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Research Article

Rethinking the landslide risk assessment for socio-ecological systems using the example of the northern Bulgarian Black Sea coast

Antoaneta Frantzova[‡], Plamen Ivanov[‡], Nikolai Dobrev[‡], Boyko Berov[‡], Rosen Nankin[‡], Miroslav Ivanov Krastanov[‡], Boyko Ranguelov[§]

‡ Geological Institute - Bulgarian Academy of Sciences, Sofia, Bulgaria
§ University of Mining and Geology St Ivan Rilski, Sofia, Bulgaria

Corresponding author: Antoaneta Frantzova (afrantzova@gmail.com)

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Abstract

In recent years, society become much more interested in nature disasters that cause damage. The consequences of these destructive processes of a meteorological, hydrological and geological nature sometimes remain for years until the affected areas are recultivated, restored and recovered. These natural processes work together, often following each other or triggering each other to create a massive system of destruction that causes a lot of damage and often leads to death and numerous casualties.

Moreover, with the changes in the global climate of the Planet, leading to the more frequent manifestation of more destructive natural phenomena - cyclones, storms, huge amounts of precipitation - lead to intensify and manifest in larger scales and volumes geological phenomena such as landslides, mudflows, mud - stone torrents, rockfalls, collapses of different character of slopes, linear and planar erosion etc.

This is extremely relevant for Bulgaria, the territory for which is no exception to the manifestation of catastrophic natural phenomena. The country is located in an active orogenic zone as part of the Alpo-Himalayan tectonic belt, characterised by a complex

tectonic structure, variable and diverse geological formations and rapid topographical changes.

The main focus in the study is to present an advanced, multi-faceted framework for natural disaster risk assessment, integrating biodiversity and archaeological sites. Moreover, the assessments of natural risks made so far do not include sufficient attention to biotopes and archaeological and historical sites.

The presented methodology is applied to landslide hazards in a pre-selected area along the northern Bulgarian Black Sea coast. The main goal of this paper is to identify socio-environmental risks in the studied region, as well as to construct risk profiles and visually represent both qualitative and quantitative risk levels in the socio-ecological system and biodiversity.

Keywords

natural hazards, risk assessment, biodiversity, archaeology, adaptive capacity

Introduction

According to the Stockholm Resilience Centre, Socio-ecological systems (SES) refers to the interconnectedness of social and ecological components within a specific geographic area or ecosystem (these systems involve both biophysical (ecological) elements (such as plants, animals, soil, water) and social elements (such as human communities, institutions and cultural practices). SES are dynamic, adaptive and influenced by feedback loops between social and ecological processes (Martín-López et al. 2012).

In recent years, there has been a growing focus on analysing the vulnerability of socio-ecological systems in the face of ecosystem loss or degradation. An essential question is: how can we establish a connection between ecological vulnerability, biodiversity and social system analysis in order to provide a comprehensive risk assessment of socio-ecological systems (Berrouet et al. 2018)?

As is stated in Behnassi et al. (2021), an essential discussion including multiple disciplines is necessary to reconsider the way socio-ecological systems interact. It is also crucial to make necessary changes in order to improve the resilience of these systems.

Undoubtedly, the presence of a natural disaster is not an isolated event, as it affects not only the affected locality and surrounding area, but also adjacent areas, with unforeseen consequences. SES considers these interactions and constructs a network that covers multiple scales, with bounds set by both environmental characteristics and societal factors (Accastello et al. 2019).

However, there has been less focus on the social-ecological aspect of risk. The lack of attention to the environmental aspect is a major knowledge gap, considering that it is a primary contributor to the risk associated with natural catastrophes.

Although ecosystem restoration is widely recognised as a vital approach for reducing disaster risks, current vulnerability and risk assessments often fail to consider the interplay between environmental health, vulnerability and population risk. This understanding is essential for developing and implementing effective strategies for adapting to ecosystems (Depietri 2019).

When natural hazards occur, the ecosystems are affected. Therefore, the incorporation of SES into risk assessments has emerged as a novel and widespread trend. Recent years have seen an increase in research, with a focus on using risk assessment to map how natural phenomena threaten regional environments (Depietri 2019, Peng et al. 2024).

The objective of the research is to propose a novel methodology for evaluating the risk of natural disasters in the socio-ecological system. This approach encompasses the analysis of hazard, exposure, vulnerability and coping capability, which are the key factors that influence the level of risk.

For the first time, the socio-ecological risk assessment includes adaptability, ecosystems and archaeology. Using archaeology for understanding the long-standing trends of socio-ecological systems might provide significant observations for ongoing activities that focus on building sustainable and resilient communities.

The new method is associated with Ecosystem-based Disaster Risk Reduction (Eco-DRR), a comprehensive concept that includes disaster risk and ecosystem-based methods (Broquet et al. 2024). Nature-based Solutions (NbS) are associated with ecosystem-based approaches (Babí Almenar et al. 2021, Sowińska-Świerkosz and García 2022). In this regard, we contend—completely in agreement with Walz et al. (2021)—that environmental degradation plays a critical role in disaster risk.

The purpose of this paper is to establish and assess the landslide risk in the socio-ecological environment of the north Bulgarian Black Sea Coast. The land area is characterised by an extensive distribution of landslides, rockfalls and rarely mudflows. The occurrence and activation of landslides is due to active sea abrasion and high seismicity in the area. We examine the impact of recent active landslides on various social activities, such as archaeology, tourism and threats to the local community, as well as biodiversity, given that Natura 2000*[1] safeguards a significant portion of the landslide-affected area. Thus, a complex assessment of the landslide risk can reveal the possible risk elements related to the social and environmental components of the regional environment.

Landslide risk assessment has so far focused mainly on the social impact and the possibilities to mitigate the negative consequences. The majority of efforts are directed at investigating local and regional resources, their use during destructive natural disasters, the potential for recovery and the potential negative impacts on the economy and society

(Ranguelov and Dimitrov 2019, Berov et al. 2024). Only a few studies have addressed national-level assessment of natural heritage potential and ecosystem services (Ranguelov et al. 2020, Nedkov et al. 2022).

