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EVOLUTION OF THE BEACH ARTIFICIAL NOURISHMENTS IN THE TOMIS NORTH SECTOR, A SHORT THERM ANALYSIS (2013-2024)

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ABSTRACT

The Romanian coastline is part of the western coast of the Black Sea, extending for about 245 km, morphologically divided into two units: the northern unit, from Musura Bay to Cape Midia, with deltaic and lagoon origin, and the southern unit, from Cape Midia to Vama Veche, characterised by well-developed cliffs and wide beaches. This last coastal sector includes both accumulating coastlines (beaches) and anthropogenic features (ports and breakwaters). Constanta, the largest and most important city in Dobrogea, claims a rich history and a variety of tourist attractions, with its beaches stretching some 6 km along the coast from Tomis Marina to the entrance of Mamaia Resort. This study analyses the recent changes observed at a popular tourist beach known as Reyna Beach, located near Mamaia Resort, following the nourishment works carried out in the framework of the "Protection and Rehabilitation of the Southern Part of the Romanian Black Sea Coast" project. The project involved extensive hydrogeographic works, including the rehabilitation of piers, the construction of submerged breakwaters and beach nourishment.
This paper aims to analyse the evolution of the coastal area from a geographical perspective, including geological and geomorphological characteristics, using various data sources such as satellite images, field measurements and previous maps associated to grounding studies.
Keywords: recent shoreline changes, hydrogeographic changes, shore rehabilitation, beach nourishment

INTRODUCTION

Coastal geomorphology studies the formation and shaping of coastal features, the processes that affect them and their evolution, while coastal geology focuses on the origin and structure of rock and sedimentary formations observed in cliffs and coastal outcrops. (Bird, 2008). The balance between accretion and erosional coastal processes in relation to beach evolution is mainly determined by geological conditions and the hydrodynamic regime. Any disturbance to this balance, whether due to natural factors or human activities (Cîndescu *et al*. 2023), can lead to changes in the coastal system and trigger intensified erosion or deposition processes.

Following the extension of inland hydrotechnical works by the Romanian state after 1970, the Romanian coast has been continuously degraded over the last 50 years due to intense erosion processes (Spătaru, 1993; Tănase *et al*, 1992). Subsequently, in 2011 the National Administration of Romanian Waters (ABADL) initiated a Master Plan for the "Protection and Rehabilitation of the Coastal Zone" (Masterplan, 2012). The aim was to improve the quality of the environment, increase safety in the Southern Coastal Unit, rehabilitate and protect the coastal adjacent areas and marine ecosystems. Since 2013, an intensive coastal protection programme has been gradually implemented in the Southern Romanian Coastal Unit. In the area of Constanta city, several coastal arrangements were made, involving artificial replenishment of beach sediments, simultaneously implementing heavy protection solutions, submerged breakwaters and groins. After the implementation stage, the beach surface balance shows a relatively stable report of the deposition/erosion processes of the newly created beach surfaces.

In addition to the direct influence of the marine regime, the adjustment of its action by the local and regional sedimentary unbalance situation is highlighted, as well as the influence of the hydrotechnical system on the artificially created emerged and submerged beach (Fig 1). Thus, the strong sedimentary input and the local redistribution induced by the design of the protection systems, including the longitudinal breakwater inserts, are responsible for the shoreline changes and the stability of the submerged beach surfaces for several sub-sectors of Constanta, the old city of Tomis. As part of the coastal protection measures, the beaches afferent to the Constanta City were divided into three lots: Tomis North, Tomis Centre and Tomis South. The Tomis North sector was chosen as a study case for the monitoring and analysis of the coastal protection performance, being the most significantly rehabilitated sub-sector.

