Mechanical Testing and Diagnosis
ISSN 2247 – 9635, 2017 (VII), Volume 1, pp. 18-27

AN ANALYSIS OF THE COASTAL RISKS IN THE ROMANIAN NEARSHORE

Catalin ANTON[1], Eugen RUSU[2], Razvan MATEESCU[3]

[1]Ovidius University Constanta, Romania
[2]"Dunarea de Jos" University Galati, Romania
[3]INCDM Grigore Antipa Constanta, Romania

E-mail: catanton@gmail.com

ABSTRACT

The evolution of the Romanian coastal zone is the result of the balance between losses and supplies of sedimentary material. The erosion phenomena are given by the numerous conflicts among the development of various economic activities. In the last years, this balance was negative for large sectors of the Romanian Black Sea shore, as a consequence of the new conditions disturbing the pre-existing natural environment. In this paper, we propose to analyze the coastal risk in the Romanian nature in order to explain the effects of moving shoreline in case of option "no intervention". For this, each coastal zone of shoreline was analyzed in order to identify critical points of coastal zone erosion based on hydro morphological process.

Keywords: coastline changes, risk analysis, erosion, Black Sea shore, the option of intervention

1. INTRODUCTION

The Black Sea is one of the most remarkable regional seas in the world, being almost completely separated from the rest of the world's oceans and embodying an abyssal basin with a maximum depth of 2300 m, adjoining a very wide continental shelf area. Its waters are permanently stratified under the influence of fresh water supplied by large rivers and the inflow of Mediterranean water through the Bosphorus and Dardanelles Straits.

A process of erosion continuously takes place over the last few decades on the Romanian Black Sea coast. Taking measures of protection is absolutely necessary, the latter leading to the coastal environment, improving quality, but also improving living conditions of the human ecosystem. In order that taken actions to be truly effective, it should be made an analysis of the general situation of the coastal zone and the development of a conceptual vision that will result in a sustainable development strategy.

The Romanian Coast is located on the West side of the Black Sea and has a length of over 240

Fig. 1. The division of Romanian Black Sea Coast [15]

km. It splits into two distinct areas, namely, the Northern unit, which stretches from the Gulf of Musura till the port of Midia, the Southern unit and between Cape Midia (North) and Vama Veche (South), Fig. 1.

"The littoral" is the area bounded on one side by the sea and on the other side of the land, from the standpoint of geography. Here are merged several processes, such as: influences of climate and land both marine processes and modelling of coastal erosion or the filing of the terrestrial and marine.

In terms of geomorphology, coastal landscape is of three strips:

- the current coastline with beaches, promenades, estuaries, lagoons, levees, firths,
- testimonies of former trails of the Romanian former sea levels in the various epochs in the past:
  - terraces, alleys, levees and sands fossil on land,
  - terraces, alleys, sands, levees and valleys of fossil submerged seabed.

At the present time, the coastline is a strip of land where the water of the sea may forward or be withdrawn and where there are modeling wave action, currents, and tides. Romanian shores are subjected to pressures, both due to human actions and pressures arising from natural causes. It has been shown that the main cause of coastal erosion has occurred as a result of realizing the needs of Danube River basin water, resulting in a reduction of over 50% of the amount of sediment transported by the Danube.

The deterioration of biodiversity of the marine environment and specially of the mollusk populations due to the pollution of marine and Danube waters is another cause of reducing the amount of biogenic sand.

Other causes of intensifying the process of erosion are: elongation towards offshore breakwaters at the mouth of the Sulina arm, the work of expansion and modernization of the ports of Midia, the sediment transported along the coast because of the Sacalin island, and the intensifying storms regimes in the recent decades.

2. DESCRIPTION OF THE STUDIED AREA

Taking into consideration all these reasons to study the process of modification of the shoreline, it is necessary to know the Romanian coastline morphology. The coastline is the product of the energy applied over the coast as a result of the action of the waves and winds.

