The Variability of the Beach Morphology and the Evolution of the Shoreline in the Strongly Anthropized Sector of Eforie North, the Romanian Coast of the Black Sea *Alexandru-Cristian Cîndescu, Silică Petrișoaia, Dragoș Marin, Luminița Buga, George Sîrbu, Alina Spînu*	**"Cercetări Marine" Issue no. 53** **Pages 6-18**	**2023**
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THE VARIABILITY OF THE BEACH MORPHOLOGY AND THE EVOLUTION OF THE SHORELINE IN THE STRONGLY ANTHROPIZED SECTOR OF EFORIE NORTH, THE ROMANIAN COAST OF THE BLACK SEA

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ABSTRACT

The Eforie Nord sector (between the southern pier of Agigea - Constanta port and the tourist port of Belona), is characterized, from a geomorphological point of view by the presence of high cliffs and narrow beaches. In the mentioned sector, a series of coastal protection works were carried out in several stages, respectively: between 1956 and 1960, 6 groins were placed to extend the perimeter beach; with the expansion of Constanța port, new coastal protection measures were imposed (1981-1986), determined by the erosion processes, made concrete by the execution of permeable submerged longitudinal dikes in addition to the transversal ones. On long term, the measurements of shore morphological parameters highlighted that the southern sector of the Romanian Black Sea coast is subject to an erosion process, due to the action of both natural and anthropogenic factors, each generating effects with different intensity, depending on local conditions. Within the project "Protection and Rehabilitation of the Southern Part of the Romanian Black Sea Coast, Phase 1" in 2014-2015 period, in the mentioned sector, extended hydrographical works were carried out, including the rehabilitation of dikes, the construction of submerged dikes and beach nourishment. The monitoring of the shore behavior at regular intervals (annual/seasonal) which is essential for an adequate management of the coastal area, highlights both cyclical/seasonal morphological changes (rapid erosion as a result of storms in the cold season and the reconstruction of the beach during summer) and progressive/multiannual changes. The monitoring of morpho dynamic changes at shore level includes the positioning of the shoreline and beach profiles in 6 locations using GPS equipment (geodetic and GIS class). The resulting spatial data were processed and included in the SANDS management system that allows comparative analysis at different time scales. The maps representations were made in the ArcGIS 10.8 system. The data analysis revealed seasonal changes of the shore morphology, both in the longitudinal profile (shoreline) and transversally (beach profiles).

Keywords: accumulation, erosion, shoreline, topographic profiles, spatial analysis

AIMS AND BACKGROUND

The Romanian coastal area, located in the northwest of the Black Sea, can be divided from a morphological point of view into: the northern unit (Musura Bay - Cap Midia) with a low shore of deltaic and lagoonal origin and the southern unit (Cape Singol - Vama Veche) with a low shore of cliffs cut in loess covering Sarmatian limestone, with heights of about 20-30 m, interrupted by coastal cordons, which barricade old harbors, interspersed with a transitional unit with cliffs and extended coastal cordons (Cap Midia - Cap Singol) (NIMRD Report, 1975).

The dynamics of the coastal zone is directly influenced by natural and anthropogenic factors. The natural factors that participate in shaping the shoreline are morphological (lithological structure, granulometric structure, shallow bathymetric characteristics, etc.), oceanographic (waves and currents in the area with a role in erosion/accumulation, sediment transport and sea level oscillations), meteorological (in general wind, precipitation regime). Anthropogenic intervention represented by coastal protection structures, port, or leisure infrastructure, etc. has a major impact both directly through the changes in the shore morphology and indirectly through the modification of the hydrological factor's natural regime. The shore responds through a continuous dynamic, which adapts to the regime and characteristics of natural and anthropogenic factors (Golumbeanu *et al*., 2015).

The Eforie North sector (located between the southern dike of Agigea – Constanta port and the tourist port of Belona), is characterized from a geomorphological point of view by the presence of high landscaped cliffs and narrow beaches at their base. In the mentioned sector, coastal protection works were carried out in several stages starting with the 50-60s, including the construction of dikes perpendicular to the shore and submerged longitudinal dikes (Spînu *et al.*, 2017). In the framework of the Protection and Rehabilitation of the Southern Part of the Romanian Black Sea Coast Phase 1 Project, in 2014-2015, works that included dike's rehabilitation, the construction of submerged dikes and beach nourishment were carried out.

