Information & Security

G. Grigorov, S. Stefanov & S. Spirdonov
vol. 55, no. 1 (2024): 55-62
https://doi.org/10.11610/isij.5521

Published since 1998

ISSN 0861-5160 (print), ISSN 1314-2119 (online)

Research Article

Use of a GIS System to Visualize the Levels of Risk in the Areas of Critical Infrastructure Objects

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ABSTRACT:

This article presents the initial stage of the development of a platform for visualizing the level of risk of industrial accidents and natural disasters in individual zones and areas of objects using a Geographic Information System (GIS). The current prototype visualizes the level of risk by stacking different layers to graphically represent dangers, danger zones, and potential casualties and damage. In addition, the authors outline guidelines for developing the platform, which will enable risk prediction in the event of industrial accidents and natural disasters and enable better planning of activities for prevention, protection, and liquidation of their consequences.

ARTICLE INFO:

RECEIVED: 05 SEP 2024
REVISED: 21 OCT 2024
ONLINE: 29 OCT 2024

KEYWORDS:

GIS, risk, danger, disaster, crisis, critical infrastructure, visualization

Introduction

In recent years, we have faced a number of major and often interrelated challenges posed by natural disasters and industrial accidents, leading to rapidly escalating crises on a regional, national, and international scale. These challenges impose the need to take preventive measures and immediate actions, especially

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if the various dangers occur near or on the territory of objects of the critical infrastructure,[1] creating an additional potential danger for the personnel and the population in the area. According to some researchers,[2] impacts on critical infrastructure objects can be caused mainly in three ways – computer impact, physical destructive impact, and indirect destructive impact, with the consequences of natural disasters and man-made accidents being examples of the last two ways. They can be visualized using a platform developed on the basis of a GIS system, which is the subject of elaboration in this article.

An analysis of the scientific publications[3] on the matter shows that actions in crisis situations are associated with risk, which is why there is a great need to reduce and/or prevent it so as to effectively limit potential, material and moral losses. One of the important features in risk management in larger-scale crises, such as disasters and catastrophes, is the visualization of threatened areas, as well as the presentation of additional information about them. When such information is correctly structured, it can significantly ease the process of pre-planning or decision-making in the course of crisis management. A modern approach to the realization of reliable visualization of threatened areas and information about them is through the use of geographic information systems (GIS). Geographic Information Systems (GIS) and Remote Sensing (RS) systems have established themselves as a reliable and frequently used tool and source of information for locating, monitoring, and analysing man-made crises and natural disasters.[4] The analysis of other scientific sources[5] on the topic shows that the use of geodata to analyse hazards such as floods or earthquakes and their impact on critical infrastructure, the use of geographic databases to perform hazards analysis, and the use of GIS to support decision-making in terms of protection of critical infrastructure provide for excellent results. This calls for the research and development of platforms based on GIS systems with open access in order to provide reliable and easily accessible information for prevention and making adequate decisions in crisis situations.

Methods

HTML, CSS, PHP, JavaScript and MySQL programming languages, as well as Google Maps JavaScript API were used to develop the risk visualization platform. In addition, heuristic methods have been used to visualize the distribution of poisonous substances as a use case.

Risk Visualization Platform using GIS

This paper presents the initial stage of the development of a risk visualization platform using GIS and outlines the possibilities for its further development. According to the crisis management function classification,[6] this task is an element of the "Develop expertise in hazard and vulnerability mapping and risk assessment" function. The platform is being developed as part of a project implemented under the National Scientific Program – Security and Defence. Part of the tasks of the project is to select or develop models for the dynamic development of crises of various nature. The authors of this report are tasked with developing a platform for mapping and visualizing hazards, affected areas, etc., which will subsequently assist in risk assessment as well as planning activities related to crisis management. There are various ready-made products and theoretical developments related to hazard and crisis mapping, such as the ones developed by Chituu,[7] ArcGIS,[8] and Dhakal and co-authors.[9] However, each of them works with their own models and different GIS systems, and they cannot find much practical significance in the implementation of the tasks of the above-mentioned project.

Google Maps was chosen as the underlying GIS for the following reasons:

- availability of the system for use, as well as the function libraries for creating applications;
- a rich set of functions for creating different visual and informational layers on the maps, as well as a simplified approach to their use;
- possibility to create WEB-based applications, which in turn are accessible to a large number of users via the Internet;
- possibility to access the applications from different hardware devices – computers, mobile phones, tablets, etc.

The risk visualization platform is developed as a WEB-based application, with a server part (back end) and a client part (front end), respectively. The server part serves to store and provide access to the necessary information as well as to build the platform's website. The client part, on the other hand, performs the visualization of the data received from the server and the communication with the users. The standard PHP, HTML, CSS, and JavaScript languages are used to develop the risk visualization platform. The Heatmap technology of Google Map API are used to build the visualizations. The information needed for the operation of the application is stored in a standard MySQL database. The structure of the database is shown in Figure 1.