2.1. The Northern Unit of The Romanian Coastline: Danube Delta

It has to be highlighted first that the Danube Delta represents a biosphere reserve. Moreover, this was also designated as an UNESCO World Heritage site, Special Protected Area of the European Union and RAMSAR site. It is the third largest delta in Europe, after Volga and Kuban rivers Deltas. The Danube Delta is one of the largest wetlands in the world and is secured with the highest degree of protection at the international level, due to the importance of the diversity of ecosystems and the variety of species of water birds. Over the past 35 years, the shoreline receded with 180 up to 300 meters in various places, so that the surfaces were lost from the beach are estimated at about 80 ha. Changes that occur and affect the costal area are mainly caused by natural processes that are heavily influenced by changes in the water

Fig. 2. Splitting the Northern Unit figure in the main coastal sediment cell (Note: sediment cell from cell, at Sulina is situated immediately north of dikes at Sulina) [15]

catchment area of the river Danube and of the major interventions made on the coast in supporting the activities of the navigation.

The Northern Unit is a deltaic coastal area, with a length of 93 km into a process of erosion, especially in the last five decades. Sectors of withdrawal represent 55.6% in the coastline, while advancing sectors and stable stretch along a ~ 48 km (29.6%), ~ 24 km (14.8%), respectively. The Danube River represents the main source of sediments of the littoral drift. In Figure 2 we present the division of coastal sediment cell in the Northern Unit.

Table 1 presents the erosive impact on Northern Unit, with the important values for accretion or erosion.

Table 1. Multiannual table of erosion Rates for 1979-2006 for Northern Unit [15]

Cell	**Sub-sectors**		**Modifying the 1979-2006 coast (m/year) Values + accretion values mean mean erosion**
Gulf of Musura to Sulina Jetty	Golful Musura		10.4
Sulina Jetty to Zatoane (N1)	Sulina		8.1
	Canalul cu Sonda		- 9.4
	Casla Vadanei		- 6.3
	Sf. Gheorghe		3.7
	Sahalin		- 17.7
	Delta secundary Sf. Gheorghe to Ciotic		-
	Ciotic to Zatoane		-
Zatoane to Midia Port (N2)	Perisor		- 2.7
	Periteasca		0.7
	Portita		- 3.9
	Periboina		- 3.5
	Chituc		- 1.5
	Corbu (Capul Midia)	Capul Midia – North	2.1
		Capul Midia – South	3.2

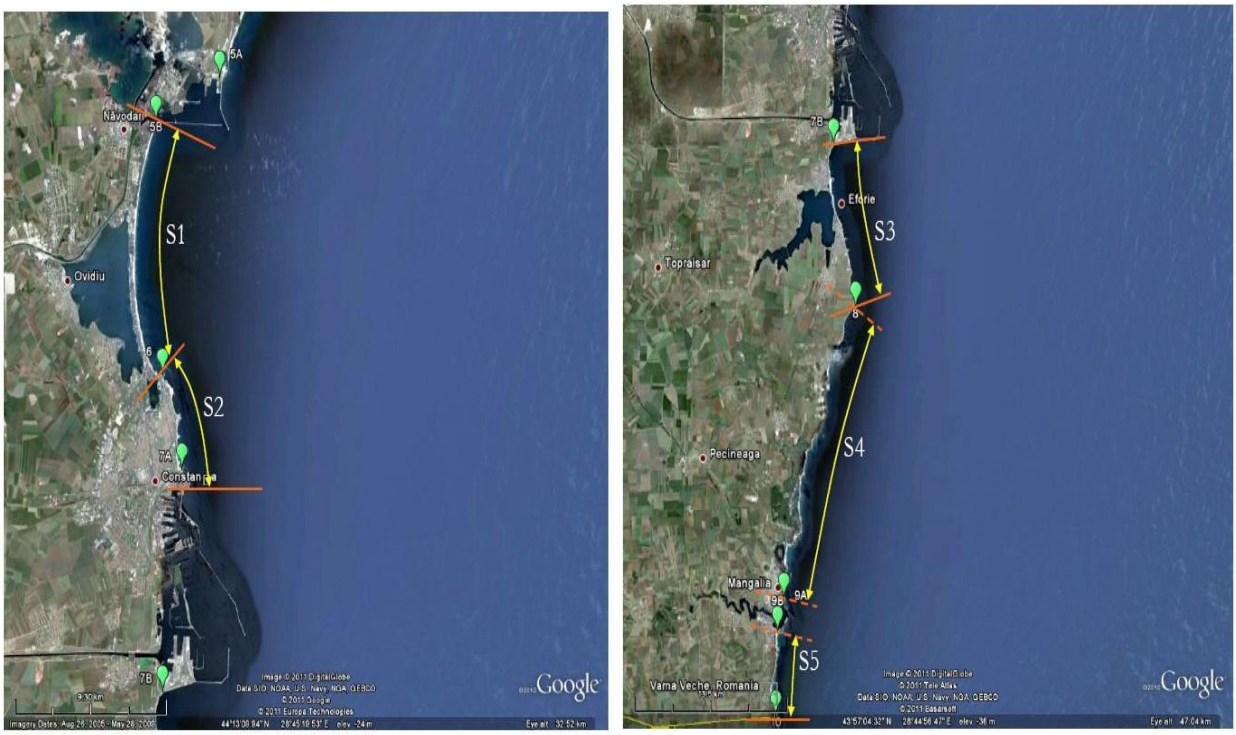
2.2. The Southern Unit of The Black Sea Coast