Beach erosion is a serious concern for coastal countries throughout the world. Physical monitoring of site-specific morphology is essential to gain a more complete understanding of the underlying causes of beach erosion (Cheng *et al*., 2016).

The aim of this paper is to evaluate the morpho dynamic changes at the level of the emerged shore in the Eforie North sector based on existing cartographic data and information, in-situ measurements and observations made annually and/or seasonally during 2015-2018.

EXPERIMENTAL

To understand the temporal behavior of the coast in the mentioned sector, historical cartographic resources were consulted: Austrian Maps 1910, topographic maps 1975-1980, orthophoto plans and satellite images.

To highlight the changes at the beach level that emerged in the transversal and

longitudinal profile in the short term (2015-2018) before and after the nourishment process), specific measurements of geomorphologic profiles and the positioning of the shoreline were performed.

6 geomorphological beach profiles (EF17- EF22) located in Eforie North area were analyzed (Fig. 1) and to highlight the relief forms of the emerged beaches, all its inflections were followed: landmark, dune ridges and their base, berms, beach front, storm wave advance limit and the wave retreat limit. The beach profile is one of the significant geographic features of coastal morphology. The term 'beach profile' refers to a cross-sectional trace of the beach perpendicular to the high-tide shoreline and extends from the backshore cliff or dune to the inner continental shelf or a location where waves and currents do not transport sediment to and from the beach (Chrzastowski, 2005).

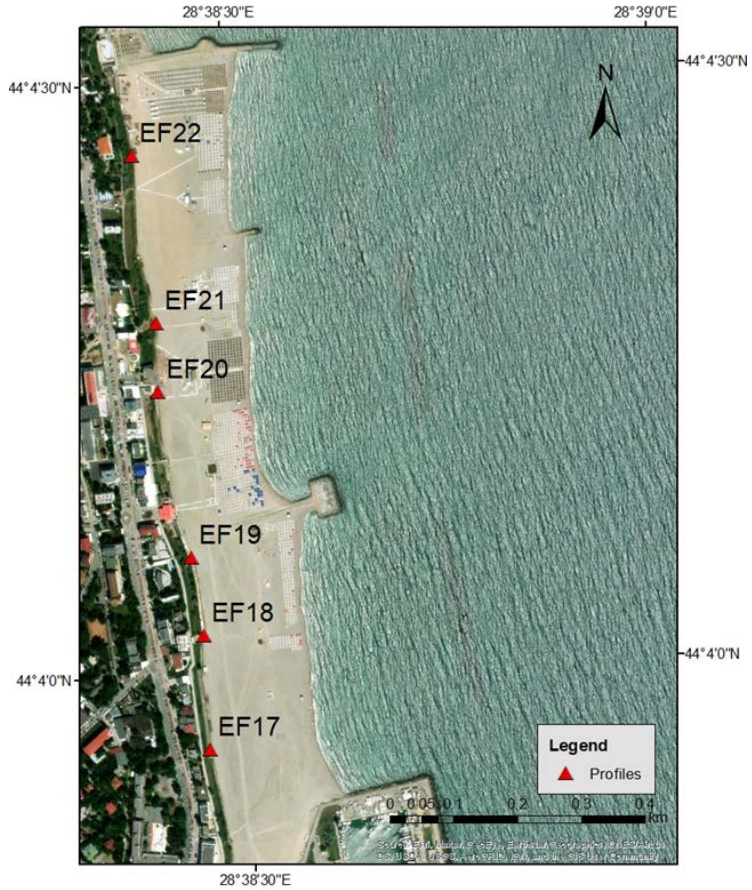

Fig. 1. Geomorphological beach profiles - Eforie North area

By tracking the movement of sand and comparing the obtained results each year, beach profiling can help the state and local communities to better manage their coastal resources (Riazi *et al*., 2022).

The changes in the transverse profile were followed on fixed sections, marked in the field by benchmarks positioned at the end of the beach. The

evaluation of losses and depositions at the beach level surface was carried out by analysing the positioning of the water line/shore at annual and/or seasonal intervals. GPS equipment from the GIS (GPS Leica Zeno 20) and geodesic class (GPS Leica VIVA NET) (RTK type with real-time ROMPOS corrections) were used to make the measurements.

