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Review on Risks to Romanian Coastal Built Environment from Natural Hazards

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Abstract **– Coastal built environment are sensitive to direct and indirect impacts of natural hazards. Nearly half of the world's major cities are located within 50 km of a coast, and coastal population densities are 2.6 times greater than those of inland areas, with a steep rise over the years [1]. Coastal built environment are home to around 40% of the world's population (nearly 2.4 billion people) and approximately 60% of the world's cities with populations above five million are within 100 km of a coastline [2]. While coastal built environment is expanding, more social and physical systems are increasingly exposed to natural-induced hazards. This review paper aims to provide an up-to-date and objective assessment based on the literature to help determine what is known and what needs the future attention of researchers to increase understanding of the risks induced by natural hazards to coastal built environment in Romania and to provide actionable recommendations for a sustainable development strategy to enhance resilience and to mitigate vulnerability to these hazards.**

Keywords – coastal built environment, natural hazards, vulnerability, coastal risks, resilience, sustainable development strategy.

1. INTRODUCTION

The coast zone is a dynamic and constantly-changing environment that is incredibly productive both ecologically and economically. Forty percent of the world’s population lives within 100 km of the coastline [3] and the trend of population migration to urban coastal areas is increasing. Living in this region brings its own set of hazards and mitigating the risk of impact from these hazards requires a dynamic and multisectoral approach. Hazards can be natural such as floods, earthquakes, storms and storm surges, as well as human-induced, for example oil and chemical spills, environmental destruction and habitat removal, algae blooms, and invasive species introduction. Further, climate change is an anthropogenic impact that exacerbates natural hazards due to higher global mean sea level and the increased frequency and intensity of storms.

The built environment refers to the human-made environment that provides the setting for human activities, ranging in scale from buildings to cities and beyond. Strengthening the risk management system for natural-induced hazards is essential to ensure security and protect communities and the built environment in the coastal zone. The interaction between the natural coastal environment and the anthropogenic built environment, on the one hand, but also the interaction between land and sea leads to a series of risks that impose a series of barriers in terms of effective, strategic and sustainable planning of activities in the coastal area and the implementation of a integrated management of the coastal zone.

The coastal built environment faces significant risks from various natural hazards, including seismic activity, floods, coastal erosion, storms, and climate change impacts.

In Romania, these hazards pose particular threats due to the country's geographical location and susceptibility to seismic events, flooding, and coastal erosion.

Climate change exacerbates these risks by increasing the frequency and intensity of extreme weather events and accelerating coastal erosion and sea level rise.

The main aims of this review paper address the risks to the coastal built environment from natural hazards in Romania including:

- *Identification of vulnerabilities:* To analyze and identify the vulnerabilities of the coastal built environment to various natural hazards, including seismic activity, floods, coastal erosion, storms, and climate change impacts.
- *Assessment of risks:* To assess the potential risks posed by these natural hazards to coastal infrastructure, including buildings, roads, utilities, and other critical assets.
- *Evaluation of impacts:* To evaluate the potential socio-economic and environmental impacts of natural hazards on coastal communities, including disruptions to services, economic losses, and threats to human safety and wellbeing.
- *Development of mitigation strategies:* To develop effective strategies and measures for mitigating the risks posed by natural hazards to the coastal built environment, including land use planning, resilient infrastructure design, early warning systems, and community preparedness initiatives.
- *Integration of climate change considerations*: To integrate considerations of climate change and its potential impacts on coastal hazards into coastal management and adaptation strategies, aiming to enhance the resilience of the built environment to future climate-related risks.
- *Policy recommendations:* To provide policy recommendations and guidelines for decision-makers at the local, regional, and national levels to strengthen resilience and reduce vulnerabilities in the coastal built environment.

Overall, the paper aims to increase understanding of the risks posed by natural hazards to coastal infrastructure in Romania and to provide actionable recommendations for enhancing resilience and reducing vulnerability to these hazards.

2. MATERIALS AND METHODS

The methodology used in this study involves a comprehensive literature review of academic articles, reports, and other relevant publications related to risks from natural hazards on Romanian coastal built environment. The literature review will be used to identify the key categories used to evaluate risks to the coastal built environment from natural hazards. Several themes and categories may emerge:

- *Physical vulnerability*: This category assesses the susceptibility of coastal infrastructure, such as buildings, roads, and utilities, to damage or destruction from natural hazards such as earthquakes, floods, storms, and coastal erosion.
- *Exposure:* This category examines the extent to which coastal communities and assets are exposed to different natural hazards, considering factors such as proximity to fault lines, floodplains, or coastal areas prone to erosion and storm surges.

- *Hazard frequency and magnitude:* This category evaluates the frequency and magnitude of natural hazards affecting the coastal built environment, including historical data on past events and projections of future occurrences, considering factors such as seismic activity, storm frequency, and rainfall patterns.
- *Socio-economic impacts:* This category considers the socio-economic consequences of natural hazards on coastal communities and infrastructure, including disruptions to services, economic losses, displacement of populations, and impacts on livelihoods and wellbeing.
- *Resilience and adaptive capacity:* This category assesses the resilience and adaptive capacity of coastal communities and infrastructure to withstand and recover from natural hazards, considering factors such as the effectiveness of disaster preparedness measures, availability of resources, and institutional capacity for response and recovery.
- *Climate change considerations:* This category examines the potential influence of climate change on coastal hazards and vulnerabilities, including rising sea levels, changing precipitation patterns, and increasing intensity of extreme weather events, and considers how these factors may affect the evaluation of risks to the coastal built environment.
- *Policy and governance:* This category explores the role of policy frameworks, regulations, and governance structures in managing risks to the coastal built environment from natural hazards, including the effectiveness of risk reduction measures, land use planning strategies, and coordination among stakeholders.