The big three Romanian Black Sea ports of Constanta, Midia and Mangalia are extremely important for the economy of national, regional and local level, being also important from the social perspective, constituting a major source of jobs in the coastal area. In addition to the positive impact of ports, dykes, which were built during 1970-1980 period, have significantly altered the coastal dynamics within the Southern Unit.

The southern sector of the Romanian coast between Cape Midia and Vama Veche (at the border with Bulgaria, in the South) is of national importance considering the value of economic, social and tourism to the famous Sea Resorts. Tourist resorts are recognized nationwide as a vacation destination, at important regional, national and international levels, attracting annually over 8.100.000 visitors. However, the value of the area is affected by the accelerated erosion of the beaches and the degradation of coastal protection which, in many cases, have exceeded the duration of operation and presents significant risks to health and public safety. The problems are aggravated by the lack of significant sources of sediment for accumulation and existing development impacts on the area. Status of water quality in the waters of the Romanian coast is largely determined by the Danube, which leads the accumulation of pressure of the entire Black Sea basin, including large quantities of pollutants from the annual intake. In some areas, protection works, meant to keep the beach surfaces, have aggravated the problems relating to water quality because their semi enclosed bays were blocked and polluting substances and algae affect the environment.

In terms of processes related to sediment in submerged Beach morphology, the Southern Unit can be divided into four coastal sedimentary cells: Cell from Cape Midia up Constanta Port, the cell till Eforie to the Cap of Tuzla, the Cap of Tuzla up to Mangalia cell and the cell 2 Mai, up to Vama Veche, as one can see in Figure 3a and b.

Coastal sediment cells are defined as units where natural processes are relatively autonomous and there are inputs (sources), the volume transported (sediment transport) and outputs (deposits or accumulations) of non-cohesive sediments. Changes along the shoreline sediment cell are generally independent of changes within the cells, either upstream or downstream, though, where there are partial boundaries for coarse sediment transport or border is essential, as the connections to be taken into account.



a) b)

Fig. 3. The Southern Division of the unit figure at a) Midia port to Gulf of Mamaia (S1) and Constanta port (S2), b) Constanta port to Vama Veche: Agigea to Tuzla (S3), Cape Tuzla-port of Mangalia (S4) and 2 May-Vama Veche (S5) [15]

The Southern Unit is characterized by cliffs (some with small beach golf), broken cords, which separate the coastal lakes in the vicinity of the coast or swampy areas of the Black Sea. A major part of this unit has been artificially stabilized from the ports of Constanta and Mangalia up to comprehensive coastal protection works at Mamaia South to Constanta, from Eforie Nord to Eforie Sud, Costinesti, from Olimp to Mangalia, and 2 Mai.

Sediments that constitute the Southern Unit of the Romanian coast have different sources, depending on the different sedimentary cells and the erosion rates are different for each sector. Table 2 presents modifications of shoreline per year, in each sector.