Building construction and infrastructure have been the primary focus of previous studies. The selected area has a wide range of old and contemporary landslides that occurred in Neogene (Sarmatian) sediments (Berov et al. 2013, Evlogiev and Evstatiev 2016, Evstatiev et al. 2021). Against the backdrop of these old landslides, numerous active landslides have impacted the entire area under investigation (Nankin and Ivanov 2019, Berov et al. 2020, Ivanov et al. 2022). An assessment of the susceptibility of terrains to landslides by various methods was made by Berov et al. (2016), Berov et al. (2020) and Ivanov et al. (2020). Monitoring of the coastal landslides along the northern Black Sea of Bulgaria using SAR data was provided by Yamaguchi et al. (2021), Nikolov and Atanasova (2023) and Nikolov and Atanasova (2024). Berov et al. (2024) carried out a landslide risk assessment scenario for the town of Kavarna. In recent decades, many counter-measures have been implemented to prevent landslide activity.

Even though these concepts exist, currently, most of the adopted strategies ignore the environmental aspect of SES and adopt standard mitigation measures (Accastello et al. 2019).

An improved risk assessment for socio-ecological systems can be a valuable instrument for maximising human profit from nature, while also protecting infrastructure and livelihoods through damage mitigation and well-planned economic activity on the territory (Arrogante-Funes et al. 2022).

Data resources

The study area is located in north-eastern Bulgaria and covers the coastal zone north of the City of Varna ending at Bulgarian-Romanian border (Fig. 1).

It is characterised by a plate-like relief, sedimentary rocks of Paleogene and Neogene age, with slightly inclined to almost horizontal layers (3–5° to the east). The Frangya Plateau (Varna, Golden Sands, Kranevo) and the southern part of the Dobrudzha Plateau (Albena, Balchik and Kavarna) are included (Popov and Mishev 1974). A strip of the Dobrudzha Plateau north and west of Kavarna, including Cape Kaliakra and north to the Bulgarian-Romanian border are also in the area of investigations. A spatial model of the Black Sea coastal region in Bulgaria was developed by Zhelezov (2023). The coast from Varna City to Cape Kaliakra is relatively higher, about 200 m (at Balchik), while, from Cape Kaliakra to the border with Romania, it is low, with an altitude below 100 m - up to 10-20 m at Krapets and Durankulak.

From a tectonic point of view, the area under discussion in this paper falls within the eastern part of the Moesian Platform, on the eastern slope of the north Bulgarian Uplifted tectonic land. The most north-eastern parts are located in the Varna monocline, which starts from the periphery of Varna, to the west is separated from the north Bulgarian Uplift tectonic form with the Venelin-Dobrich fault zone - a cluster of faults with submeridional direction and width reaching 3-4 km to 15-20 km, to the north it borders the General Toshevo saddle and the Dobrudzha massif, to the south it is separated by a fault or a bundle of faults with an almost east-west direction, passing approximately along the Kamchia River valley from the Lower Kamchia depression and to the east it passes into the Black Sea depression. The inclination of the monoclinal is to the south and east.

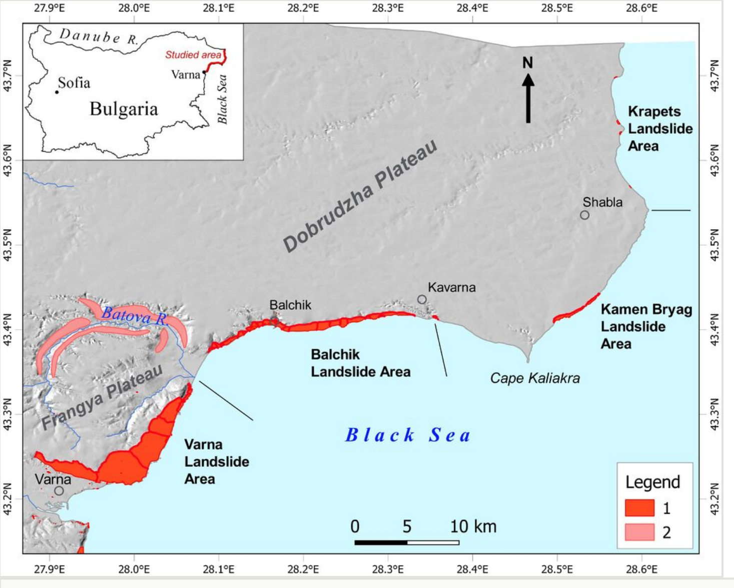

Figure 1.

Distribution of landslides along the north Black Sea coast of Bulgaria. 1 - deep landslides along the Black Sea coast; 2 - shallow landslides along the Batova River valley.

The Neogene sediments forming the coastal strip of north-eastern Bulgaria are represented by their Miocene series, to which the following lithostratigraphic units are connected: Galata Formation, Euxinograd Formation, Frangya Formation, Odartsi Formation, Topola Formation and Karvuna Formation (Cheshitev et al. 1991). Aeolian Quaternary sediments (loess formation) are widespread in the northern part of the region.

Old and recent landslides with different degrees of activity are common in this area (Berov et al. 2002, Bruchev et al. 2007, Berov et al. 2013, Berov et al. 2016, Nankin and Ivanov 2019, Berov et al. 2020). The main factors influencing the landslide activity in this region are the slow vertical movements of the Earth's crust, earthquakes, sea erosion, precipitation, fluctuations in groundwater levels and human impact. The influence of seismicity on landslide processes along the northern Black Sea coast of Bulgaria has been described by a number of authors such as Watzof (1903), Iliev (1973), Brankov (1983), Evstatiev et al. (2021) and Solakov et al. (2022). Depending on the degree of impact, geological structure and lithological composition of the rocks and their engineering geological properties, four large landslide areas can be separated namely Varna, Balchik, Kamen Bryag and Krapets. The development of landslides and the formation of the relief of the Black Sea coast is related to the palaeogeographical history of the coast during the Neogene and Quaternary (Fig. 2).

