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SHORELINE SEDIMENT CHANGES INDUCED BY COASTAL PROTECTION WORKS ON THE SOUTHERN ROMANIAN COAST

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Abstract. This study examines sedimentary changes along the Romanian Black Sea coast following coastal protection and beach nourishment works carried out between 2013 and 2023. The research focuses on three sectors—Mamaia, Constanța, and Eforie—comparing data collected before and after the interventions. Sediment samples, retrieved from standardized profiles and stored in the INCDM archive, were analyzed granulometrically using Retsch A200 and Fritsch Analysette 22 NanoTec equipment. Results were processed with the Gradistat v8 software and integrated into maps produced in ArcGIS. The findings highlight clear differences among the sectors. In Mamaia, sediment composition shifted from fine and very fine sand (approx. 69% fine and very fine sand in 2017) to predominantly coarse and medium sand (approx. 45% fine and very fine sand in 2021). Moreover, a significant increase in mean grain size (from 0.13–0.35 mm to 0.6–1.24 mm) was observed. In Constanța, changes were moderate, with the appearance of medium and fine fractions alongside coarse sand. In Eforie, north of Belona port, the sediment structure remained relatively stable, with notable changes occurring only locally at a 1 m depth, while at south of Belona port, the sediment had a increase in mean size. These results highlight the direct influence of beach nourishment and coastal protection structures on the granulometric characteristics of tourist beaches, while also emphasizing the variability of sedimentary response depending on the specific conditions of each sector.
Keywords: Romanian coast, beach nourishment, coastal protection, granulometry, sediment dynamics

1. INTRODUCTION

Coastal erosion has emerged as a critical issue worldwide, as highlighted by various studies. One of the key contributing factors is climate change, which leads to rising sea levels and intensifies shoreline erosion. Each year, the loss of coastal land from sediment transport escalates, threatening coastal cities and vulnerable coral islands (Ortega et al., 2023; Parvathy et al., 2023; Lim et al., 2025). Additionally, wave deformation resulting from coastal structures significantly impacts longshore sediment transport, altering the shoreline's configuration (Lim et al., 2021; Lim et al., 2025). A considerable body of research has examined the dynamics of sediment transport in coastal regions affected by wave action, and theoretical models have been devised to enhance our understanding of coastal erosion processes.

Understanding these processes is crucial, particularly as coastal systems act as dynamic transition zones between land and sea, influenced by intricate interactions between natural processes and human activities (Woodroffe et al., 2023).* The evolution of coastal morphology is directed by a combination of hydrodynamic forces, including waves, tides, and currents, alongside sediment availability, transport mechanisms, geological influences, and climate-related factors such as sea-level rise (Karsli et al., 2011; King et al., 2019; Creane et al., 2022; Lakku et al., 2024). In addition to these natural factors, human interventions—such as coastal urbanization, the construction of ports and harbors, and shoreline protection measures—can disrupt sediment budgets and alter the natural equilibrium of coastal environments (Ismail & Erüz, 2023; Biondo et al., 2020; Todd et al., 2019). To effectively manage coastal areas, mitigate hazards, and develop appropriate climate adaptation strategies, it is essential to achieve a thorough understanding of how both natural and anthropogenic factors interact to influence spatial and temporal variations in coastal morphology (Islam et al., 2025).

In the context of these challenges, the analysis of sedimentary changes along the Romanian coastline becomes particularly relevant. This analysis was carried out by comparing the composition and sedimentary structure of samples collected before the beach nourishment works performed as part of coastal protection measures, and those collected after nourishment. Within the project "Protection and Rehabilitation of the Southern Part of the Romanian Black Sea Coast," works were planned and executed in two phases. In the present paper, the changes occurring in the shoreline sectors of Mamaia, Constanta, and Eforie were selected for analysis for the period 2014–2021 (before and after the implementation of coastal protection works). For this period, sediment samples from the NIMRD (National Institute for Marine Research-Development "Grigore Antipa") archive were analyzed, collected along the profiles associated with the RMRI/NIMRD benchmark network.

This study explores how the beaches along the southern Romanian Black Sea coast have changed as a result of coastal protection and beach nourishment works carried out between 2013 and 2023, focusing on the Mamaia, Constanța, and Eforie sectors. By looking at sediment samples collected before and after these interventions, we aim to understand how engineered structures like groins and breakwaters influence the composition and distribution of beach sediments. Combining granulometric analysis with mapping and spatial assessment allows us to see not only how sediment size and texture change over time, but also how these changes vary from one sector to another. The insights gained from this research can help guide future coastal management decisions and improve strategies for protecting and maintaining Romania's valuable tourist beaches.