To provide a critical assessment of the assessment tools, the literature review will be supplemented by interviews with experts in the field of integrated coastal management, risk management and built environment design, including architects, engineers, environmental scientists, and sustainability consultants. These interviews will provide insights into the practical applications of integrated coastal management, as well as their strengths and limitations.

The originality of this methodology lies in its holistic and interdisciplinary approach, which combines insights from academic research with practical expertise to provide a comprehensive understanding of assessment tools for evaluating risks to the coastal built environment from natural hazards. This innovative approach enhances the relevance, credibility, and impact of the study, contributing to more effective risk assessment and management strategies in coastal areas.

A review of the principal key risks of the Romanian coastal built environment are as follows:

- *Seismic activity*: Romania is located in a seismically active zone, particularly in the Vrancea region. Earthquakes pose a significant risk to the coastal built environment, potentially causing widespread damage to infrastructure and posing threats to human life;
- *Floods*: Coastal areas are susceptible to flooding, both from heavy rainfall and storm surges. Climate change has increased the frequency and intensity of extreme weather events, exacerbating the risk of flooding along the Romanian coast. Floods can damage buildings, roads, and other infrastructure, leading to economic losses and disruption of services;
- *Coastal erosion*: The Romanian coastline is subject to erosion due to natural processes and human activities such as urbanization and coastal development. Erosion threatens coastal infrastructure, including buildings, roads, and utilities, and can also lead to loss of valuable land and habitats;

- *Storms and high winds:* The coastal areas of Romania are prone to storms and high winds, especially during the winter months. Severe storms can cause damage to buildings, infrastructure, and coastal defenses, leading to disruption and economic losses;
- *Climate change:* Climate change is expected to exacerbate many of the natural hazards faced by the Romanian coastal built environment. Rising sea levels, increasing temperatures, and changes in precipitation patterns will amplify the risks of flooding, coastal erosion, and extreme weather events, necessitating adaptation measures to protect coastal communities and infrastructure.

2.1. Romanian Black Sea coastline caractheristics

The Romanian Black Sea coastline is about 244 km long and lies down along the Eastern border of Romania, from the Danube Delta in the North to the Bulgarian border in the South. The Northern part is the Danube Delta Biosphere Reserve. The Southern part consists of an almost continous chain of seaside resorts, alternating with cities and harbours. The Romanian coastal area hosts approximately 900,000 inhabitants (4,5% of the Romanian population) and very important regional assets (e.g. Constanta has the largest seaport in the Black Sea). [4].

Fig. 1 Romanian Black Sea coastline and the built environment deliniation

This coastline is morphologically characterized by a diverse range of features, including sandy beaches, coastal wetlands, cliffs and high rocky cliffs directly exposed by coastal erosion. The region is known for its rich biodiversity, with numerous protected areas and important habitats for various plant and animal species. On the Romanian coastline, twelve tourist resorts of national interest are certified: Mamaia, Năvodari, Eforie Nord, Eforie Sud, Techirghiol, Costineşti, Neptun-Olimp, Jupiter, Cap Aurora,Venus, Saturn and Mangalia. Coastal cities and the beach resorts, such as Constanta and Mamaia, attract tourists with their historical sites, vibrant nightlife, and recreational activities.

From a geomorphological point of view, the coastal zone can be divided into two main units. The Northern unit, from Musura Bay in the north to Midia Cape in the south, is represented by deltaic and lagoon shores (sandy beaches with smooth submarine slopes).

The Southern unit, between Capul Singol and Vama Veche, is determined by the presence of the high cliff with narrow beaches formed at the base and the headlands alternation with the accumulative shore (barrier type beaches, littoral cordons, "pocket-beach"). Between these two main coastal sectors there is a transitional unit (Cap Midia-Cap Singol) represented by the Mamaia sandy barrier. The Romanian shoreline has about 80% of low-altitude shorelines – beaches and around 20% high shores – bluffs, the Northern sector representing 68%, and the Southern one 32%. Sandy beaches constitute about 68.5% (167.3 km) of the Romanian coastline and 136 km of natural beaches are located in the Northern unit of the Romanian coastline (the majority consisting of sediments transported by the Danube river and redistributed by currents and waves). The built environment and infrastructure occupies about 12.7% (31 Km). The rest of 18.8% of the coastline represents the Romanian seaport structures (Constanța harbor wih the Midia area and Mangalia harbor- are seaports whose infrastructure belongs to the public domain).

In terms of air temperature, Dobrogea region is under the influence of the continental feature typical of the temperate climate, it is conventionally delineated by the isotherm of 11ºC, showing the highest annual average temperatures country-wise. Across Dobrogea region, there is an influence of the excessive continental, sub-Mediterranean and Black Sea climate, on a strip of the shoreline.

In terms of annual rainfalls, the maritime shoreline, Razelm-Sinoe Lagoon Complex and the eastern half of the Danube Delta (Eastern Dobrogea) may be considered the poorest region in precipitations in Romania (< 400 mm). At the same time, the excessiveness nuance of the temperate continental climate typical of Dobrogea is characterized by increased torrentiality. In this regard, it is necessary to remind the fact that in C.A. Rosetti pluviometric station, in 1924, on 30 August, 690.6 mm were recorded, representing the absolute maximum amount of precipitations in Romania. In the rest of Dobrogea, annual amounts of precipitations increase towards 450 mm, showing the influences of the marine climate [5].

