International Journal of Engineering and Geosciences
https://dergipark.org.tr/en/pub/ijeg
e-ISSN 2548-0960

Seasonal morphological changes and grain size distribution mapping on the Massa beaches using topographic survey and GIS

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Cite this study: Nmiss, M., Amyay, M., Atiki, N., Ouammou, A., Benbih, M., & Nait-Si, H. (2025). Seasonal morphological changes and grain size distribution mapping on the Massa beaches using tachometer and GIS. International Journal of Engineering and Geosciences, 10 (2), 272-289.

https://doi.org/10.26833/ijeg.1598677

Keywords
Total station
GIS
Beach
Massa
topographic profile

Research Article

Received:09.12.2024
Revised: 21.01.2025
Accepted:27.01.2025
Published:01.07.2025

Abstract

Sandy beaches are complex, highly dynamic, fragile environments that are constantly evolving. Understanding the dynamics of these areas is crucial, both for fundamental science and for coastal zone management. This study presents the results of a seasonal morphological and sedimentological monitoring of the sandy beaches of Massa, located in the central-western region of Morocco. This monitoring was conducted using both an electronic total station and the spatialization of grain size indices (median, sorting index So, and skewness) through interpolation within a Geographic Information System (GIS). A total of 15 topographic profiles were surveyed perpendicular to the coastline during three field campaigns conducted between September 2019 and July 2020. The results indicate a morphodynamic equilibrium of the beaches, characterized by a normal morphological cycle with erosion during winter and accretion during summer. This balance is primarily attributed to the physical behavior of the beaches in response to wave energy, as well as the presence of a highly developed coastal dune capable of supplying sediment to the beaches during periods of shortage. Additionally, the spatialization of grain size indices from 90 samples clearly highlights the significance of hydrodynamic factors, such as waves, tides, currents, littoral drift, and winds, in the distribution of sandy sediments on the Massa beaches. Atlantic waves from the NNW sector, accompanied by a North-South littoral drift, govern the transport and deposition of sediments along beaches, while tides, currents, and local winds contribute to their redistribution across the different beach zones (foreshore, backshore, and coastal dune). Indeed, seasonal hydrodynamic conditions, as well as the proximity or distance of sediment source zones, play a critical role in sediment distribution along these beaches, providing valuable insights for coastal management strategies aimed at mitigating erosion, preserving beach morphology, and ensuring sustainable development in coastal zones.

1. Introduction

Sandy beaches, which represent 31% of the world's ice-free coastlines [1], are dynamic environments in constant evolution. Their morphology and dynamics are closely linked to sediment supply sources and the energy driving sediment transport and deposition processes [2]. The monitoring of this dynamic is conducted through morphological and sedimentological approaches, covering different long-term and short-term temporal scales [3,4].Over the long term, the study of morphological changes in beaches, carried out over periods exceeding five years, provides a comprehensive overview of their evolution. Such studies utilize advanced techniques such as video imaging, satellite or aerial imagery (drones), and LIDAR [5-11].

On shorter timescales, morphological monitoring provides detailed insights into beach responses at annual, seasonal, or event-driven scales (e.g., storms). These observations typically require intensive field campaigns lasting from a few days to several weeks and are conducted using various techniques, depending on meteorological, logistical, and spatial constraints. Modern tools such as LIDAR, drones, and video imaging are also frequently employed for short-term monitoring. However, topographic surveys using total stations remain the most commonly used method due to their independence from weather conditions, ease of use, low cost, and reliability [12]. These surveys, conducted along transverse profiles, allow cross-sectional analyses of the seasonal evolution of beaches and their morphological responses to winter and summer hydrodynamic extremes.

From a sedimentological perspective, beach dynamics can be understood through the characterization of sandy sediments distributed within the beach-dune system and their seasonal evolution. This characterization helps establish relationships between sediment properties, particularly grain size, and the transport and deposition conditions they experience. Sediment movement along most beaches is primarily controlled by marine and aeolian hydrodynamic processes and is strongly influenced by the grain size characteristics of the original sediments [13,14]. The distribution of sediments is closely linked to hydrodynamic factors such as waves, tides, currents, and winds. Additionally, grain size distribution is affected by various factors, including the distance from the shoreline, the proximity to sediment sources (e.g., rivers), the nature of the source materials, local topography, and dominant transport mechanisms [15-16].

In recent years, the use of Geographic Information Systems (GIS) has become increasingly common for monitoring beach dynamics [17-20]. GIS, with its capabilities for acquiring, compiling, storing, manipulating, analyzing, and visualizing georeferenced data [21-28], provides tools that are perfectly suited for these environments, where multiple interacting components converge. This tool facilitates the spatialization of sand grain distribution and size across a beach through the interpolation of grain size results. Such spatialization offers a significant opportunity to more precisely observe the seasonal variability of sediments on beaches.

The Moroccan Atlantic coastline is characterized by remarkable morphological diversity, with beaches forming a key component of the coastal landscape. These beaches, often associated with dunes developing in the backshore, are particularly prevalent in less anthropized areas [29-31]. They represent a valuable tourist resource that requires rigorous protection from anthropogenic pressures such as intensive urbanization and sand extraction [32-34]. These extensive beaches are typically located at river mouths, which play a crucial role as primary sediment suppliers. In recent years, numerous scientific studies have focused on the morphological evolution of the mesotidal beaches of the Moroccan Atlantic coast [35-39]. These studies emphasize the importance of using total stations (theodolites) for monitoring beach dynamics and observing morphological variations at various temporal scales, particularly annual and seasonal.