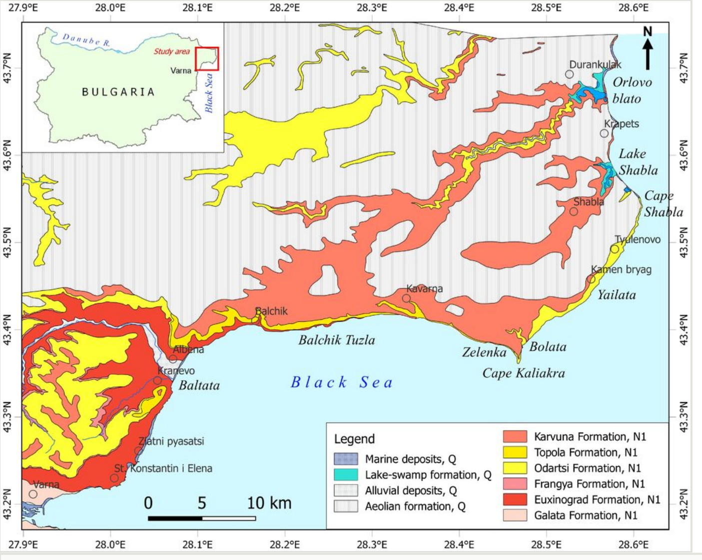

Figure 2.

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

Landslides affect approximately 55000 decares of the Black Sea coast, extending from the border with Romania to the City of Varna. Of these, about 2042 decares are active landslides (Ivanov et al. 2022).

To enhance clarity and facilitate visualisation, the area of interest is split into three distinct regions. The first region covers from the border with Romania (43°44'N, 28°34'E) to Cape Kaliakra (43°21'N, 28°28'E). The second region encompasses the area from Cape Kaliakra to the Kranevo resort (43°20'N, 28°03'E). Lastly, the third region extends from the Kranevo resort to Varna City (43°13'N, 27°55'E). Risk profiles are computed specifically for the summer period, which corresponds to the tourist season.

Around 15 Protected areas located in the areas of interest are included in Natura 2000 (https://natura2000.eea.europa.eu/). Part of them, as well as the archaeological site, are explained here due to their direct connection and specific significance in relation to risk assessment (Ihtimanski et al. 2020, Nedkov et al. 2022).

Landslides occupy approximately 55000 decares of the considered area (the Black Sea coast from the border with Romania to the City of Varna). Of these, about 2042 decares are active landslides (Ivanov et al. 2022) as follows:

- From the border with Romania (43°44'N, 28°34'E) to Cape Kaliakra (43°21'N, 28°28'E) - In this region, the area occupied by landslides is 1338 decares, of which about 4 decares are active landslides.

- From Cape Kaliakra to the Kranevo resort (43°20'N, 28°03'E) - In this region, the area occupied by landslides is 12560 decares, of which about 1168 decares are active.
- From the Kranevo resort to Varna City (43°13'N, 27°55'E) - In this third region, the area occupied by landslides is 41097 decares, of which about 870 decares is the area of active landslides.

Border with Romania (43°44'N, 28°34'E) to Cape Kaliakra (43°21'N, 28°28'E)

Geological settings and landslide processes

The landslides, along the Black Sea coast between the Bulgarian-Romanian border and Cape Shabla (Krapets landslide area), are small and affect the loess complex, which is eroded and this leads to the separation of long and narrow strips of up to 10 m from it (Prodanov et al. 2019, Prodanov et al. 2020, Prodanov et al. 2021).

The landslide strip, between Cape Shabla and Cape Kaliakra (Kamen Bryag Landslide Area) is formed by two landslides (Taukliman and Yaylata), which are step-shaped, linearly elongated, lateral thrust type. Both landslides were probably triggered by strong earthquakes, with the main prerequisite being the geological construction represented by two fundamentally different sediments in terms of engineering geology. The upper part is made of the limestones of the Odartsi Formation (odN_1^s) with an average thickness of 30–40 m and below them lie Oligocene clays with a thickness of more than 100 m. The Taukliman landslide (Rusalka Resort Complex) is formed by seven landslide steps, has a width of 1200 m and a length of 500 m, while the Yaylata landslide is smaller, with a number of visible steps of 3–4.

Biodiversity

Durankulak Lake is a natural wetland that serves as a resting site for migratory birds, making it an important location for ornithologists. It is considered a unique and representative ecosystem according to Bulgaria's national strategy for protecting biological variety.

The Shabla Lake Complex spans 3175 ha in the town of Shabla, as well as the villages of Ezerets and Krapets. The protected area is a home for 260 species of birds, with 70 of them entered within in the Red Book of Bulgaria. An artificial channel connects the Shabla and Ezerets Lakes to the Shabla Lake. It is separated from the Black Sea by a strip of sand dunes (Nature 2000).

The Bolata locality (Fig. 3) is located on the Bay of the same name and is part of the protected area Kaliakra Reserve under NATURA 2000. The area is a wetland of great importance for several rare plant and animal species.

Figure 3.
Locality Bolata (part of Kaliakra Reserve).

Archaeology

The archaeological complex Durankulak (Fig. 4 and Fig. 5) is a complex archaeological site located in the area of the Durankulak Lake near the Village of Durankulak, north-eastern Bulgaria. Researchers discovered the earliest phase of the Hamangia culture, known as Cultura Hamangia (early 5500–54000 BC). The Durankulak archaeological complex unites three sites: the settlement mound Durankulak (Big Island), Durankulak - Necropolis and Durankulak - The Fields. A prehistoric settlement is located on a large island near the village of Durankulak. People began to settle there at the start of the 5th millennium BC. The results of archaeological research on the Big Island, that several settlements and cult buildings built in the same place over a long period — from prehistory (5th–7th millennia BC) to the Early Middle Ages (9th – 11th century) phenomenon, unique to the archaeological sites of the Balkans (Todorova et al. 2013, Korzhenkov et al. 2023).

