point is closest and is located at the flood (natural disaster) zone boundary.

Under the condition $\alpha_1 + \alpha_2 < \pi$, partial options should be considered:

(1) $\alpha_1 < \frac{\pi}{2}$, $\alpha_2 < \frac{\pi}{2}$.

In this case, the distances from point A to $PT - d_1(AF \perp PT)$ and $TQ - d_2(AL \perp TQ)$ are defined.

To define d_1 the equation of line RT is written according to (1) in the form:

$$Ax + By + C = 0 \tag{8}$$

where

$$\begin{aligned} A &= y_R - y_T; \\ B &= x_T - x_R; \\ C &= x_R y_T - y_R x_T. \end{aligned} \tag{8a}$$

Equation (8) is normalized and can be written in the form [46]

$$x cos\varphi + y sin\varphi - G = 0, \tag{9}$$

where

$$\varphi = arctg\frac{B}{A};$$
$$G = \frac{C}{\sqrt{A^2+B^2}}.$$

Formula (9) allows d_1 to be calculated, i.e.,

$$d_1 = x_A cos\varphi + y_A sin\varphi - G. \tag{10}$$

Analogously, value d_2 is obtained when

$$\begin{aligned} A &= y_Q - y_T; \\ B &= x_T - x_Q; \\ C &= x_Q y_T - y_Q x_T. \end{aligned} \tag{10a}$$

If $d_1 \leq d_2$, coordinates (x_F, y_F) of point F are obtained as a base of perpendicularity, which is lowered from point A on PT,

$$x_F = \frac{B^2 x_A - A \cdot B y_A - A \cdot C}{A^2 + B^2}, \tag{11}$$

$$y_F = \frac{A^2 y_A - A \cdot B x_A - C \cdot B}{A^2 + B^2}, \tag{12}$$

where A, B, C are taken from (8a).

As a destination for the object A evacuation, the point $F(x_F, y_F)$ is taken.

If $d_2 \leq d_1$, coordinates (x_L, y_L) of point L are obtained as a base of perpendicularity, which is lowered from point A on TQ. In this case,

$$x_L = \frac{B^2 x_A - AB y_A - AC}{A^2 + B^2}, \tag{13}$$

$$y_L = \frac{A^2 y_A - AB x_A - CB}{A^2 + B^2}, \tag{14}$$

where A, B, C are taken from (10a).

In this case, as a destination for the object A evacuation, point $L(x_L, y_L)$ is taken.

(2) $\alpha_1 < \frac{\pi}{2}$, $\alpha_2 > \frac{\pi}{2}$. In this case, the point $F(x_F, y_F)$ is produced according to the procedure set out earlier (Formulas (11) and (12)). It is selected as a destination during object evacuation from point A to $D(x_D, y_D)$.

(3) $\alpha_1 > \frac{\pi}{2}$, $\alpha_2 < \frac{\pi}{2}$. In this case, point $L(x_L, y_L)$ is obtained according to the procedure set out earlier (Formulas (13) and (14)). It is selected as a destination $D(x_D, y_D)$ during object evacuation from point A.

(4) In Figure 7, a large flowchart shows the methodology used to define the closest point of the flood zone boundary that can be taken as a destination $D(x_D, y_D)$ during object evacuation from point A to $D(x_D, y_D)$.

