THE IMPACT OF MANGALIA HARBOUR’S BREAKWATERS ON THE SHORE AND CLIFF IN “2 MAI-VAMA VECHE” COASTAL AREA

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Abstract: The paperwork is part of a substantiation study about the current state of the NW Black Sea coastal area and it consists in the establishment of a reference database regarding hydrotechnical structures, the existing coastal protections, their impact and the identification of risk areas. A high-risk area is “2 Mai - Vama Veche” region, located in The Southern Romanian Coastline, due to the sharp beach erosion and the cliffs instability that endanger nearby buildings. The coastal protections, the offshore breakwaters, the industry development in the coastal region and the construction of storage lakes and dams in the river basins have influenced the conditions in which The Romanian Coast is found nowadays.

Keywords: coastal area, hydrotechnical structures, coastal protection, erosion

1. INTRODUCTION

In this paper, a practical method is presented to assess the risk of erosion of beaches and seafronts through the analysis of the main factors responsible for the erosion. To this end, 10 physical variables are integrated (such as the lithology of seafronts, features of the seafronts, waves, currents, precipitation regime etc.) and 6 socio-economic variables (such as the type of land use and population density). These variables are weighted and combined into a Hazard Index and an Impact Index, resulting in a Risk Index.

Hazard factors taken into consideration were the wind, storms at sea, waves, currents, sea level variability at the shore, rainfall and humidity, seafronts type. Wave height data, frequency of waves and marine currents have been taken from INCMD reports.

Measurements on waves and marine currents have been made at the Oceanographic Measuring Station of INCMD, equipped with underwater probes ADCP (Acoustic Doppler Current Profiler) for measurement of marine currents, wave parameters and automatic stations equipped with sensors to measure the variations in water level. The data recorded following measurements are presented in chapter 2.

Impact factors taken into account were the density of population, agriculture and fishing, tourism, transport and infrastructure, the industry and the existence of natural reservations.

The coastal zone of Romania faces significant problems in terms of the destruction of habitats, coastal erosion, water pollution and impoverishment of the natural resources. Rapid population growth and tourism, the large-scale exploitation of natural resources and the rapid development of infrastructure have led to severe degradation and decline in quality of the Romanian coastal zone.

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Of these, coastal erosion is one of the major environmental problems of the coastal zone in Romania. Integrated coastal zone management aims at the sustainable development of the coastal zone, reducing its and is inhabitants vulnerability to natural risks and maintain economic processes and biological diversity. An efficient strategy for integrated management of the coastal zone can be established after the correct assessment of the risk of erosion of the coastal zone, hazard and impact factors (vulnerability) of the area.

2. HAZARD FACTORS

The sea storms that reach the Romanian shore of the Black Sea are phenomena that happen frequently. They began to be studied more after 2000.

The Black Sea represents a space characterized by extremely active storm conditions. There is a prevalence of wind accelerations from the northern sector both during the cold season and the rest of the year.

The wind storms from the southern sector occur in every season, but the highest frequency is recorded during spring time when the wind speed reaches high values, up to 40 m/s. Short wind intensifications are specific to summer time, July – August, when wind speed reaches values between 14 – 18 m/s [1]. During the storms from North and South, the significant wave height often exceeds 5 m wide [2, 3].

Along the southern sector, the storms from the last decades led to considerable damage and an important loss of beach sediment. This trend is expected to continue and to worsen if the frequency and intensity of the storms increases.

Air temperature, rainfall, and humidity have a medium importance in controlling coastal morphodynamics along the Romanian shore, but the wind controls shore dynamics due to sand entrainment, waves formation, currents activity along the shore and irregular changes of sea level that often happen [4, 5].

There were processed 6,144 data obtained from INCMD measurements between 2003 – 2010 (Figure 1) [6, 7].

![Fig. 1. Monthly measurements of waves parameters (2003 – 2010).](image)

The waves are undulating movements of the surface water, with linear propagation, which causes the entire water mass to move and propagate radially. One important effect of the hydrodynamic energy of the waves is that it causes the erosion or the solid material settlement. These two effects are the most important agents of shoreline modeling.