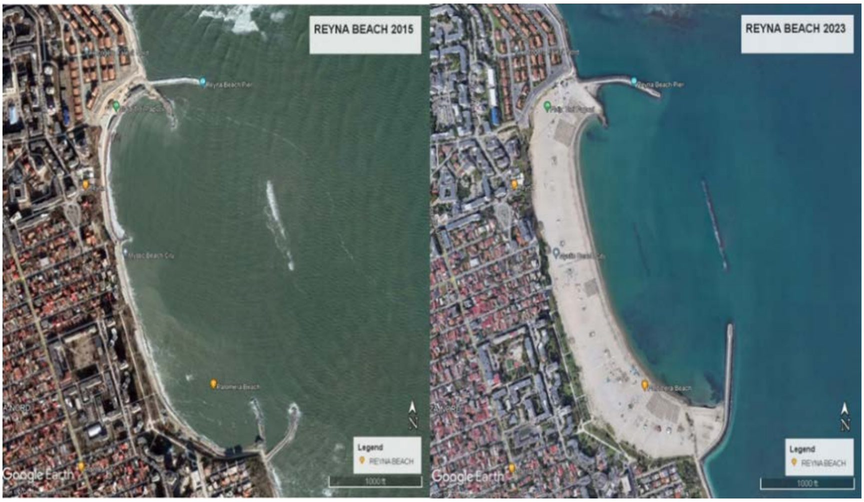


Fig. 1. Comparative images of Tomis North beach, before (2015) and after nourishment (2023) (source: Google Earth Pro)

MATERIALS AND METHODS

In order to quantify the evolution of the coastline during the coastal protection works, in-situ measurement campaigns were carried out to identify changes in shoreline dynamics and beach profile. High precision geodetic and topographic instruments were used to measure the beach profile and changes in the coastline: Leica Viva GNSS GS08 and Leica Zeno 20 GPS (RTK measurements with corrections from the ROMPOS network), dedicated software for aerial photography (DJI Go, Agisoft) and beach/coastal profile analysis (ArcGIS, CEDAS BMAP module). Four geomorphological beach profiles (CT12-CT15) were analyzed (Fig. 2) to highlight the landforms and their inflections from the reference point to the swash zone, taking into account the dune crests and bases, the beach front, the storm wave run-up limit and the wave advance and retreat limit.

In a coastal sector characterized by intensive beach nourishment, the dynamics of the coastline is a key indicator of stability. Two GPS measurement campaigns were carried out annually along the shoreline to monitor and analyze its evolution over a short period of time (Fig. 3 and Fig. 4).

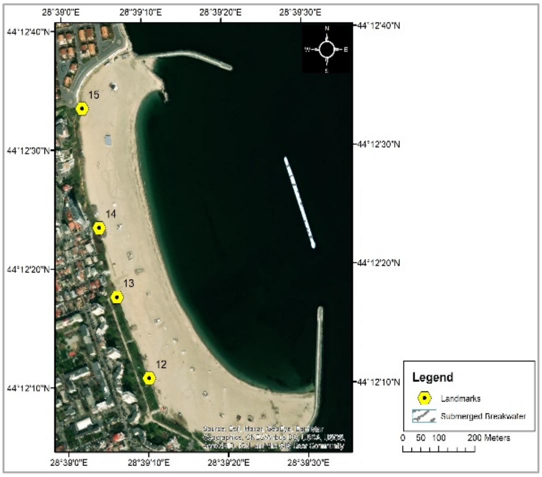


Fig. 2. Tomis North beach profile landmarks

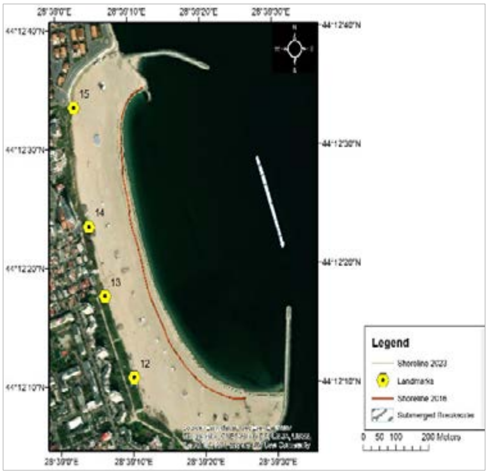


Fig. 3. In-situ measurements of shoreline variation between 2016 and 2023

Fig. 4. Wave retreat limit of the CT13 profile (GPS measurement)

Several GIS functions related to satellite optical imagery data, as well as bathymetry data, were used to extract and analyze information for over a decade (2013-2024) for the area of interest, bounded by shorelines, old and new coastal facilities and arrangements.