2. MATERIAL AND METHODS

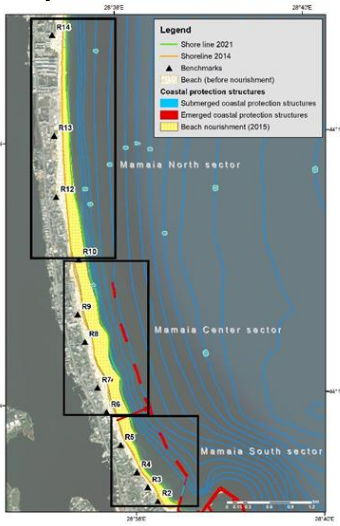
In 2014, the National Institute for Marine Research and Development (INCDM) established a coastal benchmark network aimed at monitoring and evaluating geomorphological changes of the beaches, in the context of short-term coastal protection measures implemented along the southern Romanian coast, specifically in the areas of Mamaia South, Constanta, and Eforie North. These interventions comprised a range of engineering solutions designed to mitigate wave energy and shoreline erosion, including beach nourishment works, the construction of sand-stabilizing groins, the repair of existing breakwaters, and the development of shore-perpendicular groins (spurs).

To assess the impact of these coastal protection measures, data from multiple field sampling campaigns archived in the INCDM database for the Mamaia, Constanta, and Eforie sectors were analyzed. Sediment samples collected from these areas were processed using both a Retsch A200 vibrating sieve shaker and a Fritsch ANALYSETTE 22 NanoTec laser particle size analyzer. The resulting granulometric data were further interpreted using specialized software tools (Gradistat v8 and MaS Control), while spatial analyses and cartographic representations were generated using ArcGIS 10.x.

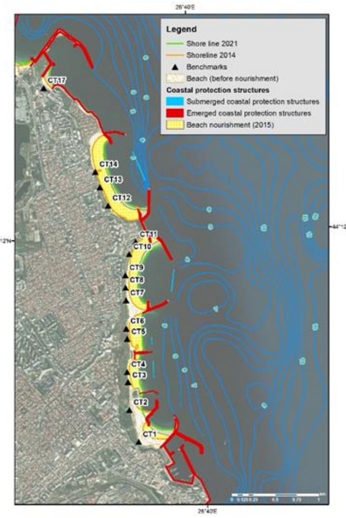
The implementation of coastal protection works was carried out in two main phases. Phase I (2013–2015) focused on reducing erosion risk and achieving coastal rehabilitation along a 7.1 km stretch of shoreline in the Mamaia South, Constanta, and Eforie North sectors. As a result of the beach nourishment activities, a newly formed beach area of approximately 33.7 ha was obtained (Figure 1). Subsequently, Phase II (2015–2023) extended the rehabilitation efforts to additional sectors, including Mamaia Central and North (covering 5.5 km of shoreline), as well as Eforie South and Central, where transversal and longitudinal groins were constructed and beach nourishment was carried out over approximately 4 km of coastline (Figure 1).

In order to evaluate sedimentological changes induced by these interventions, sediment samples collected before and after the implementation of the coastal protection works were analyzed using two types of laboratory equipment (Retsch A100 and Fritsch ANALYSETTE 22 NanoTec). The granulometric datasets were processed using the Gradistat v8 script and subsequently represented in the form of comparative charts and tables, allowing for a detailed assessment of sediment size distribution and variability.

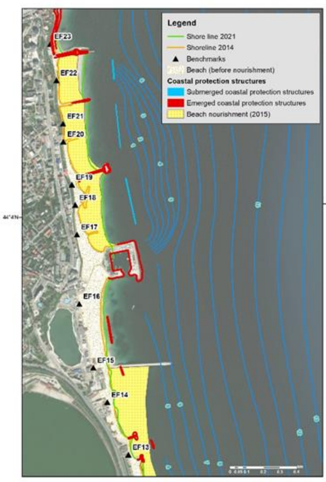
Complementary to the sedimentological analyses, a post-summer measurement campaign of the emerged shoreline morphology was conducted between November and December along the southern sector of the Romanian coast. This campaign involved the acquisition of 65 geomorphological profiles of the emerged beach, based on the IRDM/INCDM benchmark network, covering the sectors Vama Veche, 2 Mai, Mangalia, Saturn, Venus, Neptun, Olimp, Costinesti, Tuzla, Eforie South, Eforie North, Constanta, Mamaia, and Corbu. These measurements were further complemented by GPS shoreline surveys, aerial imagery analysis, and additional sediment sampling, providing an integrated dataset for evaluating shoreline evolution and the effectiveness of the implemented coastal protection measures.