Yaylata (Fig. 6), the national archaeological reserve, is located 2 km south of the village of Kamen Bryag and 18 km north-east of the town of Kavarna. It is a seaside ledge covering 300 decares (30 ha) and is detached from the sea by 50–60-metre-high rock massifs. There is a cave "city" of 101 "apartments", settled as far back as the 5th century B.C. The rocks have hollowed out three necropolises (family tombs) from the 3rd-4th centuries. Necropolis 1 is situated near a whittled-down sanctuary, facing the rising sun. The northern part of "The Big Yaila" is home to a slightly early Byzantine fortress. Four towers and one tower gate remain partially intact. There are also a sanctuary, sacrificial stones and wineries, four dug into tombs, which have been preserved since antiquity. The caves served as a monastery complex during the Middle Ages. There are some proto-Bulgarian signs on their walls—runes, crosses and stone icons.

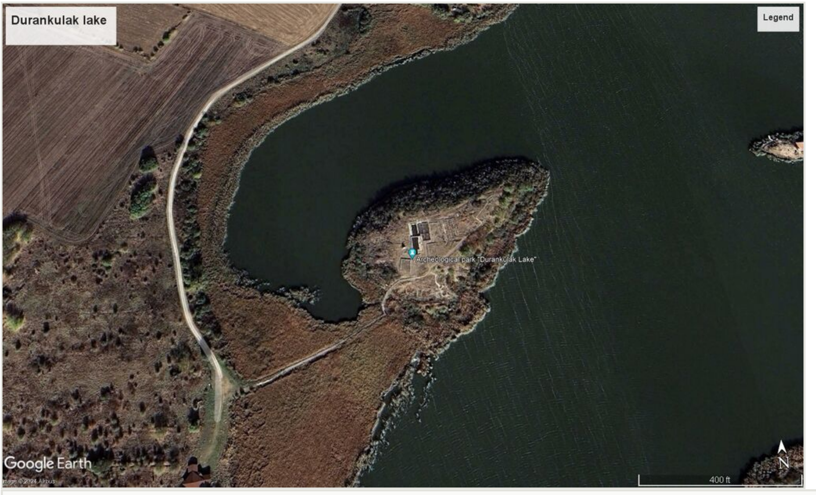

Figure 4.

Archaeological complex Durankulak (Image from Google Earth).

Figure 5.

Archaeological complex Durankulak (Todorova 2016).

Cape Kaliakra to the Kranevo resort (43°20'N, 28°03'E)

Geological settings and landslide processes

The Black Sea coast, northeast from the Batova River to the west of the town of Kavarna, is covered by old and recent landslides (Evlogiev and Evstatiev 2011, Evstatiev et al. 2017, Atanasova and Nikolov 2021, Evstatiev et al. 2021, Nikolov and Atanasova 2023, Berov et al. 2024). The landslide strip, formed by the old landslides has an average width of 400–500 m, ending at the plateau with a steep slope of 40–50 m in some places. Usually, the landslide bodies are formed by 3–4 visible linearly orientated steps and hills (landslide packages) of different heights, often behind them are formed closed undrained negative forms with permanent or temporary swamps. The toes of the landslides are below today's sea level, where 1–2 more landslide packages, invisible at the surface, were formed. The depths of the old landslides reach 40–60 m, at places in some places even more.

Figure 6.

National archaeological reserve Yaylata.

The sediments affected by the landslide processes belong to the Karvuna Formation (kvN1s), the Topola Formation (toN1s) and the Euxinograd Formation (evN1s). For their development, the sediments of the Topola Formation, made up of aragonite sediments (aragonitites), with interlayers of strong limestones, are of greatest importance (Koleva-Rekalova 1994, Evstatiev et al. 2017).

Against the background of the old (ancient) landslides, modern active local landslide processes occur. They are usually smaller in depth and range, but cause significant economic damage.

In this area, the area affected by landslides is 12560 decares, of which about 1168 decares are active.

Biodiversity

The Kaliakra Reserve covers 687.5 hectares and includes a wild large area of flat unfrosted grassland and impressive coastal rocks. More than 400 plant species thrive in the Reserve, with 47 of them being extremely rare and endangered. The Reserve is a very special location for birdwatchers, especially during the migration season (August to October). Via Pontica, the second-largest migratory route in Europe, passes through the region. Over 310 bird species inhabit Kaliakra, with 106 of them protected at the European level. The European Shag (Phalacrocorax aristotelis) also nests here.

The establishment of the Protected Zone Balchik was motivated by the desire to preserve the reproductive and migratory habitats of numerous bird species so that they might remain in an optimal state (Natura 2000). Batova Protected Zone, situated to the north of the City of Varna (near the Village of Kranevo), encompasses the Batova River, the littoral from the Albena resort complexes to Golden Sands and the surrounding seawater area. Situated at the estuary of the Batova River, the Baltata Reserve safeguards natural longose groves and wetland ecosystems. Seventy of the 184 avian species that call this region home are listed in the Red Book of Bulgaria. By means of Via Pontica, the location is situated on the western Black Sea flyway.

Archaeology

Kaliakra Cape archaeological site (Fig. 7): The first records of human habitation on Cape Kaliakra date back to the 4^{th} century B.C. when it was inhabited by the Thracian tribe Tirisis. The settlement consisted of an inner town and an outer town. The remains of many buildings, including a 4^{th}-century A.D. bath and a vaulted mason tomb, have been discovered. Several medieval churches were also found during archaeological digs. In the 14^{th} century, Kaliakra became the centre of the easternmost part of the Bulgarian state and a major international harbour (Tonkov et al. 2010).

Figure 7.

Kaliakra Cape archaeological site, Ministry of Tourism of Bulgaria.

Kranevo resort to Varna City (43°13'N, 27°55'E)

Geological settings and landslide processes

The region is composed of Miocene sediments and it is represented by several formations: Galata Formation (gN_1^{t-s}) – sands and clays, Euxinograd Formation (evN_1^{kg-s}) – sandstones, diatomaceous and spongolitic clays, Frangya Formation (frN_1^{s}) – water-bearing sands and Odartsi Formation (odN_1^{s}) – mainly from limestones (Evlogiev and Evstatiev 2016). The formation of deep-seated landslides in this area is mainly a result of marine abrasion. These are extensive landslide complexes (circus type) manifested along the eastern slope of the Frangen Plateau - from the edge to the seashore. Against the background of these ancient, conditionally stabilised landslides, as a result of the complex impact of natural factors and man-made activity, recent active local landslide processes arise (Varbanov et al. 1997, Evlogiev and Evstatiev 2011).

