JOURNAL OF THE BULGARIAN GEOGRAPHICAL SOCIETY

Journal of the Bulgarian Geographical Society 50: 129–148 (2024)
DOI: 10.3897/jbgs.e116695

Research Article

Risk assessment of landslides: Low probability scenario for the town of Kavarna, northern Black Sea coast of Bulgaria

Boyko Berov[1], Antoaneta Frantzova[1], Plamen Ivanov[1], Nikolai Dobrev[1], Miroslav Krastanov[1], Rosen Nankin[1]

1 *Geological Institute, Bulgarian Academy of Sciences, Sofia, Bulgaria*
Corresponding author: Plamen Ivanov (plivanov62@geology.bas.bg)

Abstract

As part of the Reimbursable Advisory Services on Accelerating Resilience to Disaster Risks, the World Bank worked with the Interior Ministry of Bulgaria to develop a proposal for the National Disaster Risk Profile of Bulgaria. The purpose of this document, which is the fourth technical annex to the proposal for the National Disaster Risk Profile, is to provide particular conclusions, information, and techniques that were utilised to evaluate the risk of landslides in Bulgaria. For the first time at the national level, landslide risk assessment procedures based on ISO/IEC 31010:2019 Risk assessment techniques are being developed and applied in Bulgaria. The five primary categories in which the results are presented are physical safety, economic security, social well-being, environmental security, and security of tangible assets and critical infrastructure. The uncertainty (confidence) parameter is utilised, and it is subdivided into the following three basic categories: low uncertainty, medium uncertainty, and high uncertainty. The produced results demonstrate consistent applicability to empirical data analysis and real-world situations.

Key words: Disaster, geological hazards, geological risk mapping, landslide susceptibility

Academic editor: Alexander Gikov
Received: 03 December 2023
Accepted: 21 May 2024
Published: 05 June 2024

Citation: Berov B, Frantzova A, Ivanov P, Dobrev N, Krastanov M, Nankin R (2024) Risk assessment of landslides: Low probability scenario for the town of Kavarna, northern Black Sea coast of Bulgaria. Journal of the Bulgarian Geographical Society 50: 129–148. https://doi.org/10.3897/jbgs.e116695

1. Introduction

The high frequency of landslides, which can result in the destruction of infrastructure and structures, historical sites, disturbance of land use, risks to human health, etc., makes it necessary to evaluate the risk of landslides. Numerous landslide processes develop on the territory of Bulgarian according to its geological-tectonic parameters and relief. Extended investigations and practical endeavors concerning landslides have resulted in the identification of significant correlations regarding their distribution, activation and occurrence variables, processes, and dynamics.

The concept of risk is human-centered, and the process of assessing risk is a multifaceted endeavor that lacks a universally applicable model. The existing body of literature demonstrates that methods for assessing landslide risk are intricate and necessitate a substantial quantity of input data (Bonnard et al. 2005; Clague and Stead 2012; Asian Development Bank 2021; Lee and Jones 2023).

Three main landslide risk assessment approaches are widely used throughout the world. They are qualitative, semiquantitative and quantitative approaches (Regmi and Agrawal 2022). A relationship between significant factors affecting the landslide risk has also been studied by a number of authors (Rosser et al. 2021; Dhungana et al. 2023; Esposito et al. 2023; Kuhn et al. 2023). At the time, research done in Bulgaria is based on the United Nations International Strategy for Disaster Reduction (UNISDR) and Inter-American Development Bank (IADB) methodology (Lakov et al. 2002; Dobrev et al. 2014; Frantsova 2021; Ivanov et al. 2022).

The paper presents the landslide risk assessment and scientific research carried out within the project „Landslides Risk in Bulgaria. Technical Annex 4“ under the World Bank project Reimbursable Advisory Services on Accelerating Resilience to Disaster Risks (P170629); Component 3: National Disaster Risk Profile (The World Bank in Bulgaria 2020).

The main methodology is based on International Standards IEC 31010:2019 Risk management—Risk assessment techniques and JRC-EC recommendation (Poljanšek et al. 2019).

The long-term research and applied activities on landslides by a number of Bulgarian authors, such as Berov et al. (2002), Bruchev et al. (2007), Ivanov et al. (2017b, 2022), Bruchev (2018), have led to the establishment of important dependencies for their distribution, factors for occurrence and activation, mechanism and dynamics, etc. Also, through remote sensing, from aerial and satellite instruments, an assessment of the danger of landslide processes along the northern Black Sea coast in Bulgaria was made by Atanasova and Nikolov (2021), Yamaguchi et al. (2021), Nikolov and Atanasova (2023).

Based on the available and accessible information on registered landslides in Bulgaria, some characteristic sections of the widespread landslide phenomena in certain landslide areas were selected.

The article examines one of three possible examples or case studies, conditionally divided into high, medium and low according to the degree of complexity and landslide activity carrying the corresponding risk. The present work aims to present the case study for a selected region in which to assess the landslide hazard and risk, under relatively favorable conditions for the slope stability and the engineering geological conditions of the geomorphological and geological forms of the considered terrain.

In order to fulfil the risk assessment criteria, set by the World Bank (WB), three hypothetical scenarios are selected for three distinct locations. These scenarios vary in terms of the likelihood of occurrence: low probability scenario, medium probability scenario and high probability.

The article specifically focuses on landslides in an urbanized area of Kavarna town. The main objective of the study is to carry out a risk assessment that estimates the potential damages and losses prior to a predefined likelihood of occurrence—low probability (unlikely) scenario.

The main tasks performed in the sequence of the research are: the determination of vulnerability and exposure data, the classification of landslides by groups—based on their activity and the risk they pose.

The determination of the risk elements based on economic and social significance and determined by degree of activity, types of landslides by area, urbanization of the territory and types of endangered sites.

Next is the determination of the main tasks such as the selection of landslide hazard data, hazard levels according to slope inclination, according to geological structure and scenario for seismically induced landslide.

All these steps are followed and strictly described in the methodological part of the study and the expected results of the relevant assumptions for determining the scenario.

2. Data and methods

To achieve the aim of the study, we chose to apply a methodology for building an integrated risk assessment based on scenario development in accordance with the IEC 31010:2019 recommendation.

There are some required steps that have to be followed in order to appropriately evaluate the landslide impact that are described in JRC-EC recommendation (Poljanšek et al. 2019).

National Disaster Risk Profile of Bulgaria (Ministry of Interior 2020) is the original document on which the present research is based.

The data and methods used for risk assessment are presented below as well as in a previous publication (Dobrev et al. 2023a) by the same team.

2.1. Methodology

According to globally accepted terminology, landslides are defined as the movement of a significant amount of earth mass down a slope, which occurs mainly due to the force of gravity (USGS 2021). The Program for the Prevention and Mitigation of Landslides on the Territory of the Republic of Bulgaria (Dobrev et al. 2023b) and in the Geological Risk Mapping (Ivanov et al. 2017a) consider certain types of slope movements from the Varnes classification (Varnes 1978), namely “rotational landslides”, “translational landslides”, “lateral spreads”, “earthflows” and “complex landslides”. In the article below, we refer only to these phenomena and as “landslides”. This is also the approach regarding the assessment of the risk of landslides, adopted by the Ministry of Regional Development and Public Works (MRDPW).