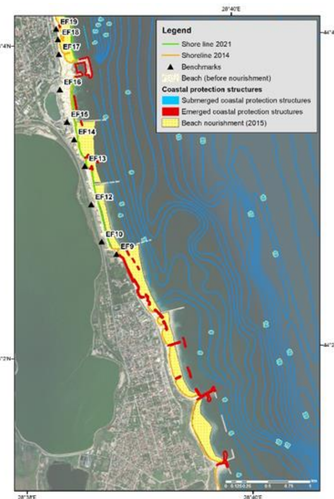
a) Mamaia



b) Constanta



c) Eforie Nord



d) Eforie Sud

Figure 1. Shoreline changes (2014-2023)

3. RESULTS AND DISCUSSION

On the Romanian Black Sea coast, sediments generally originate from three main sources (Diaconeasa, 2009):

- Terrigenous source – representing the solid discharge of rivers flowing into the northwestern Black Sea, composed mainly of sands, silts, and clays. The sands are typically grey in color and consist of quartz fragments, micas, heavy minerals etc.
- Biogenic source – generated by the fragmentation of mollusk shells. Mollusks, and especially bivalves, represent the most important group of sediment-producing organisms, contributing to the formation of the $CaCO_3$ organic fraction in the unconsolidated sediments of the Black Sea continental shelf.
- Residual source – generating accumulations of pebbles and coarse sands, mainly derived from marine abrasion and erosion of the hard substrate, represented by Sarmatian limestone plateau, particularly along the southern sector of the Romanian coast.

A comparative granulometric analysis was conducted for three sectors of the southern Romanian coastline: Mamaia, Constanța, and Eforie.

The borrow area for the dredging of sediment deposits, subsequently used for beach nourishment in these sectors, is located within Romanian territorial waters at depths of 20–30 m, covering a surface of 2.84 km² on the circalittoral shelf. According to the Environmental Agreement for the project *"Borrow Areas for the Relocation of Sedimentary Deposits (Sand) – Located in the Territorial Waters of the Black Sea"*, the total extracted volume of sediments was approximately 3,650,000 m³, consisting mainly of sands mixed with bivalve shells.

3.1 Mamaia Sector

This sector has a total length of about 7 km (excluding the Năvodari area) and, from a geomorphological perspective, represents the sandy barrier that closes off Lake Siutghiol. Beach nourishment works were carried out in three subsectors (Mamaia North, Mamaia Central, and Mamaia South) during different time intervals (2015 and 2020).
Prior to the coastal protection works, erosional processes significantly affected both the emerged and submerged shoreline, leading to a gradual narrowing of the beach. In some areas, during winter storms, the beach was completely flooded (Figure 2).

Figure 2. R10 profile before and after the nourishment

For the Mamaia North and Central subsectors, a total of 32 sediment samples were collected (16 in 2017 and 16 in 2021) along four beach profiles (R6, R10, R13, and R14) (Diaconeasa, 2014). Granulometric analysis was performed to determine grain-size distribution using the standard dry sieving technique (Anastasiu, 1983; Jipa, 1987). The resulting data were statistically processed according to the Folk and Ward (1957) method, allowing the determination of mean grain size, sorting, skewness, and kurtosis (Blott, 2001). The classification of coarse and fine fractions was based on the Wentworth scale (1922).

The sandy formation from Mamaia Beach is relatively recent (Caraivan, 1982), formed primarily from terrigenous sediments transported along a north–south axis, and secondarily from biogenic sediments transported transversally toward the shore.

In the shallow coastal zone, wave dynamics are influenced by the local geomorphology of the shoreline, the submarine relief, and existing marine and coastal structures. With the implementation of coastal protection works, including the construction of new structures, both wave and current regimes were altered. These interventions also indirectly affected sediment transport processes. In coastal waters, sediment transport is strongly controlled by high-frequency waves that generate oscillatory motion acting on sediment particles. These waves act as an "agitator," dislodging sediment grains, which are subsequently transported by coastal currents.