In this third region, the area affected by landslides is 41097 decares, of which about 870 decares is the area of active landslides.

Biodiversity

Aladzha Monastery and Batova are protected areas near Varna on an area of 17 ha - territories with a remarkable landscape and protection of the habitats of endangered and rare plant and animal species and communities. The territory of the protected area is part of the Golden Sands Nature Park and a protected area of Natura 2000 (Batova) under the Birds Directive.

Archaeology

The monastery Holy Virgin (Fig. 8): The monastery Holy Virgin in Salzitsa area (Karaach Teke), near Varna City, is one of the largest in the Balkans. It is situated in the city's outline, 4-5 kilometres from the centre. It was discovered at the beginning of the 20th century by Karel Škorpil, the founder of Bulgarian archaeology. Extensive excavations and studies began only in 1995 and, with some interruptions, continued until 2007. It is assumed that it was built at the end of the 9th century and the beginning of the 10th century by St. Tsar Boris the Baptist. The Blessed Virgin Mary was the object of its dedication. Thus far, archaeologists have cleared and partially explored only about 5 acres, which represents less than half of the monastery's total area. In the complex, archaeologists have discovered a large monastery church and a huge tower with a chapel, a vast scriptorium with an area of 400 m^2, a library, a school, monastic dormitories, as well as an altar table, a blacksmith's workshop, a sacred spring and Bulgarian, Serbian, Byzantine, Turkish and Venetian coins.

Figure 8.

Monastery Holy Virgin - Karaachteke area (Ranguelov et al. 2020).

Early Christian monastery in the Dzhanavara area (5^{th} - 7^{th} century): The archaeological remains of the early Christian church in the Asparuhovo area are located 7 km southwest of the centre of Varna and 0.5 km on the north-eastern slope of the Dzhanavara Hill, not far from the southern shore of Lake Varna (Dimitrov et al. 2022). The basilica is unique with its unusual early Christian architecture and the rare character of its 120 m^2 mosaics. Partial conservation and restoration have been undertaken in the 1960s, but not the mosaics, as the threat of their destruction led to their re-covering with earth without a complete photographic record. The site dates from the middle of the fifth century to the beginning of the seventh century. In 1997, archaeologists made a sensational discovery at the site, analysing two additional exposed walls; they were described as the remains of domestic premises, proving that the church was part of a monastery complex of the Holy Virgin.

Roman baths: The Roman baths are located in the south-eastern part of the modern city of Varna, near the port and are among the best-preserved architectural monuments from the ancient period in Bulgaria. The Romans built these baths towards the end of the 2^{nd} century, making them the largest in the Balkans.

Kastritsi Fortress: The ruins of the Late Antique and Mediaeval Kastritsi Fortress are located about 8 km from the centre of Varna, in the Euxinograd residence. The city was discovered at the beginning of the 19^{th} century. In 2004, regular excavations began, which revealed a fairly clear and picturesque picture of life in the port city.

Material and methodology

Risk is characterised by an uncertain outcome. The primary objective of risk assessment is to identify and understand the potential consequences of these hazards and formulate strategies for mitigation and identification of specific actions that can minimise the potential impact.

According to the Joint Research Centre (Poljanšek et al. 2021): Risk = function of (Hazard, Exposure, Vulnerability).

Following the previously carried out research in the field (Hahn et al. 2003, Ivanov et al. 2020, Prodanov et al. 2020a, Prodanov et al. 2020b, Yamaguchi et al. 2021, Ivanov et al. 2022, Nankin et al. 2022, Frantzova 2023, Nikolov and Atanasova 2023, Prodanov et al. 2023), the newly-proposed framework includes the concepts of resilience thinking and adaptive capacity or Socio-ecological Risk (*R*):

(Eq. 1).

$$R = (wH + wE + wV) - wA - wCC$$

where *H*, *E*, *V*, *A* and *CC* are the values of the Hazard, Exposure, Vulnerability, Coping Capacity and Adaptability. Respectively, *w* are the weights.The following are the primary determinants or elements that contribute to risk.

For the risk assessment, data should be converted or normalised to a single format without units on a common scale so that they can be compared. Thus, the total sum of the weighting coefficients must be equal to 100. Each element of risk is associated with a certain number of indicators. The indicator level are established using a three-level scale ranging from 1 to 3 (low, medium, high). In the calculations provided in this manner, the weight coefficients corresponding to the factors are quite near in value because we assume that each of the risk assessment components has the same weight in the risk assessment (Inter American Development Bank (2005)). The key elements of the methodology are described in detail in Inter American Development Bank (2005) and Frantzova (2021).

The main characteristics of indicators are specific, measurable, achievable and results orientated. Many factors identified under the proposed framework tend to be static and are inherent in the system. Other factors might be altered through human activity (Oppenheimer et al. 2014). Quantifying the different indicators is done using a pre-developed 3-stage indicator system (Indicator Description Table) shown in Hahn et al. (2003).

The present study also included basic parameters related to climate change. Following IPCC (2023a) and IPCC (2023b), for Bulgaria, they can be summarised as:

- Risks to people, economies and infrastructures due to coastal and inland flooding;
- Risks to people, economies and infrastructures due to storm surge;
- Stress and mortality to people due to increasing temperatures and heat extremes;
- Marine and terrestrial ecosystems disruptions;
- Water scarcity to multiple interconnected sectors;
- Losses in crop production, due to compound heat and dry conditions;
- Attenuation of cold extremes.

Resilience thinking and landslides ecology towards a socio-ecological system

The authors of this paper are guided by an essential principle of resilience thinking, based on Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), International Institute for Sustainable Development (IISD), Stockholm Resilience Centre, which are interconnected in novel manners. It signifies that events occurring in one location might have an immediate impact on another location.

Resilience, viewed from this point of view, is an extremely dynamic concept and a way of thinking that links individuals and the environment. It is mainly concerned with the interaction between periods of slow and rapid change. Therefore, the essence of resilience lies in the ability to adapt to change, rather than in maintaining past behaviour. It is not enough to continue doing what we have always been doing; rather, we need to think about alternative development pathways and trajectories.