Spatial data obtained through georeferencing and vectorization of existing cartographic materials and from field measurements were integrated into the ArcGIS 10.8 system for spatial analysis and for obtaining maps.

Beach geomorphological data processing was performed using SANDS software. SANDS is a management system designed to analyse coastal zone morphology data. The data resulting from the monitoring activities can be entered, stored, inspected, and compared on a synchronized time scale, allowing the simultaneous visualization of data sets (https://www.sandsuser.com/).

RESULTS AND DISCUSSION

At global level, coastal areas have a series of characteristics that define both their value and their vulnerability, representing the area with the highest population density, the direct consequence being the concentration of economic activities (especially maritime transport, port activities, tourism and agreement, industry, fishing), with all the problems arising from resource consumption, waste management and technological risks. Human uses and the action of natural factors in the conditions of current climate changes exert a strong pressure on the coastal environment (Ramieri *et al.*, 2011).

The 244 km long Romanian coastline (between Musura and Vama Veche) represents 6% of the total length of the Black Sea coast. Its relief consists of low-altitude shores, beaches (80%) and relatively higher shores, cliffs (20%). From a typological point of view, it includes both natural shores (beaches and cliffs - approx. 84%) and "built" shores, approx. 16% (ports, hydrotechnical protection constructions). The current trend of population growth and interest in coastal areas lead to the growth of urban centers and an intensive use of land.

Climate change, sea level rise and the intensification of extreme meteorological and hydrological phenomena together with human pressure have contributed to the increase of environmental risks and induced important changes in the shore configuration.

The hydrotechnical developments from the Danube and its tributaries, the construction and expansion of Sulina canal since the 19th century, the harbor dikes (Midia, Constanta, Mangalia) have substantially changed the transport and the sedimentary regime, determining the accentuation of coastal erosion for most of the Romanian coast.

The development of resorts on the Black Sea began at the end of the 19th century, following the administrative organization of Dobrogea, having in the first phase a destination for spa tourism, on a local level. Eforie North, the former part of Techirghiol village, was transformed into a spa resort starting in 1920 and

became an independent urban locality in 1933. After the Second World War, especially after 1955, Eforie North developed after a vast systematization plan of the Black Sea coast (1955-1965) with the main objective of creating two large tourist areas with different characters, south of Constanța (Eforie South, Eforie North, Techirghiol and Agigea), which were to focus on tourism spa, and the other north of Constanta, reserved exclusively for rest and recreation (Spînu *et al*., 2017).

The systematization took place through the reorganization of the urban area, the construction of new hotels, the consolidation and modernization of the beaches and the seafront, the expansion of the promenades, the establishment of all the necessary facilities and the most efficient exploitation of Lake Techirghiol. After 1990, the need for space, especially for the construction of private homes, and small accommodation units, resulted in the expansion of the city, especially in the area near the sea. Several buildings appeared in the sector adjacent to Lake Techirghiol that gradually destroyed the dune system. The constructions were made less than 100 meters from the shore, in some cases even less, and are badly damaged during storms. Currently, the urban system in the Romanian Black Sea area of Eforie is being expanded in close connection with mass tourism development, being focused on residential development/tourist and leisure infrastructure related to the coastal strip near the Black Sea or Lake Techirghiol (Spînu *et al*., 2017).

In the southern sector of the Romanian coastal zone between Cape Singol and Vama Veche (of which Eforie Nord sector is also part) the shore is alveolar, with cliffs, mostly active, and beaches with widths that vary depending on local conditions. Near the old mouths of the rivers or in front of old bays, narrow beaches formed on river-sea ports (Techirghiol, Costineşti, Tatlageac) or marine lagoons (Tasaul, Siutghiol, Comorova, Iezerul Mangaliei) have developed. The mobility of the shoreline registers a different evolution depending on the local conditions, with the lower amplitude compared to the northern sector (deltaic and lagoonal). Consequently, the destructive effects are more limited but irreversible (the destroyed cliff cannot be rebuilt). In this part of the Romanian coast, some protection works have stabilized certain sectors of the coast, but others are already in danger.

Before 2015, the shore in the Eforie North sector was characterized by beaches at the base of the landscaped cliff. The promenade, 10-15 m high, is laid out in grassy steps and slopes, with longitudinal cobbled paths and access stairs. At the base, a retaining wall with a vertical parapet of stone blocks reinforces the seawall almost along its entire length. Surface water seepage reaches the relatively impermeable clay substratum causing landslides and collapses. Added to this is the direct abrasion of waves and currents.

