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Analysis of the Possibilities for Visualizing the Risk of Disasters and Accidents in the Areas of Critical Infrastructure Sites Through GIS Applications

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Abstract **— In today's digitalized world devastated by natural disasters, accidents and catastrophes, the issue of using software applications for the purpose of monitoring and prevention of areas with a high risk of disasters and catastrophes is gaining increasing importance. The purpose of the study is to analyze the regulatory documents regulating critical infrastructure sites and activities for their identification, reporting and protection. The article presents the relationship between the national legislation of the Republic of Bulgaria and the legislation of the European Union regarding the risks of disasters and catastrophes. Using the methods of scientific research as a systematic and scientific analysis, a review of the regulatory documents regulating the protection of critical infrastructure and the possibilities for visualizing the risk of disasters and catastrophes through GIS software applications is carried out. The conclusions of the research show the need for a wider introduction and use of GIS-based software applications with free access, which would allow for the visualization of the risk of disasters in the critical infrastructure sites of the European Union countries. Integrating the collected information into a platform at a European level will enable member states to predict and manage the risks of disasters and catastrophes, which will lead to better advance planning and saving human lives.**

Keywords — Critical infrastructure, risk, disasters and accidents, GIS.

I. Introduction

Natural disasters and industrial accidents have become an integral part of human activity and evolution. Despite the attempts to predict them and take measures to prevent them, the damage and suffering they cause are sometimes enormous, and the activities to eliminate their consequences take a long time and cost colossal amounts of money. According to the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), nearly 300 million people needed assistance and protection in 2024 due to conflicts, natural disasters, accidents, economic instability, etc. [1]. In addition to the damage and victims of these events, the funds to overcome the consequences amount to billions. According to the analysis of the National Centers for Environmental Information (NCEI), disaster damage in 2024 amounted to approximately $182.7 billion. This total amount places 2024 as the fourth most expensive year in US history after 2017 ($395.9 billion), 2005 ($268.5 billion) and 2022 ($183.6 billion) [2]. When disasters and catastrophes affect the critical infrastructure facilities of a country, the consequences for the population and the country or region become even more severe. This results in the need to take preventive measures to identify critical infrastructure facilities, monitor them and visualize the risks that threaten them.

II. Materials and Methods

This study covers scientific research methods, such as systems analysis – to study the complex set of factors accompanying disasters and accidents and affecting critical infrastructure facilities; scientific analysis – to reveal the leading trends in the development of regulatory documents on the identification and protection of critical infrastructures.

III. Results and Discussion

In 2008, in order to establish a procedure for the identification and designation of European critical

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infrastructure and a common approach for assessing the need to improve its protection among the Member States in the European Union, Directive 2008/114/EC [3] of the Council of the European Union on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection within their national borders was adopted. With the introduction of the Directive, basic concepts were formulated such as:

'critical infrastructure' – an element, system or parts thereof located in the Member States which are essential for the maintenance of vital public functions, health, safety, security, economic or social well-being of the population, and whose disruption or destruction would have significant consequences in the given Member State as a result of the impossibility of maintaining these functions;

'European Critical Infrastructures' or 'ECIs' – critical infrastructures located in Member States, the disruption or destruction of which would have significant consequences for two or more Member States. The significance of the consequences is assessed according to cross-sectoral criteria, which also include the consequences of cross-sectoral dependencies on other types of infrastructure;

'risk analysis' – taking into account the relevant scenarios for action under different threats in order to assess the vulnerability and the potential consequences of the disruption or destruction of a critical infrastructure.

The concepts thus formulated and adopted allow for a common understanding between Member States on critical infrastructures and the risks that threaten them. The Directive defines the sectoral and cross-sectoral criteria for establishing ECIs.

The cross-sectoral criteria include: potential number of victims (deaths or injuries); economic consequences (loss and/or deterioration of products or services, including for the environment); societal consequences (for public trust, physical suffering and disruption of daily life; including loss of essential services). The boundaries of the relevant cross-sectoral criteria are determined by the Member States on the basis of the seriousness of the consequences of the disruption or destruction of the given infrastructure in each specific case.

