International Cartographic Association
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Cartographic Analysis of Nature Risks and a Proposal for a New Early Warning System in Bulgaria

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Abstract: This report examines the current state of data and cartographic sources for crisis management in Bulgaria, highlighting the underdeveloped nature of flood mapping and the fragmented data collection processes. The International Commission for the Protection of the Danube River (ICPDR) and the Bulgarian Academy of Sciences have initiated projects aimed at improving flood risk prediction and mapping. Satellite imagery and geographical atlases are discussed as crucial tools for visualizing disaster impacts and aiding in risk assessment.

Despite these efforts, significant gaps remain in Bulgaria's cartographic resources and early warning systems. The report reviews international examples from the Czech Republic, Africa, and France, emphasizing the benefits of GIS-based mapping, real-time data integration, and coordinated crisis management strategies. The proposed conceptual framework for Bulgaria includes comprehensive risk mapping, centralized GIS integration, public awareness programs, technological advancements, and interagency collaboration to enhance disaster preparedness and response.

By addressing these gaps and adopting a more integrated approach, Bulgaria can improve its capacity to manage natural disasters, reduce economic losses, and protect its population. The report concludes with recommendations for implementing a unified disaster database and improving public training to foster resilience, and proposes a new early warning system for Bulgaria.

Keywords: nature risk, EWS, mapping

1. Introduction

Bulgaria, located in South-eastern Europe, is prone to various natural risks due to its diverse geography and climatic conditions. These include earthquakes, floods, landslides, forest fires, and extreme weather events.

Mapping natural risks and analyzing the damages they cause are crucial for developing preventive programs to mitigate severe disaster impacts. The manner of visualizing these phenomena is equally important, as it offers a clear understanding of the disaster's nature, scope, and consequences. By leveraging available resources in Bulgaria and international experience, this report proposes advancements in cartography to support early warning systems and crisis management.

Having the geographic context, we can pay attention to the most common natural disasters: *earthquakes* – this is because Bulgaria is located in the seismically active Balkan region, particularly influenced by the Vrancea seismic zone in Romania and geodetic and cartographic tools help map fault lines and seismic zones (Pashova, 2025); *floods* - the country's river systems, including the Danube and Maritsa, are vulnerable to flooding, especially during heavy rainfall and snowmelt and floodplain maps aid in identifying high-risk areas; and *landslides* - Bulgaria's mountainous regions, such as the Rhodope and Balkan Mountains, are susceptible to landslides, particularly in regions with deforestation or human activity and forest fires - these are common in the summer months, especially in forested regions in the south (Velichkova et al, 2017).

In recent years, numerous destructive natural disasters have occurred worldwide, such as tsunamis in Asia, hurricanes in the Americas, and earthquakes in Pakistan and India. These events revealed a common issue: the lack of institutional preparedness to respond effectively. Over the past two decades, natural disasters have caused over 3 million deaths, left more than 1 billion people homeless, and resulted in widespread injuries and diseases. In 2020 99 million people were affected and more than 15 000 died and in 2021 121 million people were affected and close to 15 000 died because of natural disasters (EM-DAT).

Although retrospective analysis often highlights missed opportunities, proactive measures and accurate predictions remain challenging. Geographic Information Systems (GIS) play a pivotal role in improving responses to disasters. Using GIS, the role of cartographic analysis became very important in three directions: *hazard mapping* - identifies and visualizes areas at risk to overlay data on natural hazards; risk assessment: which combines

Advances in Cartography and GIScience of the International Cartographic Association, 5, 4, 2025.
32nd International Cartographic Conference (ICC 2025), 17–22 August 2025, Vancouver, Canada. This contribution underwent double-blind peer review based on the full paper. https://doi.org/10.5194/ica-adv-5-4-2025 |

hazard maps with data on population density, infrastructure, and economic assets to assess vulnerability; *planning and mitigation* - provides decision-makers with visual tools for urban planning, evacuation routes, and resource allocation during emergencies and *technological advances* - the use of remote sensing, drones, and satellite imagery has improved the accuracy of cartographic data and integration of real-time data from weather stations and sensors enhances the ability to predict and respond to natural hazards (Konecny et al, 2020).