The wave regime is closely related to the wind regime, which determines and influences. Due to the considerable variability of the wind regime, the state of sea agitation is seasonal and varies from one year to another. The surface waves, as a result of the energy transferred to the sea by the action of the wind, have a very important role in the formation and evolution of the beaches in the Eforie shore

sector, in the sorting of sediment deposits and the transport of sediments to the shore/sea/or, determining the current regime in the shallow area. The directional distribution of the waves corresponds to the wind regime, with the highest frequency in the NE and E directions, for the same directions the highest waves are recorded.

The considered sector is part of the Eforie-Tuzla sedimentary cell. In this sector, a divergence is created from the general direction of sediment transport (north south) generated by the southern dike of Agigea port (which stretches 11 km offshore). In the sector close to the harbour dikes, south of Lake Techirghiol barrier beach, longitudinal sediment transport is generally from south to north, due to wave refraction and the significant role of storm waves from the south. Coastal structures (such as Belona tourist port, submerged and/or perpendicular dikes) have a local impact on alluvial transport and erosion/accumulation rates (Masterplan Protection and Rehabilitation of the Coastal Zone, 2012).

Due to sector development as a tourist destination and the need to expand/protect the beaches, coastal protection works were carried out in several stages. Between 1956 and 1960, 6 groins were placed to extend the perimeter of the beach, diverting the flow of alluvium, and creating bypass currents, which led to the retreat of the shoreline (Diaconeasa, 2009). During 1981-1986, with the expansion of the Constanța port, new coastal protection measures were imposed, determined by erosion processes, made concrete by the execution of permeable submerged longitudinal dykes in addition to the transverse ones (Masterplan Protection and Rehabilitation of the Coastal Zone, 2012).

In the short term (2013-2015) within the "Coastal erosion reduction phase I" project, five priority projects were planned and carried out to reduce the risk of erosion and coastal rehabilitation: Mamaia Sud, Tomis Nord, Tomis Centru, Tomis Sud and Eforie North. The work included measures to reduce wave energy, protect the beach with dykes for sand stability and nourishment (Masterplan Protection and Rehabilitation of the Coastal Zone, 2012).

In the Eforie North sector (from Steaua de mare area to Belona port), the coastal protection works carried out consisted of (Fig. 2):

- the rehabilitation of dikes perpendicular to the shore with more than 500 m
- the construction of 3 surfaced dikes and 3 submerged dikes of the "break" type wave" parallel to the shore - 675 m
- artificial nourishment of the beach on 1.2 km, with over one million cubic meters of sand, the beach area being exapanded from 3.4 ha to 18.5 ha.

Until 2015 (when nourishment began), only Belona beach was wider and in good condition, the rest of the beaches being narrow or non-existent in some sectors (Spînu et al., 2017). The coastal erosion not only threatens the tourism industry in summer season through the loss of beach area but also endangers the safety of housing and public welfare (JICA, 2007).