In the present study, the experience of some European countries (European Soil Data Centre 2023) in the assessment of landslide susceptibility and landslide risk was very useful, such as the landslide risk assessment procedures in Austria (Schweigl and Hervás 2009), Greece (ThinkHazard 2020) and Bosnia and Herzegovina (EU Floods recovery Programme 2015), the risk assessment guidelines of the Joint Research Center of the European Union, the guidelines for disaster risk management of the Australian Society of Geomechanics (Walker et al. 2007), and the approach to risk assessment of natural phenomena used in the National Risk Profile of the Netherlands (National Risk Profile 2016).

The preparation of various maps, such as distribution maps, susceptibility maps, hazard maps, and risk maps, is a key component of landslide risk assessment (Fell et al. 2008; Ivanov et al. 2017b, 2022). The following function is used for risk calculation:

$$R = f\,(V,H,E) \tag{1}$$

where risk (R) depends on vulnerability (V), hazard (H) and exposure (E) (Poljanšek et al. 2019).

Methods for hazard, vulnerability and exposure assessment are described in detail in Frantsova (2021). This methodology was used to assess a complex level of risk from geological processes on the example of the northern Bulgarian Black Sea coast region (Frantzova 2023).

Landslide susceptibility for Bulgaria is presented in Fig.1 as well as the location of the study area (Kavarna town). The map was helpful in selecting an area suitable for the scenario described in the present study. Namely, a low probability scenario—activation of a landslide in the town of Kavarna.

Figure 1. Landslide susceptibility map of Bulgaria (after Ivanov et al. 2017b) with the location of the study area (red rectangle).

2.2. Vulnerability and exposure data

The landslide risk assessment (risk scenario) is directly related to analysis of exposure and hazard (Dobrev et al. 2014). The assessment encompasses many attributes (point-scored indicators) associated with the condition of landslides and the components of risk expressed by:

$$Pi = S * E \tag{2}$$

Where: Pi—indicator, S—characteristic of the state of landslides, E—elements of risk.

Formula 2 can be represented as a sum and multiplication of elements concerning the features (characteristics) of the landslide process and risk elements. This is presented by formula 3:

$$Pi = (S1+S2) * (E1+E2) \tag{3}$$

The current situation regarding landslides (S) is determined by:

- degree of activity S1 (Table 1);
- size/volume S2 (Table 2).

The elements at risk are based on economic and social significance (E) and are determined by:

- urbanization of the territory E1 (Table 3);
- category of endangered sites E2 (Table 4).

Table 1. Landslides by level of activity (modified after UNESCO/WPWLI 1993).

Determination by degree of activity, S1	Points
Active, with periodic activity	4
Potentially hazardous landslide-prone areas (dormant landslides)	3
Stabilized incl. ancient landslides and reinforced landslides	1

Table 2. Scale of landslide processes (Dobrev et al. 2014, 2023b).

Types of landslides by area, S2	Points
Area over 20 000 m^2 (class I)	4
Area from 10 000 to 20 000 m^2 (class II)	3
Area from 1 000 to 10 000 m^2 (class III)	2
Area less than 1 000 m^2 (class IV)	1

Table 3. Urbanization of the territory and endangered sites.

Urbanization of the territory and types of endangered sites, E1	Points *
Residential buildings, schools, hospitals, public buildings	5
Motorways and/or national roads class I, railways, dam facilities of national importance	5
Endangered cultural and historical monuments, sites of national and international importance	5
Republican roads class II, III and IV, dam facilities of regional importance	4
Municipal roads, streets, alleys, beaches, industrial buildings, massive buildings in villa areas, landfills, electricity distribution and transmission grid facilities, communication facilities	3
Temporary buildings, lighthouses	2
Arable lands	2
Agricultural lands - uncultivated (meadows), forest fund and areas specified in the registration table as “land” or “property”	1

* Maximum total number of points is 21 according to the Methodology for assessment of geological risk (Dobrev et al. 2014) and Program for the prevention and mitigation of landslides on the territory of the Republic of Bulgaria, erosion and abrasion along the Danube and Black Sea coasts for the period 2022–2027 (Dobrev et al. 2023b).

Table 4. Category of endangered sites (Dobrev et al. 2014).

Category of endangered sites, E2	Points
Residential and public buildings over 15 m high, highways and roads class I, main railway lines, facilities of national and regional importance	4
Residential and public buildings 10 to 15 m high, roads class II and III, railway lines not specified in category A, facilities of regional importance	3
Residential and public buildings up to 10 m high, roads and facilities of local importance	2
Light structure buildings, temporary buildings, local roads allowing for by-passing, forest and agricultural roads	1

Landslides are categorized into three groups based on these priority criteria (according to the points obtained), depending on the level of activity and risk they pose (Dobrev et al. 2014, 2023b):

- Group I—for priority implementation of countermeasures and activities;
- Group II—for carrying out preventive measures and/or geo-protective measures and activities;
- Group III—for monitoring.

2.3 Landslide hazard data

The approach utilised for assessing the hazard and risk associated with landslides is described in Methodology for geological risk assessment (Dobrev et al. 2014). This methodology is subsequently applied in the development of geological risk mapping. The primary component of the input data (Ivanov et al. 2017c) can be seen in Tables 5–8. The landslide susceptibility map of the Bulgarian Black Sea coast, used the Mora & Vahrson method (Mora and Vahrson 1994), complemented and modified by Berov et al. (2016, 2020), Ivanov et al. (2020).

Table 5. Landslide occurrence probability classification (P). Source: Fell (1994), Dobrev et al. (2014).

P	Description	Annually
12	Extremely high	1
8	Very high	0.2
5	High	0.05
3	Medium	0.01
2	Low	0.001

Table 6. Classification by landslide hazard (H = M * P). Source: Fell (1994), Dobrev et al. (2014). The levels are derived from statistical data considering research and monitoring of about 900 landslides in Bulgaria.

H	Category
≥30	Extremely high
≥20–<30	Very high
≥10–<20	High
≥7–<10	Medium
≥3–<7	Low
≥2	Very low

Table 7. Hazard levels according to slope inclination (α).

α	Inclination range, degrees
0	>45
2	30–45
3	24–30
5	18–24
8	15–18
9	12–15
10	9–12
5	5–9
0	< 5

Table 8. Hazard levels according to geological structure (G).

G	Geological description
7	Quaternary (clay, sandy clay)
10	Neogene (clay, sandy clay)
6	Paleogene (stiff clays)
5	Quaternary and Cenozoic coarse-grained sediments, slightly lithified
4	Mesozoic (rocks and weak rocks)
2	Paleozoic and Precambrian (rocks)

The landslide magnitude (M) shall be approximated utilising the formula:

$$M = \alpha * G * k \tag{4}$$

where, α is the threat level according to slope inclination and G is the threat level according to geological structure (Ivanov et al. 2017b). The purpose of the coefficient k that is used in the formula is to make the result that is obtained equal to the magnitude of the final values (Dobrev et al. 2023a, 2023b; Frantzova 2023). Through the use of this coefficient k, Fell's seven magnitude classes (Fell 1994) can be related to this methodology, i.e. the highest magnitude value cannot exceed 7 (Dobrev et al. 2014).