Sectoral criteria take into account the characteristics of the individual sectors with ECIs. The sectors envisaged in the directive are only two – energy (including infrastructures and facilities for the production and transmission of electricity, oil and gas) and transport (road, rail, air, river and maritime).

Based on Directive 2008/114/EC, each Member State should harmonize its national legislation and develop the relevant regulations for the identification, designation and protection of ECIs and their territory. As an EU Member State, the Republic of Bulgaria brought its national legislation into line with the requirements of Directive 2008/114/EC by adopting the Disaster Protection Act [4], and later two regulations – 'Regulation on the procedure, manner and competent authorities for the identification of critical infrastructures and their sites and risk assessment for them' [5] and 'Regulation on the procedure for the identification and designation of European critical infrastructures in the Republic of Bulgaria and measures for their protection' [6].

According to the Disaster Protection Act, it is necessary to carry out preventive activities in order to reduce the risk of disasters, which also include the identification of critical infrastructures and their sites and risk assessment for them, and the specified activities are implemented under a regulation of the Council of Ministers. As for the establishment of a potential European Critical Infrastructure (ECI) on the territory of the Republic of Bulgaria, it is carried out by the relevant minister [4]. Updating of the information in relation to the identification and designation of ECI is carried out periodically every two years by submitting it to the European Commission. The two regulations [5], [6] determine the procedure and responsibilities of the competent authorities for the identification, designation and risk assessment of national and European critical infrastructures and their sites, which will facilitate the adoption of measures to reduce the risk of disasters and protect the population.

The Council of Ministers' Decree № 181 of 20 July 2009 [7] defines the strategic sites and activities that are important for the national security of the Republic of Bulgaria and that are part of the critical infrastructure. 14 sectors are specified, each of which includes the relevant strategic activities and sites:

- Sector 'Agriculture, Food Production and Safety';
- Sector 'Ecology';
- Sector 'Water Resources';
- Sector 'Healthcare';
- Sector 'Energy';
- Sector 'Transport';
- Sector 'Telecommunications and Information';
- Sector 'Government';
- Sector 'Finance';
- Sector 'Education, Science and Technology';
- Sector 'Strategic Objects and Activities of the Ministry of Interior';
- Sector 'Strategic Objects and Activities of the Ministry of Defense';
- Sector 'Strategic Objects and Activities of the National Intelligence Service';
- Sector 'Strategic Objects and Activities of the National Security State Agency.

Decree №181 also defines the obligations of the heads of specific ministries and departments for the implementation of measures for the protection of strategic activities and sites, including the financing of these measures. In 2019, with the onset of the COVID-19 epidemic, a review of Directive 2008/114/EC was carried out, which established that due to the increasingly interconnected and cross-border nature of activities using critical infrastructures, protective measures related only to individual assets are not sufficient to prevent the occurrence of all types of violations. In order to better account for risks, better define and ensure more consistently the role and obligations of critical entities as providers of services essential for the functioning of the European Union and the resilience of critical entities, Directive (EU) 2022/2557 [8] of 14 December 2022 on the resilience of critical entities was adopted, which repeals Council Directive 2008/114/EC. Directive 2022/2557 provides for obligations on Member States to take specific measures to ensure the uninterrupted provision of services that are significant for the maintenance of essential societal functions or economic activities of the Union. In addition, the document sets out obligations on critical entities responsible for critical infrastructures, and these obligations are aimed at increasing their resilience and their ability to provide services to the internal market. Given the increasing interdependencies between infrastructures and sectors as a result of the increasingly complex cross-border interdependencies in the European Union service provision network, in addition to the existing two sectors, energy and transport, 10 (ten) more sectors with their associated sub-sectors were identified as follows: banking; drinking water, wastewater; food production, processing and distribution; healthcare; space; public administration, financial market infrastructure and digital infrastructure. It is the obligation of each Member State to harmonize its national legislation with the requirements of the Directive by 17 July 2026 and to identify the critical entities for the above-mentioned sectors with their associated sub-sectors.