Early warning systems (EWS) are essential for mitigating the impact of natural disasters and crises. They combine monitoring, prediction, and communication tools to provide timely alerts to populations at risk. The components of EWS could be the following ones: *Risk Knowledge* - understanding hazards and vulnerabilities through historical data and modeling; *Monitoring and Prediction* - continuous observation of environmental indicators, such as seismic activity, weather patterns, and water levels; *Dissemination of Information* - ensuring that warnings reach affected populations effectively, often using SMS, social media, sirens, or traditional media; Preparedness and Response - educating communities on how to react to warnings and implementing contingency plans (Johnson, 2000). Global Examples could be shown: *Japan* - advanced earthquake early warning systems using a network of seismometers provide alerts within seconds of detecting seismic activity; *United States* - the National Oceanic and Atmospheric Administration (NOAA) operates sophisticated weather prediction and storm tracking systems; *India* - the Indian Ocean Tsunami Warning and Mitigation System monitors seismic activity and ocean conditions to issue tsunami alerts; *Bangladesh* - community-based warning systems for cyclones combine high-tech monitoring with local communication networks, saving thousands of lives.

The Challenge for cartography and related specialists is ensuring coverage in remote or underserved areas; Addressing technological and infrastructure disparities between developed and developing countries and Combating misinformation or lack of public trust in warnings. The *innovations in EWS* are the following ones: *Artificial Intelligence (AI)* enhances prediction models by analyzing vast datasets; *Mobile Technology* expands the reach of alerts through smartphones and *wearable devices and Satellite-Based Systems* which improve coverage and accuracy in monitoring natural hazards could be used for meeting the good results. Another opportunity for all specialists is the integration of cartographic analysis and EWS which creates a powerful tool for crisis management. In Bulgaria and globally, these integrated systems can enhance real-time risk mapping; support targeted evacuations and resource allocation, and reduce loss of life and property through timely interventions (WMO, 2018 and 2020).

By leveraging technology and global best practices, all nations can strengthen resilience to natural risks and improve crisis response. One of the key points for increasing this resilience is the availability of reliable and up-to-date data and cartographic sources, especially when addressing crisis situations in specific regions, such as Bulgaria.

2. Analysis of Data and Cartographic Sources for Crisis Situations in Bulgaria

In Bulgaria, the practice of mapping flood-affected areas remains underdeveloped. Data collection lacks systematic and detailed processes to support institutions involved in civil protection adequately.

2.1 Current Initiatives

The International Commission for the Protection of the Danube River (ICPDR), headquartered in Vienna, has proposed an integrated early warning system to predict flood risks based on factors like regional rainfall and snowmelt. This system is expected to issue warnings up to ten days in advance (ICPDR, 2024).

A large-scale project addressing climate change impacts is under development by the National Institute of Meteorology and Hydrology at the Bulgarian Academy of Sciences and the Ministry of Environment. The project aims to produce flood risk maps and pilot an early warning system in Sofia's fields, where the economic consequences of flooding could be severe. This system is designed to be adaptable for other high-risk regions, integrating all relevant agencies into a national information system (Bocheva et al, 2023).

2.2 Examples of Cartographic Visualization

2.2.1 *Satellite Imagery*

Satellite images play a crucial role in the cartographic visualization of natural disasters by providing accurate, timely, and comprehensive data. They could help in *pre-disaster mapping* by creating base maps. They are reference points to compare changes and assess damage (Voigt ae al, 2007). Another help is the *hazard assessment*. It helps identify areas vulnerable to disasters, enabling proactive planning. During a disaster, the helpful instrument is *real-time monitoring*. Satellites provide real-time or near-real-time imagery that is critical for understanding the disaster's scope and dynamics (Pacheco da Costa et al, 2024). The last step could be the *post-disaster damage assessment*. Comparing pre- and post-disaster images helps visualize the extent of destruction, such as collapsed buildings, inundated areas, or scorched land (Lozano and Tien, 2023).