The Black Sea is part of the category of intercontinental seas and represents the receiver of the Danube River and the water courses of the Littoral basin, directly or through the littoral lakes. The length of the sea coast, between Musura Bay, in the north and the border with Bulgaria, in the south, is 244 km, out of a total of 4,020 km, as far as the Black Sea coast is concerned. The water balance is characteristic of small and medium-sized continental sea basins, in that fluvial input and evaporation predominate among the components. In the fluvial supply approximately 78% belong to the rivers in the north-west of the basin and among them, obviously, the Danube River. The hydrographic network of Dobrogea – Litoral Watershed Area includes 16 permanent water courses. The total length of permanent water courses on the entire territory is of 542 km. The distribution by river basins is the following: 71% belong to Litoral Basin and 29% to Danube Basin. The water courses in Dobrogea are characterized by an intermittent flow regime with a pronounced torrential nature, due to the morphological features of the relief in the hydrographic basins and the climatic characteristics of the area. The hydrographic network of Dobrogea includes only a few watercourses with permanent drainage, which are less than 80 km long, multiannual average flows between 0.01 - 0.7 m3/s, on which six hydrometric stations are located where daily measurements are made, as well as numerous valleys with intermittent flow that dries up during the summer, but which, following short-term and high-intensity rainfall, can form floods that cause damage.

The Romanian Black Sea coastline faces various natural hazards, including floods, storms, coastal erosion, and seismic activity, which pose risks to coastal communities and built infrastructure.

Seismic hazard in the Romanian Black Sea coastline area

Seismic hazard is the expected ground movement caused by earthquakes at a given location. In order to determine the level of seismic risk, in addition to the seismic hazard value, the degree of exposure of the elements of interest in the respective location (buildings, people and goods) must be considered, as well as their vulnerability to earthquakes.

Although the seismic hazard of the Romanian territory is controlled largely by intermediate-depth seismicity of the Vrancea region, around Dobrogea the seismic hazard sources corresponds to shallow earthquakes (0-10 km) [6]. There are three areas concentrating the focus of shallow earthquakes: Western part of North Dobrogea, the South-East of Central Dobrogea and North-West of South Dobrogea). However, the seismic hazard derived from shallow earthquakes is higher in South Dobrogea, controlled by the events in the Shabla region (Figure 2).

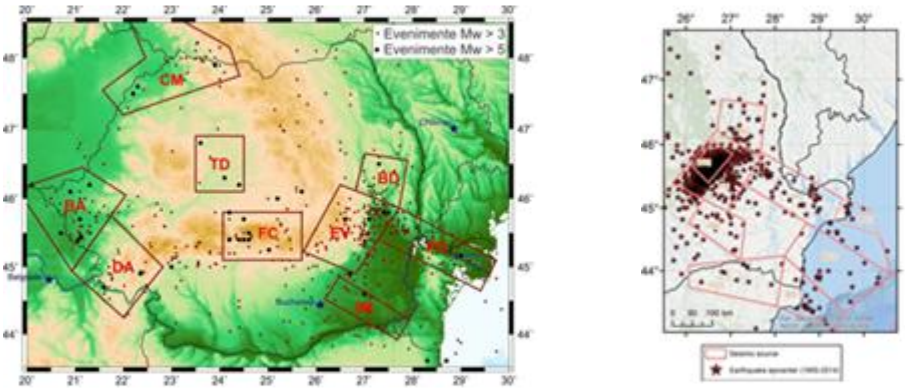

Fig. 2 INFP-Seismic zones and earthquakes magnitude map [7]

According to the map presented above, the Predobrogen Depression (PD) is characterized by moderate earthquakes, below 5.6 magnitude.

In the coastal area of the Black Sea, the earthquake catalog of the National Institute for Earth Physics Research and Development (INCDFP) includes 2131 events recorded in the period 1900-2022 (Figure 3) [8].

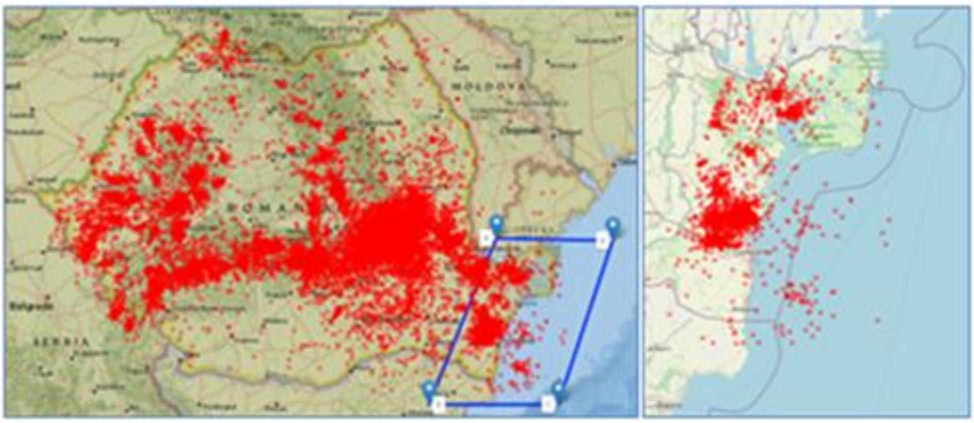

Fig. 3 The earthquake catalog of the INCDFP [8]

The earthquake with the highest magnitude recorded in the study area between 2010 and 2021 was the one recorded on 03/02/2013 at the TIRR-Târguşor seismic station (Latitude 45.03N and Longitude 29.59E): MI =4.2 (Mw=4.0).

According to the data of the National Institute of Earth Physics (INFP) (cited by http://media.imopedia.ro), the coastal area is among the safest areas in Romania, in case of an earthquake. The seismographic history of our country shows that Constanța county is among the counties where earthquakes are felt the least. Although the Constanța county is among the safest in the event of an earthquake, we must not neglect the existence of buildings classified as seismic risk, which may collapse. According to a recent centralization of the Constanța Civil Protection Inspectorate (IPC), there are 61 such buildings in Constanța. Of these, five are in seismic risk class I (buildings marked with a red dot) and may collapse at any time. Another 28 are listed as Class II and could fall in an earthquake of at least 6.5 on the Richter scale, but may suffer major structural damage in smaller quakes. Another 26 buildings are in class III, and another two buildings - in class IV of seismic risk, which means that they are not in very great danger. In a case of an earthquake, the risk of additional disasters is high: building and installation collapses; damage or destruction of hydrotechnical works (dykes, quays); technological accidents; fires, isolated or large explosions; chemical accidents; naval accidents; transport accidents of people, ordinary or dangerous goods; landslides (Constanța seaport coastline).