Sediment cell from Cape Media from the port of Constanta was filled with silt carried by the river Danube, brought here by seaside transport, before the expansion of the port of Midia dams, in 1980. For the last three decades, since the initial source was blocked by dikes from Midia, there has been a significant increase in the role of fragments of the mollusk shells as a source of sediment to the beach.

It has executed a limited volume of artificial nourishment about 25 years ago in the Mamaia South from Lake Siutghiol. Not all three coastal cells South of Constanta are powered by the Danube River. They are derived, mainly, from fragments of shells and, in a small extent, from limestone outcrops on seabed. There are also small volumes of terigene sands, which were transported here, most likely during the late Holocene era of active valleys at that time (Techirghiol, Mangalia, etc.) and redistributed by currents of littoral and waves.

The main feature of this Unit is the southern origin of the majority of coastal limestone sediments. Sand granules have a specific weight, lower (as compared to 2.4-2.7 for terigene granules). In addition, grains derived from shells tend to be more flat than terigene granules. This fact explains the peculiarities of sediment distribution along transverse profiles, as well as their behavior.

Another general characteristic of cells between Agigea and Vama Veche is the presence of submerged limestone platform Neogen. It is generally covered by a thin layer of sand, but the distribution of sediments on the unconsolidated limestone platform surface is very irregular.

Table 2. Multi-annual table of erosion rates for the Southern Unit, 1979-2006, collected from maps [15]

Cell	Sub-sectors	Modifying the 1979-2006 coastline (m/year)
Midia - Constanta	Navodari Nord	0.15
	Navodari Sud	0.23
	Mamaia Nord	-0.79
	Mamaia Central	-1.38
	Mamaia Sud	-1.21
	Tomis Nord	3.12
	Tomis Sud	1.42
Eforie - Capul Tuzla	Eforie Nord	1.17
	Eforie Central	-0.52
	Eforie Sud	0.78
	Tuzla Nord	-0.38
Capul Tuzla - Mangalia	Tuzla Sud	-0.29
	Costinesti	-1.11
	23 August	-0.92
	Olimp - Venus	-0.37
	Venus - Saturn	-2.12
	Saturn - Mangalia	-1.49
2 Mai - Vama Veche	2 Mai	-2.24
	Limanu	-1.75
	Vama Veche	-1.19

3. COASTAL RISK ANALYSIS IN TERMS OF NO-INTERVENTION

3.1. The Northern Unit

Taking into consideration the fact that Romanian Coast is heavily influenced by human intervention in the present, its evolution in the future depends in a considerable measure of strategy options chosen by local decision makers regarding the integrated management of the coastal zone. In the following, we will carry out an analysis of coastal erosion risk assessment in a case of "lack of intervention". It involves a hypothetical case for the future management of the coastal zone, in which there would be no human intervention in the future for attenuating the erosion of coastal area. Although this is very unlikely to be a strategic option for the entire management competency, it offers to policy-makers an assessment in relation to the reference which can be measured by ~~the~~ benefits and costs of the intervention for the management of risks of erosion.

Preliminary forecasts of future trends of erosion and accretion along the coast have been derived from historical data of the withdrawal line coast, coming from the existing maps. An example of a conceptual map is presented in Fig. 4.