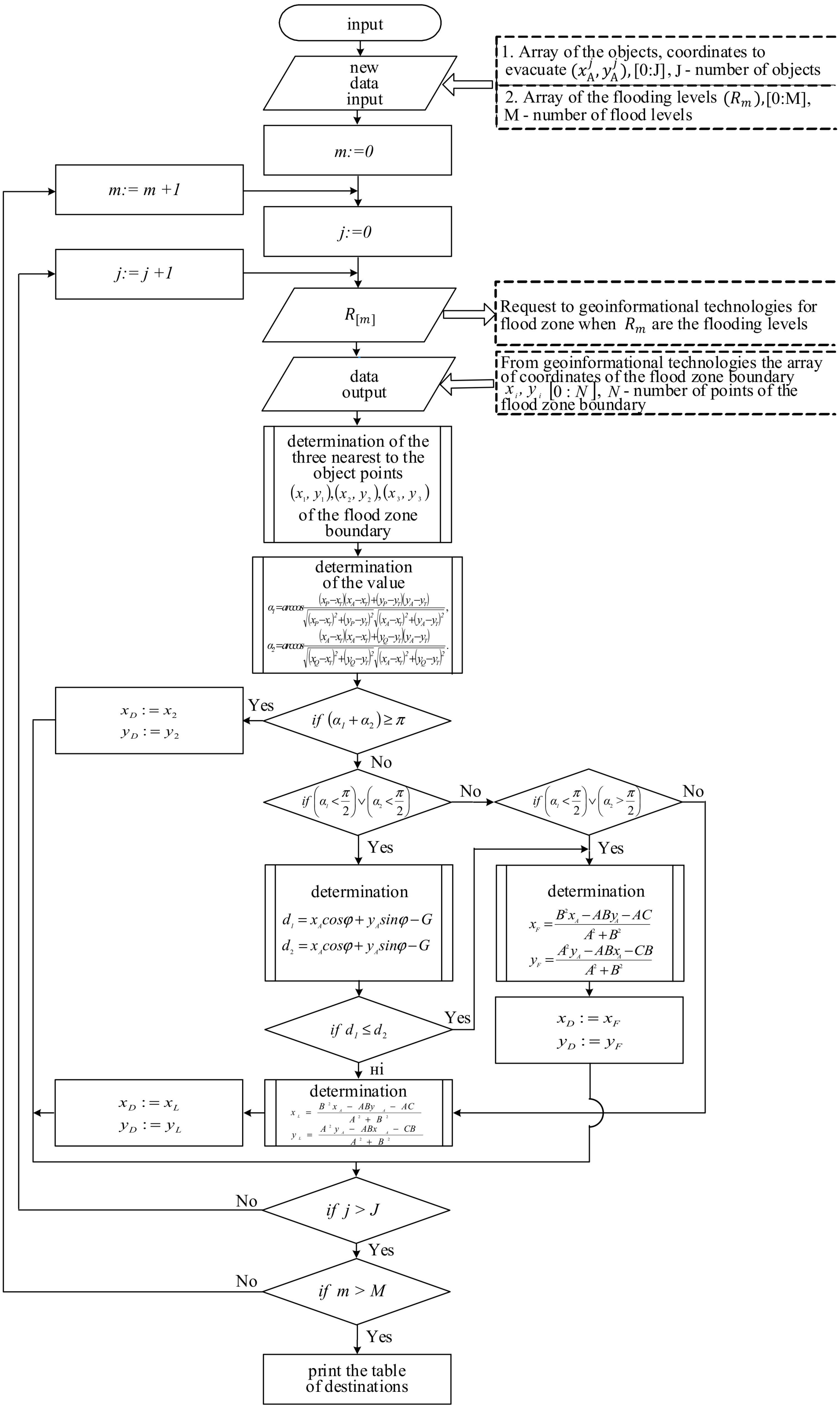


Figure 7. Flowchart of the methodology used to define the closest point of the flood zone.

Usually, the proposed algorithms for flood zone determination are based on spatial analyses considering land cover and model of the terrain and GIS tools [9,13–15]. In cases where the model of the terrain is not taken into account, the algorithms can be applied for flat and low slope areas [47].

Given the progressive automation in terms of acquiring and processing information concerning natural phenomena, new technological solutions are constantly being sought. When determining the nearest destinations for the evacuation of people and equipment from a disaster area to a safe area, land cover and the terrain model should be taken into account. The tool that enables real-time monitoring of the environment is laser scanning [48], classical surveying, and the LiDAR technique [49,50]. The LiDAR technique provides X, Y, Z coordinates for any number of terrain points with sufficient accuracy. The research conducted by Kotlarz et al. [49] showed some limitations of the LiDAR data acquisition method. This method does not allow the determination of coordinates of measurement points describing topography in places inaccessible for a laser beam.

As a rule, GIS tools provide extensive opportunities for spatial analysis. However, many phenomena are identified at a high level of generality. We usually do not have detailed information on how this problem is solved and implemented. We offer a methodology, which is based on a new way of solving the problem of finding the nearest safety points for evacuation of people, animals, equipment, etc., from the flooding zone for any number of flooding stages. The proposed method is presented in the form of analytical relationships (mathematical model). The method is well algorithmic (a block diagram of the algorithm is given). It allows the development of a computer program and can be implemented into modernized and promising GIS software.

4. Model Problem for the Calculation of Coordinates of Evacuation Points of Objects for Different Levels of Inundation

A computer program was developed in the MATLAB environment to illustrate the algorithm. It was used to solve the model problem of calculating the coordinates of evacuation points for different levels of flooding. The results of the calculations are given below.

Figure 8a–c shows a coordinate plane with the X and Y coordinate axes on which the relative coordinates are plotted to the scale of the conventional unit of length. The coordinate plane shows the position of the five objects and the original boundary line (black bold line). The red, green, and purple dashed lines mark the boundaries of the first, second, and third levels of flooding, respectively. An evacuation point at the flood zone boundary is determined for each flooded object. An object that is not flooded remains in place. For each flooded object at all levels of inundation (for convenience of algorithm performance analysis), thin lines illustrate the implemented configuration of the object's position relative to the inundation boundary.