Natural hazards such as earthquakes, do not recognize geographical borders. The recent major earthquakes in Syria and Türkiye (2023), Afghanistan (2022), Haiti (2021), Indonesia (2018) and Nepal (2015) came as a tragic reminder of the urgent need for nations to make optimum use of knowledge and technology to reduce disaster risk [9]. Several factors increase the risk of seismic disasters, for example, insufficient building compliance regulations; a lack of -or outdated- earthquake-resistant designs; low-quality building materials; and a lack of awareness of the necessity to invest in safer buildings. During a seismic hazard, most casualties result from collapsing structures, which makes earthquake-resistant constructions vital.

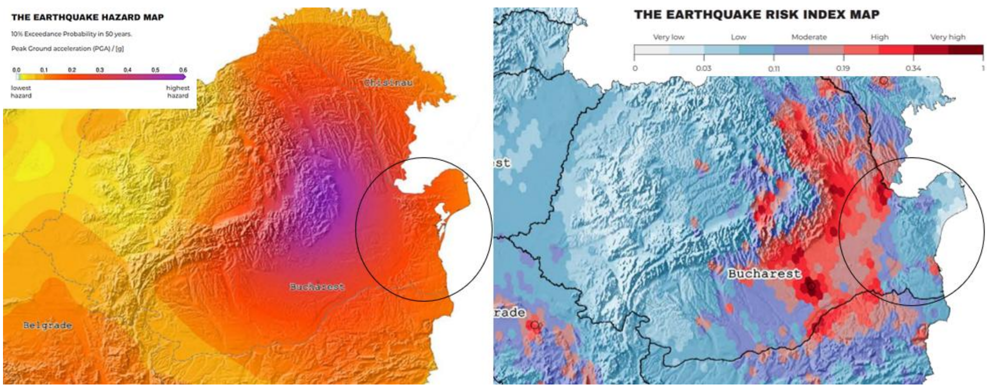

Fig. 4 The earthquake hazard map (left) and the risk index map (right) [10]

Flooding in the coastal area of the Black Sea

The flood, by definition, represents the covering of the land with a layer of stagnant or moving water that, by its size and duration, causes human casualties and material destruction that disrupts the smooth running of social-economic activities in the affected area. According to their genesis, floods can be classified as follows: floods caused by natural phenomena; floods caused by accidental phenomena; floods caused by human activities.

Romania is a flood prone country. The overall annual expected damage due to flooding in Romania is EUR 1.7 billion affecting an average of 150.000 citizens every year. The World Bank supported Romania to assess the risk of flooding and to develop and publish new Flood Maps for all of the country's 526 Areas of Potential Significant Flood Risk. The new flood maps are a key instrument for flood risk management. They are an important tool for raising awareness about areas at risk of flooding and for helping communities develop strategies for reducing these risks through structural and non-structural measures [10].

Dobrogea is divided, from a hydrological point of view, into two hydrological basins: the Danube Catchment and the Littoral Catchment (Figure 5).

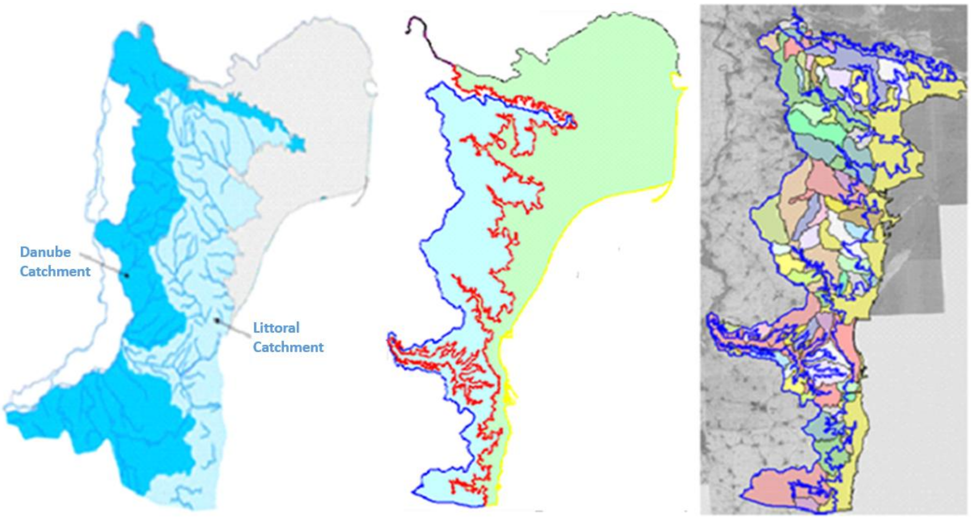

Fig. 5 Dobrogea watersheds and delimitation of coastal watershed

The hydrographic network is divided into two distinct units, namely: the Danube group and the maritime group. The rivers of the Danube group drain the western part of the region. The rivers of the maritime group generally drain the eastern part of the region, the most important of which are Casimcea, Istria, Nuntași, Taița.

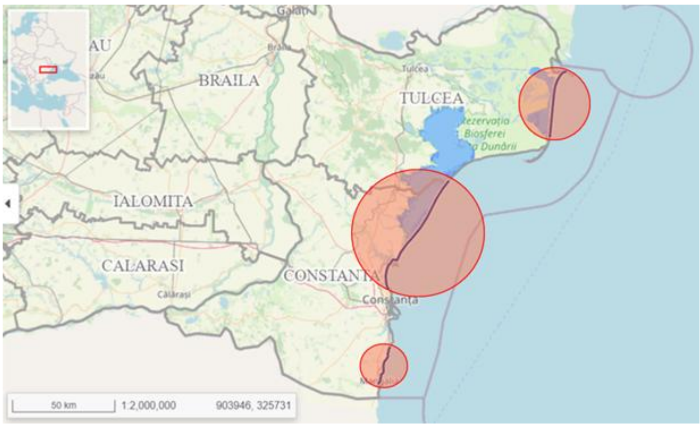

Fig. 6 Coastal floods - Areas of Potential Significant Flood Risk

Flood hazard and risk maps are drawn up as a component of flood risk management plans for hydrographic basins by the National Administration "Romanian Waters". The Dobrogea - Littoral Water Basin Administration has designated the Mangalia-Costineşti coastal sector (around 20 km) with high risk of flooding. Also, the Mangalia, Limanu, Mamaia, Năvodari and Corbu areas present a medium-level flood risk (Figure 6).