The review of the regulatory framework of the European Union and the Republic of Bulgaria gives reason to conclude that in recent years, a large number of documents have been adopted regulating critical infrastructure sites, providing guidelines for assessing the risk in them and taking measures to minimize it. This contributes to the harmonization of the national legislation of the member states with that of the European Union. However, there are still not enough software applications generally available to citizens-non-specialists which would allow for the visualization of the risk of disasters and accidents in critical infrastructure sites, especially in populated areas and in their vicinity where there is a large population potentially threatened by specific risks. One of the tools for visualization and monitoring of the risk of disasters and catastrophes, which is increasingly being used in this direction, are various platforms based on Geographic Information Systems.

In recent years, a large number of software based on GIS have been developed and introduced. They have become increasingly used to visualize and monitor areas of disasters and catastrophes, so we will examine their development and application for visualizing risk in critical infrastructure facilities.

A geographic information system is a system that integrates software and hardware for storing, managing, analyzing, visualizing, and sharing geographically-based information (Fig. 1).

These systems integrate specific information with a specific area on a map, linking location data with all kinds of descriptive information. GIS allows users to create interactive queries, analyze spatial information, collect and edit data, maps, and visualize the results of all these activities.

GIS has a wide range of applications, and can be used for engineering design, scientific research, resource management, environmental impact assessment, urban planning, telecommunications, mapping, forensic analysis, historical research, marketing research, and logistics planning.

The origins of GIS date back thousands of years when people painted images of the animals they hunted on cave walls. These drawings were maps of routes and migration paths of animals. One of the earliest successful applications of GIS was in 1854, when John Snow, an epidemiologist and physician, was able to identify a pumping station as the source of a cholera epidemic in London by using spatial analysis.

The founder of modern GIS is considered to be Dr. Roger Tomlinson [9]. In 1962, he created the Canadian Geographic Information System, developed by the federal Department of Forestry and Rural Development in Ottawa, Canada. The system is used to store, analyze, and process land data in rural Canada by mapping information on soils, agriculture, recreation, wildlife, and forestry on maps at a scale of 1:50,000.

Increasingly, GIS-based applications have developed the concept of overlaying different mapped features on top of each other to determine patterns and causes of spatial phenomena (See Figure 2).

In the early 1980s, companies such as M&S Computing (later Intergraph), Environmental Systems Research Institute (ESRI), and CARIS began offering services as GIS software providers, incorporating many of the features of the Canadian GIS, combining a first-generation approach to separating spatial and attribute information with a second-generation approach to organizing attribute data into database structures. More of the software's usability features were developed primarily in a graphical manner with a user-friendly

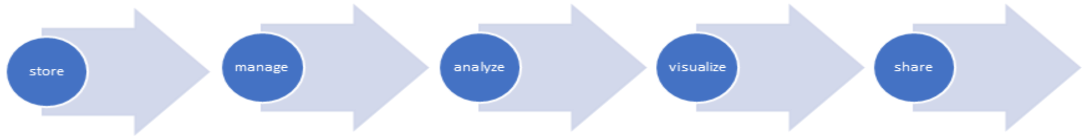

Fig. 1. Geographic information system, presented as software and hardware for storing, managing, analyzing, visualizing, and sharing geographically oriented information.

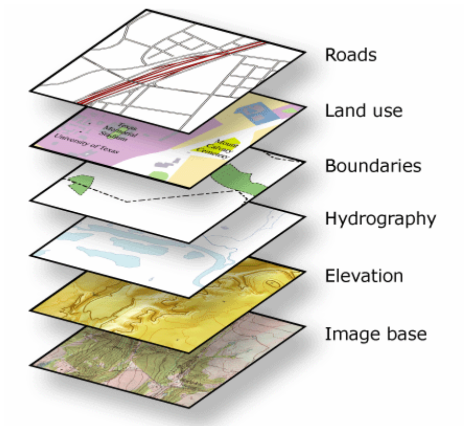

Fig. 2. The following figure illustrates how geographical elements are portrayed in maps through a series of map layers (sfr. ESRI)

Graphical User Interface (GUI) that provided the ability to sort, select, extract, reclassify, reproject, and display data based on complex geographic, topological, and statistical criteria. At the same time, the development of a public-use GIS began at the United States Army Engineering Research Laboratory (USA-CERL) in Champaign, Illinois, a branch of the United States Army Corps of Engineers. The development was provided to meet the United States Army's need for software for land management and environmental planning.