This article aims to analyze the dynamics of the Massa beaches (Sidi Ouassai and Sidi Rbat) on a seasonal scale (winter and summer) from September 2019 to July 2020 , based on topographic surveys conducted using a total station. The study pursues several objectives. First, it seeks to monitor the seasonal evolution of the beaches to understand how winter and summer hydrodynamic variations influence measured beach profiles. Second, it aims to characterize the impact of seasonal hydrodynamics on sediment distribution in these coastal areas. To this end, a grain size analysis of collected sandy sediments was conducted, extracting and comparing various grain size indices and their spatial distribution. Additionally, a comparative study of sediments collected during winter and summer seasons was carried out using a Geographic Information System (GIS) to evaluate the effect of seasonal hydrodynamics on sediment distribution across different beach compartments: the intertidal zone, the dry beach, and the foredune. Understanding the seasonal morphological cycle and sediment distribution on the Massa beaches is fundamental for assessing their current dynamics and contributing to more effective and sustainable coastal management.

2. Method and material

2.1 Study area

In central-western Morocco, approximately 30 km south of Agadir, two picturesque beaches form at the mouth of the Massa River: Sidi Ouassai Beach on the left bank, which is vast and expansive, and Sidi Rbat Beach on the right bank, which is narrower. These two river-mouth beaches display a marked difference in beach extent and intertidal zone width. Together with the Massa estuary, they form a 4.2 km coastal cell bordered to the north and south by coastal cliffs (Figure 1 c).The genesis and evolution of these beaches are deeply connected to the sediment input from the Massa River, which drains the waters of a 4,907 km^2 Anti-Atlas watershed. The river originates in the Anti-Atlas Mountains, and its basin is characterized by a hot semi-arid climate (BSh, Köppen classification), marked by irregular precipitation and river flows. The average annual precipitation located 15 km from the Massa estuary, are 163.6 mm and 22°C, respectively (Figure 1 b). The annual mean discharge recorded and temperature recorded at the Melk Zhar station, at the Youssef Ibn Tachafine Dam hydrometric station, which regulates 80% of the basin's total area, is 3.91 m^3/s for the period 1976–2018. This rate varies from year to year, with a maximum flow rate of 18.26 m^3/s and a minimum flow rate of 0.83 m^3/s. However, during exceptional floods, such as the one in 2014, the hydrometric station at the dam recorded an average annual flow rate of 50 m^3/s.

The Massa coastal cell is highly exposed to energetic Atlantic waves from the NNW sector. According to daily forecasts from the Spanish SIMAR system at point 1040022 (coordinates 30.500 N, -10.000 E), 82.5% of waves have a significant height below 2.5 m, while 17.5% exceed this height (Figure 1 d). Regarding wave periods, 47.14% last longer than 10 seconds (Figure 1 d). This wave regime highlights the predominance of swell-driven conditions in winter and mixed swell and shorter-period wave conditions in summer [35]. Regarding the tide, it is semi-diurnal, very regular, and almost sinusoidal. This type of tide is predominant along the mesotidal Moroccan Atlantic coasts. The tidal range varies between 3.55 meters during exceptional spring tides and 1.15 meters during exceptional neap tides. The dominant wind direction along the Massa coastline is NW, accounting for 82% of wind occurrences, as recorded at the Melk Zhar station (Figure 1 e). Other wind directions include 14% from the southeast and 4% from the west [40].

With its unique location within the boundaries of the Souss Massa National Park, a region of significant ecological and environmental value, the Massa beaches exhibit remarkable morphological diversity. On one side lies Sidi Ouassai Beach, which is broadly open to the continent, featuring a relatively wide intertidal zone and a foredune dominated by giant nebkhas stabilized by Macaronesian Chenopodiaceae species such as Traganum moquini (Figure 2 a). On the other side, Sidi Rbat Beach is characterized by a short intertidal zone bordered by a high beach dune pressed against the cliff (Figure 2 b). Between these two beaches lies the 750-meter-long Massa estuary, located in a morphologically low area. Designated as a Ramsar wetland in 2005, the estuary is recognized as a national and international biological and ecological site of interest (Figure 2 c). It remains typically closed, opening only sporadically during heavy winter floods and/or water releases from the Youssef Ben Tachafine Dam (Figure 1 b).The closure of the Massa estuary results, on one hand, from NW winds that transport sand inland, forming a sandbar that is difficult for the Massa River to breach. On the other hand, the construction of the Youssef Ben Tachafine Dam upstream of the Massa River in 1971 has significantly reduced sediment supply and discharge, further contributing to the obstruction of the estuary downstream.