By examining the effects of flooding from the period 2001 – 2005 in Dobrogea-Litoral Watershed Area, it is noted that the flash flood from the period 22-23.08.2005 is the most serious one. In Costinesti, there was a flash flood leading to households damaged in the former village of Schitu. There were material damages caused by the destruction of the railway embankment on a length of approximately 1.5 km (an embankment that actually blocked the flow on the torrential slope), of many access roads, houses and motels, terraces and restaurants. There were also casualties recorded. On this occasion, a large area of Costinesti Lake turned again into a bay by flooding the barrier beach and the beach area on a length of around 2 km [5]. Effects on flooding, in terms of number of settlements, houses and socio-economics objectives affected, from the period 2010-2016 are illustrated in the following graphs. (Figure 7).

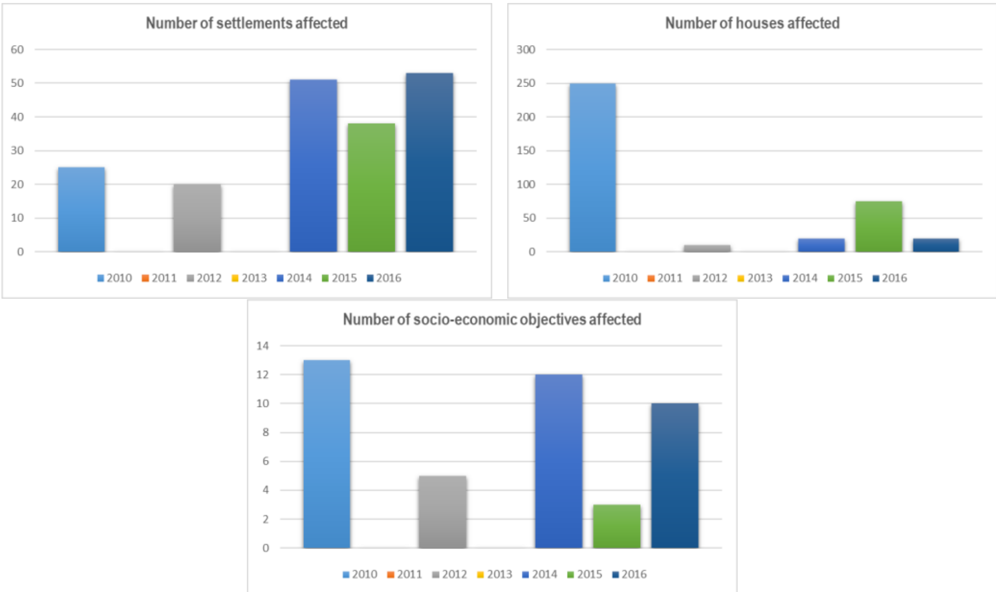

Fig. 7 Effects of flooding from the period 2010 – 2016 in Dobrogea-Littoral Watershed Area

In Constanta county, there were heavy rainfalls, when significant quantities of precipitations were recorded, exceeding, in certain areas, the known historical values (the multi-annual average value of precipitations for Constanta county is of 377 l/sqm, the most significant amount recorded in one day is of 111 l/sqm on 1 July 1992). Significant amounts of precipitations recorded within a relatively short period of time, in combination with slope runoffs and under-sized sewage networks, caused serious flooding affecting 14 localities, with significant damages, as well as one casualty.

In the Romanian coastal area storms, tornadoes cause a lot of destruction. In the areas of the Costinești resort and the Constanta Municipality, several storms broke out over time, being areas where winds and sea currents meet.

In the event of an increase in inland river flows and overflows from the slopes, the areas that may be affected in the coastal area are: Mihai Viteazu, Istria, Nuntași, Corbu, Agigea, Eforie, Costinești.

In seaports, floods with serious consequences are improbable, the configuration of the land ensuring the free flow to the sea of the possible accumulations of water due to heavy rains. Local floods may occur, but without major consequences for people, goods or port activity.

In the urban environment, as a result of torrential rains (precipitation amounts of more than 50 l/m2), the transport capacity of the storm sewer network can be exceeded and the premises of economic operators, traffic arteries can be flooded, torrents can occur, especially through the drainage of rainwater from the city towards the port.

The potential flood impact of present-day storm surges is large and is likely to increase in the future as the climate changes.

Storms and High Winds

Relative sea level rise is 2.5 - 3.7 mm/year, of which subsidence accounts for 1.5 - 1.8 mm/year. Mean significant wave height is 1.16 m in the winter and 0.79 m in the summer. The water level rise due to storm surge is up to 1.2-1.5 m [11].