RESULTS AND DISCUSSIONS

The energy to shape the coastline through sediment transport, erosion and deposition is given by the interactive action of the environmental factors (wind, waves, storm surges and coastal current dynamics). Since the 1960s and 1970s, the anthropogenic factor has played a significant role in reducing sediment input through the construction of dams along the Danube and its tributaries. In addition, sediment transport has been hindered by the coastal structures associated with Romania's main seaports, Midia and Constanta. The jetties of the Sulina navigation channel retain almost 70% of the sediments transported by the Danube. These sediments are discharged at a certain distance from the shore, about 2 nautical miles. In 2015, the coastal zone rehabilitation program within the project "Protection and rehabilitation of the southern part of the Romanian Black Sea coast in the area of Constanta and Eforie North, Constanta County", financed by the Environment Sectoral Operational Program, was completed. As a result, 7.3 km of coastline were rehabilitated in the areas of Mamaia South, Tomis North, Tomis Central, Tomis South and Eforie North (Master Plan, 2012).

The Tomis North sub-sector has a length of 1.4 km. The beach protection and restoration measures carried out in 2015 included the construction of two groins, a submerged breakwater and sand nourishment of the beach, calculated for a period of 50 years, with an expected beach area of approximately 20 ha and a width of 150 m, Fig. 5(a) and 5(b), respectively. In the process of redistribution of sedimentary deposits in the post-construction phase, there was also an expected withdrawal of the shoreline (Table 1), more intense in the first two years, but after the execution, it was registered a relative stabilization of the processes on an area of 17.9 ha, with the need to separate the net change from the variation.

Fig. 5(a) and **5 (b).** Tomis North Sector before and after coastal protection works (winter 2014 - spring 2015)

The bay adjacent to the Tomis North beach cell is flanked by lateral groins and a submerged breakwater located 555 m from the R13 benchmark profile (approximately 407 m from the shoreline). Thus, the sand nourishment extends over 100 m for the exposed beach and 400 m for the submerged beach.

Following the sand nourishment in 2015, the measurements carried out in 2024 revealed a new beach area of approximately 179600 square meters. This area, located outside the pre-defined transects planned to be measured, was observed and attributed to the effective operation of the coastal protection system designed to trap and retain sediment within the beach cell (Bădoiu *et al.*, 2022). Between November 2015 and April 2023, based on the comparative analysis of beach profiles, the average geomorphological change in beach width in the Tomis North sector was 12.8 m. Only accretion was detected, with values ranging from 3.7 m (CT14 profile) to 18.4 m (CT12 profile). The analysis shows a trend of natural stabilization towards an equilibrium profile with relatively stable sections (Table 1).

Table 1. Beach width variation in sector Tomis North between 2015 - 2023 (L-landmark, WRL-wave retreat limit)

Profile	Date	Distance L-WRL(m)	Date	Distance L-WRL(m)	Variation(m)
CT12	11.11.2015	153.8	20.04.2023	172.2	18.4
CT13	11.11.2015	130.2	20.04.2023	147.9	17.7
CT14	11.11.2015	147.2	20.04.2023	143.5	3.7
CT15	11.11.2015	158.8	20.04.2023	147.5	11.3

The beach profiles were measured using National Institute for Marine Research and Development (NIMRD) type topographic landmarks to highlight changes in the geomorphological characteristics of the developing afferent beaches. Starting from the landmark (Fig. 6(a) and 6(b)), the profiles followed the relief features of the emergent beach to the wave retreat limit (Fig. 7) and 0.5 m depth.