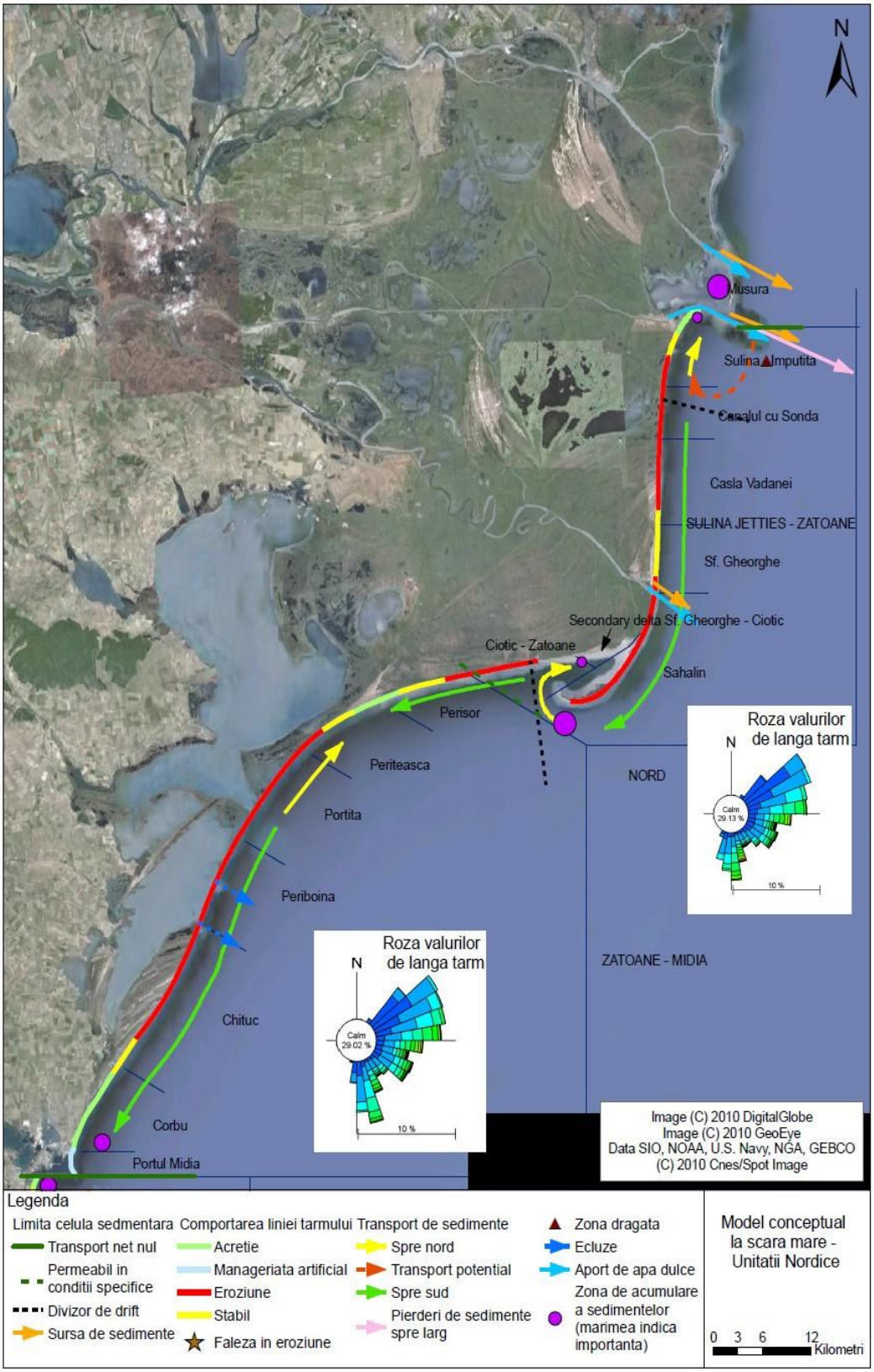


Fig. 4. Conceptual figure of the Nordic Model Unit [15]

There were taken into account two scenarios: a "reference case" scenario and the "worst case" for the risk analysis. In this case, the reference supposes that the sea level continues to grow with the current rate (3 mm/year). The worst case scenario assumes that the rate of increase in sea level increases from 10 mm/year. Using these two scenarios, several 'facings' risk of erosion were made (Table 3).

Table 3. North Unit - Estimates of withdrawing foreseen until 2040 Bruun rule applying in two hypotheses concerning the increase of the sea level [15]

Sedimentary Cell	**Sub-sectors**	**Estimates of the annual level of removal and shoreline (m/year) using the Bruun rule (2010-2040)**	
		Increasing sea level with 3, 3 mm/yr (0.1 m until 2040)	**Increasing sea level with 10 mm/year (0, 3 m until 2040)**
Golful Musura to Sulina	Golful Musura	-	-
Sulina to Zatoane (N1)	Sulina	-7.5 m *(0.25 m/an)*	-22.6 m *(0.75 m/an)*
	Canalul cu Sonda		
	Casla Vadanei		
	Sf. Gheorghe		
	Sahalin		
	Sf. Gheorghe to Ciotic	-	-
	Ciotic to Zatoane	-	-
Zatoane to Midia Port (N2)	Perisor	-9.0m *(0.3m/an)*	-27.0 m *(0.9 m/an)*
	Periteasca		
	Portita	-4.9 m *(0.16 m/an)*	-14.6 m *(0.49 m/an)*
	Periboina		
	Chituc	-2.5 m *(0.08 m/an)*	-7.6 m *(0.25 m/an)*
	Corbu (Capul Midia)	-5.3m *(0.17 m/an)*	-15.9 m *(0.53 m/an)*

