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THE USE OF GIS FOR THE MANAGEMENT OF NATURAL DISASTERS AND CRISIS SITUATIONS

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ABSTRACT: *The increasing frequency and intensity of natural disasters highlight the urgent need for effective tools to support crisis management. Geographic Information Systems (GIS) have established themselves as a key platform for collecting, analyzing, and visualizing spatial data, providing decision-makers with timely and reliable information. This paper explores the role of GIS in disaster management across all critical phases: prevention, monitoring, response, and recovery. The study emphasizes the integration of real-time data, IoT sensors, and satellite imagery, which enhance early warning systems and improve coordination between institutions. In addition, technological innovations such as artificial intelligence, cloud computing, and AR/VR visualization extend the potential of GIS for predictive analytics, training, and rapid response. By examining international best practices and national applications, the paper outlines the challenges and opportunities for developing resilient GIS-based solutions. The findings demonstrate that GIS is not only a technological tool but also a strategic instrument for reducing risks, optimizing resource allocation, and supporting sustainable development in the face of natural disasters.*

KEY WORDS: *GIS, Disaster management, Real-time data, Crisis response, IoT, Artificial intelligence, Cloud computing, Predictive analytics, Resilience.*

1. Introduction

In recent decades, Bulgaria has been exposed to a variety of natural hazards such as floods, landslides, earthquakes, forest fires, droughts, strong winds, heavy snowfalls, extreme temperatures, and hailstorms, with the first three being the most prominent. The disasters caused by these phenomena have a detrimental impact on economic and social development, leading to inevitable cascading effects on poverty, food and water supply, the spread of diseases, human migration, and conflicts. The risks of disasters facing the country are expected to increase due to growing urbanization, industrial development, and climate change [1]. In this context, effective disaster management requires the integration of sufficient, reliable, and timely information about the specific situation to support informed decision-making, sustainable management, and efficient resource allocation.

Geographic Information Systems (GIS) have emerged as one of the most powerful technological tools in this regard. They enable the collection, processing, and visualization of spatial data, providing decision-makers with a comprehensive real-time picture of the situation and the ability to model various scenarios [2,3]. Unlike traditional information systems, GIS offers the advantage of integrating data from multiple sources - sensors and detectors, satellite and terrestrial imagery, incident and event signals - i.e., utilizing shared geospatial data, information, applications, and services, which allows for multidimensional analysis of complex phenomena [4].

The role of GIS in disaster management is evident across all key phases: prevention, preparedness, response, and recovery. During a disaster situation, GIS allows authorities to identify high-risk areas, simulate disaster scenarios, improve inter-agency coordination, optimize evacuation routes, support disaster risk assessment and damage evaluation, and contribute to the development of resilient infrastructure and sustainable policies. The integration of modern technologies - including artificial intelligence and machine learning, 5G networks and IoT devices, cloud technologies and edge solutions, as well as AR/VR visualizations and simulations - further expands the potential of GIS in disaster management.

The main objectives of this paper are:

- To analyze the role of GIS in the management of natural disasters and crises across all phases;
- To present the technological innovations that expand the capabilities of GIS in real-time applications;
- To highlight the challenges and opportunities for the effective use of GIS as a strategic tool for crisis management and sustainable development.

By examining these aspects, the paper emphasizes that GIS is no longer just a technical system but a powerful tool for planning, design, and decision-making across various public sectors and businesses of different scales and nature. GIS can be considered a critical component of integrated disaster risk management strategies at both national and international levels.

2. Exposition

2.1. Natural Disasters and the Challenges of Their Management

Natural disasters such as floods, earthquakes, droughts, forest fires, hurricanes, and landslides are among the most destructive events affecting populations and infrastructure. Their unpredictability, combined with their rapid development and escalation, complicates the efforts of responsible institutions to respond effectively and manage recovery operations. The main challenges include the need for rapid situational awareness, effective inter-institutional coordination, and efficient use of limited resources. Geospatial data is a critical component in this process, as it enables the identification of risk-prone areas, the modeling and tracking of various scenarios, and the visualization of descriptive data on the impacts on infrastructure and populations [2,3].