The next two charts contain information regarding the monthly medium frequency and annually medium frequency of the waves, expressed as a percentage. The data average was calculated for the period of study 2003 – 2010 (Figure 2 and Figure 3) [6, 7].

It can be observed that the highest frequency of the waves and storm swells was recorded in 2010 (39.1 %), and the lowest frequency was recorded in 2008 (18.8 %).
Streams and general circulation of the water. The streams in the Black Sea are influenced by the wind, the water flow of the rivers, the water density distribution, the coastal perimeter, the seabed topography and the presence of coastal and harbor structures. The main factor that influences the surface streams system is the wind. The other factors do not have such a significant influence; they generally produce duration and direction variations. There is a coastal longitudinal stream along the shelf of the Black Sea, almost permanent, which has a cyclonic displacement at the edge of the shelf and surrounds the entire Sea Basin. Inside the Basin are two other cyclonic circulations (eastern and western), due to the existence of Crimea Peninsula, and at the periphery are formed other anticyclonic circuits, at a medium scale (Figure 4). The average wind speed is 15 – 30 cm/s [1].

In order to analyze the spatial distribution of the streams, there were made numerical simulations, with or without in-situ studies and it could be observed that along the Romanian shore of the Black Sea, the streams have high instability, both in terms of direction and speed, mainly due to wind variations.

In the Romanian Black Sea coast northern and northeastern waves, which are much stronger than the others, are prevailing, and the superficial streams resultant is approximately from northeast to southwest. From the distribution of the streams measured in February, 2010 with ADCP (Acoustic Doppler Current Profiler) in the western shelf of the Black Sea, follows that near Gurile Dunarii are two streams: one from North to South which flows right in the coastal area (near the shore) along the entire depth with speeds between 0.33 – 0.45 m/s and the other one from South to North which flows like a compact dense mass at a depth of 10 m with a speed of 0.47 m/s.

In the southern region of the Romanian coast, due to shoreline orientation, southern and northern streams are prevailing. At the surface, streams speed has values between 20 and 40 cm/s, reaching, in exceptional situations, 100 cm/s [6 - 8].
Fig. 4. Surface streams distribution in January 2012 (left) and in May 2012 (right) as a result of circulation model for the NV area of the Black Sea [6].

By comparing the results of circulation modeling (Figure 5) with the ones measured with ADCP, it was concluded that there is a congruence between geostrophic circulation and the measured one; discrepancies appear only in the warm season. In the cold season, the streams are more settled, because of wind intensity and stability. Hence, there is a good correlation between geostrophic and real streams during cold seasons.

Fig. 5. Waves distribution in February 2010 in the western Black Sea Shelf (cm/s) [6].

3. DESCRIPTION OF THE CURRENT STATE OF 2MAI-VAMA VECHE AREA

2 Mai. This subsector, which stretches between Mangalia-South Waterbreak and Fishing area 2 Mai, is characterized by loess cliffs and two small gulf beaches (Figures 6-9).

The significant waves come from northeast, those from southeast are less important. The general alluvial transportation system is orientated to South, with the exception of a local swirl stream generated by Mangalia-South Breakwater, which creates a small sedimentary deposit. The major sources of sediment for the beaches are the shells and the fragments of limestone eroded from the seabed. Therefore, they are under supplied with sediment.
There is only one coastal protection structure made of rocks and reinforced concrete elements, which is currently used as a dam by the local fishermen. Apart from this, there are no other coastal protection measures in this area. In the northern part of this subzone, the beach is relatively stable because of the influence of Mangalia breakwater. The other areas are affected by a pronounced erosion tendency together with the loss of shore sediments. The cliffs are prone to erosion and collapse by landslides.

**VAMA VECHE.** This subzone extends to the Romanian border with Bulgaria. The subzone includes cliffs and a beach. The main sources of beach sediment are seashells and limestone fragments eroded from the seafloor. The most significant waves are those coming from northeast; the southeast waves are of secondary importance. The general direction of alluvial transportation is to the South, but the contribution will be reduced because of sediment deficiency.

The beach is relatively stable, but the cliff is prone to landslides (Figures 10-11).
Table 1 presents results regarding the advancement or withdrawal of the shoreline in the sectors of the southern coast. It can be observed that in 2 Mai – Vama Veche area were recorded intensive erosion processes of the beach and cliffs.