Satellite imagery is an indispensable tool for cartographic visualization during natural disasters. It enhances decision-making, facilitates efficient resource allocation, and helps save lives and property through accurate, visually compelling maps.

Satellite images (e.g., Figures 1 and 2) highlight the difference between normal and critical river states, such as the Danube River and Sofia city during a crisis.

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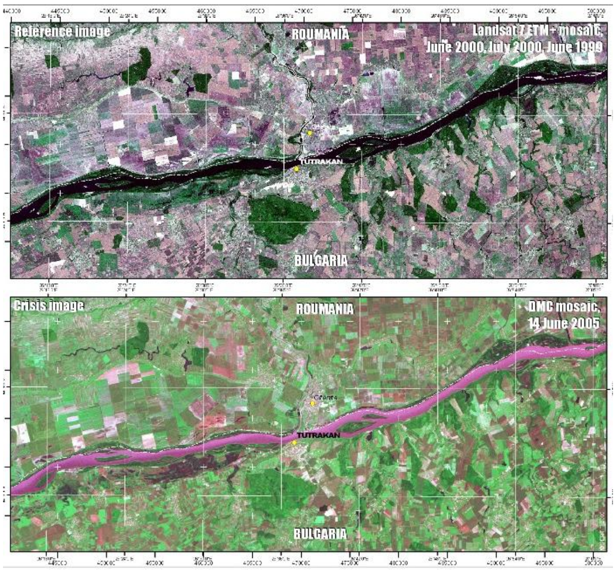

Figure 1. Satellite images of the Danube River

2.2.2 *Geographical Atlases*

Geographical atlases are invaluable tools for early warning and crisis management because they provide organized, visualized data that supports decision-making before, during, and after crises. Here's how they can be used effectively. In risk identification, atlases can highlight areas prone to specific hazards like earthquakes, floods, droughts, or tsunamis using hazard maps. They provide insights into geographical features contributing to risks, such as floodplains, fault lines, or areas with high cyclone frequencies. When integrated with real-time data (e.g., weather systems, seismic activity), atlases can help forecast disasters. For example, combining rainfall data with a hydrological atlas can predict flooding in vulnerable river basins. Atlases often include socioeconomic data, such as population density and infrastructure distribution, allowing authorities to identify at-risk communities.

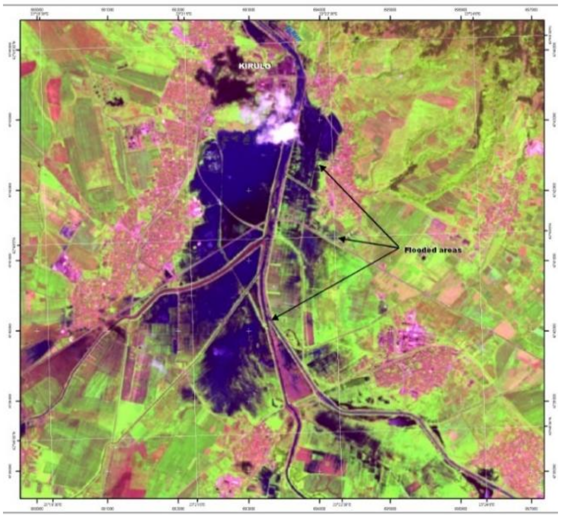

Figure 2. Satellite image of Sofia Region during a flood

Atlases help map the distribution of resources, such as emergency shelters, hospitals, and food storage facilities, ensuring they are located strategically. They assist in planning evacuation routes and identifying areas that need infrastructural reinforcement.

Atlases can be used to create public awareness about risks and preparedness measures. For instance, atlases showing evacuation routes and hazard zones can be distributed to communities. Maps in atlases can display key communication infrastructure, helping design robust emergency communication networks.

Here are several examples of specific atlases in action:

- Hydrological Atlases: Used for monitoring flood risks and managing water resources during droughts.
- Seismic Atlases: Identify earthquake-prone areas and help plan infrastructure with seismic resilience.
- Climatological Atlases: Show historical weather patterns to predict storms or assess drought risks.
- Urban Risk Atlases: Highlight vulnerabilities in city infrastructure, helping planners mitigate risks in densely populated areas.