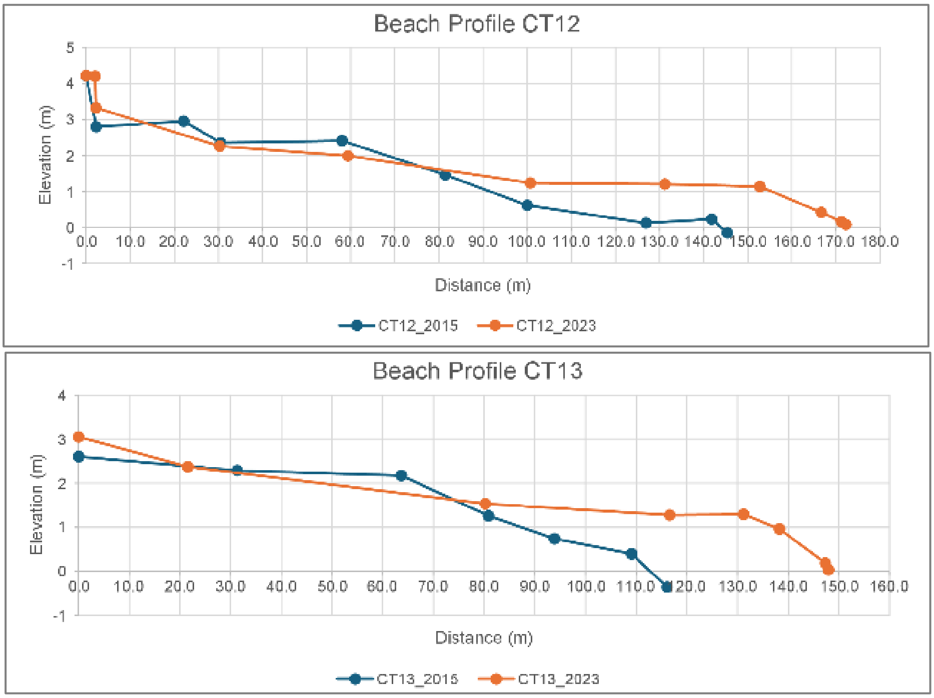
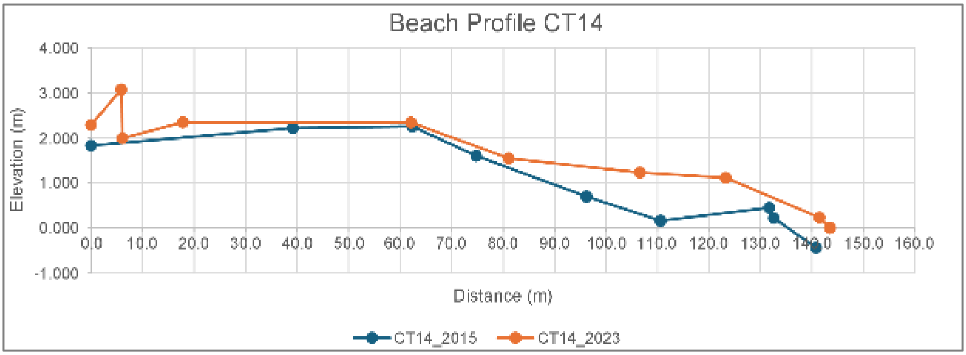


Fig. 6 (a). Evolution of geomorphological beach profiles CT12 and CT13 measured between 2015 and 2023