2.2. The Role of GIS in the Phases of Disaster Management

GIS provide the capability to integrate and visually represent available data - including sensor and detector inputs, satellite and terrestrial imagery, and incident and event signals - into a single operational picture, thereby supporting disaster management across all stages: from risk assessment and prevention, through detection and early warning, to mitigation, response, and post-disaster recovery [5].

GIS technology supports all aspects of disaster and emergency management, including activities related to [5]:

- Management of response forces and their resources;
- Management of critical infrastructure;
- Operational coordination;
- Deployment and coordination of mobile teams;
- Monitoring, analysis, and assessment of critical factors;
- Public alerting and notification;
- Integration with emergency call services (e.g., 112);
- Tracking of mobile assets;
- Access to real-time meteorological conditions;
- Publishing information online for the needs of other organizations or for informing the public.

GIS enables all responsible institutions involved in disaster situations to exchange information in real time - whether for forecasting and preventive measures or for managing the consequences of emergency events.

Prevention and Preparedness

GIS plays a crucial role in disaster prevention by mapping risk zones and modeling potential scenarios. In this context, GIS ensures rapid access to up-to-date information about the situation on the ground, as well as about potentially hazardous and vulnerable sites based on the passportization of critical infrastructure. It also enables the simulation of various possible scenarios and the modeling of their potential outcomes.

For example, flood-prone areas can be identified through the analysis of historical precipitation data, terrain elevation, and river dynamics. Similarly, seismic hazard maps are created to assess areas vulnerable to earthquakes. These analyses support urban and territorial planning, infrastructure development, and the design of risk mitigation measures.

During the preparedness phase, GIS facilitates strategic planning, staff training, and the development of evacuation plans [4].

Monitoring and Early Warning

Through the integration of remote sensing data, IoT devices, and satellite imagery, GIS platforms enable continuous monitoring of environmental conditions. In real time, they provide valuable information on noise levels, total concentrations of pollutants, river levels, soil moisture, vegetation conditions, and atmospheric parameters - all of which are critical for early warning systems. Additionally, GIS allows the generation of various reports based on specific queries and provides detailed information on measurement points, air pollutants and their concentrations, water acidity levels, and deviations from established norms.

Modern GIS systems also support communication with the public by disseminating alerts and evacuation instructions. This significantly reduces response times and helps minimize human and material losses [6].

Response During a Disaster

The response phase is the most critical stage in disaster management. GIS enhances institutional communication and coordination by integrating multiple data sources into a shared platform accessible to government agencies, emergency services, and local authorities. By integrating satellite and terrestrial imagery to visualize affected areas and critical points, GIS helps identify priority zones for rescue operations, facilitates the efficient allocation of resources, and optimizes logistics and transportation routes. Real-time navigation systems powered by GIS ensure that rescue teams can reach those in need quickly and efficiently [7].

Post-Disaster Recovery

GIS is an indispensable tool for disaster risk assessment and damage evaluation, contributing significantly to the development of resilient infrastructure. Integrated data from multiple sources - both satellite and terrestrial - within GIS platforms provides accurate information on affected infrastructure, communication networks, agricultural lands, vegetation cover, and ecosystems. It is preferable for the metadata to be in digital form and to constitute an integral part of the measurement. Data quality can be ensured through automatic (non-interactive) and manual (interactive) quality control [8]. Spatial analyses support the prioritization and optimization of recovery activities and guide investments toward sustainable development policies. The lessons learned from post-disaster activities and the demonstrated best European practices (see Section 2.4) contribute to improving prevention and preparedness, creating a cycle of continuous enhancement and adaptation [9].

2.3. Technological Aspects of GIS in Disaster Management

Modern GIS applications are being enhanced by technological innovations that significantly increase their effectiveness and scope.

Cloud computing has emerged as a key technological trend across nearly every industry - including the GIS community - and is rapidly entering mainstream use. It enables large-scale storage and processing of spatial data, making GIS more accessible to institutions with limited resources [10]. Edge computing ensures that data is pre-processed close to its source, thereby reducing latency and improving response times. 5G networks and IoT devices provide a continuous flow of real-time information, which is crucial for timely decision-making [9].

Artificial intelligence (AI) and machine learning (ML) assist in uncovering hidden patterns in spatial data and predicting disaster events. For example, AI algorithms can forecast the spread of wildfires or the progression of floods based on meteorological conditions and terrain characteristics [7].