The results show that the estimated withdrawal using Bruun rule is lower than that obtained with the help of the historian. This situation is not unusual in the case of a dynamic shoreline of the Romanian Coast, because the rule is a two-dimensional Bruun method and it does not take into account the transportation along the shoreline and sediment loss caused by the processes of beach washing.

3.2. The Southern Unit

Preliminary forecasts of future trends of erosion and accretion along the coast have been derived from historical data of the coastline withdrawal coming from the existing maps. We have taken into account two scenarios: a "reference case" scenario and the "worst case" for the nearshore risk analyze. In this case the reference is supposedly the sea level continues to grow with the current rate (3 mm/year). The worst case scenario assumes that the rate of increase in sea level increases from 10 mm/year using these two scenarios were made a number of ' facings ' risk of erosion, Table 4.

Table 4. South Unit - Estimates of withdrawing foreseen until 2040 Bruun rule applying in two hypotheses concerning the increase of the sea level [15]

Sedimentary cell	**Sub-sectors**	**Increasing sea level with 3.3 mm/yr (0.1 m until 2040)**	
		Increasing sea level with 3.3 mm/yr (0.1 m until 2040)	**Increasing sea level with 10 mm/year (0.3 m until 2040)**
Capul Midia to Portul Constanta	Navodari Nord	-4.8m *(0.16m/an)*	-14.4m *(0.48m/an)*
	Navodari Sud		
	Mamaia Nord		
	Mamaia Centru		
	Mamaia Sud		
	Tomis Nord	-6.0m *(0.3m/an)*	-18.0m *(0.6m/an)*
	Tomis Sud		
Eforie to Capul Tuzla	Eforie Nord	-3.0m *(0.1m/an)*	-9.1m *(0.3m/an)*
	Eforie Centru		
	Eforie Sud		
	Tuzla Nord		
Capul Tuzla to Mangalia	Tuzla Sud	-3.0m *(0.1m/an)*	-9.1m *(0.3m/an)*
	Costinesti	-3.2m *(0.11m/an)*	-9.5m *(0.32m/an)*
	23 August		
	Olimp-Venus		
	Venus - Saturn (balta Mangalia)		
	Saturn-Mangalia		
2 Mai to Vama Veche	2 Mai	-2.6m *(0.09m/an)*	-7.9m *(0.26m/an)*
	Limanu		
	Vama Veche		

In Figure 6, we can see a risk analysis in the nearshore area, taking into account several factors. Thus, a first analysis refers to the degree of erosion and its impact on shore in each of the beach sectors. Another analysis refers to the impact of environmental, social and economic factors, and shows gradual aspects between positive and negative impacts. The role of this circular diagram is to provide a clear picture to the decision makers on each beach sector, as a support for the creation of appropriate nearshore protection policies.