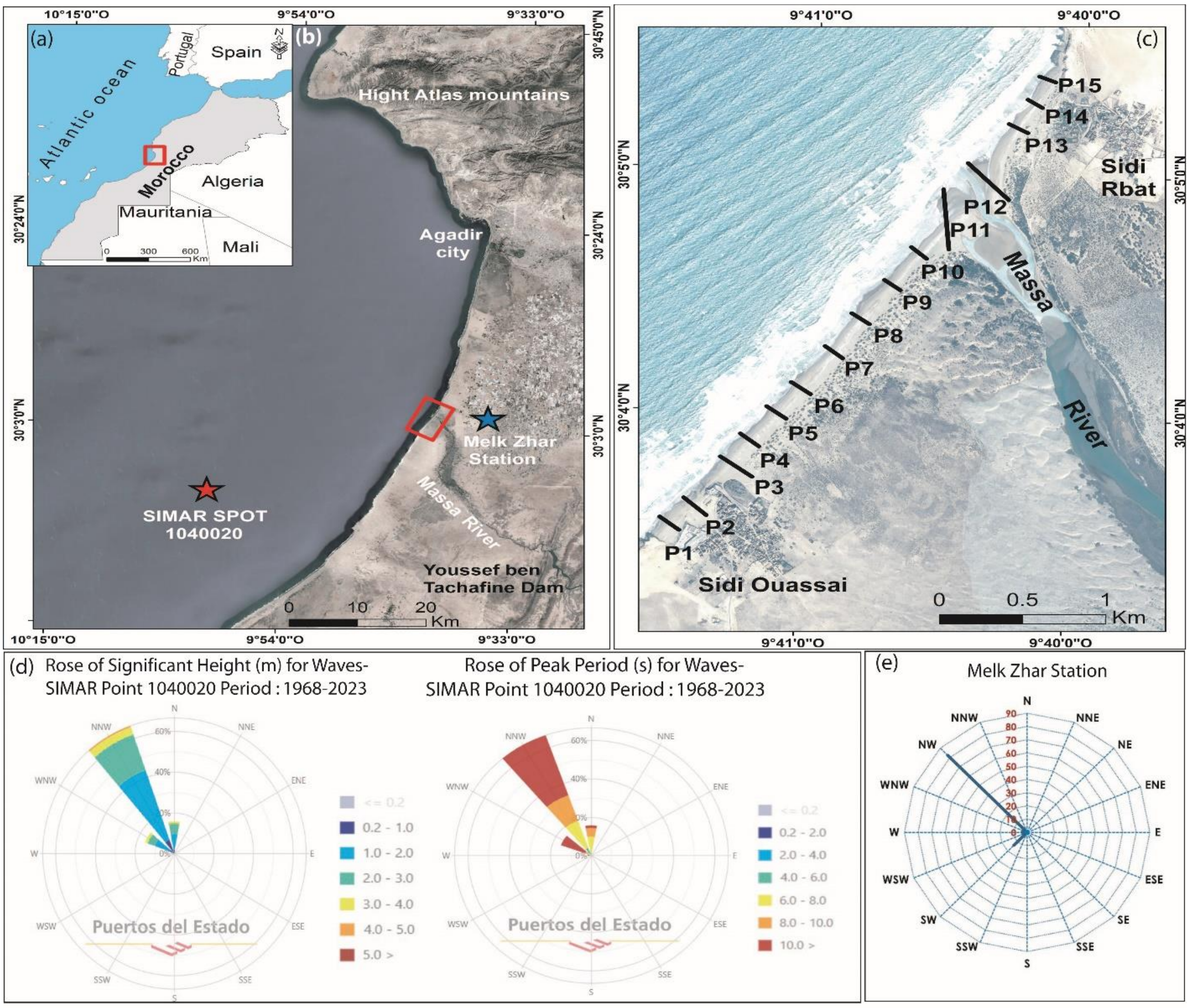


Figure 1. Location of the study area; (a) Overview of the study area location on the map of Morocco, (b) Location of the Massa beaches south of Agadir; the blue star marks the Melk Zhar climatic station, and the red star indicates measurement points provided by the Spanish port authorities under reference number 1040020.(c) A satellite image from the Pleiades satellite (taken in October 2018) showing the locations of surveyed topographic profiles.(d) Significant wave height and period. (e) Dominant wind direction.

Figure 2. The Massa beaches (a) Sidi Ouassai beach (b) Sidi Rbat beach (c) The mouth of Massa River

Two methodological approaches were adopted to monitor the dynamics of the Massa beaches (Sidi Ouassai and Sidi Rbat). The first approach involved tracking the morphological evolution of the intertidal and supratidal zones of the beaches from September 2019 to July 2020 through topographic surveys using a total station (theodolite). The second approach focused on characterizing the sandy material distributed across the beaches to extract the dominant sand texture parameters and analyze their seasonal evolution.

2.2 Measurement of Seasonal Beach morphology changes

To monitor the morphological evolution of the sandy beaches, topographic surveys (profiles perpendicular to the coastline) were conducted, with repetition at seasonal intervals (winter/summer). The field measurements were based on the use of a high-resolution electronic total station (with a manufacturer's estimated accuracy of ± 1.5 mm) (Figure 3 b). The principle of the total station involves aiming at a reflective target held by a person at the measurement point (Figure 3 a). The total station is used to measure horizontal and vertical angles, as well as the distance between two targets. These three measurements allow for positioning the observed point relative to a reference centered on the total station [41]. Indeed, the person holding the target climbs a pole and stops at each break in slope, while the operator of the device records points by aiming at the target at each stop (Figure 3 b). The margin of error in using this total station is estimated at 5 cm, which is due to the variable penetration of the target into the ground. This means that when the leveling staff is placed on loose surfaces, such as sand, its penetration may vary depending on the consistency and bearing capacity of the ground. These irregularities in support can lead to slight discrepancies in elevation measurements, thus affecting the accuracy of topographic surveys.