By leveraging geographical atlases for visualization, analysis, and communication, emergency managers can enhance early warning systems, prepare effectively, respond efficiently, and plan long-term recovery. Combining traditional atlas data with real-time technology like GIS and satellite imagery further amplifies their utility in crisis scenarios. Maps from geography and economics atlases for grades 9 and 10 depict flood-prone areas and other risks but require more comprehensive and updated content to enhance student education on disaster-affected zones (See Figure 3). Other information about atlases presenting information on natural disasters can be found in Siteva and Marinova (2022).

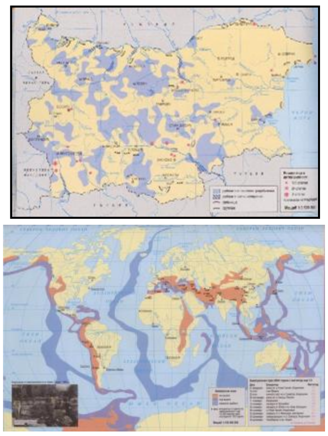

Figure 3. Maps from geography educational atlases showing natural hazards in Bulgaria and the world (Bandrova, 2018, 2019)

2.2.3. Economic Impact Maps

Detailed maps visualizing the economic impact of disasters are critical, especially for countries like Bulgaria, where resources for managing crises are limited. Attempts for cartographic visualization of impacts and affected areas and population are being made by the National Statistical Institute (NSI) which publishes annual reports with summarized information on disasters, people affected, and material damage. These reports include cartographic representations (Figure 4), although they tend to be overly simplified and general and can serve as a general idea of the disasters that have occurred and the economic impact they have caused.

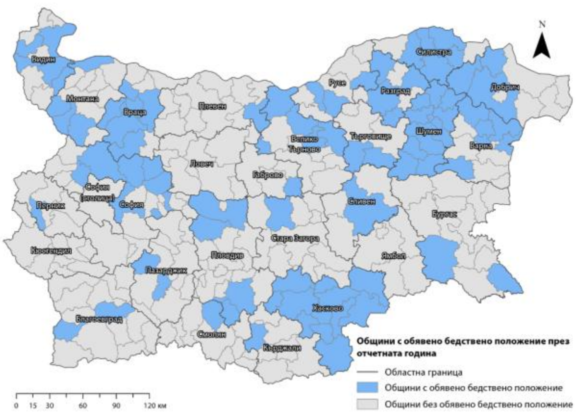

Figure 4. A map showing municipalities with a full or partial state of emergency declared in 2023 (in blue) (National Statistical Institute, 2024)

2.3 Identified Gaps

Despite examining multiple online and literary sources, a significant shortage of cartographic materials and data on crisis situations in Bulgaria remains evident. Timely and accurate information is essential for effective early warning and disaster response. Risk and hazard assessments are based on GIS analyses and thematic cartographic products. Preparedness activities are carried out before a disaster to prevent its occurrence and minimize potential impact. The lack of up-to-date thematic maps creates serious obstacles for planning preventive actions and coordination between responsible authorities. This gap in thematic data also hinders efficient early warning and population preparedness for action in a crisis situation.

3. Existing Early Warning and Crisis Management Systems

Effective emergency response systems should be a primary focus of modern cartography. Utilizing digital cartographic products offers flexibility in responding to dynamic environmental processes. GIS-based systems can provide valuable spatial data for resource planning, damage estimation, and informed decision-making

3.1 Bulgaria

Early warning is the provision of timely and effective information about an approaching or imminent threat of a disaster to a certain group of people - executive authorities, members of the Unified Rescue System described in the Disaster Management Act (2006), and the population (Ordinance on early warning and disaster notification, 2009). The purpose of early warning and notification is to reduce the disaster risk and help authorities prepare for a response, organize rapid and effective management of disasters that have occurred, and reduce their consequences. Early warning and notification are carried out through a communication and information system called the "National Disaster Early Warning and Notification System". The national early warning system primarily focuses on issuing alerts about an impending or ongoing disaster. According to the ordinance on early warning and disaster notification (2009), the early warning and notification system for the population is designed to simultaneously warn and notify large groups of people in a certain territory of an impending or actual disaster and to broadcast instructions for the necessary measures and actions through acoustic signals and voice information, but it is not yet so much related to monitoring and GIS-based risk and hazard mapping.