In addition, AR/VR technologies are increasingly used in disaster management training and simulations. They enable emergency response teams to visualize complex scenarios and practice coordinated actions in a safe and controlled environment [11].

Given the sensitivity of disaster-related data, cybersecurity is another critical aspect. Ensuring the protection of data from unauthorized access or cyberattacks is vital, especially when GIS platforms are used by multiple institutions and international organizations [12].

2.4. Examples and Best Practices

GIS is increasingly applied in disaster management at both national and international levels.

For example, the Federal Emergency Management Agency (FEMA) in the United States uses GIS for coordinating emergency responses and managing resources during hurricanes and wildfires. In the European Union, the Copernicus Emergency Management Service (CEMS) provides satellite data and GIS analyses to support member states in disaster response and recovery efforts [13]. The Global Disaster Alert and Coordination System (GDACS) offers near-real-time alerts on natural disasters worldwide and provides web-based tools for monitoring and coordinating response actions.

In Bulgaria, GIS is applied in wildfire management, flood monitoring, and epidemiological control during the COVID-19 pandemic, among other areas. The Center for Remote Sensing Application – RESAC and the Agency for Sustainable Development and European Integration have already developed 163 flood simulation models with different inundation levels. The Bulgarian Spatial Data Infrastructure continuously expands thematic information on various risks in GIS format. Additionally, Esri Bulgaria provides a wide range of fundamental and specialized digital geographic data for Bulgaria at different scales - including terrain, hydrology, road networks, settlements, administrative divisions, transportation infrastructure, and points of interest - through its official online platform. This enables simultaneous access to information at local, regional, and global levels.

These examples demonstrate the growing recognition of GIS as a critical tool for disaster management on both national and international scales.

2.5. Challenges and Limitations

The distributed computing environment enabled by the internet introduces a new set of challenges and opportunities. The integration and adaptation of the latest technological advancements make GIS easier to use, more interoperable, more powerful, and ultimately more effective in fulfilling their intended purpose.

Despite its potential, the use of GIS for disaster management faces several limitations, particularly in terms of financing, human resources, and platform integration.

Financial and organizational barriers remain significant, as the development of GIS platforms requires substantial investments in hardware, software, and training. The shortage of adequately trained specialists limits the effective implementation and utilization of these systems. Another key challenge is interoperability: different institutions often use different GIS platforms and data formats, which complicates data exchange and coordination between stakeholders [4,10].

2.6. Future Trends

The geospatial industry, the IT environment, and the world around us are changing rapidly. GIS has a long history of successfully adapting to new technologies, applications, client types, and business models. Key trends shaping the future development of GIS in disaster management include the integration of IoT and 5G networks, artificial intelligence (AI) and machine learning (ML), cloud technologies and edge computing, as well as AR/VR and blockchain technologies.

The integration of IoT and 5G networks can enhance real-time data collection and enable more efficient decision-making. Machine learning and predictive analytics can provide more accurate forecasts of disaster events. Cloud and edge solutions deliver scalability and speed, while AR/VR technologies support training and operational planning. At the same time, blockchain can ensure data authenticity and build trust between institutions involved in disaster management [6,11].

3. Conclusion

Real-time Geographic Information Systems (GIS) have become an indispensable component of disaster risk management and crisis response. By integrating spatial data from diverse sources, they provide decision-makers with timely and accurate information that supports rapid action in complex and dynamic environments. Their role spans all phases of disaster management - prevention, preparedness, response, and recovery - highlighting their strategic value for institutions and societies.

At the same time, the effective use of GIS still faces barriers, including high financial costs, organizational limitations, a lack of interoperability, and a shortage of trained specialists. Overcoming these challenges requires continuous investment in infrastructure, the development of common standards, and enhanced inter-institutional cooperation.

It is important to emphasize that real-time GIS should not be viewed merely as a technological platform but as a foundation for building resilience. By improving coordination, optimizing resource allocation, and supporting data-driven decision-making, GIS contributes to reducing human and material losses, accelerating recovery, and promoting sustainable development. In the face of increasingly frequent and severe disasters, GIS will continue to evolve as a strategic tool for protecting lives, infrastructure, and the environment.

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