Table 1. Observations of erosion process and shoreline changes in the sectors of the southern coast.

<table>
<thead>
<tr>
<th>Zones</th>
<th>Subzones</th>
<th>Sectors</th>
<th>Observations of erosion process and shoreline changes (withdrawals/ balance/ advancements)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southern zone of the Coast</td>
<td>Mâmaia – Constanța</td>
<td>Mâmaia</td>
<td>the shoreline advanced with values between 2 m and 13 m</td>
</tr>
<tr>
<td></td>
<td>Agigea - Eforie</td>
<td>Eforie Nord</td>
<td>the shoreline advanced up to 7 m</td>
</tr>
<tr>
<td></td>
<td>Tuzla – Mangalia Nord</td>
<td>Tuzla - 23 August</td>
<td>withdrawals up to 7-8 m</td>
</tr>
<tr>
<td></td>
<td>Mangalia Nord – Mangalia Sud</td>
<td>Olimp- Neptun</td>
<td>the shoreline advanced up to 10-13 m</td>
</tr>
<tr>
<td></td>
<td>Mangalia Sud – Vama Veche</td>
<td>2 Mai and Vama Veche</td>
<td>accelerated erosion accompanied by cliff collapse phenomena the shoreline advanced up to 10-13 m</td>
</tr>
</tbody>
</table>

The prediction for the Romanian Black Sea coast, considering that conditions have not changed in the last decades, is the continuous erosion of the greater part of the southern Romanian coast.

The protection solutions proposed in various studies and reports for erosion risk reduction are:
- In the Master Plan “The protection and rehabilitation of coastal area”. TECHNICAL ASSISTANCE FOR PROJECTS PREPARATION PRIORITY AXIS 5. Key area (major field) of intervention 2: “The reduction of coastal erosion” of A.N.R. Romanian Waters developed by Halcrow Romania S.R.L. in 2011. There are proposed rehabilitation works for the existing waterbreak and for the protection of the cliff base, if needed, together with measures to reduce the impact on habitats.
- Projects/ Medium term works 2014 – 2021 for 2 Mai area for the sector between Mangalia-South breakwater and Pescarie 2 Mai.

4. EROSION RISK AND ENVIRONMENTAL IMPACT OF EXISTING STRUCTURES

The proposed approach allows for zoning the coast, according to risk, danger and/or levels of impact, including recognition of the critical areas where specific intervention strategies should be adopted. The method presented in this paper is practical and, at the same time does not require extensive and detailed surveys of the area where it is to be applied. In this way, the method is simple to use, it is a valuable tool for decision-making on the planning and management of strategies in the active coastal zones in the active.

Hazard factors and impact factors are presented in Tables 2 and 3. As an example, the assessment of erosion risk in the 2 Mai coastal area is presented.

Table 2. Variable hazard ranking.

<table>
<thead>
<tr>
<th>A- Cliff lithology</th>
<th>B- Cliff structure</th>
<th>C- Cliff slope</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- plutonic, volcanic, resistant metamorphics</td>
<td>1- no significant discontinuities</td>
<td>1- slope &lt; 25°</td>
</tr>
<tr>
<td>2- limestones, sandstones, conglomerates</td>
<td>2- alternate sequences of soft and hard materials</td>
<td>2- slope 26°-50°</td>
</tr>
<tr>
<td>3- non-resistant metamorphics, fine consolidated sediments, coarse unconsolidated sediments</td>
<td>3- isolated gullies and/or evident groundwater flow and/or moderate cracks/joints/faults</td>
<td>3- slope 51°-75°</td>
</tr>
<tr>
<td>4- fine unconsolidated materials</td>
<td>4- coastal badlands and/or dense cracks/joints/faults</td>
<td></td>
</tr>
</tbody>
</table>

Table 3. Variable impact ranking.