The assessment of the landslide hazard is determined through statistical analysis of data obtained from information maps sourced from the National landslide registry of Bulgaria. Two primary factors considered are the geological composition of the formations where landslides occur and the steepness of the slopes.

Information from a total of 916 registered landslides is utilised. Each indication has a maximum score of 10 points. The Neogene formations, which are more prone to landslide occurrences, receive the highest score in indication G, which assesses the geological structure. Regarding the second indication, statistical data reveals that the highest frequency of landslides occurs within the range of 12–15° slope inclination, with a total of 10 point.

3. Risk assessment via impact and low probability scenario for seismically induced landslide

The presented scenario provides a comprehensive description of the circumstances, triggers and potential outcomes associated with the risk events. On the other hand, each complex scenario is based on an expert theoretical proposition derived from available data and knowledge. The probability (or likelihood) of the selected scenario occurring in the next five years has a 119-year return period (low probability scenario).

3.1 Low probability scenario—seismically induced landslide (Kavarna region)

The scenario is set in an urban town (Kavarna) on the northern Black Sea coast of Bulgaria. This area (between Varna and Kavarna) is known for its large landslides (Berov et al. 2013; Evlogiev and Evstatiev 2013; Nankin and Ivanov 2019; Atanasova and Nikolov 2021). The main part of the town is located on a plateau and its foothills reach above the sea. The rest of the town is situated on the slope of a large erosional valley that descends to the sea.

The town is moderately economically developed: About 60% of the population is of working age, while the unemployment rate for 2020 is 6.2%. The town has about 10000 inhabitants, with about 2500 residential buildings and almost 4000 apartments. There are three schools, three kindergartens, a large municipal hospital, and twenty hotels, villas, and guesthouses of varying capacity. The largest hotel can accommodate 400 people. The total capacity of the hotels in the valley is about 2000 people. Most of the town is located on the plateau, but 17 houses are built on the slope and on the edge of the plateau. On the slopes of the valley there are the history museum, the cultural monument “Hamama”, a pumping station, hotels and cottages. A power line runs across the slope.

Part of the town—from the plateau on the slopes to the sea—consists of a deluvial cover several meters thick (Cheshitev et al. 1991). The aragonite sediments (Koleva-Rekalova 1994; Nankin et al. 2022; Yaneva et al. 2019) of the Topola Formation (N_1^s), which are characterized by special physical and mechanical indicators, are of great importance for the landslide processes. They are unstable to dynamic impacts. Landslides often occur on the sediments of the Euxinograd Formation (N_1^s) (Fig. 2).

The scenario develops in daytime, at the beginning of the tourist season.

Initial conditions: A long period with light and continuous rainfall is a prerequisite for slow runoff and water saturation of deluvial deposits on the slope. An earthquake from the Shabla-Kaliakra zone is a triggering and destabilizing factor with a magnitude over five and intensity I ≥ VII degree (MSK scale). Landslides (Fig. 3, 4) are activated quickly and without warning. In the uppermost area of the valley, part of the slope between the church and the Dobrotitsa Hotel (central part of the town of Kavarna) slides down. Shallow landslides affect different parts of the valley slopes.

The landslide in the resort part of the port is activated. Seventeen houses are deformed and destroyed; hotels in the landslide area are cracked and are deformed. Thirty people are left without shelter; about four hundred tourists are evacuated from the hotels. The church is damaged. A power line is cut and a

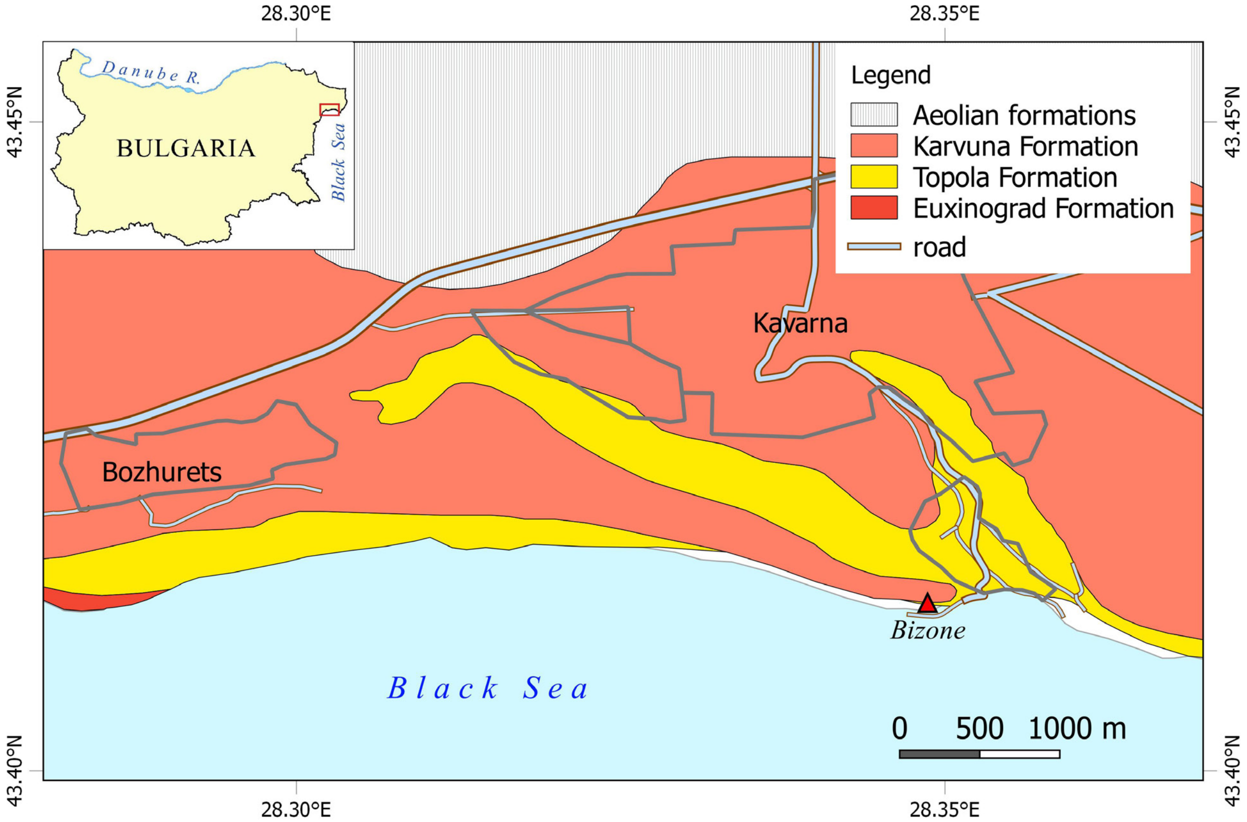

Figure 2. Geological map of the area (after Cheshitev et al. (1991)).