Landslide Ecology is a field that integrates biological aspects of landslides into efforts to manage slope hydrology, soil erosion and the stabilisation of slopes. It recognises the intricate relationship between geological events (such as landslides) and their ecological consequences.

Here are some key points including in our framework, and on landslides ecology (Walker and Shiels 2013, Deutsche Gesellschaft für Internationale Zusammen- arbeit (GIZ) GmbH and Working Group of the Conservation Measures Partnership (CMP) 2020, Tucker 2023):

- Impact on ecosystems: Soil disturbance, species displacement, habitat alteration, nutrient cycling, water quality, geographical and climate contexts, types of landslides;
- Ecosystem recovery after landslide challenges: erosion, soil composition, vegetation regrowth, invasive species; invasive animal species;
- Ecosystem conservation: landslides' overlap; vunerable mountain areas, protected areas; Nature-Based solutions; riparian, buffer, forest restoration, green Infrastructure;
- Landslides and Cultural Heritage.

Adaptive capacity is incorporated in recent studies as an integral part of resilience thinking. In this context (including landslide ecology), it refers to a system's ability to adjust, modify or change its characteristics or behaviour in order to mitigate possible damage or deal with the effects of shock or stress.

Improving adaptive capability is essential for reducing the risk of landslides and responding to climate disasters that are getting worse. Incorporating both social and ecological adaptive capacity into adaptation decisions can be achieved through a transdisciplinary approach such as (IPCC 2023a, Shammin et al. 2021): Forest-Related Adaptive Capacity; Strategic Protection; Health and Social Indicators; Climate Change Adaptation; Improve the rate and quality of recovery (Fig. 9).

Results

Socio-Ecological Systems (SES) often rely on natural resources (e.g. forests, soil, water) for livelihoods. Landslides disrupt these resources. According to Turner (2018), SES in landslide-prone areas face challenges related to land management, awareness and sustainable practices. Additionally, understanding landslide risk and implementing effective mitigation strategies is crucial for SES.

Therefore, the suggested risk assessment algorithm comprises the subsequent fundamental operations:

- Identifying and categorising the regions, based on their distinct attributes and the particular landslide disaster;
- Determining the key risk elements to incorporate into the calculations;

- Identifying signs that align with the risk variables. Indicators are categorised into predetermined levels, based on numerical values;
- Quantifying indicator values (low, medium and high);
- Establishing the categorisation of risk elements into several levels of severity, including very low, low, medium, high and very high;
- Re-assessing the risk levels and expressing them as percentages;
- Determining the risk levels for each chosen area and displaying the results visually;
- Assessing risk for each of the chosen regions, along with the visualisation of the outcomes.

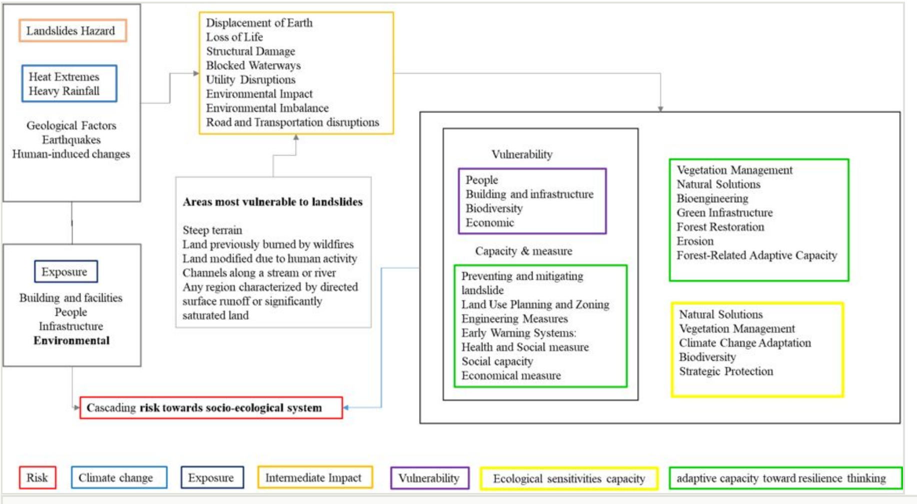

Figure 9.

Impact chains: key elements for risk assessment and analysis.

Evaluation findings are displayed in Fig. 10, Fig. 11 and Tables 1, 2.

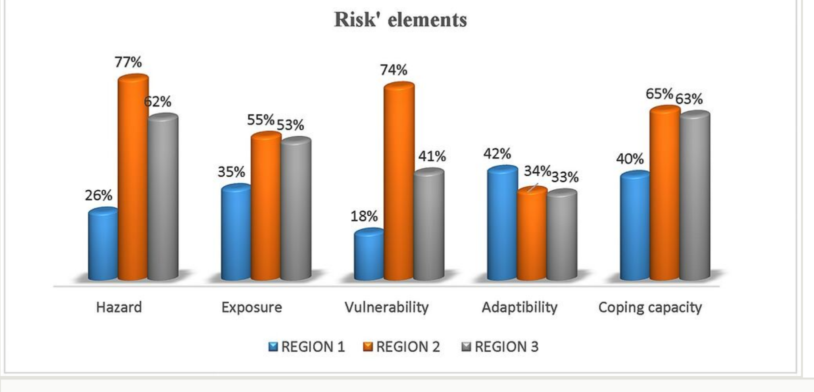

Figure 10.

Levels of risk elements for all regions expressed as a percentage.

Table 1.

Levels of risk elements for all regions expressed as a level.

	Hazard	*Exposure*	*Vulnerability*	*Adaptability*	*Coping Capacity*
Region 1	Very low	Low	Low	Medium	Medium
Region 2	High	Medium	Very high	Low	High
Region 3	High	Medium	Medium	Low	High

Table 2.

Risk levels of the Archaeological sites and Biodiversity at risk.