To facilitate the analysis of the process dynamics, Figure 9 shows the combination of situations that are shown in Figure 8a–c. The thin dashed red, green, and purple lines starting from the initial location points of the objects show their evacuation points at the realized inundation levels.

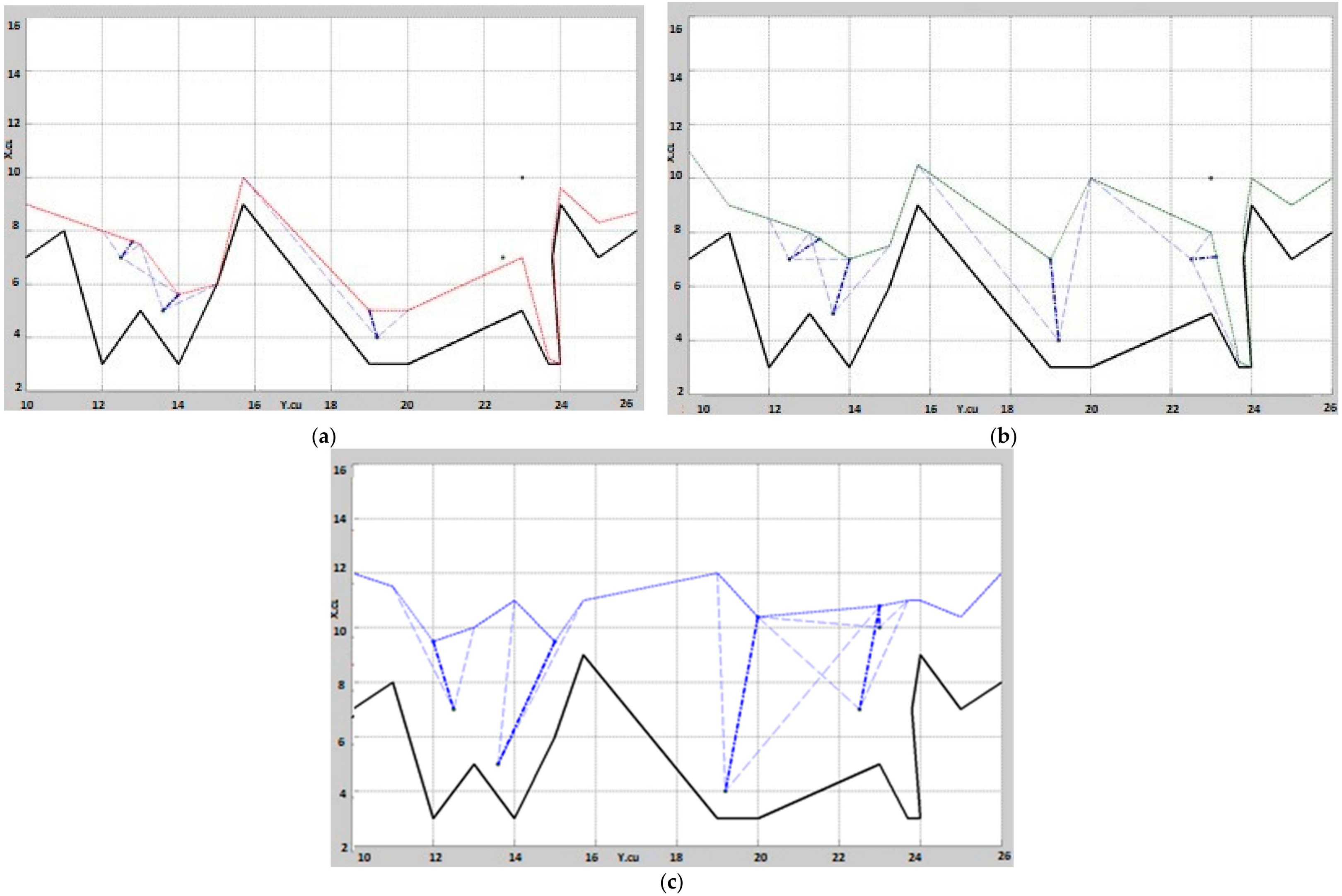


Figure 8. Determination of evacuation points for different levels of flooding. (**a**) First level of flooding. (**b**) Second level of flooding. (**c**) Third level of flooding.