In the backshore zone (upper and middle beach), the sediment composition in 2017 was dominated by fine and very fine sands, accounting for 69.3% on average, with values ranging from 49.9% (R13) to 95.5% (R14). The fine sand fraction represented, on average, 53.3% of the total, with variations between 40.5% and 68%. Very fine sands accounted for an average of 15.8%, with values ranging from 6.9% (R10) to 28.5% (R14).

Mean grain size ranged between 0.13 mm and 0.35 mm. Sorting varied from poor to very well sorted across the four analyzed profiles. The sedimentary deposits generally displayed a coarse distribution, with kurtosis values most frequently mesokurtic in the southern profiles, while in the northern profiles they ranged from leptokurtic to mesokurtic and platycurtic.

Table 1. Variation of granulometric parameters along profile R14 (2017-2021)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
R14 2017	Bsh-up	Fine	0.26	Weak	Very coarse	Mesokurtic
	Bsh-c	Fine	0.13	Very good	Simetrical	Leptokurtic
	Sw	Medium	0,32	Weak	Very coarse	Very platykurtic
	H = -1m	Fine	0,15	Good	Very coarse	Very platykurtic
R14 2021	Bsh-up	Medium	0,60	Weak	Very coarse	Mesokurtic
	Bsh-c	Coarse	0,92	Weak	Very coarse	Platykurtic
	Sw	Coarse	1,24	Very weak	Simetrical	Very platykurtic
	H = -1m	Medium	0,54	Weak	Very coarse	Very leptokurtic

After beach nourishment in 2021, the fine and very fine sand fractions accounted for an average of 44.7% of the total sand, ranging from 31.8% (R10) to 65.5% (R14). Fine sand represented, on average, 38.95%, with values varying between 27.9% and 52%. The very fine sand fraction averaged 5.82%, ranging from 1.8% (R6) to 13.5% (R14).

Mean grain size showed a wide variability, ranging from 0.6 mm to 1.02 mm. Sorting was generally poor across all four beach profiles. The sedimentary deposits were typically characterized by very coarse skewness (R14, R13, R6) and coarse skewness (R10), with kurtosis values most frequently mesokurtic and platykurtic.

Table 2. Variation of granulometric parameters along profile R13 (2017-2021)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
R13 2017	Bsh-up	Fine	0,18	Moderate	Very coarse	Very leptokurtic
	Bsh-c	Medium	0,35	Weak	Very coarse	Platykurtic
	Sw	Medium	0,39	Weak	Simetrical	Very leptokurtic
	H = -1m	Fine	0,14	Good	Very coarse	Very leptokurtic
R13 2021	Bsh-up	Coarse	0,7	Weak	Very coarse	Mesokurtic
	Bsh-c	Coarse	0,84	Weak	Very coarse	Platykurtic
	Sw	Coarse	0,83	Weak	Coarse	Platykurtic
	H = -1m	Coarse	1,22	Weak	Very coarse	Platykurtic

For the swash zone samples, the accumulated sediment deposits were classified as medium sand in 2017, and as medium to coarse sand in 2021, following the nourishment works. Mean grain size ranged from 0.31 mm to 0.39 mm in 2017, while after nourishment it increased, ranging between 0.67 mm and 1.24 mm. Sorting was predominantly poor both before and after nourishment, with a single change at profile R14, which shifted from poorly sorted to very poorly sorted. Skewness in both periods ranged from very coarse to symmetrical, while kurtosis was largely very platykurtic in the 2017 samples and platykurtic in those collected after nourishment.

Table 3. Variation of granulometric parameters along profile R10 (2017-2021)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
R10 2017	Bsh-up	Fine	0,22	Weak	Very coarse	Leptokurtic
	Bsh-c	Medium	0,26	Weak	Very coarse	Mesokurtic
	Sw	Medium	0,39	Weak	Simetrical	Very platykurtic
	H = -1m	Fine	0,23	Weak	Very coarse	Very leptokurtic
R10 2021	Bsh-up	Coarse	0,98	Weak	Coarse	Platykurtic
	Bsh-c	Coarse	1,02	Weak	Coarse	Platykurtic
	Sw	Coarse	0,78	Weak	Very coarse	Platykurtic
	H = -1m	Medium	0,47	Weak	Very coarse	Leptokurtic

The morphology of the shallow water zone (−1 m) is primarily the result of wave dissipation, which generates turbulence that agitates sediment particles, keeping them in suspension and facilitating their transport and deposition on the seabed. In this zone, sediments tend to become more homogeneous due to environmental conditions such as waves and currents.