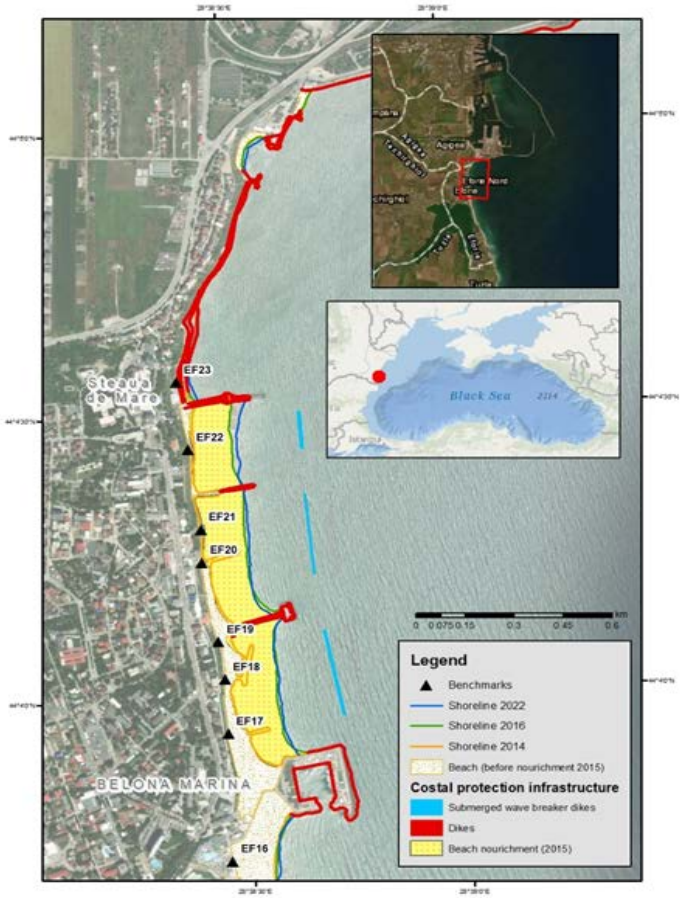

Fig. 2. Coastal protection works in Eforie North area

By analysing maps from different periods and by performing in-situ measurements, negative changes in the shoreline have been found, retreating approximately 40-50 m in the last 75-100 years. The calculated erosion rates vary in the targeted sector, on average 0.3-0.5 m/year, depending on local conditions and the presence of protection works (Spînu *et al*., 2017).

Beach profile studies give information on cyclic/seasonal morphological changes in the coastal area, being essential to identify the erosional and depositional features, which in turn help to understand changes in oceanographic processes in the coastal areas (Das Adhikari *et al.*, 2016).

Analyzing the geomorphological profiles in the Eforie North area, variations in the length profiles were determined, according to the studied period.

EF 17 profile (Fig.3) recorded a length of 44.1 m before nourishment, after nourishment completion in 2015, the width of the beach was 176.9 m. It can be observed that in 2016 after the warm season and 2018 after the cold season the phenomenon of erosion appears, unlike the year 2017 after the cold season where an accretion of 9.2m occurred, the length of the profile reaching 178.2 m.

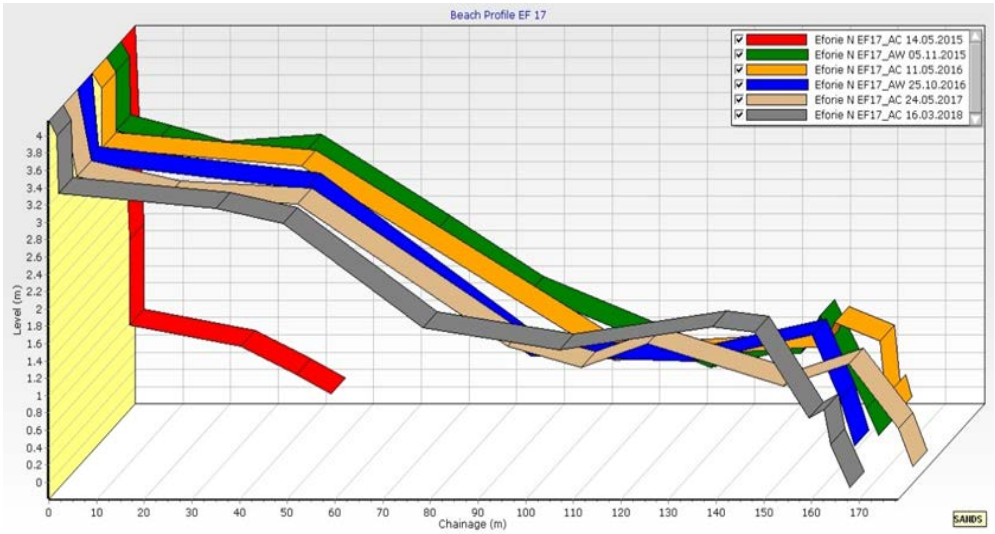

Fig. 3. Geomorphological profile EF 17 (AC -after cold season, AW- after warm season)

The beach width on EF 18 profile (Fig. 4) was initially 23.3 m, after nourishment it reached 150.3 m. In 2016, 2017 and 2018 the phenomenon of accretion appears, the maximum length of the profile (166.9 m) being recorded in 2018, after the cold season.