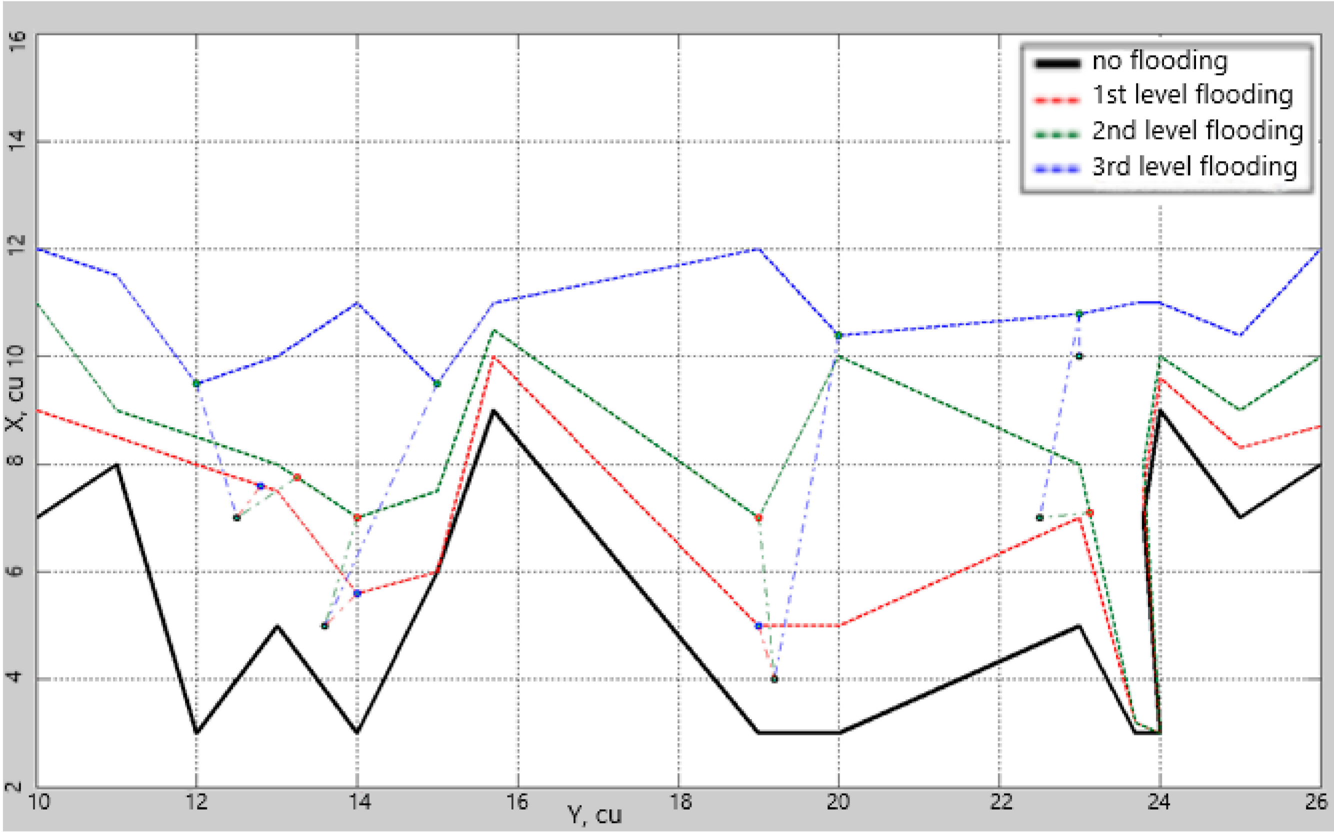


Figure 9. Evacuation points at realized, three levels of flooding.

Table 1 lists the initial coordinates of the site and the coordinates of the corresponding evacuation points for the considered flood levels.

Table 1. Coordinates of objects and their corresponding evacuation points.

Object Number	Object Code		Evacuation Level 1 Flooding		Evacuation Level 2 Flooding		Evacuation Level 3 Flooding	
	X	*Y*	*X*	*Y*	*X*	*Y*	*X*	*Y*
1	7.00	12.50	7.60	12.80	7.75	13.25	9.50	12.00
2	5.00	13.60	5.60	14.00	7.00	14.00	9.50	15.00
3	4.00	19.20	5.00	19.00	7.00	19.00	10.40	20.00
4	7.00	22.50	7.00	22.50	7.09	23.13	10.80	23.00
5	10.00	23.00	10.00	23.00	10.00	23.00	10.80	23.00

Table 2 shows the coordinates of the vertices of the polygons modeling the boundaries of the original shoreline and flood zones obtained from the GIS system.