Each profile has a fixed station head, which allows, on one hand, for re-establishing a station in case of loss, and on the other hand, serves as orientation points. Additionally, each beach profile is characterized by a specific horizontal angle (Hz), which facilitates regular monitoring of the same profile. During the topographic surveys, the total station is installed on the station head, and the operator places the prism rod at the base of the beach, then moves upward along the defined axis (Hz). Topographic measurements were taken along the profiles, and whenever an apparent morphological change was observed, a point was recorded. The main geographical characteristics of the various profiles surveyed are summarized in Table 1.

The selection of the topographic profiles on the Massa beaches was based on observed morphological variations. A total of 15 profiles were surveyed, distributed as follows: 10 profiles for Sidi Ouassai Beach, 2 profiles at the Massa estuary, and 3 profiles at Sidi Rbat Beach (Figure 1 c). These profiles were surveyed during three measurement campaigns. The first and third campaigns were conducted during the summer, in September 2019 and July 2020, while the second campaign was carried out in winter, in January 2020 (Figure 4). The choice of these two seasons, winter and summer, is based on the significant morphological variations observed during these periods. Two summer campaigns and one winter campaign were selected to examine the morphological cycle of the Massa beaches, analyzing the changes affecting the different morphological compartments between summer 2019 and January 2020, and then between January and July 2020. The objective is to highlight how the studied beaches responded to the impacts of extreme winter conditions, characterized by powerful waves capable of eroding the beaches, and the effects of calmer hydrodynamic periods, marked by less intense waves that promote sediment deposition.

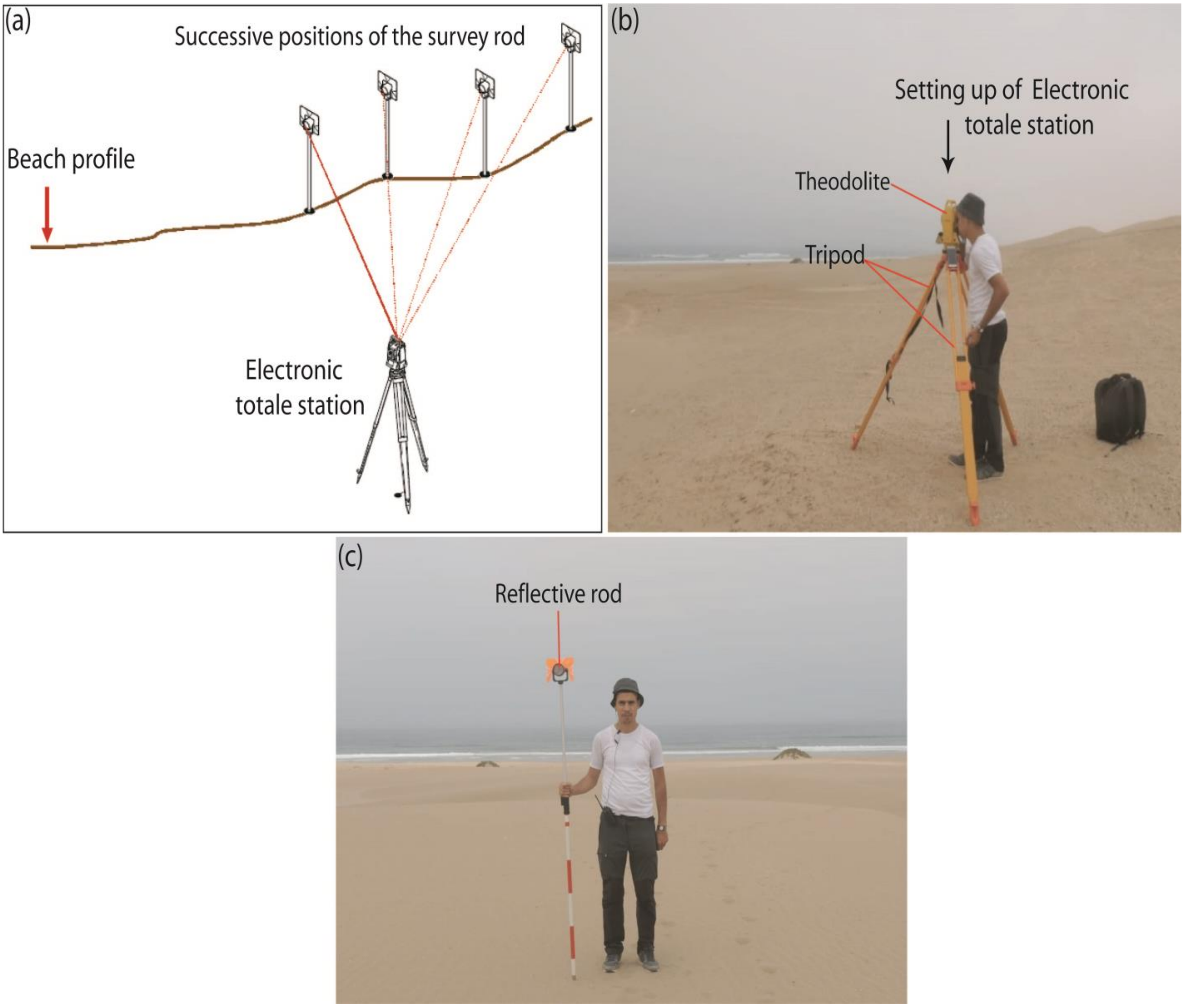


Figure 3. Measurement instrument used for topographic surveys, (a) Principle of beach profile surveys, (b) Setting up the SOUTH NTS-375R total station, (c) The reflective target.