<table>
<thead>
<tr>
<th>A- Main land use type</th>
<th>B- Percentage of developed areas</th>
<th>C- Presence of nature reserves</th>
</tr>
</thead>
<tbody>
<tr>
<td>1- natural areas</td>
<td>1- development 0-25%</td>
<td>1- not considered</td>
</tr>
<tr>
<td>2- cropland</td>
<td>2- development 26-50%</td>
<td>2- absent</td>
</tr>
<tr>
<td>3- sparse buildings and/or parking lots</td>
<td>3- development 51-75%</td>
<td>3- present</td>
</tr>
<tr>
<td>4- densely urbanized areas and/or industrial areas</td>
<td>4- development 76-100%</td>
<td></td>
</tr>
</tbody>
</table>
4- slope > 75º

D- Protective beach
1- wide/high beach (waves reach the cliff at spring tides coinciding with storm surges) 3
2- intermediate beach (waves reach the cliff at spring tides or during storm surges) 3
3- narrow/low beach (waves reach the cliff during daily high tide) 3
4- no beach 3

D- Presence and type of transportation networks
1- no structures for vehicular traffic 3
2- minor roads 3
3- major roads 3
4- motorways and/or railways 3

E- Rocky shore platform
1- wide, continuous intertidal rocky shore platform 4
2- narrow, discontinuous intertidal rocky shore platform 4
3- submerged rocky shore platform 4
4- no rocky shore platform 4

E- Population density
1- density ≤ 50 persons/km² 3
2- 51 persons/km² ≤ density ≤ 300 persons/km² 3
3- 301 persons/km² ≤ density ≤ 1000 persons/km² 3
4- density > 1000 persons/km² 3

E- Population rate of change
1- annual change ≤ 0% 2
2- 0.1% ≤ annual change ≤ 2% 2
3- 2.1% ≤ annual change ≤ 5% 2
4- annual change > 5% 2

F- Engineering structures at cliff foot
1- seawall or revetment at the cliff foot (whole) 4
2- not considered 4
3- seawall or revetment at the cliff foot (partial) 4
4- no structure at cliff foot 4

F- Population rate of change
1- annual change ≤ 0% 2
2- 0.1% ≤ annual change ≤ 2% 2
3- 2.1% ≤ annual change ≤ 5% 2
4- annual change > 5% 2

G- Exposure to storm wave fronts
1- roughly shore-normal storm wave fronts (angle 81º - 90º) 3
2- angle 46º - 80º 3
3- angle 11º - 45º 3
4- shoreline subparallel to main storm wave fronts (angle < 10º) 3

H- Difference between storm and modal wave height
1- difference< 0.5 m 4
2- difference 0.5 m - 2 m 4
3- difference 2 m - 3.5 m 4
4- difference > 3.5 m 4

I- Relative sea level trend
1- change< -1 mm/yr (RSL fall) 4
2- change -1 mm/yr to +1 mm/yr (RSL stable ) 4
3- change +1 mm/yr to +2.5 mm/yr (RSL moderately rising) 4
4- change > +2.5 mm/yr (RSL strongly rising) 4

K- Rainfall
1- mean annual precipitation < 500 mm 1
2- mean annual precipitation 500-1000 mm 1
3- mean annual precipitation 1000-1500 mm 1
4- mean annual precipitation > 1500 mm 1

Risk is the product of the probability of occurrence of erosion and the value of the natural environment, economic and social, which is vulnerable to the random factor (table 4 and 5).

In the case of coastal erosion, the hazard is due to natural processes and/or of anthropogenic nature we call hazard factors.

Vulnerability indicates that if the phenomenon of coastal erosion takes place, it will produce direct and indirect damage, accompanied, eventually, by the loss of human lives. The vulnerability function is extremely complex, depending on a large number of variables, some of which are often difficult to determine. These variables we will denote as factors of impact.

Table 4. Risk rating.

<table>
<thead>
<tr>
<th></th>
<th>very rarely</th>
<th>rarely</th>
<th>moderately</th>
<th>frequently</th>
<th>very frequently</th>
</tr>
</thead>
<tbody>
<tr>
<td>linear</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>nonlinear</td>
<td>0.05</td>
<td>0.1</td>
<td>0.2</td>
<td>0.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Table 5. Risk rating Impact ranking.