The number of objects and flood levels is determined exclusively by user requirements. The detail of the modeling of the flood zone boundaries depends solely on the capabilities of the GIS.

It should be remembered that in order to guarantee the location of the evacuation point in the "dry" zone, it is necessary to take into account the level of the predicted flooding with a certain excess.

Table 2. Coordinates of the vertices of the polygon modeling the floodplain boundary.

No. in Order	Flood Level Number							
	No Flooding		1		2		3	
	X	Y	X_1	Y_1	X_2	Y_2	X_3	Y_3
1	7.0	10.0	9.0	10.0	11.0	10.0	12.0	10.0
2	8.0	11.0	8.5	11.0	9.0	11.0	11.5	11.0
3	3.0	12.0	8.0	12.0	8.5	12.0	9.5	12.0
4	5.0	13.0	7.5	13.0	8.0	13.0	10.0	13.0
5	3.0	14.0	5.6	14.0	7.0	14.0	11.0	14.0
6	6.0	15.0	6.0	15.0	7.5	15.0	9.5	15.0
7	10.0	15.7	10.0	15.7	10.5	15.7	11.0	15.7
8	5.0	19.0	5.0	19.0	7.0	19.0	12.0	19.0
9	5.0	20.0	5.0	20.0	10.0	20.0	10.4	20.0
10	7.0	23.0	7.0	23.0	8.0	23.0	10.8	23.0
11	3.2	23.7	3.2	23.7	3.2	23.7	11.0	23.7
12	3.0	24.0	3.0	24.0	3.0	24.0	11.0	24.0
13	7.5	23.8	7.5	23.8	8.0	23.8	11.0	23.8
14	9.6	24.0	9.6	24.0	10.0	24.0	11.0	24.0
15	8.3	25.0	8.3	25.0	9.0	25.0	10.4	25.0
16	8.7	26.0	8.7	26.0	10.0	26.0	12.0	26.0

This article is the first proposed in the series and is devoted to developing a methodology for finding potentially suitable evacuation points for different levels of flooding. Having a defined (calculated) nearest destination for the evacuation site allows tackling the problem of finding the best route to be started (taking into account the road network, infrastructure, and where there is none, relief and passability). This forms the content of the nested article. In solving this problem, a situation is assumed in which a shorter route to a "dry" point is realized. In this case, an adjustment of the evacuation point is allowed.

If there is no specified (calculated) nearest destination for the evacuation point, the problem becomes misplaced: it is not clear where to look for the optimal route. Available GIS tools allow indicating the evacuation route from the danger zone without indicating a safe place (evacuation point). The proposed algorithm brings a new solution indicating at the same time the safe place of evacuation, defined as the shortest path taking into account land development and layout of the terrain, available roads, and infrastructure.

5. Conclusions

The motivation behind researching this topic was the fact that floods represent a natural phenomenon that cannot be completely prevented. With the rise of civilization and economies, they have become more frequent and result in increased destruction, causing severe ecological, material, and cultural losses. People can limit the damage caused by floods, as well as the size, effects, and range of their occurrence. The current article proposes a new approach related to flood hazards.

A methodology for determining destinations (points of destination) for the evacuation of people and equipment from a predicted flood zone (of a natural disaster) to a safe area was provided. This ensures that the shortest distance to cover to reach these safe areas is found.

This methodology, unlike the known approaches, allows the nearest places for the evacuation of people and equipment from a flood zone (of a natural disaster) to safe areas to be determined for several variants, depending on the possible development of future events. The methodology is versatile for various configurations of locations of evacuation facilities relative to the predicted boundary of the flood zone.

The methodology is algorithm-driven and is presented in the form of a flowchart that is suitable for use in the appropriate software. In the future, the authors intend to develop a methodology for determining optimal evacuation routes, taking into account the infrastructure and road network, or in the absence of these, taking into account the terrain and patency of the terrain.

Author Contributions: Conceptualization, V.K. and K.K.; methodology, V.K. and K.K.; software, I.M.; validation, Y.Z. and I.M.; formal analysis, I.M. and O.K.; investigation, O.K. and H.K.; resources, O.K. and Y.Z.; data curation, I.M.; writing—original draft preparation, Y.Z., I.M. and O.K.; writing—review and editing, V.K., O.K., K.K., H.K. and Y.Z.; visualization, Y.Z.; supervision, V.K.; project administration, K.K. and H.K.; funding acquisition, K.K. and H.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Not applicable.

Acknowledgments: Special thanks to Imagis, S.A. Warsaw, official distributor of the MapInfo Discover software for providing analysis materials.

Conflicts of Interest: The authors declare no conflict of interest.

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