Gradually, GIS applications began to be developed by many private companies, the most widely used of which are: ESRI, GRAM++ GIS, Autodesk, Cadcorp, Intergraph, ERDAS IMAGINE, SuperGeo, SuperMap GIS, IDRISI, MapInfo, MapPoint, Caliper, Pictometry, Black Coral Inc, STAR-APIC, CARIS (Computer Aided Resource Information System), GMS, Manifold System, Oracle Spatial, Safe Software, Smallworld, TatukGIS, Axpand.

One of the applications of GIS is risk management in critical infrastructure areas. Risk management through GIS-based applications is a complex, interdisciplinary field involving computer science, mathematics, statistics, finance, and management [10].

Risk management itself is a process containing the steps of identifying, assessing and treating risks [11]. Risk identification is a complex activity that includes an analysis of the sources and threats of a negative event, the probability of achieving objectives and the occurrence of certain scenarios. Then, based on the identification, risks are assessed in terms of their potential severity of losses and casualties and the probability of the occurrence of the risk events themselves. The final stage of risk management – treatment, includes taking measures to avoid (also known as elimination), reduce (also known as mitigation), assume or transfer risks.

Risk management in complex systems, such as critical infrastructures, which consist of multi-component geographical areas, understanding all the factors involved in a risk situation, is a difficult process. For this reason, risk assessment approaches require taking into account all social, economic, cultural and political aspects in order to determine the vulnerability, resilience and response capacity of the specific system against various threats.

According to some authors, the two main challenges for risk management and resilience of critical infrastructure are the interconnectedness between infrastructures and the multi-actor relationships in which they operate [12]. For this reason, they should be considered as a system in which changes in the state of one of the elements of the system lead to a change in the state of the entire system.

Of great importance for the assessment of the risk of natural disasters or industrial accidents is that they depend on the location, and in many cases, there is sufficient historical information which includes specific data on previous such events (for example, previous earthquakes, floods, fires and potential damages). For the needs of risk assessment, mathematical models are usually prepared in order to establish the probability of a given event occurring with a certain degree of intensity at a given location. The main limitation of this type of approach is that risk necessarily involves uncertainty, and it is necessary to make realistic hypotheses about possible future scenarios.

Once the risk assessment for the occurrence of a specific disaster or accident in critical infrastructure sites is prepared, they are visualized on maps by linking the data about the event to the specific geographical terrain. In this way, GIS technologies visualize the identified risks, the affected areas and the potential damages that can be caused. Presented in this way, spatial information can visualize

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relationships, patterns and trends that would not be noticeable otherwise. In a previous study [13], the possibilities of using GIS were discussed, presenting an initial stage of the development of a platform for visualizing the level of risk from industrial accidents or natural disasters in individual zones and regions of critical infrastructure sites using a geographic information system (GIS).

Risk assessment in critical infrastructure sites can be considered as a set of two main components – hazard and vulnerability [14]. Hazard is a measure of the physical intensity of the threat at a given location and the associated probabilities of these intensities, depending on the location (e.g. a location surrounded by seismic faults, near the shore of a water basin, mountainous terrain, etc.). Vulnerability is a measure of the damage that the hazard can cause to the critical infrastructure under study and/or its objects (e.g. in urban areas damage to infrastructure, communications and service provision). The synthesis of these data, presented on a map with the spatial relationships between natural or anthropogenic factors (earthquake, landslide, industrial accident, physical or logical attacks) and the elements at risk (people, buildings, infrastructure), represented through the use of GIS tools, can facilitate crisis response planning and taking preventive measures to protect critical infrastructures.

IV. Conclusions

GIS applications for visualizing risk in critical infrastructure facilities provide a wide range of opportunities for unifying and visualizing information on potential risks from disasters and accidents that could lead to disruption of normal life in society, cessation of essential services, human casualties, and large-scale damage. Free access to these data and their rapid use could significantly facilitate the preliminary planning of activities to minimize the identified risks in critical infrastructures, assessment of potential damage and casualties. This requires the implementation and use of open access GIS software applications for visualizing and assessing the risk of disasters occurring in critical infrastructure facilities not only at the national but also at the European level, using a unified system for their forecasting and management.