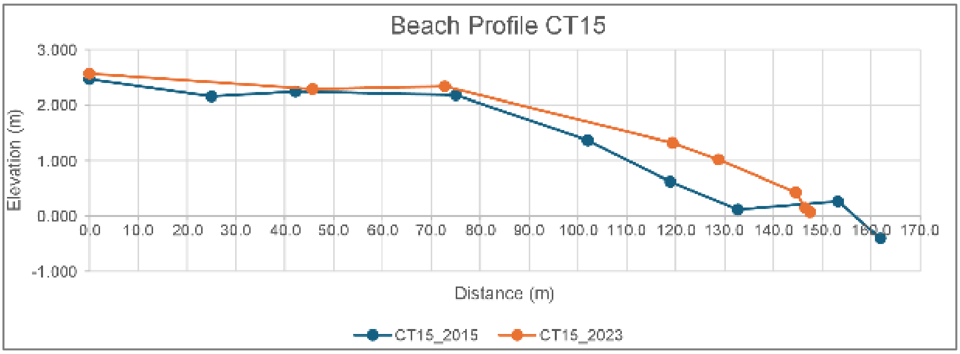


Fig. 6 (b). Evolution of geomorphological beach profiles CT14 and CT15 measured between 2015 and 2023

The transformation of the submerged beach was assessed based on bathymetric profiles mapped and analyzed in the BMAP software, as well as based on bathymetric measurements taken in 2013, 2023 and 2024. The field measurements were carried out in the more exposed, southern part of the submerged beach area to assess the influence of waves and currents on the solid seabed and the influence of the submerged breakwater and groin system on isobath dynamics. The comparative analysis of the bathymetric data during the period 2013 - 2024 (Fig. 7), highlights an asymmetric evolution of the shoreline, reduced in magnitude, with an equilibrium point in the case of the P15/norther landmark, where it remained relatively stable. Although the -1 m, -2 m, -3 m isobaths were extended seaward, the -4 m and -5 m isobaths remained relatively in the same position, with a small shoreward translation of them in the southern part of artificially created cell sedimentation.

Thus, the isobaths of - 5 m and - 6 m advanced towards the shore by 75 meters and 90 meters, respectively, highlighting an erosion of the solid seabed in the corridor between the submerged breakwater and the southern groin, but also in the shadow of the submerged dike, as well as a parabolic development of the sandy submerged beach.

The comparative analysis of the bathymetric variations between the years 2013 and 2024 shows that in the central part, from the land side, of the longitudinal dyke, the submerged beach has been stabilized, given the specific hydrodynamic conditions of a pocket beach.