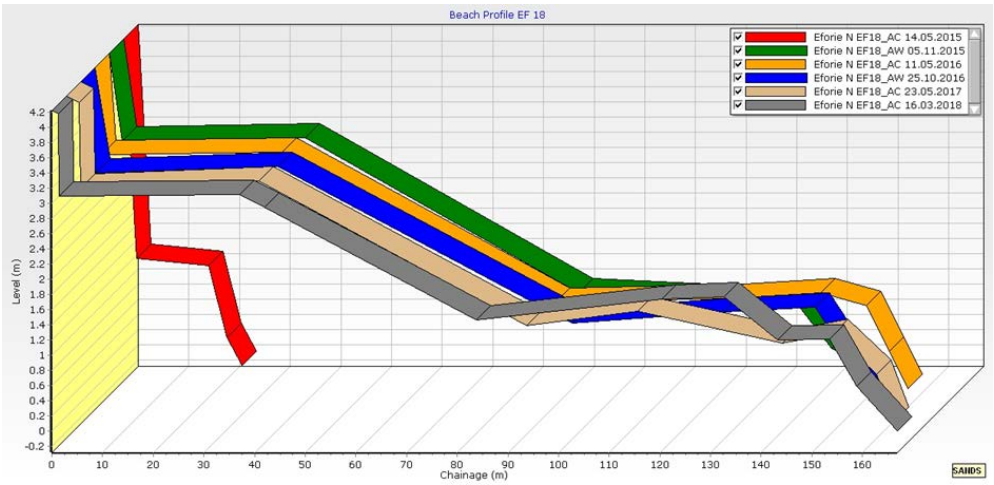

Fig. 4. Geomorphological profile EF 18 (AC -after cold season, AW- after warm season)

EF 19 profile (Fig. 5) in 2015 (before nourishment) had a length of 53.1, after nourishment it reached the maximum value of 177.6m. In 2016, after the cold season, the beach profile eroded by 6 m, reaching a length of 171.6 m. After the warm season of 2016 and the cold seasons of 2017 and 2018, the phenomenon of accretion appeared.

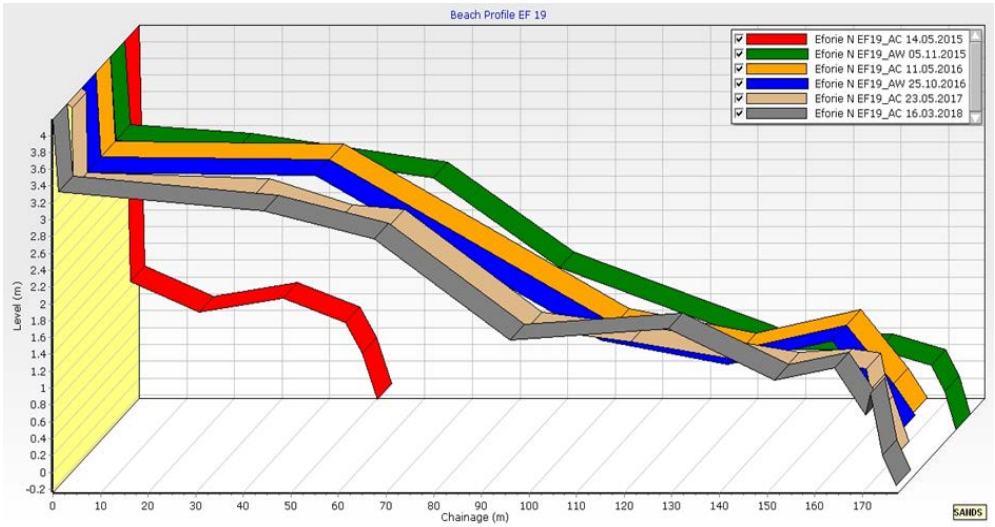

Fig. 5. Geomorphological profile EF 19 (AC -after cold season, AW- after warm season)

On EF 20 profile (Fig.6) in 2015, after cold season, a profile length of 19.3 m was determined before nourishment, recording a length of 154.3 m after nourishment. In 2016, after the cold season, it was determined a maximum erosion value of 13.6m, after the warm season a maximum accretion of 14.9m was observed.