Table 1. Geographical Characteristics of Surveyed Beach Profiles

Massa coastal cell	Profile	Coordinates (Universal Transverse Mercator) X	Coordinates (Universal Transverse Mercator) Y	Altitude in (m)	Angle relative to North (°)	Average profile length (m)
	1	86457.53	347356.75	4.56	235.35	152.52
		86305.01	347204.23			
	2	86599.27	347499.98	6.75	393.27	189.88
		86409.39	347310.11			
Sidi Ouassai	3	86898.99	347810.94	6.58	305.18	297.41
		86601.58	347513.53			
	4	87131.01	348080.70	5.02	253.64	154.10
		86976.91	347926.61			
	5	87135.06	348314.33	6.78	365.5	136.20
		86998.86	348178.13			
	6	87028.02	348451.67	6.83	252.12	136.47
		86891.55	348315.21			
	7	87298.94	348603.29	6.74	332.23	159.26
		87139.68	348444.03			
	8	87073.73	348861.84	5.13	235.15	156.01
		86917.72	348705.83			
	9	86880.43	348690.82	5.28	254.2	130.51
		86749.92	348560.31			
	10	86695.62	348813.59	4.21	336.68	157.01
		86538.61	348656.58			
Mouth of the Massa River	11	86604.66	348816.16	6.84	397.58	357.76
		86246.91	348458.41			
	12	86537.44	348891.03	4.92	398.12	288.89
		86248.55	348602.14			
	13	88600.04	350323.31	4.21	246.12	151.31
Sidi Rbat		88448.73	350172.00			
	14	88734.18	350718.31	6.30	238.39	117.27
		88556.91	350601.04			
	15	88750.02	350739.65	8.31	334.21	89.01
		88661.01	350650.64			

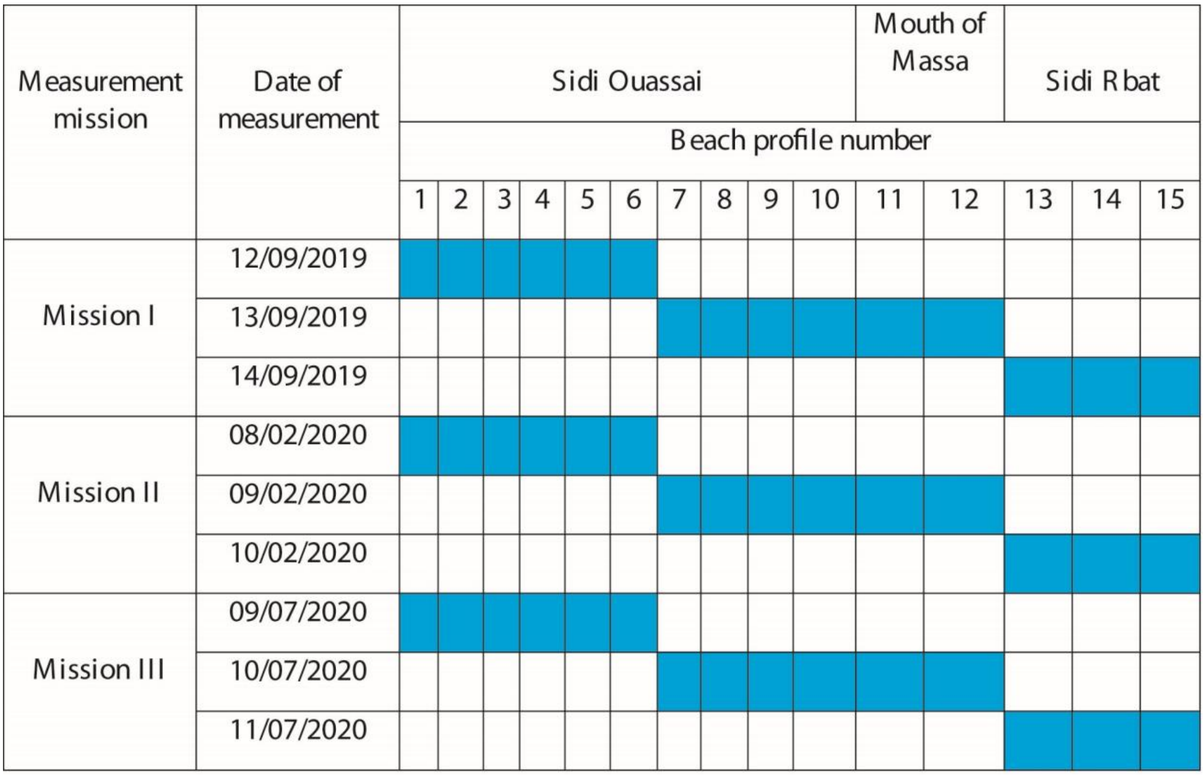


Figure 4. The Measurement Campaigns Conducted on the Beaches of Massa

The topographic profiles were also used to quantify volumetric variations (sediment balance) of sediment inputs and losses on the different beaches studied. The calculation of these variations primarily relies on monitoring the seasonal morphological evolution of the intertidal and supratidal zones of several beach profiles. In this study, we used the software PROFILER 3.1 to calculate the sediment balance. The choice of this software is based on its ability to provide precise and reliable measurements of sediment budgets. It allows for the quantification of volume variations, which is crucial for determining sediment budgets in coastal environments. This free tool allows for the construction and descriptive analysis of topographic profiles, particularly beach profiles, and can also be used for other types of terrain [42]. While other software packages exist for calculating volumetric variations, such as BMAP (Beach Morphology Analysis Package) and BPAT (Beach Profile Analysis Toolbox), as well as AutoCAD modules like Covadis, these tools can be complex or expensive.