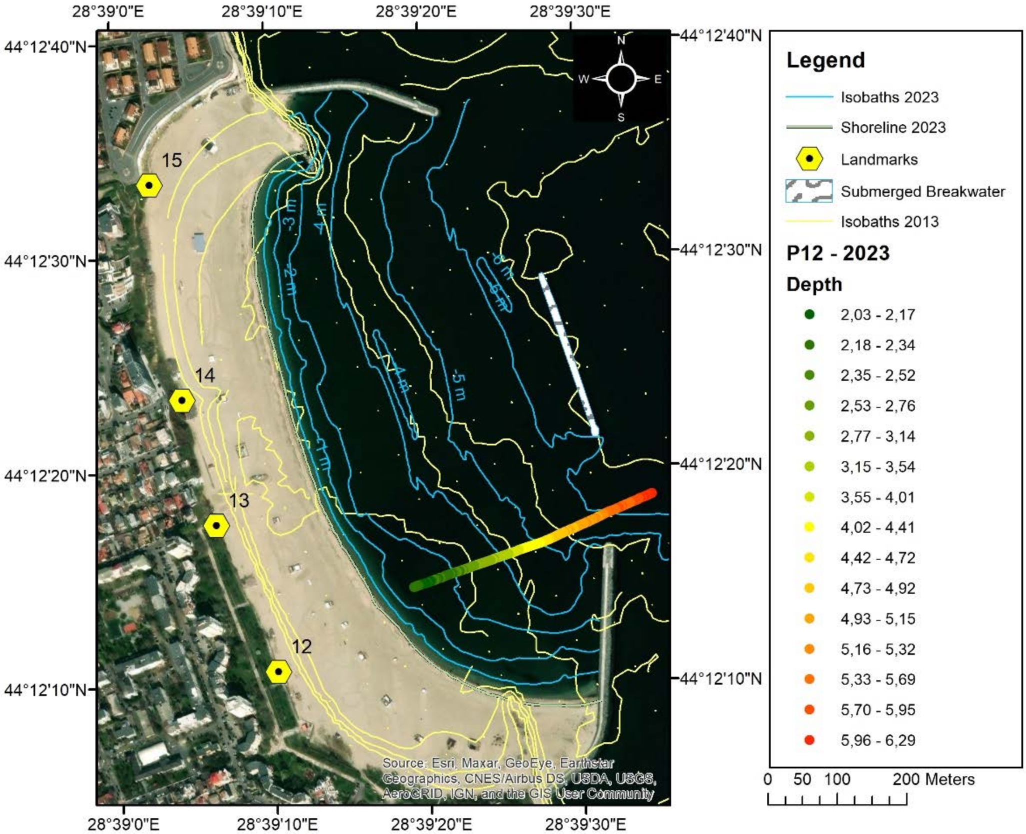


Fig. 7. The comparative situations regarding the changes of the submerged beach - bathymetric map of the Tomis North protected sector (data obtained by ABADL curtesy)

However, the displacement of the 6 m isobath towards the coast is a worrying fact, revealing, in addition to a local asymmetry of wave exposure and sediment distribution, as well the continuation of sectoral erosive processes, specific to the transitional marine coastal zone. On the vertical dimension of the cross-sections, after the initial nourishment, the reshaping process moves to a new equilibrium profile, which is subject to small changes over time as a result of the balance between the erosive and constructive forces acting on the slope of the submerged beach profiles. In the most active part, the southern part of the artificial beach, the submerged profiles in cross-section 12 (afferent to 12 landmark/note P12) show the seaward extension of the beach and the redistribution processes in the shallow water area.

Therefore, in addition to the comparison of the measured profiles (Fig. 8), the calculation of the volumes associated with the positive and negative transversal surfaces between the two selected profiles is also emphasized (Table 2), under the hypothesis that the transversal transport of sediments, associated with erosion and/or redistribution processes, has induced the change in the beach cross-section in the specified spatial interval, for the last geomorphological annual cycle.

Table 2. The calculation of the positive and negative changes produced on the two successive profiles of 2023-2024

Cell #	Ending Distance (m)	Ending Elevation (m)	Cell Volume (cu. m/m)	Cell Thickness (m)	Cumulative Volume (cu. m/m)	Gross Volume (cu. m/m)
1	1.25	4.2	-0.004	0	-0.004	0.004
2	88.12	1.47	6.995	0.08	6.991	7
3	149.28	1.15	-7.867	-0.13	-0.876	14.867
4	165.63	0.47	1.08	0.07	0.204	15.947
5	168.3	0.32	-0.032	-0.01	0.172	15.979
6	528.37	-6	160.904	0.45	161.076	176.883

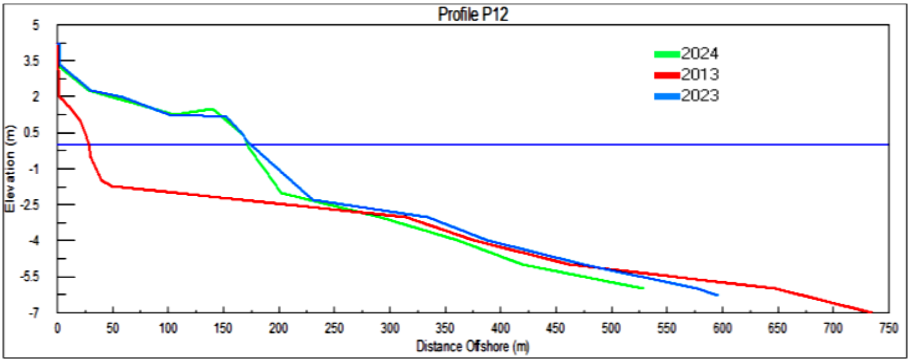


Fig. 8 Beach profiles in the exposed and submerged cross-sections of P12 at three-time horizons: 2013, 2023 and 2024 (southern part of the Tomis North sector)