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References

[1] Sevil Omer, Aubrey Leasure, 11 Worst Disasters of 2024, https://www.wvi.org/worst-disasters, [Accessed: 18 Feb 2025]

[2] B.Adam, Smith, 2024: An active year of U.S. billion-dollar weather and climate disasters, 10 January 2025, https://www.climate.gov/news-features/blogs/beyond-data/2024-active-year-us-billion-dollar-weather-and-climate-disasters, [Accessed: 18 Feb 2025]

[3] Directive 2008/114/EC of 8 December 2008 on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection, Official Journal of the European Union OJ L 345, 23 December 2008, http://data.europa.eu/eli/dir/2008/114/oj, [Accessed: 18 Feb 2025]

[4] Disaster Protection Act, Promulgated in the State Gazette, issue 102 of 19 December 2006, amended and supplemented in the State Gazette, issue 60 of 7 July 2020

[5] Regulation on the procedure, manner and competent authorities for the identification of critical infrastructures and their sites and risk assessment for them In force since 23 October 2012, Adopted by Council of Ministers' Decree № 256 of 17 October 2012, Promulgated in the State Gazette, issue 81 of 23 October 2012, amended and supplemented in the State Gazette, issue 19 of 26 February 2013, amended in the State Gazette, issue 27 of 5 April 2016

[6] Regulation on the procedure for the identification and designation of European critical infrastructures in the Republic of Bulgaria and measures for their protection Adopted by Council of Ministers' Decree № 38 of 18 February 2013. Promulgated in the State Gazette, issue 19 of 26 February 2013.

[7] Decree of the Council of Ministers №181 of 20 July 2009 on the designation of strategic sites and activities of importance for national security, Promulgated in the State Gazette, issue 59 of 28 July 2009, supplemented, issue 71 of 13 September 2011, in force from 13 September 2011, issue 77 of 4 October 2011, amended and supplemented, issue 33 of 20 April 2021, in force from 20 April 2021

[8] Directive (EU) 2022/2557 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 December 2022 on the resilience of critical entities and repealing Council Directive 2008/114/EC, Official Journal of the European Union OB L 333, 27 December 2022, http://data.europa.eu/eli/dir/2022/2557/oj, [Accessed: 18 Feb 2025]

[9] D.Pant, M. Kumar, S. Goyal, Fundamentals of GIS, Department of Sensing and GIS School of Earth and Environment Science Uttarakhand Open University Haldwani (Nainital), GIS-503/DGIS-503/CGIS-503, Published By: Uttarakhand Open University, Haldwani, Nainital-263139 , ISBN No.: 978-93-90845-49-1, Edition First, 2021, https://www.uou.ac.in/sites/default/files/slm/GIS-503.pdf, [Accessed: 20 Feb 2025]

[10] J.Stanik, and M. Kiedrowicz, "Risk In Gis Systems", GIS Odyssey Journal, 2022, 2(1), 39–56. https://doi.org/10.57599/gisoj.2022.2.1.39

[11] N. Dimitrov, Security Risk Management in the QUAZAR Competence Center, Nikola Vaptsarov Naval Academy, Varna, 2022, ISBN 978-619-7428-86-5 (print), ISBN 978-619-7428-87-2 (e-book), DOI: 10.13140/RG.2.2.31640.78089

[12] B. Arvidsson, J. Johansson, N. Guldåker, Critical infrastructure, geographical information science and risk governance: A systematic cross-field review. Volume 213, 2021, 107741, ISSN 0951-8320, https://doi.org/10.1016/j.ress.2021.107741

[13] G. Grigor, S. Stefanov, and S. Spirdonov. 'Use of a GIS System to Visualize the Levels of Risk in the Areas of Critical Infrastructure Objects.' Information & Security 55.1 (2024): 55-62. ISSN 0861-5160 (print), ISSN 1314-2119 (online), https://doi.org/10.11610/isij.5521

[14] M. Peggion, A. Bernardini, M. Masera, Geographic Information System and Risk Assessment, European Commission, Joint Research Centre, Institute for the Protection and Security of the Citizen, January 2008, ISSN 1018-5593