In 2017, before nourishment, sand samples were dominated by fine and very fine fractions, exceeding 76% at profile R10 and over 90% at the other three profiles (R14 – 93.2%; R13 – 91.6%; R6 – 91.8%). Mean grain size varied in a narrow range, between 0.14 mm and 0.23 mm, with sorting ranging from good to poor, and very coarse skewness.

After nourishment in 2021, the sand composition changed significantly. Fine and very fine sands averaged 56.6%, with the lowest proportion at R13 (35.6%) and the highest at R14 (74.7%). Mean grain size increased as well, ranging from 0.4 mm to 1.22 mm, with predominantly poor sorting and very coarse skewness.

Table 4. Variation of granulometric parameters along profile R6 (2017-2021)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
R6 2017	Bsh-up	Fine	0,20	Moderate	Very coarse	Mesocurtic
	Bsh-c	Medium	0,24	Weak	Very coarse	Mesocurtic
	Sw	Medium	0,31	Weak	Coarse	Mesocurtic
	H = -1m	Fine	0,14	Good	Very coarse	Very leptokurtic
R6 2021	Bsh-up	Coarse	0,814	Weak	Very coarse	Platykurtic
	Bsh-c	Coarse	0,89	Weak	Very coarse	Platykurtic
	Sw	Coarse	0,67	Weak	Very coarse	Platykurtic
	H = -1m	Medium	0,4	Weak	Very coarse	Very leptokurtic

3.2 Constanta Sector

For the Constanța sector, a selection of existing profiles was chosen for a comparative analysis of sand quality to evaluate the differences before and after beach nourishment.

Table 5. Variation of granulometric parameters along profile CT17 (2014-2017)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
CT17 2014	Bsh-up	Coarse	1,15	Weak	Negative	Very leptokurtic
	Bsh-c	Coarse	0,78	Weak	Negative	Leptokurtic
	Sw	Coarse	0,78	Weak	Strongly negative	Platykurtic
	H = -1m	Fine	0,11	Very good	Positive	Very leptokurtic
CT17 2017	Bsh-up	Coarse	0,74	Weak	Positive	Leptokurtic
	Bsh-c	Coarse	1,43	Weak	Positive	Mesokurtic
	Sw	Medium	0,58	Weak	Positive	Very Platykurtic
	H = -1m	Fine	0,12	Very good	Negative	Very Platykurtic

It can be observed that, in both periods, the sediment contains fine, medium, and coarse fractions.

Coarse sand was predominant in 2014, with grain sizes ranging from 0.78 to 1.15 mm, poorly sorted, negatively skewed, and with kurtosis values varying from platykurtic to very leptokurtic.

Compared to 2014, in 2017 there was a decrease in mean grain size on the upper beach and in the swash zone. Sorting remained predominantly poor, with positive skewness, and kurtosis ranging from very platykurtic to leptokurtic.

Mean grain size on the mid-beach in 2017 showed a significant increase. The amount of very coarse sand on the mid-beach nearly doubled compared to 2014, and skewness became positive, compared to the negative skewness observed in 2014.

Table 6. Variation of granulometric parameters along profile CT5 (2014-2017)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
CT 5 - 2014	Bsh-up	Medium	0,43	Weak	Strongly positive	Very leptokurtic
	Bsh-c	Coarse	0,99	Relatively good	Positive	Leptokurtic
	Sw	Coarse	1,34	Moderate	Simetrical	Mesokurtic
	H = -1m	Coarse	2,14	Moderate	Strongly negative	Very platykurtic
CT 5 - 2017	Bsh-up	Medium	0,43	Weak	Strongly negative	Mesokurtic
	Bsh-c	Coarse	1,26	Weak	Strongly positive	Very platykurtic
	Sw	Medium	0,33	Moderate	Strongly negative	Leptokurtic
	H = -1m	Coarse	0,88	Weak	Simetrical	Very platykurtic

In the 2014 samples, coarse sand was present on the upper and mid-beach, with grain sizes ranging from 0.43 to 0.99 mm, moderately to poorly sorted, strongly positive to positive skewness, and very leptokurtic to leptokurtic kurtosis.