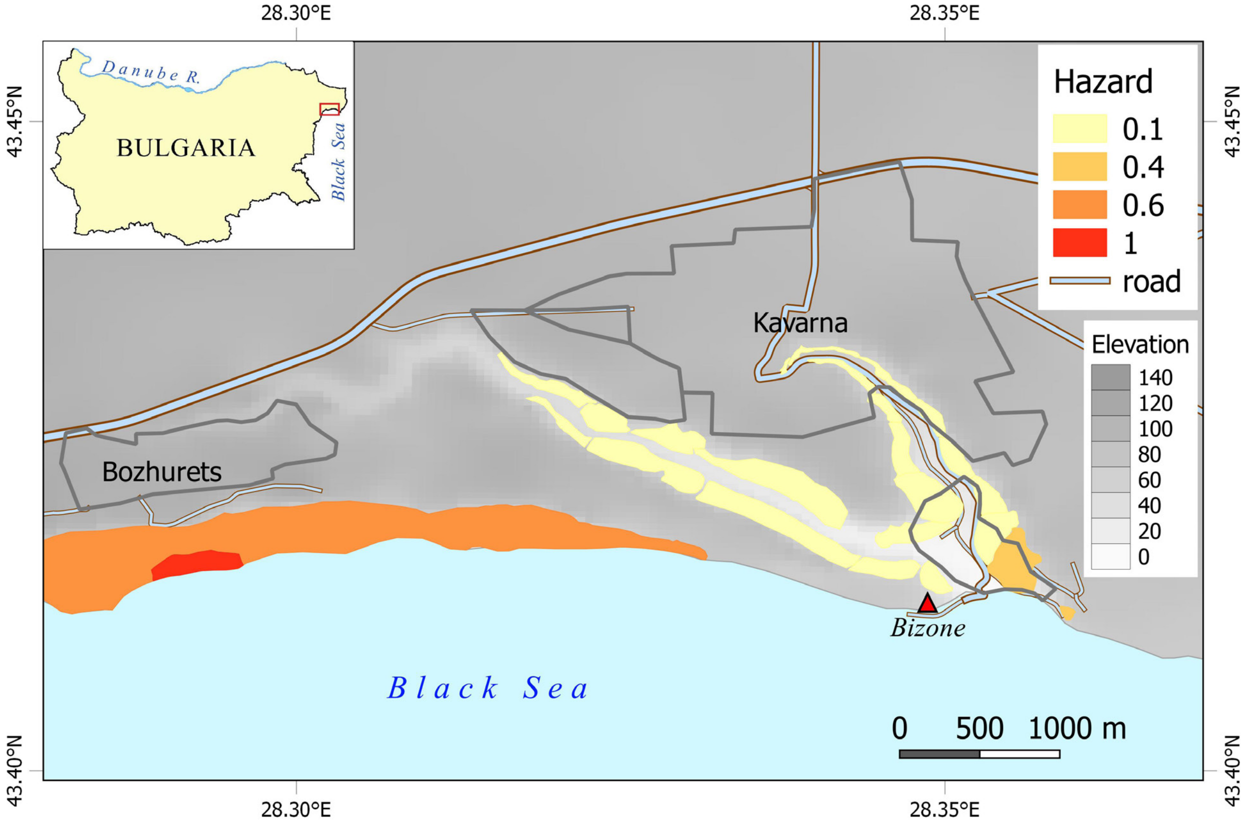

Figure 3. Location of the landslides (Kavarna Region). Indicative level of hazard according to equation (2) ranging from 0 to 1. Legend: 0.1—very low; 0.4—low; 0.6—medium; 1—very high. With a red triangle—the location of Cape Chirakman (ancient city of Bizone).

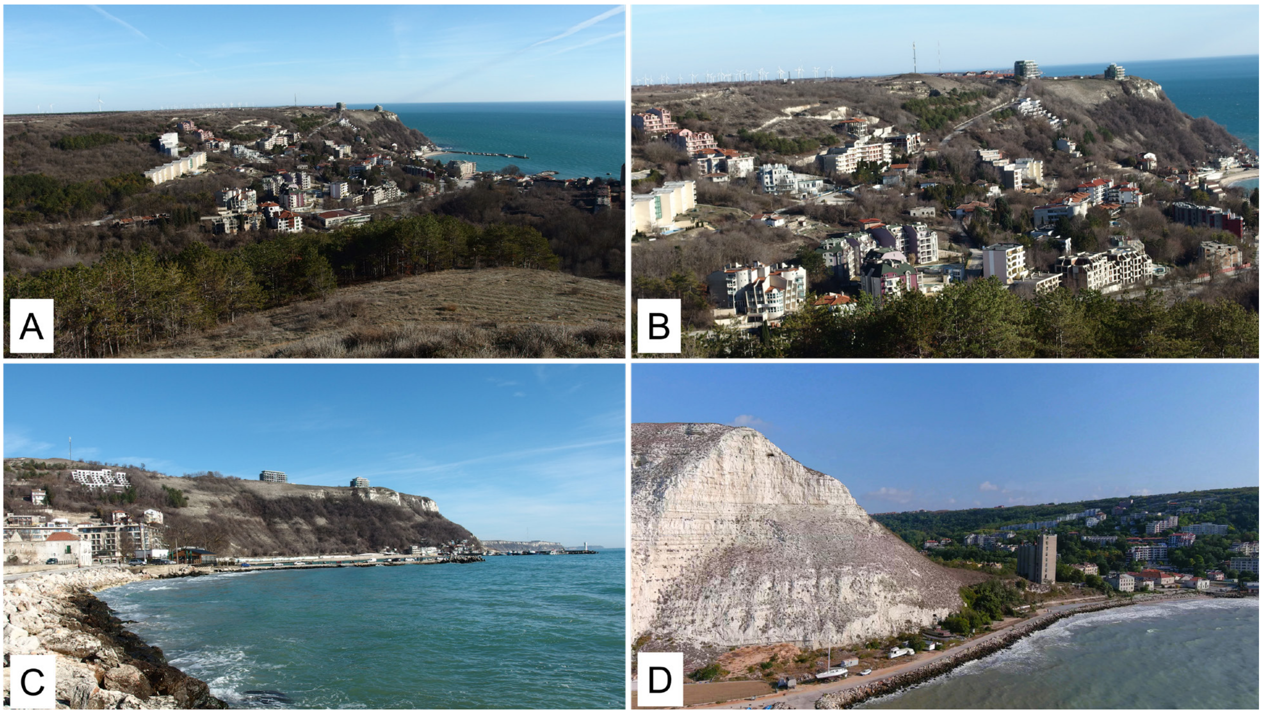

Figure 4. View of the considered area. **A** the valley descending to the sea, built up in the lower part **B** the left valley slope **C** the left valley slope by the sea **D** Cape Chirakman (near the Kavarna port)—the site of the ancient town of Bizone, which sank into the sea in the first century B.C. after a strong earthquake and a resulting landslide.

pumping station is damaged. The road to the port is interrupted in a few places. A local road, passing through the resort, is severely distorted. Access to the history museum has also been cut off.

Commercial fishing, canned seafood manufacturing, and museum operations are anticipated to be suspended. The tourist industry is to be hampered for a long period. Nearly 530 people will lose their jobs. Of these, 320 are temporarily and 210 for a longer period. Unemployment will rise temporarily to 12.6%, but for a longer period, to 8.7%. There are no casualties among the tourists. 1–2 people with limited mobility were injured during the evacuation.