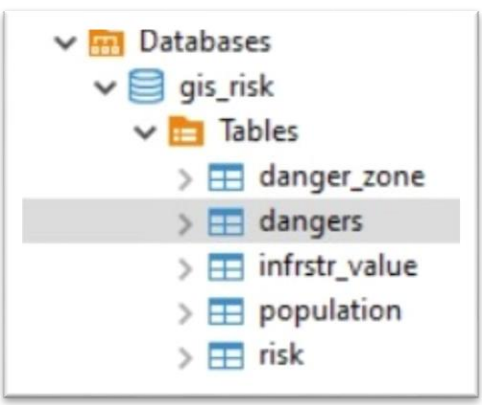


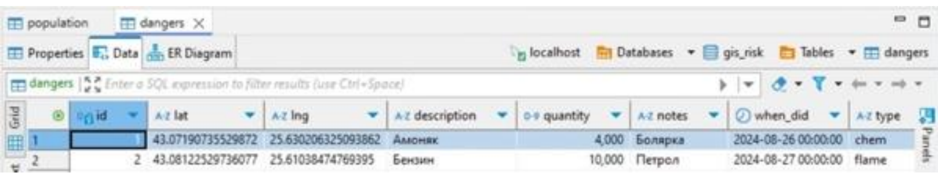
Figure 1: Structure of the database of the risk visualization platform.

The choice of standard tools allows us to easily maintain, update, and further enhance the developed application.

When creating the risk visualization platform, an approach was chosen to build different information layers that could be displayed separately or in different combinations on the screen map.

The following layers have been developed so far:

- *Dangers* – this includes all man-made or natural objects that may threaten their adjacent areas in some way, for example, places for storing poisonous chemicals, radioactive, flammable substances and fuels, explosive substances and ammunition, reservoirs, rivers, landslides, etc. For each of them, the database (DB) stores information about the exact location, the type of danger (toxicity, radioactivity, biological, etc.), the type of substance, its quantity, and notes, which most often show the owner of the object. The structure of the table is shown in Fig. 2.



id	lat	lng	description	quantity	notes	when_did	type
1	43.07190735529872	25.630206325093862	Амоняк	4,000	Болярка	2024-08-26 00:00:00	chem
2	43.08122529736077	25.61038474769395	Бензин	10,000	Петрол	2024-08-27 00:00:00	flame

Figure 2: Structure of table 'Dangers' in DB.

The representation on the map is done by means of icons with signs of the corresponding danger. When the mouse is placed on the icon, additional information from the table is displayed (see Fig. 3.).

- Population (population density) – through this layer, average information about the population density in individual regions is visualized. Data are presented as the number of people per square metre and are colour coded. Blue is chosen as the main colour. Places with a high population density are represented with a darker shade, and those with a low density – with a lighter shade. This allows, by adding the danger zones on this layer, to determine an approximate number of people at risk. Such an approach was used in another scientific development.[10] A visual representation of this information is shown in Figure 3.
- Infrastructure (infrastructure value) – an average infrastructure value is displayed here, similarly to the previous layer. The dimension is levs (value) per square metre, and the main idea here is to add the danger zones over this layer to enable an approximate evaluation of the expected damage to the infrastructure. In addition, taking into account the availability of roads in dangerous areas, such an approach allows the determination of safe and accessible evacuation routes, the movement of

teams of specialists, or the transportation of material resources even at the pre-planning stage of crisis activities.