Very coarse sand was found in the swash zone, with a mean grain size of 1.34 mm, moderately sorted, symmetrically distributed, and mesokurtic.

In 2017, a decrease in mean grain size was observed in the swash zone and at 1 m water depth, while the upper and mid-beach showed only minor changes.

3.3 Eforie Sector

Before the implementation of coastal protection works, the central and northern parts of this sector were protected by stone groins. The granulometric structure and sediment characteristics were analyzed on samples collected from two geomorphological beach sections (profiles EF 15 and EF 17).

Table 7. Variation of granulometric parameters along profile EF17 (2014-2017)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
EF 17 - 2014	Bsh-up	Fine	0,28	Good	Positive	Leptokurtic
	Bsh-c	Medium	0,39	Moderate	Positive	Leptokurtic
	Sw	Medium	0,36	Good	Simetrical	Mesokurtic
	H = -1m	Medium	0,32	Good	Positive	Mezocurtic
EF 17 - 2017	Bsh-up	Fine	0,29	Good	Weak	Mezocurtic
	Bsh-c	Medium	0,32	Relatively good	Weak	Mezocurtic
	Sw	Medium	0,56	Relatively good	Negative	Leptokurtic
	H = -1m	Medium	0,48	Relatively good	Weak	Mesokurtic

For profile EF 17, sediments ranged from fine to coarse, with grain sizes between 0.28 mm and 0.39 mm in 2014, and between 0.29 mm and 0.56 mm in 2017. Sorting was predominantly good to very good in both periods, with kurtosis values ranging from leptokurtic to mesokurtic. Changes were observed in skewness, which was predominantly positive in 2014 and weakly positive in 2017.

Table 8. Variation of granulometric parameters along profile EF15 (2014-2017)

Sample		Sediment class	Mean Size (mm)	Sorting	Skewness	Kurtosis
Ef 15 - 2014	Bsh-up	Medium	0,42	Relatively good	Simetrical	Mezocurtică
	Bsh-c	Medium	0,38	Good	Simetrical	Mezocurtică
	Sw	Medium	0,36	Good	Simetrical	Mezocurtică
	H = -1m	Medium	0,42	Good	Simetrical	Mezocurtică
Ef 15 - 2017	Bsh-up	Medium	0,4	Good	Simetrical	Mezocurtică
	Bsh-c	Medium	0,39	Good	Simetrical	Mezocurtică
	Sw	Medium	0,47	Very good	Simetrical	Leptocurtică
	H = -1m	Coarse	1,12	Weak	Weak	Leptocurtică

The sediment characteristics at profile EF 15 did not show significant changes between the periods before and after nourishment. In both 2014 and 2017, mean grain size was similar, except at 1 m water depth, where a notable increase was observed in 2017. Sorting was predominantly good, skewness was generally symmetrical, and kurtosis was mostly mesokurtic.

Figures 3 and 4 show the classified granulometric fractions (coarse, medium, fine) for Mamaia and Eforie after beach nourishment. In the Mamaia sector, coarse and medium sand fractions predominated, with fine sand generally accounting for less than 50%, with few exceptions.

In the Eforie sector, a significant difference can be observed between the two profiles. On profile EF15, the fine sand fraction is very low compared to the medium and coarse fractions, whereas on profile EF17, the proportion of fine sand increases considerably.

4. CONCLUSIONS

The comparative analysis of sediment characteristics, before and after beach nourishment works, highlighted significant changes in sand quality along the tourist beaches of Mamaia, Constanta, and Eforie, particularly at the sea–land interface. In the Mamaia sector, the sand fraction changed noticeably, from fine sand before the interventions to predominantly coarse sand afterwards, reflecting the direct impact of coastal protection structures and artificial beach replenishment on local sediment dynamics. In Constanta, changes were more moderate, with a slight improvement in sand quality, characterised by a mixture of coarse, medium, and fine sands. In Eforie, sediment characteristics remained largely stable, with only minor variations in mean grain size and no change in the dominant sand class.

However, the study has certain limitations. Although the period analysed covers several years, it does not fully capture long-term sedimentary evolution or seasonal variability. Additionally, while granulometric analysis provides detailed information on sand texture and distribution, it does not fully account for other influencing factors such as hydrodynamic energy, wave climate variations, or other human activities beyond beach nourishment projects. In some sub-sectors, data coverage was limited, which may affect the representativeness of some observations.