Access to the resort area is difficult. The main road is interrupted, and it will take about a week to clear it. The short road from the resort area to the plateau is distorted, and deformations will continue for several months until movements subside. For this reason, it is urgent to build a new road of about 400 m from the plateau to the hotels in order to carry out restoration work. It is possible to use the port for evacuation as well as helicopters. There are difficulties in medical care, as three out of the 30 medics in town live in the affected houses in the area.

The area has high seismicity (Table 9) (Solakov et al. 2022). The consequences in the Republic of Bulgaria of the Vrancea earthquake in 1977 (including slope deformations) are described by Brankov (1983). Publications discussing the occurrence of landslides caused by seismic activity and the assessment of geodynamic hazards and risks along the Bulgarian Black Sea coast are presented in the works of Iliev (1973), Konstantinov et al. (1992), Lakov et al. (2002). Near the port of Kavarna is Cape Chirakman—the site of the ancient town of Bizone, which sank into the sea in the first century B.C. after a strong

Table 9. Seismic data of the study area.

Date	Coordinates	Magnitude	Depth, km	Intensity *	Source
15.07. 2015	N43.29/E28.41	4.3	15	IV	EMSC
03.12.2012	N43.41/E28.65	4.9	10	V	EMSC
11.10.2011	N43.60/E28.53	4.1	15	IV–V	EMSC
05.08.2009	N43.45/E28.69	5.0	10	VI	USGS
30.06.1956	N43.6/E28.5	5.4	60	VI–VII	BCEQ
08.09.1911	N43.4/E28.1	4.8	10	VI	BCEQ
08.02.1904	N43.5/2E8.5	4.5	15	V–VI	BCEQ
25.05.1902	N43.5/E28.5	4,5	10	VI	BCEQ
30.06.1901	N43.4/E28.5	6.0	10	VII–VIII	BCEQ
06.06.1901	N43.4/E28.3	5.2	10	VII	BCEQ
26.04.1901	N43.4/E28.5	4.5	10	VI	BCEQ
25.04.1901	N43.4/E28.5	5.0	10	VI–VII	BCEQ
31.03.1901	N43.4/E28.7	7.2	14	IX	BCEQ
1832	N43.3/E28.4	-	-	VIII	BCEQ

Note: *—Intensity in the area of the considered scenario, EMSC—Euro-Mediterranean Seismological Centre (EMSC 2023), USGS—U.S. Geological Survey (USGS 2023), BCEQ—Balkan catalogue of earthquakes (Shebalin et al. 1974; AHEAD 2023).

Table 10. Input data used to calculate the probability of an earthquake with intensity above V in the study area.

Period	No. of years	Cases	Return interval, RI (years)	Probability of occurrence in 5 years, P
1901–2012	112	6	18.67	23%
1902–2020	119	1	119	4%

Note: 6 aftershocks for the period 1901–1904 are not included.

earthquake and a resulting landslide (Evstatiev et al. 2021). In 1901, the region was shaken by a strong earthquake of magnitude M=7.2 (Watzof 1903). Seismogenic faults in the area and their role in shallow methane seeps southeast of Kavarna as possible precursors of sea earthquakes is reviewed by Parlichev and Vasilev (2021).

Traces of shallow landslides (Fig. 3) can still be observed along both banks of the valley. A landslide has occurred in the area near the port, where most of the hotels are built. Activation after rains in 2004 is known, because of which two villas were destroyed. Retention walls have been built.

A 4% probability of landslide activation within 5 years has been calculated.

Other main characteristics related to the hazard and susceptibility to landslide processes, such as lithology, soil humidity, seismicity-triggering hazards, and precipitation-triggering hazards, are presented in Ivanov et al. (2020), and Berov et al. (2020).

3.2. Results

The acquired results demonstrate a comprehensive landslides risk assessment by applying the scenario-development approach.

The results are presented in a tabular format (Table 11), focusing five national interests: physical safety, security of physical assets and critical infrastructure, economic security, social well-being, and natural environment security specific to Bulgaria.

Table 11. Landslides scenario impact summary (town of Kavarna)—population and infrastructure impacts.

Scenario likelihood

	Almost certain	Very likely	Likely	Unlikely	Very rare	Extremely rare	Explanation
Likelihood of scenario occurring in the next 5 years				X			119-year return period

Scenario impact

National interest	Impact criterion	Impact severity					
		Insignificant	Minor	Moderate	Major	Catastrophic	Explanation of the impact
Physical safety	Fatalities		X				1–2 fatalities in houses located on the slope
	Injured and chronically ill	X					2–3 cases of injuries due to difficult evacuation
	People requiring temporary accommodations or permanently displaced			X			About 500 people will be evacuated, most of them tourists; about 30 locals will need to be permanently moved to stable terrain
Security of physical assets and critical infrastructure	Damage to buildings		X				Damage and destruction of houses located on the slope and of resort hotels
	Damage to cultural heritage			X			Serious damage to church; interrupted/difficult access to the museum
	Damage to CI and disruption to operation of CI			X			Shaft wells (for water supply), pump station, water supply system, and sewerage system are affected; parts of the electricity transmission network are affected
Economic security	Impact on the economy		X				Tourism and commercial fishing are affected
	Impact on key economic sectors				X		Hotels could be affected during the tourist season
Social well-being	Disruption of everyday life			X			Lack of electricity and water for a short period
	Income loss and unemployment		X				Local economy will not stop working, but jobs will be affected by decrease in tourism
	Disruption to key societal functions	X					No disruption
Natural environment security	Destruction of natural assets		X				Impact on the habitat of some rare birds
	Long-term disruptions to the environment	X					No impact

Note: grey = low uncertainty; yellow = medium uncertainty; red = high uncertainty. The levels are described in details in Dobrev et al. (2023a).

The table presents a defined set of impact criteria for each national interest. The significance scale utilized for rating each impact criterion encompasses a range of categories, namely insignificant, minor, moderate, major, and catastrophic impacts.

The Uncertainty (confidence) parameter is applied to reflect the reliability of the data used. It is expressed qualitatively and ranges from low confidence (inconclusive evidence or disagreement among experts) to very high confidence (strong evidence and high consensus).

Severity impact essentially refers to the quantitative level of the risk, respectively vulnerability and exposure.

The outcomes of the given scenario acknowledge the primary risks linked to: impact on key economic sectors, people requiring temporary accommodations or permanently displaced, disruption of everyday life and damage to critical infrastructure.

The high levels of exposure of structures in the area of interest can be seen as having a significant impact on important economic sectors. The primary consequences that need to be addressed are related to social systems and infrastructure—people requiring temporary accommodations or permanently displaced, damage to critical infrastructure and disruption to everyday life. Since the impact severity is only expected to be moderate, no fatalities or significant injuries will be expected.

On the other hand, more investigation is required for the most severe situations with the lowest probability to allow for an in-depth analysis and risk assessment for the area in question.

4. Discussion and perspectives

By considering these perspectives and integrating their findings, risk assessment experts can develop comprehensive strategies for landslide risk management, including early warning systems, land-use planning, and mitigation measures.