PROFILER 3.1 is an add-in for Microsoft Excel, offering ease of access and flexibility. Its principle is based on calculating the sediment volume of topographic profiles, using the relationship between cumulative distance and profile altitude. However, this software introduces uncertainties primarily related to the morphology of each profile. The calculations performed by PROFILER 3.1 assume that the topographic base of each profile is flat, resembling a marine abrasion platform.

To understand the various processes shaping the morphology, it is important to establish a morphodynamic classification of the Massa beaches to assess their response to wave energy. Establishing such a classification is based on an in-depth analysis of the morphological characteristics of the studied beaches, taking into account the wave dynamics and their interaction with the beach geometry. This classification allows for categorizing the beaches based on their responses to hydrodynamic variations, particularly the effects of waves and currents.

To establish a morphodynamic classification of the Massa beaches, we adopted the surf similarity index (ξb). This index is a parameter used to characterize the morphodynamics of beaches based on the properties of the waves affecting them. It helps identify beaches with similar behaviors in terms of wave regimes. This index uses the Iribarren number, expressed by the following formula [43]:

$\xi b = \tan \beta / (Hb/L0)0,5$

Where:
Hb is the wave height at breaking (in meters),
L0 is the wavelength offshore (in meters),
β is the beach slope (in degrees).

The beach is classified as dissipative when ξb<0.23ξb<0.23, intermediate if ξbξb is between 0.23 and 1, and reflective when (ξb > 1) [43].

2.3 Seasonal grain Size distribution

Grain size analysis is a key element in understanding beach dynamics, as it provides relevant information about the size, composition, and distribution of sediments. These characteristics directly influence how beaches respond to hydrodynamic forces such as waves, currents, and tides. To evaluate the seasonal distribution of grain size, two sampling missions were conducted during this study. The first mission took place on February 8th, 9th, and 10th, 2020, and the second on July 9th, 10th, and 11th, 2020, corresponding to the second and third measurement campaigns (Fig. 4). The objective of these missions was to collect sediment samples from various coastal units, including the foreshore, the dry beach, and the foredune (Figure 5 a). The selection of this coastal units for sampling is based on their distinct role in coastal dynamics and their importance in the overall functioning of the coastal system. These different morphological units respond differently to the dominant hydrodynamic processes. However, they function as a morphosedimentary system in which the elements are closely interconnected. Samples were uniformly collected at a constant depth to enable comparisons between the different collected samples. Subsequently, the geographical coordinates (X, Y) of each sample were recorded using a mobile GPS device. This allowed us to spatially map these samples along different beach profiles and to characterize the transverse and longitudinal spatial evolution of various grain-size indices on the beaches.

A total of 90 samples were collected during the two missions. Particle size distribution was determined using a Rop-Tap sieve shaker for 15 minutes with an AFNOR mesh grid (Figure 5 b). Statistical parameters (mean, sorting, skewness) were calculated using the GRADISTAT software version 8.0. This program enables the rapid computation of grain-size statistics based on the Folk and Ward methods [44] and moment methods [45]. It is integrated into a Microsoft Excel spreadsheet, providing both tabular and graphical outputs.

To characterize sediments more precisely, it is necessary to calculate several granulometric indices and parameters. Among these, the most frequently used are the median (Md), the Trask sorting index (SO), and the skewness index (SK). The median is a positional parameter that divides the distribution into two subsets of equal size, where 50% of the values are higher and 50% are lower.Sorting parameters provide insight into the history of grain populations by characterizing the conditions of sediment deposition and transport. The sorting parameters we used include the Trask sorting index (SO), calculated using the following formula: $SO = \sqrt{Q1/Q3}$, where Q1 and Q3 represent the 25th and 75th percentiles of grain diameters on the cumulative curve.As for the skewness index, it characterizes the deviation of the granulometric curve from the normal Gaussian curve. This index is calculated as follows: $SK = \sqrt{(Q1\text{-}Q3)}/\text{Median}$.

Figure 5. (a) Morphological units sampled on the Massa beaches, (b) Laboratory work: sieving using an AFNOR-type sieve.

2.4 Wave Hydrodynamic forcing

Hydrodynamic factors such as swell, waves, and tides play a decisive role in the dynamics and evolution of beaches, as they determine the processes of erosion, sediment transport, and deposition. The study of these factors is essential for understanding the mechanisms that govern coastal dynamics. In the context of this research, their analysis helps explain the morphological variations observed on the studied beaches.