<table>
<thead>
<tr>
<th></th>
<th>very low</th>
<th>low</th>
<th>moderately</th>
<th>high</th>
<th>very high</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
</tbody>
</table>

\[ HI_{abs} = \sum an fn = 2.23 – Absolute Hazard Index \]  

\[ range HI_{abs} = max HI_{abs} - min HI_{abs} = 3.2 - 0.1 = 3.1 - the normalization of the Absolute Hazard Index \]
HI_{rel} = \frac{HI_{abs} - min\, HI_{abs}}{range\, HI_{abs}} \times 100 = \frac{2.23 - 0.1}{3.1} \times 100 = 68.71\% - \text{Relative Hazard Index} \tag{3}

Impact Index = 50.88\% \tag{4}

RISK INDEX- RI = 62.02\% \text{ result HIGH RISK} \tag{5}

The southern area is very different as shape and has soft cliffs with small “pocket beaches” in front, separated by coastal sand bars. These beaches have steeper submarine slopes unlike those from the northern part.

The unstable cliffs made of soft rocks and located along the southern zone are likely to collapse in landslides. The loess layers allow water infiltration but the clay layers from the cliffs base are impermeable, which leads to slip planes forming: the cliffs situated above the clay layers slips downwards and the sediment, which are usually too fine to accumulate on the beach, are transported offshore by waves.

Cliff erosion in the southern area is not significant for the adjacent beaches. Soft loess is to fine, thus is has the tendency to be transported offshore, while rough limestone, from the base, is very resistant to wave action and generates small amounts of sediment (mainly rocks and stones, rarely sand) and during long periods of time.

**The impact of human actions.** There are several human activities that had influenced the state of the Romanian coast nowadays, such as:
- Coastal protection measures;
- Harbour breakwaters for protection;
- The industrial capacity development in the coastal area;
- The introduction of species in the ecosystem that are not indigenous;
- The construction of water reservoirs and dams in the hydrographic rivers basins;
- Coastal interventions that affected sediment settlement.

The breakwaters of Mangalia Harbour affected, at their turn, the transportation along the shoreline and the general sediment movement, an amount of sediments being carried offshore. Mangalia Harbour has a significant influence in the cliffs and beaches erosion between 2 Mai and Vama Veche villages. Unlike the maps from 1960 and 1979, there are important changes of the shoreline appearance in this subzone at present. Due to Mangalia Harbour’s breakwater there is a strong erosion of the beaches and the waves reaching the base of the cliffs produce collapses, endangering the nearby buildings. In the Northern part of this subzone the beach is relatively stable because of the influence of Mangalia breakwater. The other areas are affected by a pronounced erosion tendency together with the loss of shore sediments. The cliffs are prone to erosion and collapse by landslides.

In this region, in terms of coastal protection, there is a breakwater of rocks and reinforced concrete elements, which is currently used as a dam by the local fishermen. The dam is in an advanced state of decay. Apart from this, there are no other coastal protection measures in this area. It is necessary to carry out urgently rehabilitation and improvement works of the existing coastal defense structures, in order to stop the beach erosion and cliffs instability phenomena.

There are proposed rehabilitation works of the existing breakwater and protection works of the base of the cliff, where necessary, together with reducing measures of the impact on habitats.

5. CONCLUSIONS

There are a number of human activities that have influenced the Romanian coast, such as coastal protection measures, protective breakwaters harbor, development of industrial capacities in the coastal zone, the introduction in ecosystem of not indigenous species, and the construction of reservoirs and dams in the river basin. The coastal interventions have affected deposits sediment. Breakwaters harbors Mangalia in turn affect the transport along the shoreline and the general circulation of sediments, parts of these being transported to offshore. Mangalia Port affects the sea walls and the beach erosion of 2 May and Vama Veche.

The dynamic of waves is a very important factor with significant effects on the erosion or the deposition of solid materials; therefore it leads to the shoreline changes.
In the littoral area of the Black Sea in Romania, erosion is a real threat to the environment. The phenomenon appears at various levels of intensity along the 245 km of coastline, measured (from North to South) from Chilia Channel (Musura Bay) to Vama Veche (The border with Bulgaria).

Any delay in taking this problem into consideration can lead to irreversible negative consequences on the environment and life quality.

ACKNOWLEDGEMENT

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