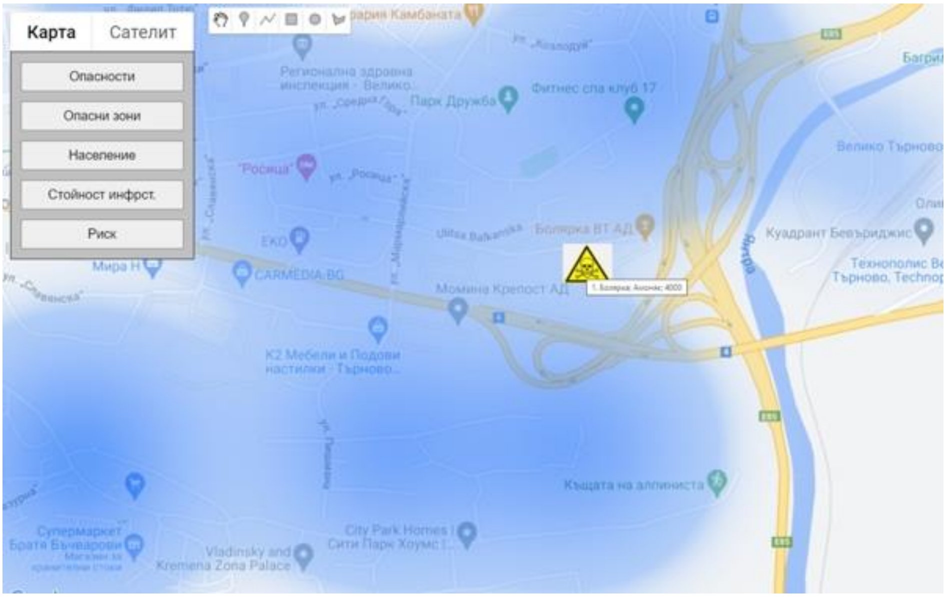


Figure 3: Visualization of dangers and population density.

- Danger zones - in essence, this is a set of separate layers, since for each danger, the threatened area is defined separately. Areas of different intensities of danger are outlined by colour coding, with red showing the places with the highest degree of danger, and yellow – those with the lowest degree. Showing and hiding the danger zone for each individual dangerous object is possible by clicking with the mouse on its icon. A visual representation of this information is shown in Figure 4.

This allows considering the dangers of individual objects or different combinations between them. Determining the intensity, geographic location, and area of threatened areas is done by means of mathematical or simulation models or other approaches. They depend very much on the type of danger and are not the subject of this paper.

The data by which the images in the paper were obtained at the moment do not correspond to reality, but they provide information about the capabilities of the platform and, subsequently, they can be given correctly for the purpose of its proper functioning.

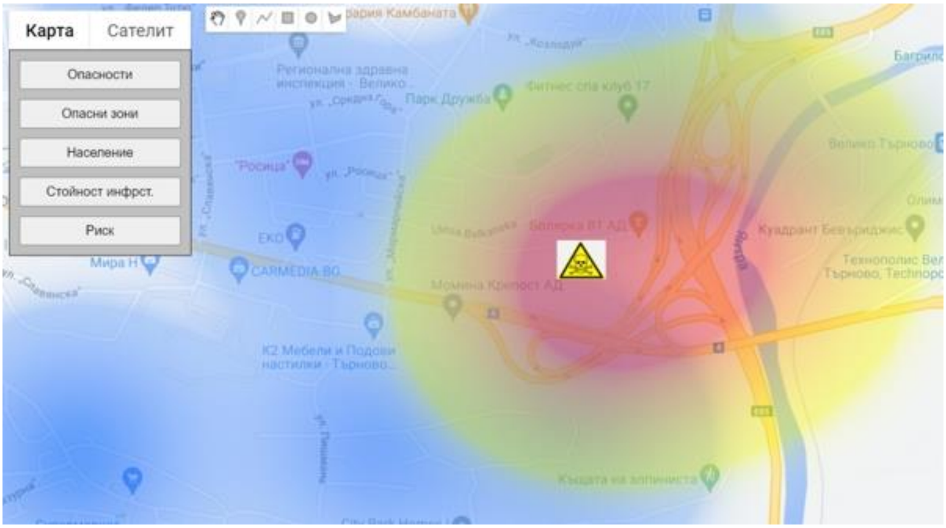


Figure 4: Visualization of the 'Danger zone' layer over other layers in the platform.

As mentioned above, this is the initial stage in the development of the risk visualization platform. More layers of damage and danger assessment, such as consideration of environmental risks, are to be created. An option for visualizing the development of a crisis over time is considered, i.e., a dynamic representation of the increase and, subsequently, the decrease of dangers. An option for numerical presentation of the estimates mentioned above in the paper is yet to be developed. The possibilities of connecting the platform with sensors and monitoring systems that provide real-time information on the presence or development of crisis situations are being explored.

Even in its current form, the risk visualization platform shows that it can be an extremely useful tool for security professionals at the regional and national levels.

Conclusions

The development of a platform for visualising risks in the area of critical infrastructures is not new, but the increasing importance of the information they provide with open access facilitates the use by many people and the making of adequate decisions. A similar platform provides a free open-source geographic information system QGIS software to identify selected critical infrastructure objects based on available GIS open data from the regions of Malaysia and Poland. The development of this and other similar platforms could only enrich the information about the existing dangers caused by anthropogenic and natural factors, which will help to assess better the risk in the areas where they occur for the purposes of prevention and protection of the population and infrastructure.

Acknowledgement

The article presents research results within the National Scientific Program "Security and Defence," funded by the Ministry of Education and Science of the Republic of Bulgaria in implementation of the National Strategy for the Development of Scientific Research 2017-2030, adopted by the Decision of the Council of Ministers No. 731 of 21 October 2021.

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