During the various measurement campaigns, the dominant hydrodynamic conditions, namely the significant wave height and the significant wave period, were recorded using daily forecasts managed by Spanish port authorities at the SIMAR point 1040020 (coordinates 30.500 N, -10.000 E) (Figure 1b).During the field missions, wave heights varied between 2 and 3 meters (Figure 6a). As for the significant wave period (Ps), it fluctuated between 7 and 12 seconds (Figure 6b). Figure 6 below clearly illustrates the seasonal variations in wave height and period. Energetic waves, with a significant height exceeding 4 meters, were recorded during the winter seasons, from September to March. From March to September, the waves become less energetic. Regarding tidal coefficients, the values recorded during the various measurement campaigns were moderate to high, ranging between 52 and 78.

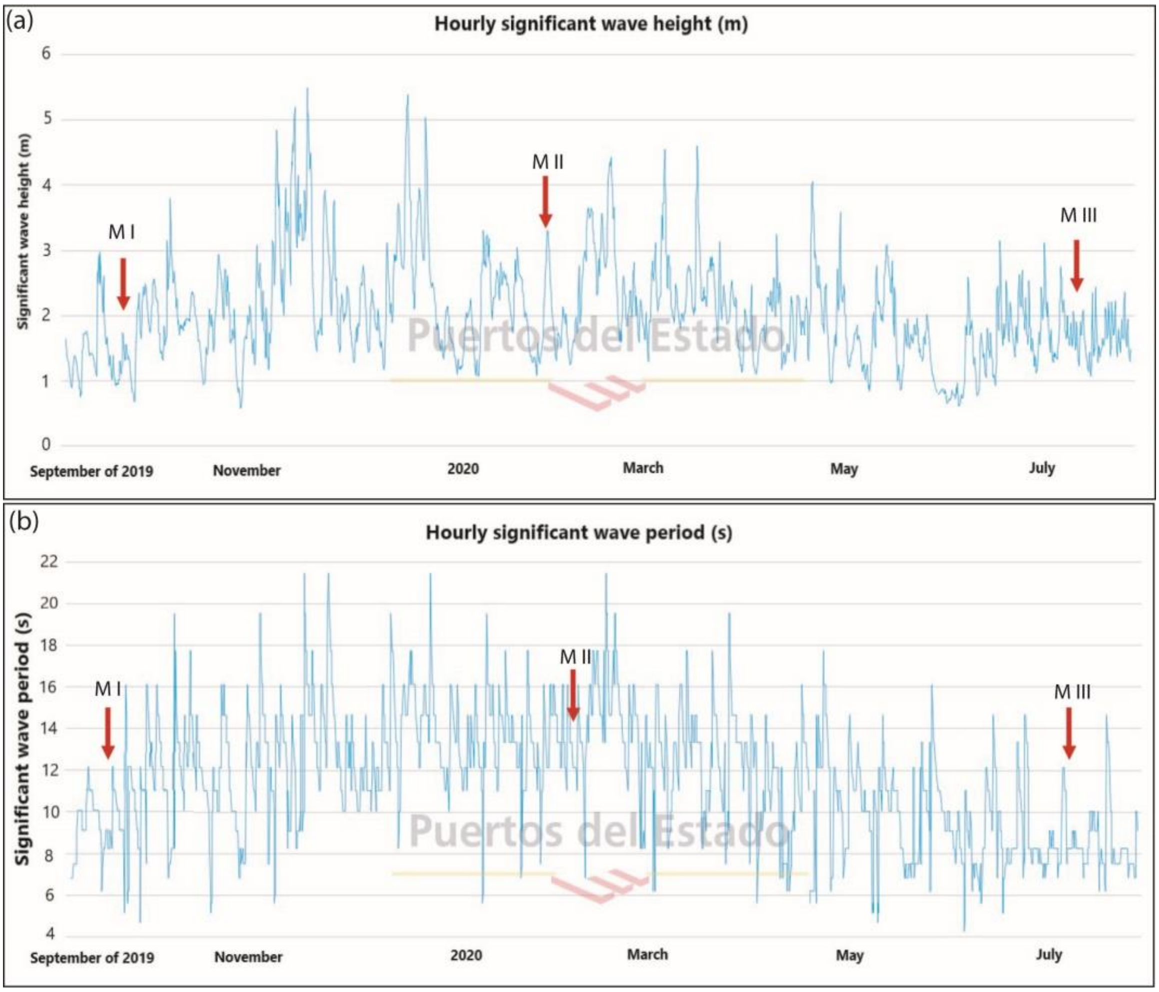


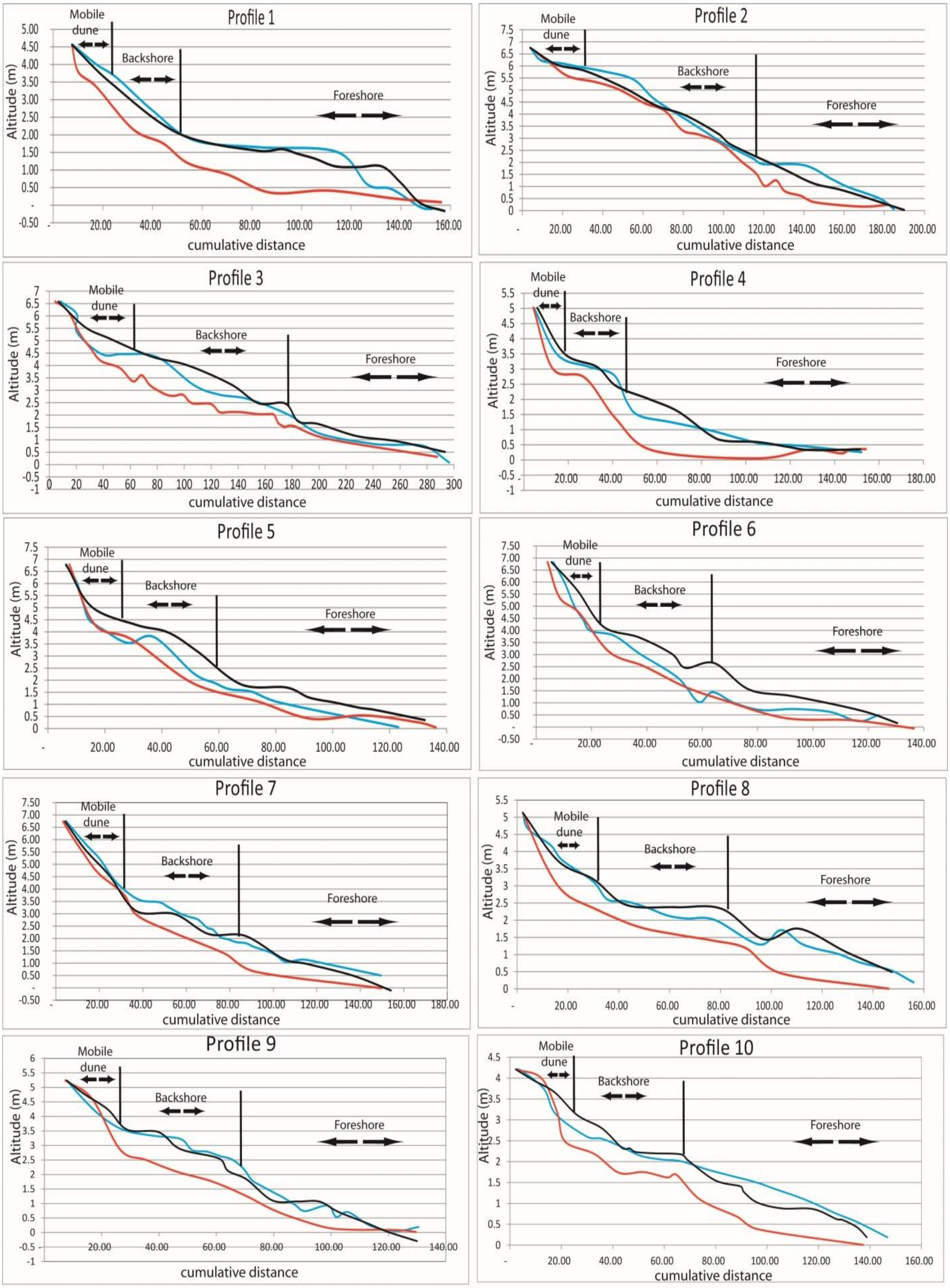
Figure 6. Dominant wave conditions during the various field missions. (a) Significant wave height, (b) Significant wave period, M I, M II, M III indicate field missions.

3. Results

3.1 Seasonal Beach morphology change

On the Massa beaches (Sidi Ouassai and Sidi Rbat), the surveyed profiles generally exhibit different topographical patterns, including convex, concave, concave-convex, and regular shapes (Figure 7). Seasonal variations have significantly impacted the morphology of the beaches, as visually reflected in the topographical profiles. The dominant trend observed during the three measurement campaigns is erosion in winter and accumulation in summer on the foreshore, dry beach, and foredune. The average slope recorded during the field missions is as follows: 1.5 (P1), 2.25 (P2), 1.19 (P3), 1.85 (P4), 2.8 (P5), 2.84 (P6), 2.39 (P7), 1.63 (P8), 2.4 (P9), 1.69 (P10), 1.41 (P11), 0.89 (P12), 1.44 (P13), 3.2 (P14), and 6.22 (P15).