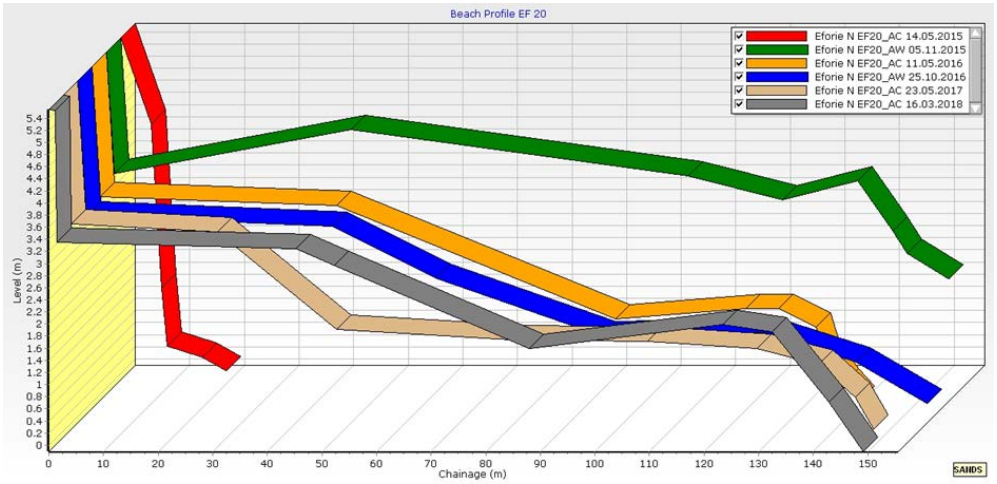

Fig. 6. Geomorphological profile EF 20 (AC -after cold season, AW- after warm season)

Beach erosion during cold season and accretion during milder summers (warm season) is a commonly recognized phenomenon (Kennedy *et al.*, 2019). The cold season of 2017 was characterized by erosion, unlike 2018, where accretion was recorded.

From a length of 8 m before nourishment, EF 21 profile (Fig. 7) reached a maximum value of 152.4 m in 2015, after nourishment. After the cold season of 2016, the erosion of the profile is observed, reaching a minimum length of 134.1 m, in 2016 after warm season and in 2017 and 2018 the accretion phenomenon being determined.

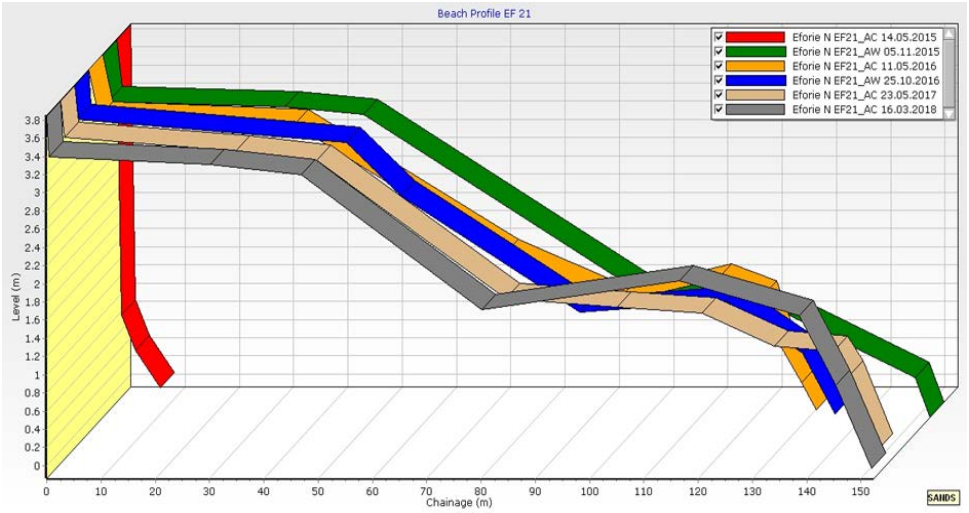

Fig. 7. Geomorphological profile EF 21 (AC -after cold season, AW- after warm season)

Starting from a length of 8.3m before nourishment, EF 22 profile (Fig. 8), reached a length of 117.7m after nourishment. In 2016 after cold and warm season and cold season of 2017, the accretion phenomenon is observed, with a maximum of 145 m, in 2018 the profile recorded erosion, reaching a length of 143.1 m.