Risks caused by changing sea levels have long-term effect, current growth rates causing damage in the coming 25-50 years. Climate risks, should be considered in terms of widening opportunity for all processes in the coastal area, with effects in profound changes of morphology, ecosystems, coastal environment and, ultimately, causing property damage by destruction of facilities in this built environment. For the entire Romanian Black Sea coastline the wind is a natural factor of high risk, being characterized by strong dynamics, which is generated by sea surface that influences atmospheric circulation system and the movement of air masses in the atmospheric boundary layer above the sea [12]. The Black Sea wind climate is influenced by the action of the continental, marine tropical, and polar air masses. The impact of the polar air masses (coming from north and northeast) is more visible during the winter season, when low temperatures and frequent storms may occur in this region. Also, it is estimated that the joint evolution of the North Atlantic Oscillation and El Nino-Southern Oscillation systems influence the storm occurrences over the Mediterranean area, and one of the effects is the increase of the wind conditions in the Black Sea during the winter time. In general, it is considered that the western part of the Black Sea is defined by more important wind resources, with average wind speed values of 8 m/s during the winter [13]. Climate risks should be considered in terms of widening opportunity for all processes in the coastal area, with effects in profound changes of morphology, ecosystems, coastal environment and, ultimately, causing property damage by destruction of built environment.

Landslides hazard in the coastal area of the Black Sea

In the Romanian coastal area, the geological composition of the soils and the occurrence of extreme hydrometeorological phenomena determine the frequent hazard of landslides. Due to unfavorable hydrometeorological conditions and as a result of the non-execution of drainage and stabilization works, new landslides have occurred in recent years or some older landslides have been reactivated and amplified, such as the landslides reported in Cumpăna settlement. The coastal areas prone to landslides are the North Cliff Area of Constanta City, the cliff of Eforie Sud, Tuzla, Costineşti and 23 August. Also, the coastal area between Gate 1 and Gate 6 of Constanţa Harbor is subject to the risk of landslides with major implications.

Landslide hazard maps can indicate the probability that a landslide of a given magnitude will occur in a given area and is an important tool for the risk management to improve the resilience against landslide disaster and to protect the coastal built environment. In this context a goal of one research paper [14] was to assess the landslide susceptibility area maps (LSA) based on FEMA (Federal Emergency Management Agency) method on the Romanian Black Sea coastline using GIS technique. This model was applied on the Romanian south coastline from Constanta to 2 Mai village, which is about 50 km along the Black Sea coast, crossing the Danube – Black Sea Channel at Agigea and passing through several resorts: Eforie Nord, Eforie Sud, Techirghiol, Costinesti and Mangalia. According to FEMA methodology [15], landslide susceptibility of geologic groups under static conditions was described as a function of the site condition that refers to the topography, geology and groundwater level. Landslide susceptibility was measured on a scale of I to X where I is less susceptible and X most susceptible (Figure 8).

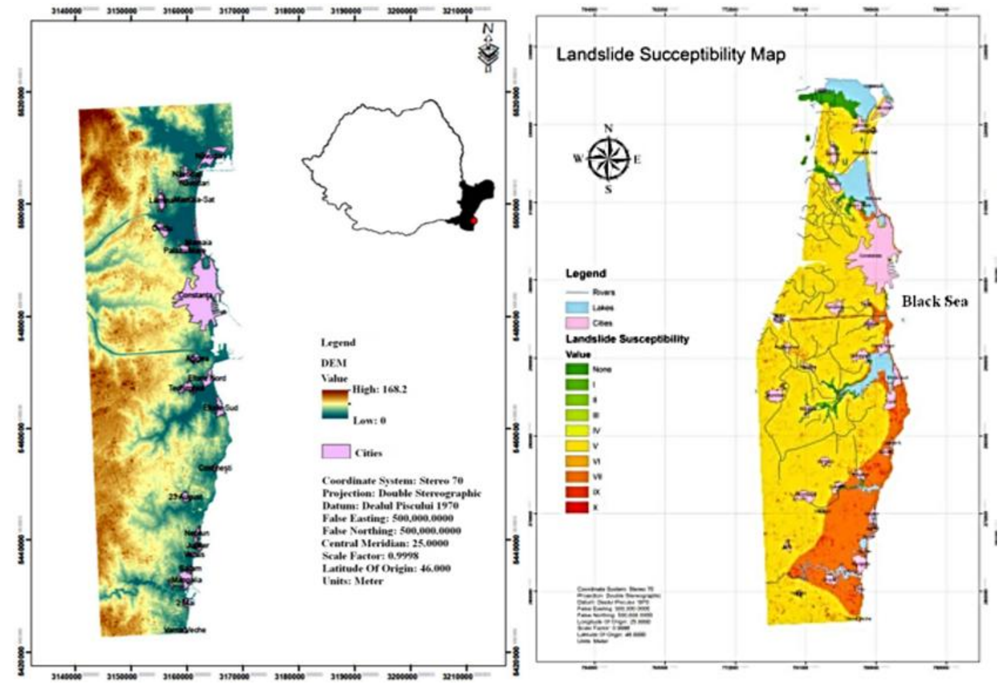

Fig. 8 Landslide susceptibility map for the South part of Romanian coastline[14]

Based by the methodology proposed, the landslide susceptibility map resulted shows that the coastal area without the cliffs fall within V and VI class of medium landslide susceptibility. The Eforie Sud cliffs area, and 2 Mai and Vama Veche are the subject to most landslide susceptibility (VII and IX classes).

Coastal erosion hazard

In the Romanian coastal area, coastal erosion hazard represents a risk for the built environment, the phenomenon manifesting itself at different levels of intensity along the approximately 244 km of coastline, measured from north to south, from the Chilia Branch (Musura Bay) to Vama Veche (border with Bulgaria). Based on the research carried out in the last 30 years by the Water Basin Administration Dobrogea-Litoral, National Research

Institute - Development for Marine Geology and Geoecology - GeoEcoMar, I.N.C.D.M. "Grigore Antipa", Royal Haskoning, JICA, USAID and others studies regarding the evolution of the coastal zone, it was concluded that coastal erosion reaches a rate of about 3-4 m/year in some areas [16].