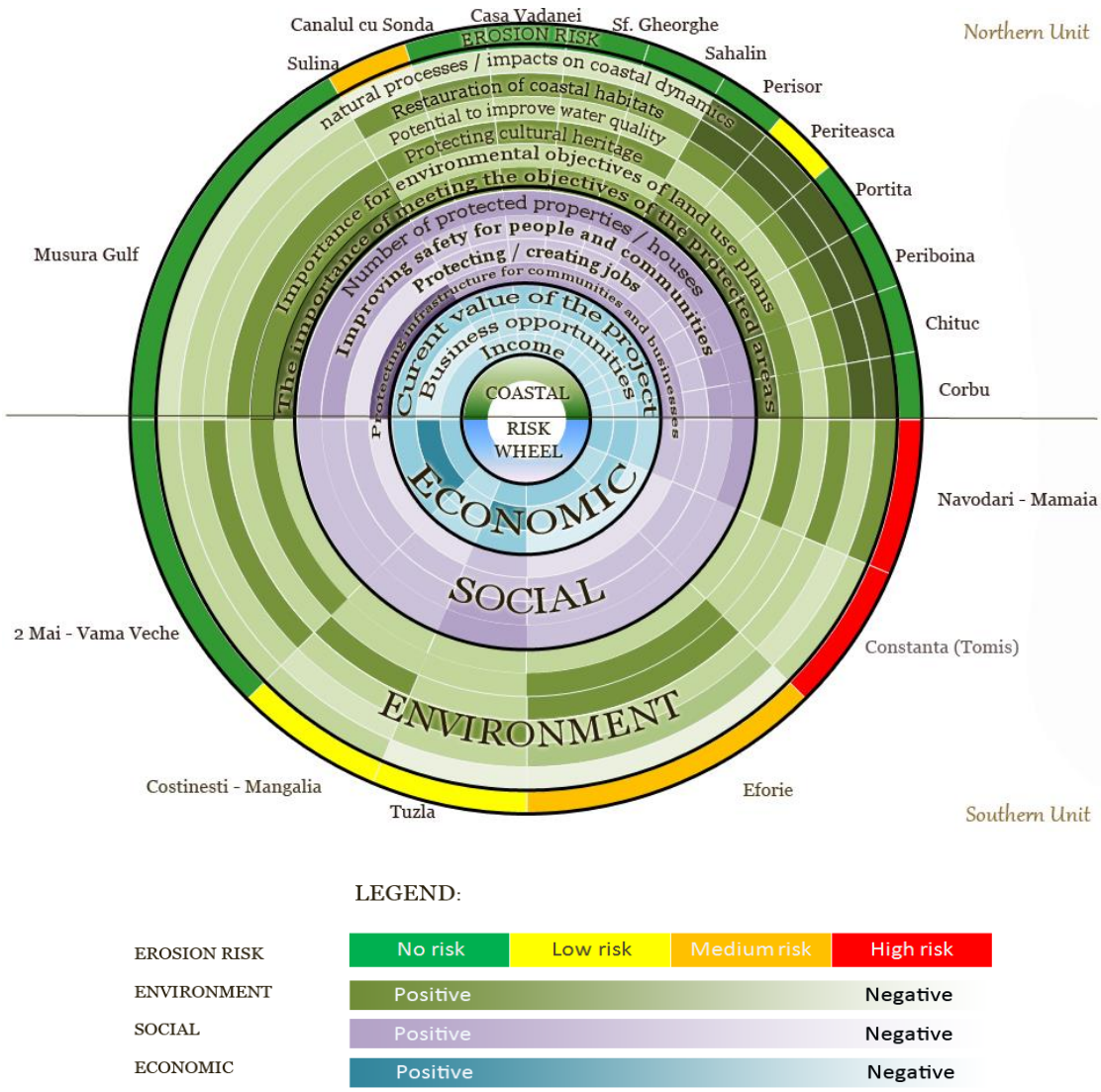


Fig. 6. Coastal risk wheel

4. CONCLUSIONS

Coastal risk analysis on the Romanian Black Sea shore takes into account the impact of a scenario without intervention on the coastline, from the point of view of the environment. It shows information about the processes currently in existence, the nature and the coastal state of existing protection structures and risk of erosion. The potential impacts are taken into account on the natural characteristics of the environment on the Romanian Coast but, at the same time, analyzing human factors influence through the imprint that they put on the environment.

This paper provides an overview of the Romanian Black Sea coast in the event in which human intervention for the development of works upon the coastal zone will not occur.

This conceptual model provides a description or a "story" of how it works by bringing together all the coast available information relating to the characteristics of the coast, the factors that cause the alteration of the coast, influences of human factors (and other factors) on the speed of change and information relating to the modification of the line the shoreline in the past. This constitutes a reference basis for the evaluation of morphological changes likely caused by the actions of the Administration, which has been used for forecasting potential future evolutions of the coast in the absence of any human intervention. Furthermore, the model has been used in the development of options for managing the coast in the future.