Future research should include continuous monitoring of these beaches to better understand long-term morphological changes and sediment transport patterns. Combining hydrodynamic modelling with granulometric and geomorphological analyses could provide more accurate predictions of shoreline response to both natural processes and human interventions. Moreover, evaluating the ecological impact of beach nourishment on benthic communities and coastal habitats would provide a more comprehensive understanding of the effects of such interventions.

From a practical perspective, these findings are useful for coastal management and tourism planning. Understanding how different sectors respond to protection and nourishment works can help develop more effective sediment management strategies, optimise beach replenishment projects, and promote sustainable coastal tourism. Furthermore, the results emphasise the need for a sector-specific approach, recognising that sedimentary response varies depending on local conditions, hydrodynamics, and the history of previous interventions.

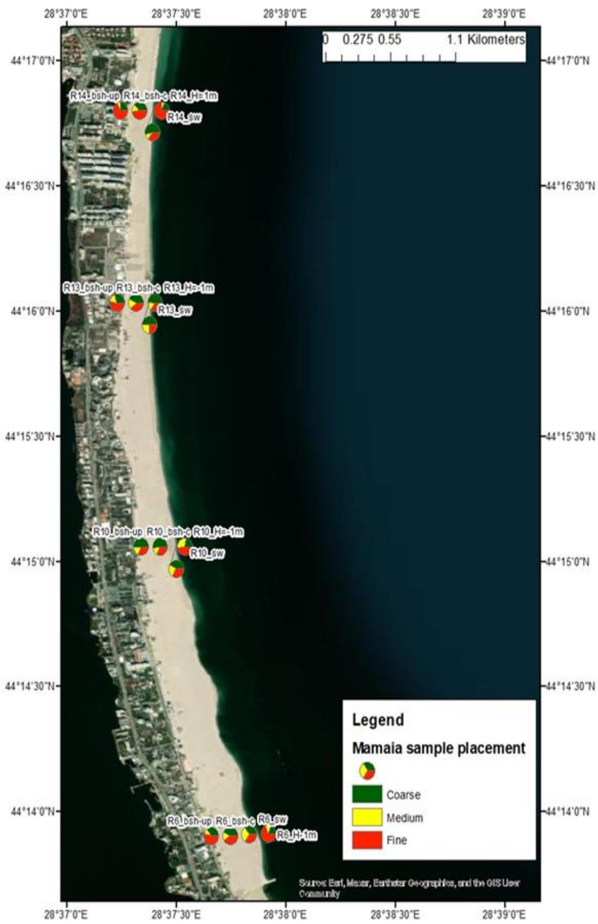


Figure 3. Sediment granulometry in Mamaia sector after the nourishment

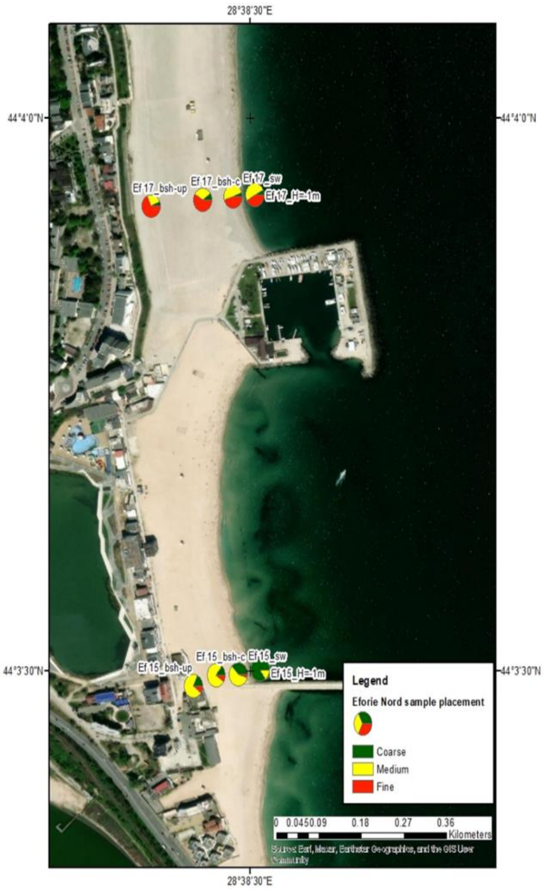


Figure 4. Sediment granulometry in Eforie Nord sector after the nourishment

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