Risk assessment for landslides involves considering various perspectives to ensure a comprehensive evaluation. Here are some key perspectives to consider:

1. Geological and engineering geological perspective: Engineer geologists play a crucial role in assessing landslide risks. They study the geological conditions, such as slope stability, rock types, soil composition, and past landslide occurrences, to identify areas prone to landslides.
2. Topographical perspective: Topographic data, including elevation, slope steepness, and drainage patterns, are essential for evaluating landslide risks. Steep slopes, concave terrain, and areas with poor drainage are more susceptible to landslides.
3. Hydrological and hydrogeological perspective: Understanding the hydrological and hydrogeological conditions is vital as water plays a significant role in triggering landslides. Factors such as rainfall patterns, groundwater levels, and the presence of water bodies near slopes contribute to landslide susceptibility.
4. Climate perspective: Climate change can influence landslide risks. Assessing long-term climate patterns, including changes in precipitation,

temperature, and extreme weather events, helps determine if landslides are likely to increase or decrease in the future.

5. Human activities perspective: Human activities, such as deforestation, urbanization, mining, and construction, can significantly impact landslide risks. Assessing land-use changes and their effects on slope stability is essential to understand the human-induced factors contributing to landslides.
6. Historical perspective: Examining historical landslide events in the area provides valuable insights into recurring patterns, identifying high-risk zones, and understanding the factors that triggered past landslides.
7. Technological perspective: Advances in technology, such as remote sensing, LiDAR (Light Detection and Ranging), and satellite imagery, can aid in landslide risk assessment. These tools help in mapping and monitoring terrain changes, detecting ground movement, and identifying potential landslide-prone areas.
8. Socio-economic perspective: Assessing the vulnerability of communities living in landslide-prone areas is crucial. Factors such as population density, infrastructure vulnerability, and socioeconomic conditions help determine the potential impact and consequences of landslides on human lives and property.

The current assessment is being done for the first time and its main purpose is to serve as a model for subsequent assessments for other regions, in Bulgaria or abroad, where similar geological and infrastructural conditions exist.

5. Conclusion

The study provides a methodology for building an integrated risk assessment based on scenario development as recommended by IEC 31010:2019. The methodology was created and implemented for the initial evaluation of landslide hazards and risk in Bulgaria. The impact of landslides on the elements at risk is assessed by following mandatory procedures.

Scenarios are categorised into three primary types: high probability scenarios, medium probability scenarios, and low probability scenarios. The previous study conducted by Dobrev et al. (2023a) provides the data and methodologies utilised for risk assessment. It also presents a probable (likely) scenario, namely the possibility of a landslide occurring within the next five years, along a mountain road.

The present article presents a rare situation (unlikely scenario) that describes the possibility of landslide activation in the vicinity of the town of Kavarna, located on the northern shore of the Black Sea in Bulgaria under certain impacts.

In order to attain outcomes that are highly credible, the uncertainty (confidence) parameter is employed, and it is categorised into three primary levels: low, medium, and high uncertainty. The data collected for the current scenario exhibit a strong correlation with actual events, the examination of empirical data, and the authors' personal investigations. The collaborative efforts of the authors, who conducted field research and individually evaluated specific hypotheses, enhanced the trustworthiness of the findings. Through the engineering-geological research of the area in question, the different assumptions regarding the level of overall risk were confirmed. Prior to this, surveys were carried out among the municipal personnel who are accountable for the planning and implementation of civil infrastructure projects. The authors ensure the veracity of all the data they used.

Acknowledgments

The research was conducted as part of the World Bank's project titled "Reimbursable Advisory Services on Accelerating Resilience to Disaster Risks" (P170629), specifically focusing on Component 3: National Disaster Risk Profile. A portion of this work has been carried out in the framework of the National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters", approved by the Resolution of the Council of Ministers № 577/17.08.2018 and supported by the Ministry of Education and Science (MES) of Bulgaria (Agreement № D01- 27/06.02.2024).

References

AHED (2023) European Archive of Historical Earthquake Data https://www.emidius.eu/AHEAD/study/SHAL974 [Accessed on 20.12.2023]

Asian Development Bank (2021) Landslide Risk Assessment. Landslide Risk Management Sector Project (RRP KGZ 53022). 173 pp. https://www.adb.org/sites/default/files/linked-documents/53022-001-sd-05.pdf

Atanasova M, Nikolov H (2021) Use of two contemporary remote sensing technologies for mapping the Thracian Cliffs landslide (Northern Bulgarian Black Sea Coast). Review of the Bulgarian Geological Society 82 (3): 159–161. https://doi.org/10.52215/rev.bgs.2021.82.3.159

Berov B, Dobrev N, Brouchev I, Fukuzono T (2002) Landslides in Bulgaria. Journal of the Japan Landslide Society 38 (4): 334–343. https://doi.org/10.3313/jls1964.38.4_334

Berov B, Ivanov P, Dobrev N, Nankin R, Krastanov M (2013) State of the art for landslides along the North Bulgarian Black Sea coast. In: Margotti C, Canuti P, Sassa K (Eds). Landslide Science and Practice. Springer, Berlin, Heidelberg, 5: 97–102. https://doi.org/10.1007/978-3-642-31427-8_12

Berov B, Ivanov P, Dobrev N, Krastanov M (2016) Addition to the method of Mora & Vahrson for landslide susceptibility along the Bulgarian Black Sea coast. In: Aversa S, Cascini L, Picarelli L, Scavia C (Eds) Landslides and Engineered Slopes. Experience, Theory and Practice: Proceedings of the 12th International Symposium on Landslides Napoli (Italy), 12–19 June 2016. CRC Press, A Balkema book 2: 397–403. https://doi.org/10.1201/9781315375007

Berov B, Nikolova N, Ivanov P, Dobrev N, Krastanov M, Nankin R (2020) Landslide susceptibility mapping using GIS: A case study along Bulgarian Black Sea coast. In: Bandrova T, Konečný M, Marinova S (Eds) Proceedings of the 8th International Conference on Cartography and GIS, Nessebar (Bulgaria) 2020. Bulgarian Cartographic Association, 1: 287–296.

Bonnard C, Forlati F, Scavia C (2005) Identification and mitigation of large landslides risks in Europe: advances in risk assessment. Balkema, 317 pp.

Brankov G (Ed) (1983) The earthquake in Vrancha in 1977. Consequences in the Republic of Bulgaria. Bulgarian Academy of Sciences Academic Press, Sofia, Bulgaria, 425 pp. (in Bulgarian)

Bruchev I (2018) Hazardous geological processes on the territory of the Republic of Bulgaria – conditions, factors, geoprotection. Engineering Geology and Hydrogeology 32: 57–64. https://doi.org/10.52321/igh.32.1.57 (in Bulgarian)

Bruchev I, Ivanov P, Frangov G, Varbanov R, Dobrev N, Berov B, Nankin R, Krastanov M (2007) The Landslides in Bulgaria – Factors and Distribution. Geologica Balcanica 36 (3–4): 3–12. https://doi.org/10.52321/GeolBalc.36.3-4.3

Cheshitev G, Chontova C, Popov N, Kojumdgieva E (1991) Geological Map of Bulgaria on Scale 1:100 000, Balchik and Shabla Map Sheets. Committee of Geology, Dept. of Geophysical Prospecting and Geological Mapping, Sofia.