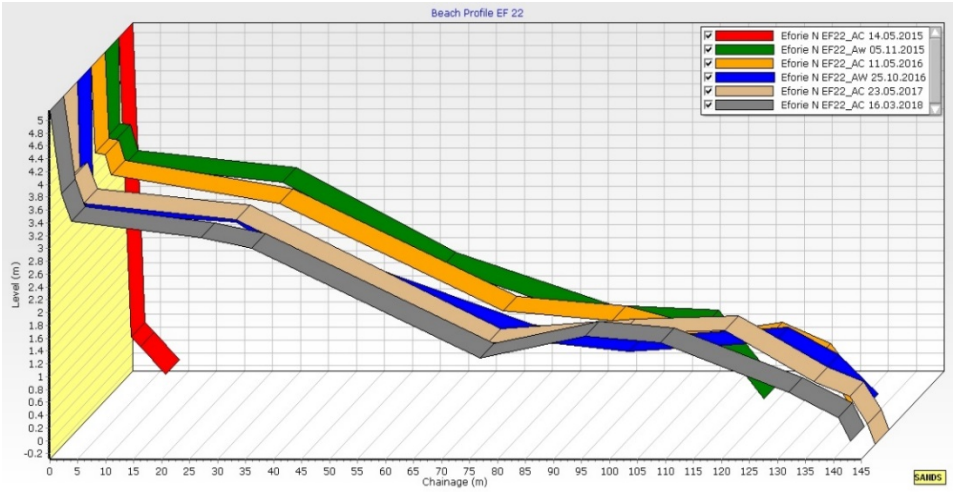

Fig. 8. Geomorphological profile EF 22 (AC -after cold season, AW- after warm season)

Analyzing the beach variation range on the EF17-EF 22 profiles, taking into consideration the period before and after nourishment, it can be observed that on EF 22,

EF 18 and EF 17 the accretion occurred, while on EF 21, EF 20 and EF 19 erosion was recorded (Fig. 9).

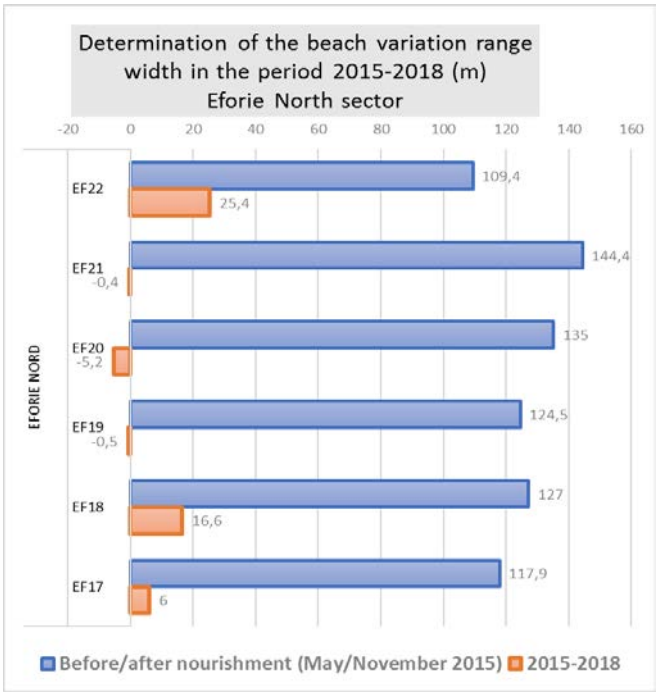

Fig. 9. Beach variation range width in Eforie North area

CONCLUSIONS

For the analysis of the beach geomorphological changes, a number of 6 geomorphological profiles (EF17-EF22), on a length of 1.2 km, and GPS measurements were made to determine the shoreline.

In 2015 - 2018, based on the comparative analysis of the profiles, the average value of the geomorphological changes regarding the width of the beach in the Eforie North sector was 134.1 m. In this beach sector, the maximum erosion value of 5.2 was determined on the EF 20 profile, the maximum accretion value of 25.4 being determined on EF 22 profile.

Even though the nourishment has only been done for 5 years (2015) and the area has been extended, the beaches are flooded during winter storms with medium intensities, showing a relative instability of the coastal protection, along with the need to maintain the natural beach profile and the installation of complementary solutions against erosion, as well as the compensation of the sediments transported to the sea with new deposits.

Seasonal changes in beach profile occur as a result of erosion during winter storms and are counteracted by benign summer conditions that can act to rebuild the beach. Monitoring shoreline behavior at regular intervals, distinguishing between cyclical and progressive change, is essential for coastal zone management.

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