Fig. 9 Dynamic balance, erosion-accretion, across the Romanian coastline. [17]

The coastal protection hydrotechnical structures in Mamaia, Agigea, Eforie, Costinești, Olimp, Jupiter-Neptune, Balta Mangalia-Venus-Aurora, Mangalia Saturn and 2 Mai that no longer serve their intended purpose or that contribute to erosion have been proposed for demolition. Measures will be taken to cover the beaches with sand and reshape the submerged or exposed portions of the beach to stabilize the shoreline and make it more resistant to erosion. Also, new structures have been built and will be built to support the adaptation of coastal protection systems to climate change. In general, the works was and will be carried out in the coastal areas of: Periboina and Edighiol, Mamaia, Tomis, Agigea, Eforie, Costinești, Olimp, Jupiter Neptun, Balta Mangalia-Venus-Aurora, Mangalia-Saturn, 2 Mai. The system designed for each area will protect the shoreline by reducing the impact of waves and increasing resistance to extreme weather conditions.

3. RESULTS AND DISCUSSIONS

The coastline is dynamic, coastal zones are continually developing to sustain major changes in growing population, the tourism sector, commercial activities, and coastal protection. Reducing the risk to Romanian coastal built environment caused by coastal natural hazards, associated or not with changes climate, is largely related to how legislation and administrative decisions will be managed in the future. To mitigate these risks, effective land use planning, investment in resilient infrastructure, early warning systems, and community preparedness measures are crucial. Integrating climate change considerations into coastal management strategies can enhance the resilience of the built environment to natural hazards, protecting coastal communities and infrastructure.

The implementation and monitoring of action priorities in the coastal zone must respect those that form the basis of the *National Disaster Risk Reduction Strategy 2023-2035*, established by the *Sendai Action Framework*, [18] and summarized as follows:

- knowledge and awareness of the types of risk and their effects,
- increasing the risk management capacity of public administration authorities by supporting inter-institutional collaboration and the involvement of all interested factors,
- encouraging investments in structural and non-structural measures to reduce the risk of disasters and increase resilience,
- strengthening the training of intervention forces, to ensure an effective response at all levels.

To achieve this specific objective - strengthening the risk management system for natural and anthropogenic hazards, considering the impact of climate change - the following strategic measures are necessary:

(a) *Identification and assessment of risks*: Identification of all natural and anthropogenic hazards specific to the coastal zone, as well as the assessment of their probability and impact, also considering anticipated climate changes.

(b) *Monitoring and forecasting*: The development of a robust system for monitoring weather and climate conditions can contribute to the early detection of hazards. This may include automated weather stations, satellites, and other advanced observing technologies.

(c) *Education and awareness*: Promoting education and public awareness of natural and human-caused risks, as well as climate change, is essential for increasing the resilience of communities. People must be prepared to deal with emergencies and understand the importance of climate change adaptation.

(d) *Develop emergency plans*: Improving emergency planning and preparedness is crucial. This may include the development of evacuation plans, the establishment of shelter areas, the preparation of response equipment, as well as the identification and allocation of resources.

(e) *Infrastructure improvement*: Development and strengthening of coastal zone infrastructure to cope with natural and man-made risks is essential. This may include construction and specific hydrotechnical arrangements to protect the coastal area against erosion, against flooding, strengthening buildings and critical infrastructure to withstand earthquakes, floods, landslides, or climate change.

(f) *Use of digital technology and artificial intelligence*: The integration of advanced technology, such as numerical modeling, artificial intelligence, and machine learning, can significantly improve the ability to anticipate risks and make more informed decisions in real time.

(g) *Involvement of the private sector*: Involvement of the private sector in risk management is essential, as many aspects of infrastructure and the economy can be vulnerable to natural hazards and climate change. Collaboration between the public and private sectors can contribute to the development of integrated strategies and the identification of effective solutions.

(h) *Regional and international coordination*: Some risks can cross national borders, so it is important to have coordination between different countries and regions to address common challenges. Sharing information, experiences and resources can be beneficial in managing major risks.

(i) *Long-term planning and adaptability*: A long-term and adaptable approach is needed to deal with ongoing climate change and the potential new risks that may emerge. Risk management plans must be regularly updated and revised according to new data and developments.

(j) *Funding and Assurance*: Ensuring adequate funding for risk reduction and emergency response measures is critical to the successful implementation of the risk management plan.

Engineering infrastructure - Coastal protection / flood defense

Recently, efforts restarted to protect coastal areas against erosion and flood risk, after they were stopped in different of execution phases in 1991. The Romanian approach to coastal protection consists in the design and implementing measures that come from a range of "soft" and "hard" structural rehabilitation solutions, methods introduced by coastal engineering, which provide solutions in Integrated Coastal Zone Management.

These hydrotechnical works include measures to reduce the energy of incident waves to the shore, dikes built for sand stabilization and measures to retain sand on the beach by building new breakwaters and repairing the existing breakwaters, as well as construction of groins.

In the period 2013 - 2015, through the first phase of the *Master Plan "Protection and rehabilitation of the coastal zones*" beach protection measures against the risk of accelerated erosion were implemented for five areas in the central part of the Romanian coastline (Mamaia South, Tomis North, Tomis Center, Tomis South and Eforie North), covering a coastline length of approximately 7.3km. [19].

In 2018, the "Romanian Waters" National Administration through the Dobrogea-Litoral Water Basin Administration signed the financing contract for the project "*Reducing coastal erosion, Phase II (2014-2020)*". The project is co-financed by the Large Infrastructure Operational Program (POIM) 2014-2020, Priority Axis 5-Promotion of adaptation to climate change, prevention and risk management, Specific objective 5.1 Reduction of the effects and damages on the population caused by the natural phenomena associated with the main risks accentuated by the change's climate, mainly from floods and coastal erosion [20].

Between 2020-2023, the coastal protection works are planned and implemented in different stages of execution, both in the Northern area (between Periboina weir and Edighiol weir) and in the Southern coast (Mamaia, Constanța/Tomis, Agigea, Eforie, Costinești, Olimp, Jupiter-Neptun, Venus, Saturn, Balta Mangalia-Venus Aurora, Mangalia-Saturn, and 2 Mai).