Clague J, Stead D (Eds) (2012) Landslides: Types, Mechanisms and Modeling. Cambridge University Press, 420 pp. https://doi.org/10.1017/CBO9780511740367

Dhungana G, Ghimire R, Poudel R, Kumal S (2023) Landslide susceptibility and risk analysis in Benighat Rural Municipality, Dhading, Nepal. Natural Hazards Research 3: 170–185. https://doi.org/10.1016/j.nhres.2023.03.006

Dobrev N, Bruchev I, Nakov R et al. (2014) Methodology for assessment of geological risk. Geological Institute of Bulgarian Academy of Sciences, Ministry of Regional Development and Public Works, Sofia, 123 pp. (in Bulgarian). http://gis.mrrb.government.bg/KGR/

Dobrev N, Ivanov P, Berov B, Frantzova A, Krastanov M (2023a) Scenario risk assessment of landslides – Asenovgrad mountain road. Geologica Balcanica 52 (2): 75–82. https://doi.org/10.52321/GeolBalc.52.2.75

Dobrev N, Ivanov P, Frangov G et al. (2023b) Program for the prevention and mitigation of landslides on the territory of the Republic of Bulgaria, erosion and abrasion along the Danube and Black Sea coasts for the period 2022-2027. Ministry of Regional Development and Public Works, Sofia, 134 pp. (in Bulgarian). https://www.mrrb.bg/bg/programa-za-prevenciya-i-ogranichavane-na-svlachistata-na-teritoriyata-na-republika-bulgariya-eroziyata-i-abraziyata-po-dunavskoto-i-chernomorskoto-krajbrejie-za-perioda-2022-2027-g/

EMSC (2023) Euro-Mediterranean Seismological Centre. Earthquakes https://www.emsc-csem.org/ [Accessed on 20.12.2023]

Esposito G, Salvati P, Bianchi C (2023) Insights gained into geo-hydrological disaster management 25 years after the catastrophic landslides of 1998 in southern Italy. International Journal of Disaster Risk Reduction 84: 103440. https://doi.org/10.1016/j.ijdrr.2022.103440

EU Floods recovery Programme (2015) Floods and landslides risk assessment for the housing sector in Bosnia and Herzegovina, 125 pp. https://europa.ba/wp-content/uploads/2015/12/HRA_Final_web.pdf

European Soil Data Centre (2023) Landslides https://esdac.jrc.ec.europa.eu/themes/landslides [Accessed on 20.12.2023]

Evlogiev Y, Evstatiev D (2013) Landslides near Topola village (Northern Black Sea Cost). Engineering Geology and Hydrogeology 27: 13–69 (in Bulgarian).

Evstatiev D, Evlogiev Y, Nedelcheva M (2021) The catastrophic landslide on the Black Sea coast which destroyed the Roman town of Bisone (south of Kavarna town). Review of the Bulgarian Geological Society 82 (2): 3–25. https://doi.org/10.52215/rev.bgs.2021.82.2.2

Fell R (1994) Landslide risk assessment and acceptable risk. Canadian Geotechnical Journal 31 (2): 261–272. https://doi.org/10.1139/t94-031

Fell R, Corominas J, Bonnard C, Cascini L, Leroi E, Savage W (2008) Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning. Engineering Geology 102 (3–4): 99–111. https://doi.org/10.1016/j.enggeo.2008.03.014

Frantsova A (2021) Comprehensive Methodology for Natural Disaster Risk Assessment. LAP Lambert Academic Publishing, London, 132 pp.

Frantzova A (2023) Disaster Risk Assessment of North Bulgarian Black Sea Coast. Mining Revue 29 (2): 82–92. https://doi.org/10.2478/minrv-2023-0018

Iliev I (1973) Effect of the earthquakes on the appearance and activation of landslides along the Dobrudja Black Sea Coast. Review of the Bulgarian Geological Society 34 (1): 75–85

Ivanov P, Berov B, Dobrev N, Krastanov M, Frangov S (2017a) Principles for the assessment and mapping of integrated geological hazard in Bulgaria. Geologica Balcanica 46 (2): 103–109. https://doi.org/10.52321/GeolBalc.46.2.103

Ivanov P, Berov B, Dobrev N, Varbanov R, Krastanov M, Frangov G (2017b) Analysis and mapping the landslide hazard in Bulgaria. In: Mikoš M, Tiwari B, Yin Y, Sassa K (Eds) Advancing Culture of Living with Landslides. WLF 2017. Springer, Cham, 1111–1118. https://doi.org/10.1007/978-3-319-53498-5_126

Ivanov P, Dobrev N, Brutchev I, Nakov R, Karastanev D, Berov B, Krastanov M, Frangov G, Varbanov R, Stoynev S, Lakov A, Jelezov G, Karadinkova S, Gavrilov I, Yordanov J (2017c) Elaboration of analysis, evaluation and mapping of geological risk. Geological Institute and Ministry of Regional Development and Public Works, Sofia, Bulgaria, 228 pp. http://gis.mrrb.government.bg/KGR/ (in Bulgarian)

Ivanov P, Nankin R, Zaalishvili V (2020) Assessment of Landslide Susceptibility and Hazard along the Northern Bulgarian Black Sea Coast. In: Gadzhev G, Dobrinkova N (Eds) Proceeding of the 1st International Conference on Environmental Protection and Disaster Risks, September 2020, Sofia, (Bulgaria). Az-buki National Publishing House, Sofia, 392–404. https://doi.org/10.48365/envr-2020.1.36

Ivanov P, Dobrev N, Berov B, Frantzova A, Krastanov M, Nankin R (2022) Landslide risk for the territory of Bulgaria by administrative districts. Geologica Balcanica 51 (3): 21–28. https://doi.org/10.52321/GeolBalc.51.3.21

Koleva-Rekalova E (1994) Sarmatian aragonite sediments in North-Eastern Bulgaria – origin and diagenesis. Geologica Balcanica 24 (5): 47–64. https://doi.org/10.52321/GeolBalc.24.5.47

Konstantinov B, Angelov K, Lakov A, Stojnev S, Konstantinov V (1992) Landslides activization from earthquake motions. Sixth International Symposium on Landslides (ISL 1992): 1181–1186.

Kuhn D, Hermanns RL, Torizin J, Fuchs JM, Schüßler N, Eilertsen RS, Redfield TF, Balzer D, Böhme M (2023) Litho-structural control on rock slope failures at Garmaksla, Billefjorden coastline, Svalbard. Quarterly Journal of Engineering Geology and Hydrogeology 56: 1–15. https://doi.org/10.1144/qjegh2022-069

Lakov A, Stoynev S, Konstantinov B (2002) Geodynamic hazard and geodynamic risk along the Bulgarian Black Sea coast. Proceedings of the 9th National Mine Surveying Conference with International Participation “Analysis, Modelling and Control of Geological Risk in Disturbed Territories”, 263–268. (in Bulgarian)

Lee M, Jones D (2023) Landslide Risk Assessment, Third edition. ICE Publishing, Leeds, 478 pp.