For the cross-section P12, an intense rate of redistribution of sediment input is highlighted both in the emerged part, from beach volume of 37.15 m^3/m (in 2013) to a volume of 290.58 m^3/m (in 2023) and respectively 290.05 m^3/m (in 2024), but also in the submerged part, for the area delineated by the submerged breakwater, XOff(590m), and the shoreline position after sand nourishment, XOn(173m), where the redistribution started from a volume of 837.87 m^3/m (in 2013) to a volume of 942.71 m^3/m (in 2023), after a decade from replenishment. In order to determine the current net change after almost a decade of sand nourishment, the BMAP software's cut and fill function shows a volume change of more than 0.53 m^3/m, above Datum, and 160.54 m^3/m, below Datum, a total volume of 161.07 m^3/m, for a shoreline change of 2.53 m, from 174.19 m (2023) to 171.66 m (2024), (Fig.9).

Despite an average grain size of 0.04 cm of the borrowed sediment, for cross-section P12, the calculated equilibrium profile shaping the actual slope of the submerged profile is associated with a predominance of the 0.08 cm grain size on a submerged beach, showing the potential for future changes in the nourished area and the existence of an adjacent limestone submerged plate with complex bathymetry in the vicinity of the new artificial coastal arrangements of the Tomis North area (Fig. 10). Sediment transport is defined as the movement of sediment material induced by various hydrodynamic processes (wind, waves, currents).

In the marine coastal area, outside the surf zone, sediment transport is concentrated in a layer above the seabed, mostly as bedload transport (rolling of material), closely associated with the formation of small waves or submerged bars and dunes parallel to the wave crests (Shore Protection Manual, 1984).

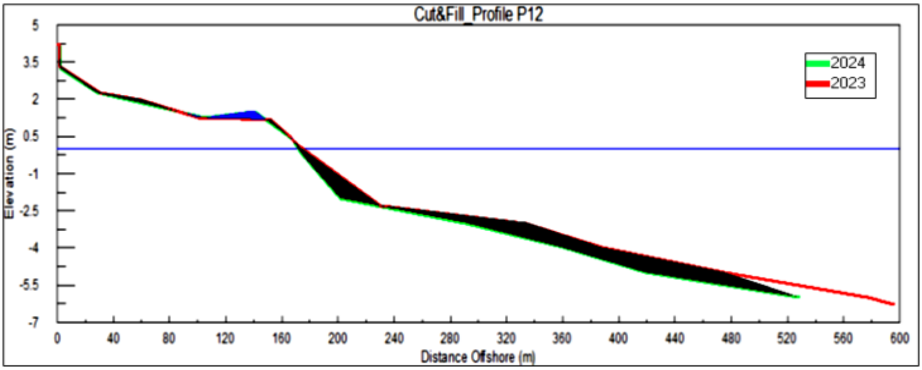


Fig. 9. The sediment redistribution emphasized in the cuts and fills of the profile P12 between 2023 and 2024