3.2 International Examples

3.2.1 *Czech Republic*

The Czech Republic employs a comprehensive crisis management system, including an integrated rescue service and a newly adopted flood prevention strategy. The system incorporates:

- GIS-based mapping of natural risks;
- Centralized databases accessible to government and regional bodies;
- Well-coordinated responses during the 2002 Central European floods.

In general, early warning systems in Czech Republic are based on robust and reliable communication infrastructure hardware, operate 24 hours a day, and use multiple communication channels. Some early warning systems consider multi-hazard scenarios. Heavy rain and pluvial flood early warning systems deal either with meteorological or hydrological data or with a combination of both types (Rainman, 2024).

3.2.2 *Africa*

Africa’s early warning systems primarily address drought and floods, incorporating processes like: data collection and analysis and satellite monitoring (e.g., METEOSAT, NOAA). Public awareness campaigns and training programs. Challenges include limited financial resources, insufficient expertise, and poor communication networks. The Continental Early Warning System (CEWS) is envisaged by the African Union (Cilliers, 2005).

3.2.3 *France*

France’s system focuses on critical rivers and regions, utilizing predictive services such as the Central Hydrometeorological Flood Prediction Service. Recommendations for improvement include:

- Direct communication with citizens.
- Enhanced funding for predictive tools and monitoring systems.
- Better integration of meteorological and hydrological data.

Now the Cap'Alert research program about the alert system in France is proposed on the base of the models of warning systems proposed by 4 countries (Belgium, United States, Australia and Indonesia) (Douvinet et al, 2020).

3.3 Analyses

There are many different variants of EWS in many countries. Some of them are developed on a national level, others are international or local. In most of countries different organizations are responsible for EWS caused by different disasters (like in the Czech Republic, Konecny et al, 2011). Another example shows that EWS for landslides is developed for a region in Italy (Segoni et al, 2015). The last mentioned EWS by Segoni et al has a simple architecture using a web-based GIS interface. Others have more complicated structures as the EWS Mechanism Flow Chart Province and District/Community Level in Afganistan (Mohanty et al, 2019). In our point of view, the most effective systems include rapid mapping, GIS analyses and web-based survives like in Wania et al, 2021. The power of using map production is visible from the schema in Figure 5 when developing EWS with five distinct steps, actors and roles, as well as related actions.

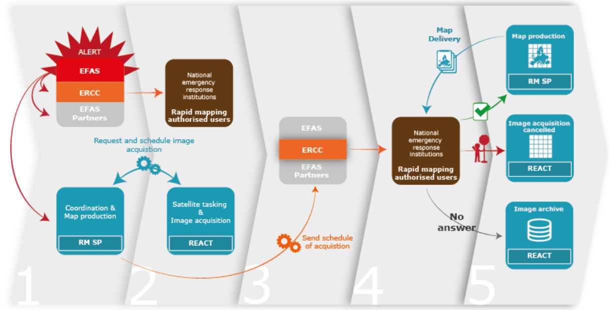

Figure 5 Workflow for EFAS-based pre-tasking for Rapid Mapping (Wania et al, 2021)

Meteoalarm is a warning system in Europe, which provides the most relevant information related to extreme weather expected over Europe by hundreds of reports from 30 countries (Konecny et al, 2011). Bulgaria as a European country is not included. By our proposal for a framework, we aim to be useful and cooperative in European family.

4. Conceptual Framework for an Early Warning System in Bulgaria

Using all experience pointed above by different countries and organizations and building on the analysed data and systems, a tailored early warning system for Bulgaria should include (Figure 6):

1. **Comprehensive Risk Mapping:**
- Flood-prone zones.
- Earthquake histories.
- Landslide-prone areas.
2. **Centralized GIS Integration:**
- Accessible to all relevant agencies.
- Real-time data updates.
3. **Public Awareness and Training:**
- Educational programs in schools.
- Public drills and information campaigns.
4. **Interagency Collaboration:**
- Unified communication channels between emergency services, municipalities, and government bodies.
5. **Technological Advancements:**
- Mobile applications for real-time alerts.
- Satellite monitoring systems integrated into GIS platforms.