ACKNOWLEDGMENT

This work was presented at the 5th Scientific Conference of the Doctoral Schools from 'Dunărea de Jos' University of Galati (CSSD-2017) and it carried out in the framework of the project proposal ACCWA (Assessment of the Climate Change effects on the WAve conditions in the Black Sea), submitted under the number PN-III-P4-IDPCE-2016-0028 to the Romanian Executive Agency for Higher Education, Research, Development and Innovation Funding, UEFISCDI.

REFERENCES

[1] Anton I. A., 2015, *Monitorizarea riscului si aplicatia web pentru sistemul Rkfmea pe bazinul Marii Negre*, Final Book Risk Management and Assessment for prevention of ecological and technological risks in the Black Sea basin, Editura Nautica, pp. 398-404.
[2] Diaconu S., Rusu E., 2013, The environmental impact of a Wave Dragon array operating in the Black Sea, *The Scientific World Journal*, pp. 1-20, http://www.hindawi.com/journals/tswj/aip/498013/
[3] Kuroki K., Goda Y., Panin N., Stanica A., Diaconeasa D.I., Babu G., 2006, Beach erosion and coastal protection plan along the southern Romanian Black sea shore, *Coastal Engineering 2006*.
[4] Panaitescu F.-V., Panaitescu M., Anton I.-A., 2016, Experimental researches of marine wave parameter in the Black Sea Basin, Proc. SPIE 10010, Advanced Topics in Optoelectronics, Microelectronics, and Nanotechnologies VIII, 1001026 (December 14, 2016)
[5] Panaitescu M., Panaitescu F.-V., Anton I.-A., 2016, A method for flow modelling of vulnerable areas, Journal of Marine Technology and Environmental, Editura Nautica, vol. II, pp. 43-48.
[6] Panin N., 1997, On the geomorphologic and the geologic evolution of the river Danube – Black Sea interaction zone, *Geo-Eco-Marina*, 2, pp. 31-40.
[7] Panin N., 1998, Danube Delta: geology, sedimentology, evolution, Ass. Sedimentologistes Francais 65, Fontainbleau
[8] Panin N., 1999, Global changes, sea level rise and the Danube Delta: risks and response, *Geo-Eco-Marina 4*, pp. 19- 29. Bucharest, Romania
[9] Rusu, E., Onea, F, 2013, Evaluation of the wind and wave energy along the Caspian Sea, *Energy*, vol 50, pp. 1-14.
[10] Rusu L., Butunoiu D., Rusu E., 2014, Analysis of the extreme storm events in the Black Sea considering the results of a ten-year wave hindcast, *Journal of Environmental Protection and Ecology (JEPE)*, vol.15, no. 2, pp. 445-454.
[11] Stanica A., Dan, S., Jiménez, J. A., Ungureanu G. V., 2011, Dealing with erosion along the Danube Delta coast. The CONSCIENCE experience towards a sustainable coastline management, Ocean & Coastal Management.
[12] Stanica A., Dan S., Ungureanu Gh., 2007, Coastal changes at the Sulina mouth of the Danube River as a result of human activities, *Marine Pollution Bulletin*, 55/10-12, pp. 555-563.
[13] Stanica A., Panin N., 2009, Present evolution and future predictions for the deltaic coastal zone between the Sulina and Sf. Gheorghe Danube river mouth (Romania), *Geomorphology* 107, pp. 41-46.
[14] Zanopol A., Onea F., Rusu, E, 2014, Evaluation of the coastal influence of a generic wave farm operating in the Romanian nearshore, *Journal of Environmental Protection and Ecology*, vol. 15 (2), pp. 597-605, http://www.jepe-journal.info/vol-15-no-2-2014.
[15] ****** Halcrow, 2011, Raport Diagnostic al Zonei Costiere.
[16] ******JICA, 2007, Final report. The study on protection and rehabilitation of the southern Romanian Black Sea shore in Romania, vol. 1, Basic Study and Coastal Protection Plan. Japan International Cooperation Agency: ECOH Corp.
[17] ****** Royal Haskoning, 2004, Outline Strategy for the integrated management of the Romanian Coastal Zone, Towards Implementation, Draft Report.