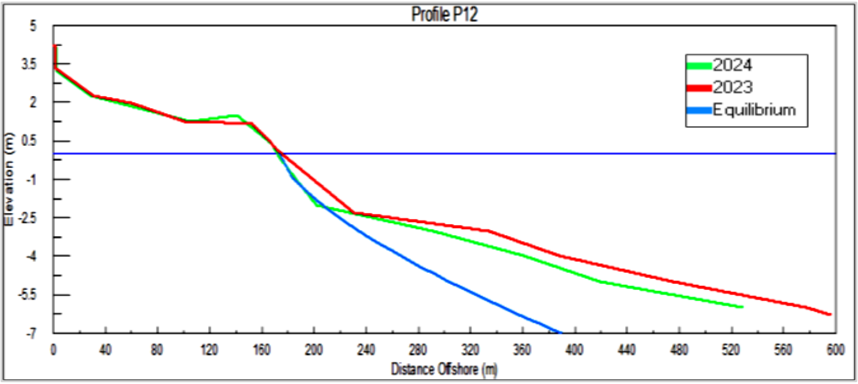


Fig 10. Equilibrium profile of the submerged beach profile P12

In the surf zone, sediment transport is dominated by waves and wave-induced currents acting along and perpendicular to the shore. Wave breaking processes can mobilize large amounts of sand that can be transported in suspension by currents (Kraus, 2019).

A series of four sediment samples were collected from CT13 beach profile in the summer of 2017, at the top, middle and water's edge, and at a depth of 1 meter. Sediment analyses were performed to determine grain size using standard dry sieving techniques (Anastasiu & Jipa, 1983; Jipa, 1987), with classification between coarser and finer particles based on the Wentworth scale (Marin *et al.*, 2022).

Fine and very fine grey mineral sands composed of angular bioclasts and corbules were found along the profile. On the upper beach, dimensions ranged from 2.5 cm to 0.04 cm (11.7%) and dominated by minerals (88.3%). The middle beach showed the same characteristics and types of shells with slight differences in size, with a percentage of 31.8% angular bioclasts between 6.3 cm and 0.4 cm and 68.2% minerals. Rolled bioclasts formed by wave action were observed at the water's edge, with sizes ranging from 5.0 cm to 0.4 cm (21.8%) and a mineral content of 78.2%. In the sample taken from 1 m depth, in addition to angular and rolled bioclasts, bivalves (36.4%) and minerals (63.6%) were found. Thus, the dominance of fine and very fine mineral sands with sizes less than 0.04 cm, with an average percentage of 74.6%, can be highlighted from the data collected. As it was expected during the design phase of the coastal restoration project, the distribution of the sediments is more pronounced at the northern and southern ends, especially in the southern part, resulting in an overall convex shape of the coastline.

CONCLUSIONS

The study on the evolution of the coastal area in the Tomis North sector shows that the coastal protection and restoration actions completed in 2015 were significantly successful in restoring the stability and width of Tomis North beach. By 2023, the effectiveness of the sand nourishment works and the protective structures, such as the breakwaters, will have increased the beach area by approximately 160 000 square meters.

The geomorphological profiles (CT12-CT15) show a positive accumulation, with an average increase in beach width of 12.8 m between 2015 and 2023. The most significant changes were observed in profile CT12, with an increase of 18.4 m, demonstrating the effectiveness of the interventions in certain areas. Sediment analysis from different points along the beach profile showed a dominance of fine and very fine mineral sands. The grain size distribution showed variations in different areas of the beach, with higher concentrations of angular bioclasts and minerals near the water's edge and at increasing depths.

Hydrodynamic processes, including asymmetric wave exposure and current action, play a crucial role in shaping the beach profile and influencing sediment transport in Tomis North sub-sector, where the introduction of hydraulic structures has altered these natural processes, increased sediment retention and reduced erosion.

Significantly, timescales of the bathymetric data changes at the Tomis North coast show a specific evolution to a pocket beach on decadal time interval. These investigations in the submerged part of the area illustrate its relative stability and normal post-construction induced coastline changes, as well as the decompensation potential for the times who comes of 50 years designed coastal beach.

Continuous monitoring and adaptive management are needed to maintain the positive trends observed. Future studies could focus on the long-term sustainability of protection measures and the need for additional interventions based on evolving environmental conditions. These conclusions underline the importance of integrated coastal zone management and the need for continued efforts to conserve and enhance the coastal environment.

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