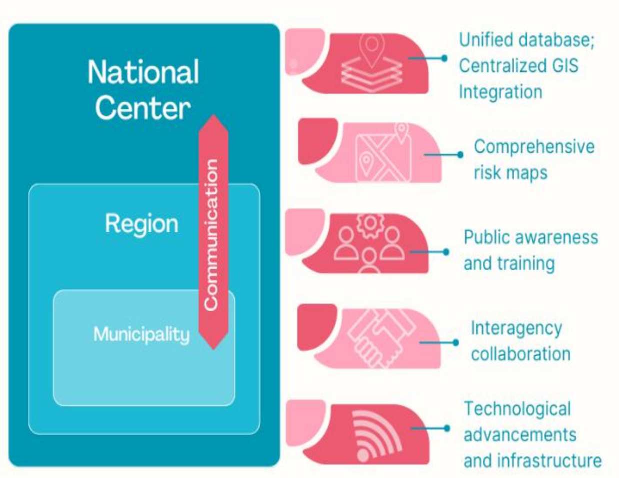

Figure 6. Proposal for a new Early Warning System in Bulgaria

To effectively implement this system, a combination of advanced methods must be integrated. Hazard models can be used to map disaster-prone zones, while multi-layered GIS platforms should integrate data on hazards, vulnerabilities, and exposures. Crowdsourced information from mobile apps and social media can enhance real-time situational awareness. The integration of remote sensing technologies enables near-instantaneous updates on changing environmental conditions. Machine learning algorithms can support pattern recognition and predictive modeling, such as flood forecasting and landslide prediction. A centralized, GIS-based decision support system will facilitate real-time data sharing and coordination across agencies. Community-based training programs and simulation exercises are essential to strengthen preparedness and response capacities.

Cartographic products are essential for research, analysis, and assessing disaster risks. Thematic maps are used to plan and coordinate rescue and evacuation activities during disasters and crises that have already occurred. Mapping for crisis management is carried out using ground-based observations and/or remote sensing methods to obtain data on the territory affected by the disaster and additional information on its duration, intensity, consequences, etc.

Successful crisis management starts with identifying hazards and risks. Risk mapping helps identify and analyze areas most vulnerable to disasters, so it is a key element of any early warning system. Risk mapping as part of pre-disaster activities is one of the first steps in disaster preparedness, as it provides a visual representation of the risks faced by the country. According to the Disaster Protection Act in Bulgaria (2016), disaster protection plans are developed at the national, regional, and local levels, and they must determine the hazards and risks of disasters. Developing plans and risk assessment for floods and earthquakes is mandatory (Disaster Protection Act, 2016), but since landslides are some of the most common disasters in the country, landslide risk assessment and mapping are also essential. Effective risk mapping helps mitigate damage by providing critical information on where preventive measures might be necessary.

Effective early warning, decision-making for disaster protection, crisis management, and the design of specialized cartographic products all depend on good information provided and the availability of well-structured geo-data. The thematic data necessary for mapping various natural and anthropogenic disasters occurring in Bulgaria, such as earthquakes, floods, forest fires, landslides, hail, avalanches, pollution, and others, is collected from various sources. To implement preventive actions and reduce the negative consequences of crises, it is necessary to unify data from ministries, agencies, and organizations and build a Unified Database for all disasters occurring in our country (Marinova, 2018).

The unified disaster protection database should provide for the following two categories of activities: pre-disaster activities: analysis and research, risk assessment, prevention, preparation, and post-disaster activities: response, recovery, and reconstruction according to these two categories of activities, there are two categories of data: Pre-disaster baseline data for the territory; Post-disaster data - on its impact and the resources available to deal with it (Pareta & Pareta, 2011). The initial data can be subdivided into the following categories: digital elevation model, hydrography, road infrastructure, settlements (with information on the number of inhabitants), soil and vegetation cover, administrative boundaries, critical infrastructure, medical facilities, hazard and risk zones, evacuation sites (Marinova, 2018).