Ministry of Interior (2020) General Directorate “Fire Safety and Protection of the Population” – Disaster Risk Reduction (in Bulgarian) https://www.mvr.bg/gdpbzn/ [Accessed on 06.02.2024]

Mora S, Vahrson W-G (1994) Macrozonation Metodology for Landslide Hazard Determination. Bulletin of the Association of Engineering Geologists 31 (1): 49–58. https://doi.org/10.2113/gseegeosci.xxxi.1.49

Nankin R, Ivanov P (2019) Current state of the landslides affecting the Northern Bulgarian Black Sea Coast. Review of the Bulgarian Geological Society 80 (3): 176–178. (in Bulgarian)

Nankin R, Krastanov M, Ivanov P (2022) Erosion of Coastal Slope in the Zelenka locality, Northern Black Sea coast of Bulgaria. Engineering Geology and Hydrogeology 36: 3–14. https://doi.org/10.52321/igh.36.1.3

National Risk Profile (2016) An all Hazard overview of potential disasters and threats in the Netherlands. The National Network of Safety and Security Analysts. National Institute for Public Healthand the Environment, Bilthoven, 200 pp. https://www.clingendael.org/publication/national-risk-profile-2016

Nikolov H, Atanasova M (2023) Monitoring coastal landslides along the Northeast Black Sea of Bulgaria using SAR DATA. Aerospace Research in Bulgaria 35: 63–79. https://doi.org/10.3897/arb.v35.e07

Parlichev D, Vasilev A (2021) New opportunities for identification of precursors of sea earthquakes. Engineering Geology and Hydrogeology 35: 15–22. https://doi.org/10.52321/igh.35.1.15

Poljanšek K, Casajus Valles A, Marin Ferrer M, De Jager A, Dottori F, Galbusera L, Garcia Puerta B, Giannopoulos G, Girgin S, Hernandez Ceballos M, Iurlaro G, Karlos V, Krausmann E, Larcher M, Lequarre A, Theocharidou M, Montero Prieto M, Naumann G, Necci A, Salamon P, Sangiorgi M, Sousa ML, Trueba Alonso C, Tsionis G, Vogt J (2019) Wood M. Recommendations for National Risk Assessment for Disaster Risk Management in EU. Publications Office of the European Union, Luxembourg, 162 pp. https://dx.doi.org/10.2760/084707

Regmi A, Agrawal N (2022) A simple method for landslide risk assessment in the Rivière Aux Vases basin, Quebec, Canada. Progress in Disaster Science 16: 100247. https://doi.org/10.1016/j.pdisas.2022.100247

Rosser N, Kincey M, Oven K, Densmore A, Robinson T, Pujara DS, Shrestha R, Smutny J, Gurung K, Lama S, Dhital MR (2021) Changing significance of landslide Hazard and risk after the 2015 Mw 7.8 Gorkha, Nepal Earthquake. Progress in Disaster Science 10: 100159. http://dx.doi.org/10.1016/j.pdisas.2021.100159

Schweigl J, Hervás J (2009) Landslide Mapping in Austria. JRC Scientific and Technical Report EUR 23785 EN, Office for Official Publications of the European Communities, Luxembourg, 61 pp. https://esdac.jrc.ec.europa.eu/ESDB_Archive/eusoils_docs/other/EUR23785EN.pdf

Shebalin NV, Karnik V, Hadzievski D (Eds) (1974) Catalogue of earthquakes of the Balkan Region, Part I and Part II. UNDP/UNESCO Survey of the seismicity of the Balkan region, UNESCO, Skopje, 600 pp.

Solakov D, Simeonova S, Raykova P (2022) Deterministic earthquake scenario for the city of Varna. In: Trofymchuk O, Rivza B (Eds) International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 22(1.1): 517–524. https://doi.org/10.5593/sgem2022/1.1/s05.060

The World Bank in Bulgaria (2020) Country Snapshot https://pubdocs.worldbank.org/en/780231587128617024/Bulgaria-Snapshot-Apr2020.pdf [Accessed on 06.02.2024]

ThinkHazard (2020) Greece. Landslide https://thinkhazard.org/en/report/97-greece/LS

UNESCO Working Party on World Landslide Inventory (1993) A suggested method for describing the activity of a landslide. Bulletin of the International Association of Engineering Geology 47: 53–57. https://doi.org/10.1007/BF02639593

USGS (2021) What is a landslide and what causes one https://www.usgs.gov/faqs/what-a-landslide-and-what-causes-one?qt-news_science_products=0#qt-news_science_products [Accessed on 20.12.2023]

USGS (2023) Earthquake Hazards Program https://www.usgs.gov/programs/earthquake-hazards/earthquakes [Accessed on 20.12.2023]

Varnes DJ (1978) Slope movement types and processes: In: Schuster RL, Krizek RJ (Eds) Landslides: analysis and control. Transportation Research Board Special Report 176. National Academy of Sciences, Washington, DC, 11–33.

Walker B, DaviesW, Wilson G (2007) Commentary on Practice Note Guidelines for Landslide Risk Management (2007) Journal and News of the Australian Geomechanics Society 42(1): 64–114. https://landsliderisk.org/wp-content/uploads/2017/04/ags_2007c2.pdf

Watzof S (1903) Tremblements de terre en Bulgarie en 1901. Imprimerie de l'Etal, Sofia, Bulgaria, 46 pp. (in Bulgarian)

Yamaguchi M, Yastika PE, Shimizu N, Milev N, Vrkljan I (2021) Application of SBAS-DInSAR to monitoring landslides along the northern Black Sea coast in Bulgaria. In: Ferrero AM, Moraci N, Scavia C (Eds) Proceedings of IOP Conference Series: Earth and Environmental Science (Eurock 2021), Turin (Italy) 833(1): 012151. https://doi.org/10.1088/1755-1315/833/1/012151

Yaneva M, Koleva-Rekalova E, Nikolov P, Ognjanova-Rumenova N (2019) Topola Formation, Northeastern Bulgaria – biostratigraphical and palaeoecological aspects. Review of the Bulgarian Geological Society 80 (3): 133–135.

Additional information

Conflict of interest

No conflict of interest was declared.

Ethical statement

No ethical statement was reported.

Funding

World Bank's project titled "Reimbursable Advisory Services on Accelerating Resilience to Disaster Risks" and National Science Program "Environmental Protection and Reduction of Risks of Adverse Events and Natural Disasters".

Author contributions

Conceptualization: ND, PI, BB, AF. Data curation: BB, ND, RN, PI. Formal analysis: MK, AF. Investigation: BB, RN, ND. Methodology: AF, ND. Visualization: MK, PI, RN. Writing - original draft: MK, AF, BB.

Author ORCIDs

Boyko Berov https://orcid.org/0000-0002-4931-4655
Antoaneta Frantzova https://orcid.org/0000-0002-0732-1240
Plamen Ivanov https://orcid.org/0000-0002-7139-7303
Nikolai Dobrev https://orcid.org/0000-0001-5301-1959

Miroslav Krastanov https://orcid.org/0000-0002-0250-0346
Rosen Nankin https://orcid.org/0009-0006-8146-3614

Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.