Objects in risk / region	Archaeological object	Risk level	Environmental	Risk level	Social	Risk level
Region 1	Shabla (ancient port)	Medium	Biodiversity	Low	People Houses Buildings Infrastructure Ports	Low
	Durankulak (ancient diggings)	Low				
	Kaliakra – (Bastion and ancient town)	High	Biodiversity	Medium	People Houses Buildings Infrastructure	Medium
	Yailata (Ancient bastion)	High	Biodiversity	Low	People	Medium
	Kamen briag (Ancient tombs)	High				
Region 2	Balchik town	High	Biodiversity	Medium	People Houses Buildings Infrastructure Ports	High
	Cybele temple Balchik	High				
	Balchik Palace (Ancient town)	High				
	(Chirakmana)	High				
Region 3	Scriptoriuma Kastritsi Fortress	Low	Biodiversity	Medium	People Houses Buildings Infrastructure	High
	Early Christian monastery (Dzhanavara) area	Low				
	Varna (Roma Thermi)	Low				
	Holy Virgin Monastery (Karaachteke)	High				

Comparison between different risk elements and different areas of interest show some important results:

- It has been found that Regions 2 and 3 have significant levels of both susceptibility and the capacity to cope with the effects of natural hazards. It may be said that the adaptive capacity, in relation to socio-ecological resilience, exhibits relatively moderate to low levels in comparison to the coping ability. Even though participating in adaptive practice is a component of coping ability, it is not sufficient on its own to achieve the levels of resilience that are essential for lowering risks. Both resilience and adaptability are very flexible notions that need the ability to continually adjust and adapt, while maintaining the same trajectory of growth and advancement without deviating from it.

- The transformability problem, which encompasses the capability to shift development paths or create capacity to move into new ones, ought to be the major emphasis of socio-economic risk management. This challenge should be the primary focus of the management effort. The efforts that are made to decrease socio-economic risk should be concentrated on both the improvement of inefficient components of the system and the creation of a few different alternative possibilities.
- The high levels of hazards, susceptibility and exposure logically lead to a high degree of socio-ecological risk and the complex risk connected with landslides grows as a result of this.
- There is a clear connection between the presence of socio-economic risk and the relationship between humans and nature. According to the findings, the most efficient strategies for reducing socio-ecological risk are those which seek to reduce vulnerability and increase adaptive capacity in response to transformability challenges. This is applicable in its entirety to regions that contain both archaeological sites and protected natural areas in close proximity to one another.
- At high levels of risk, the findings indicate that, in the case of a disaster, the socio-ecological implications can be very high, which can result in the loss of biodiversity and damage to the ecosystem that cannot be reversed.
- The results can be described in both quantitative and qualitative terms and represented graphically in a risk matrix (Fig. 12).

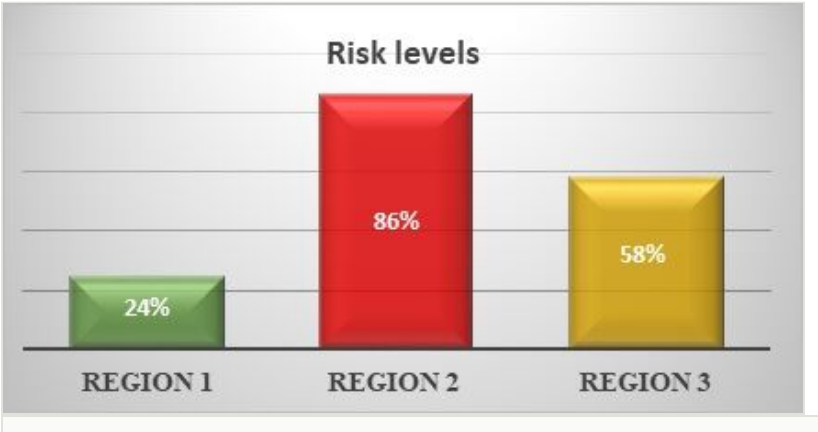

Figure 11.

Landslide risk levels.

Finally, our results have been quantitatively assessed due to the methodology used: Region 1 demonstrates variable risk levels for the considered elements of archaeology sites – from low through medium to high. We observe a similar trend in biodiversity. The social risk varied from low to medium. Up until now, only the social risk was considered, thus ignoring the archaeological sites (which are important from a historical and tourist point of view) and biodiversity. In total, the percentage of integrated risk is about 24–25%. Region 2 is the riskiest and this is supported by the calculations. The integrated risk is about 85-86% and the influence is dominated by archaeological sites as the most vulnerable component, as well as the social impact. Both show a high level of risk. The biodiversity is assessed as medium. With an integrated risk of 58%, Region 3 occupies an intermediate position and has a risk level that is significant enough to warrant attention. Again, the archaeological sites are differentiated (with levels high to low) and the social sites are rather vulnerable because of the intensive population distribution. The biodiversity risk is predominantly medium.

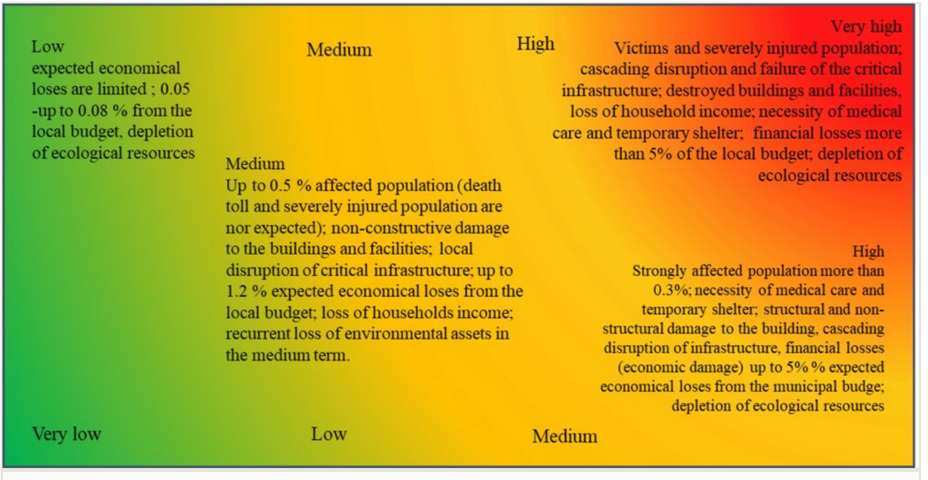

Figure 12.