Up-to-date and high-quality data are the basis for decision-making in the disaster protection process, especially in cases where human lives must be saved and material losses minimized, and above all, the data must be easily accessible and presented in a form suitable for the users (Kohler, 2005) ensuring it is available to all relevant agencies and responsible authorities. Effective crisis management requires the provision of accurate information at the right place at the right time. Providing crisis management authorities with such information helps them make timely management decisions. The data must be in a form suitable for use and for the specific tasks of the actors at the different stages of crisis management. Therefore, the information must be integrated and presented in the most appropriate way to support the specific tasks of their users (Parker & Stileman, 2005). The unified database should integrate spatial disaster data from various institutions, as well as specific information on earthquakes, floods, storms, thunderstorms, tornadoes, hail, landslides, snowdrifts, avalanches, etc., obtained through direct measurements and observations.

After a disaster/crisis occurs, the integrated database must receive information about the date and time of occurrence, location, type, origin, territorial scope, method of occurrence, duration, people affected, material damage, and others (Marinova, 2018). This data provides a better understanding of the specific disaster and assists in the warning process and the development of a particular crisis management plan. The data collected from different ministries and agencies should be integrated to ensure rapid spatial localization of territories affected by natural disasters, to support the compilation of thematic maps of natural disaster risks, distribution areas, rescue plans, damage, and consequences, etc., as well as to support the interaction of participants in crisis management.

Technologies are developing rapidly and real-time data is now collected not only by specialized services but also by citizens, who can submit information about the condition of an affected area through precise location, images, voice, and text messages, using only mobile phones.

A centralized GIS-integrated platform would ensure that various ministries, agencies, and local and regional governments can use and share data in real time. This would allow for coordinated crisis management and decision-making in case of an emergency. The real-time data updates would contribute to timely warning and informed decision-making to reduce the impact of disasters.

In emergencies, rapid and coordinated action between responsible authorities is key to an effective early warning system and to saving lives and minimizing damage which can be achieved through unified communication channels between emergency services, municipalities, and government bodies.

Another important point for effective early warning and disaster management is public awareness and training that are essential for reducing the number of affected people and property damages. Training the population, starting from early childhood, on topics related to disaster awareness, preparedness, and protection is crucial for developing both sustainable theoretical and practical knowledge needed to respond effectively to crises (Marinova and Kehayova, 2016).

5. Conclusions

The increasing frequency and severity of natural disasters globally highlight the urgent need for robust early warning systems. This report has analyzed existing cartographic resources, identified critical gaps in Bulgaria's current systems, and proposed a framework for a comprehensive early warning system tailored to the country's needs.

International examples, such as those from the Czech Republic, Africa, and France, demonstrate that integrating GIS-based mapping, real-time data collection, and strong interagency coordination significantly improves disaster preparedness and response. These systems emphasize the importance of centralized databases, public education, and predictive tools, elements that are essential for effective crisis management.

Bulgaria's current efforts, such as the ICPDR's flood prediction initiatives and the flood risk mapping pilot in Sofia, are commendable starting points. However, the lack of detailed cartographic materials, systematic data collection, and comprehensive public awareness campaigns present significant obstacles to effective disaster mitigation.

The proposed early warning system in Bulgaria emphasizes the following key components:

Comprehensive Risk Mapping to identify flood-prone areas, earthquake zones, and landslide risks.

Centralized GIS Integration for real-time data sharing among relevant agencies.

Public Awareness and Training Programs to enhance community resilience.

Enhanced Technological Infrastructure, such as mobile applications and satellite monitoring, to ensure timely alerts.

Interagency Collaboration to unify efforts across emergency services, municipalities, and government bodies.

By investing in these initiatives, Bulgaria can significantly enhance its capacity to manage natural disasters, minimize economic losses, and protect lives. Future work should focus on the development and deployment of pilot projects, ensuring that theoretical models translate into practical, real-world applications.

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