Nr.	Zones	Coastal works	Capacity
Phase I			
1	Edighiol and Periboina (Weirs)	weir rehabilitation	2
2	Mamaia	coastline protection	6950 m
3	Tomis (Casino)	coastline protection	790 m
4	Agigea	coastline protection/ clif consolidation	1200 m
5	Eforie	coastline protection	5750 m
Phase II			
6	Costinesti	coastline protection	2550 m
7	Olimp	coastline protection	3500 m
8	Jupiter-Neptun	coastline protection	2550 m
9	Mangalia Lake-Venus -Aurora	coastline protection	3100 m
10	Mangalia -Saturn	coastline protection	2500 m
11	2 Mai	coastline protection/ clif consolidation	1650 m

Fig. 10 Project "Reducing coastal erosion Phase II (2014 - 2020)"
Proposed coastal protection works completed or under implementation [20]

The main measures aimed at preventing coastal erosion and limiting its negative effects on the Romanian coast, by carrying out rehabilitation and protection activities, including artificial beach extension, construction of coastal structures connected to or parallel to the coast, artificial reefs, coastal dikes to stabilize beach shoreline /cliffs, retaining walls, etc.

They also have several required measures such as the use of satellite monitoring techniques for identification of areas affected by erosion, use of remote sensing to highlight the phenomenon of erosion and impact assessment of the selected measures to limit the phenomenon of coastal erosion.

At the local level, in the beaches area the defense hydrotechnical structures have changed both hydrodynamic processes, as well as the configuration of emerged and submerged beaches. However, although the coastal constructions had the intended effect in stabilizing the shoreline, they negatively affect the adjacent areas to them.

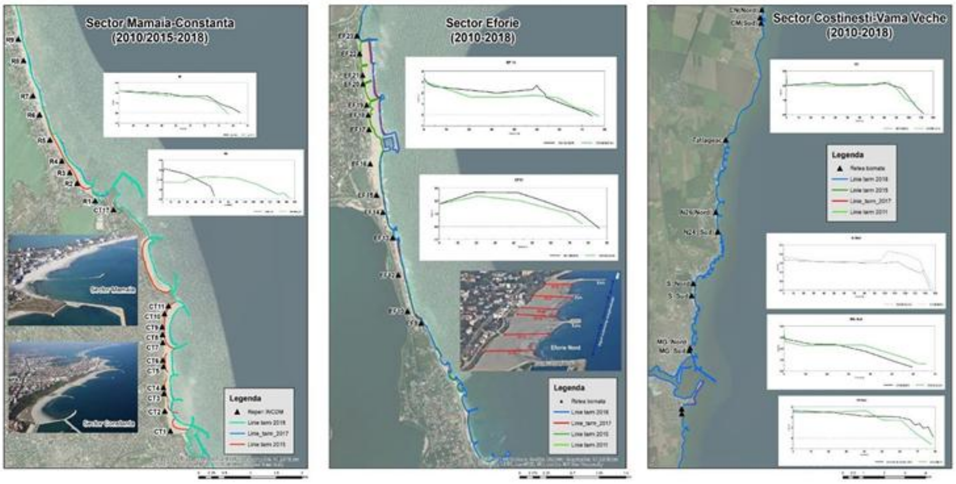

Fig. 11 Existing coastal protection structures [19]

Management of coastal resources and conservation efforts are essential to sustain the ecological integrity and socio-economic vitality of this dynamic coastal environment. Building codes and land use regulations have proven to be successful strategies in limiting the impacts of natural hazards as they reduce casualties and insurance costs while either reducing the likelihood of disruption, shortening the period of disturbance or limiting the consequences of natural hazards.

4. CONCLUSION

In recent years there was an intense tendency to identify and analyze detailed coastal problems, as well as to find optimal solutions for the sustainable management of the impact of coastal hazards on the Romanian Black Sea coast, and several research projects addressing these aspects have been funded. However, there is still a need to discuss and solve several scientific, legislative, administrative, communication and operational problems. In conclusion, some proposals for measures and strategic policies that should help us in the future to properly manage our coast and prevent the risks generated by natural hazards on the built environment would be the following:

- Clear definition and delimitation of the boundary from the seawater line where permanent constructions are prohibited. This must be done by each local administrative unit that manages a coastal built environment.

- Permanent monitoring of coastline behavior and dynamics. Data recording and long-term databases is critical for obtaining reliable data at the long time scales required for the safety design of the hydrotechnical protection works. In this regard, continuous databases of offshore hydrodynamic conditions (wave height and direction, speed and direction of coastal currents), wind speed and direction, water temperature and salinity, and other physical and chemical water parameters are absolutely necessary for the entire Romanian coastline.
- Solving the coastal erosion problems through 'soft' measures, in line with concepts like 'building with nature' successfully applied in other European countries or the world, instead of 'hard' interventions in the coastal environment which cause, most of the time, disturbances of the optimal functioning of the coastal zone. Minimally invasive protective measures such as the replenishment of sandy beaches should be taken into account as they help to solve the problem of coastal erosion in a sustainable and resilient manner;
- The need to consider in future civil protection plans the assessment of coastal risks generated by natural hazards based on a solid scientific foundation and the need to implement some operational approaches (e.g. early warning systems).
- A better communication between public authorities, researchers, coastal engineers on the one hand and local communities on the other. It is essential to organize public campaigns to raise awareness of the coastal risks induced by natural hazards, along with explaining the need to apply certain protection solutions for the built environment;
- A better cooperation between research institutes and universities involved in coastal zone monitoring, management and planning. In this sense, it is essential to create a common database/web portal that gathers all the data available in the archives of these institutions and that is made available free of charge to those interested in the benefit of the coastal community.

Optimal coastal zone management to prevent risks to Romanian coastal built environment from natural hazards requires multi-sectoral efforts from governance institutions, the private sector, and local communities, as well as political support.

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