Qualitative description of risk levels in a risk matrix.

- There is a strong link between disaster risk management and socio-ecological risk management (Fig. 13). Socio-ecological risk management considers the interaction between social systems (people, communities) and ecological systems (natural resources, ecosystems). It recognises that human well-being and environmental health are interconnected. Thus, disaster risk management and socio-ecological risk management cannot be considered separately.

Discussion

There is little doubt that human activities have a significant influence on the occurrence and impact of disasters. Natural hazards may arise from natural phenomena, but it is the manner in which society has evolved that transforms them into disasters. The majority of disasters are not preventable. However, their impacts can be mitigated.

The relationship between disaster risk management and socio-ecological risk management can be characterised as:

- Communities facing socio-economic risks are simultaneously more vulnerable and less resilient. Even low-intensity hazards can lead to disasters due to increased vulnerability;
- Even slow-onset disasters related to critical resource scarcities (e.g. water, fertile land, food) can trigger socio-economic crises as well as high disaster risks can incubate socio-economic and ecological problems. These problems, in turn, exacerbate disaster risks;
- Financial and socio-economic crises result in losses for collective and private agencies. These losses are not only financial, but also physical, human, social and political. Additionaly, the crisis has a negative impact on resilience by affecting properties.

Figure 13.

Link between disaster risk management and socio-ecological risk management.

In this investigation, the main focus is on the risk assessment of the landslides to the socio-economic and ecological problems. All those are discussed extensively. A well-known methodology for the complex risk assessment is applied, giving the possibility of the quantitative assessment of three regions on the north Bulgarian Black Sea coast. As previously stated, the majority of research efforts and risk assessments have focused on natural hazards and the assessment of human losses, building destruction and other negative consequences that are critical to society (Ranguelov and Dimitrov 2019). For the first time, complex thinking is applied, incorporating specific components of the vulnerable objects to the landslide influence, including archaeological sites (as part of the cultural heritage), biodiversity (as part of the natural preserves) and social impact (as part of the tourist industry and building stock).

The latter were the focus of extensive research earlier and, in these investigations, they are included only for completeness and because they are an important factor in the risk assessment. It is important to mention that, while individual papers address cultural heritage and ecological influence (Nedkov et al. 2022), none includes biodiversity.

Previous research shows that the regional economic resources (natural ore and non-metallic deposits), natural mineral waters, high level local production of foods etc. provided enough economic potential to meet the low to medium risks. The high risks due to the large earthquakes, tsunamis, mass activation of landslides and huge fires and floods will need a much higher amount of resources at the national level (Ranguelov et al. 2020). The incorporation of new and recent technologies like space exploration, drones etc. increase the ability to make a highly effective assessment of the landslide hazard (for example) (Atanasova and Nikolov 2021, Nikolov and Atanasova 2023). The use of high technologies, in parallel with quantitative methodology is a direct step to support the rethinking of risk assessment and mitigation. In our view, the familiarisation of the local population with the results of these investigations will support the rethinking of policy at the local and regional levels.

According to Kotz et al. (2024), the average loss of income worldwide will be 19% by 2049, in comparison to a baseline without the impacts of climate breakdown. It is expected that the reduction in Europe will be approximately 11%. The interaction between climate change and the environment becomes significant in this manner. The methodology's adaptability allows the incorporation of various climate parameters and indicators.

While it is impossible to completely eliminate the danger of disasters, it is possible to mitigate it. Therefore, disaster risk assessment is a crucial tool for analysing and directing activities to limit the impacts of disasters.

Conclusions

To rethink the assessment of possible risks within socio-ecological systems, it is necessary to adopt a new perspective that emphasises comprehensive, flexible and collaborative methods.

This study provides an assessment of the landslide risk for the socio-ecological system along the northern Bulgarian Black Sea coast. This area is characterised by an intensive spread of landslide processes, as well as protected biodiversity areas and archaeological sites. For the purposes of the study, three regions were identified for which the evaluation was carried out.

By examining the interaction between human and natural systems, we can more effectively address complex issues and establish the ability to recover and adapt for a long-lasting future. The acquired data show a consistent correlation with actual occurrences and empirical data analysis. The methodology shows its potential to be flexible, adaptable and sustainable while dealing with a range of challenges.

Incorporating archaeology and biodiversity into research, impact on ecosystems, spatial patterns and ecological consequences and considering the ecosystem recovery after landslides challenge, we rethink the possibility of ecosystem conservation and preservation of landslide occurrence and cultural heritage. In this way, socio-ecological systems are characterised as interconnectedness of social and ecological components within a specific geographic area or ecosystem.

The results obtained from this research are essential and particularly important for the prevention and control of landslides. They can be used to re-evaluate the measures for the foreseen prevention and security in both wider landslide areas and in specific limited landslide sections. The given results suggest that the new approach should focus on capacity building and resilience.

In our case, the combination of landslide hazard (risk) and socio-economic impact on biodiversity and archaeology sites (cultural heritage) is revealed. It shows that the impact can be weak, medium or strong, but in any case, it is not negligible. Thus, the proposed new framework is essential and should be incorporated in risk assessment and management.

Limitation

Along the northern Black Sea coast of our country, there are relatively numerous, interesting and archaeological sites preserved to varying degrees. Their importance for our past and present history is currently being assessed in different sciences and by different types of specialists. The preservation of archaeological sites and historical landmarks is a current task that requires the involvement of specialist geologists, engineering geologists and those who can assess the contemporary hazard and risk for these sites. However, until now, no comprehensive and detailed hazard and risk assessment for the archaeological sites along the northern Black Sea coast has been made. Ancient earthquakes and their effects on coastal settlements are mentioned in separate sections of articles. An initial and in-depth research work on the assessment of the contemporary geological hazard and risk for our archaeological sites on the northern Bulgarian Black Sea coast is needed.

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Conflicts of interest

The authors have declared that no competing interests exist.

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Endnotes

*1 **The Natura 2000 protected areas network**: Natura 2000 is a network of protected areas covering Europe's most valuable and threatened species and habitats. It is the largest coordinated network of protected areas in the world, extending across all 27 EU Member States, both on land and at sea. (EU 2020).