The volumetric variations calculated between September 2019 and February 2020 show a negative sedimentary balance, with values ranging from -1 m^3/m to -0.1 m^3/m. In contrast, summer volumetric variations between February 2020 and July 2020 indicate a positive sedimentary balance, with values ranging from +1 m^3/m to +0.1 m^3/m (Figure 8). During the winter period (January 2020), high-energy meteomarine conditions are typically frequent, and waves are stronger. This is reflected not only in the topographic shape of the various beach profiles but especially in volumetric variations (losses). As a result, rip currents carry a larger quantity of sediments offshore. These sediments are stored lower in the profile in the form of sediment bars. Consequently, the general trend observed across all winter profiles is one of erosion. In contrast, summer periods (September 2019 and July 2020) are characterized by less powerful waves, which facilitate the movement of sediments accumulated on nearshore sandbars toward the upper part of the beach, contributing to its thickening. This summer situation favors beach accretion, with the formation of littoral bars on the foreshore and the aerial beach, as well as the development of sand ridges at the foredune level.


Profile 1
Mobile dune
Backshore
Foreshore
Altitude (m)
cumulative distance
Profile 2
Mobile dune
Backshore
Foreshore
Altitude (m)
cumulative distance
Profile 3
Mobile dune
Backshore
Foreshore
Altitude (m)
cumulative distance
Profile 4
Mobile dune
Backshore
Foreshore
Altitude (m)
cumulative distance
Profile 5
Mobile dune
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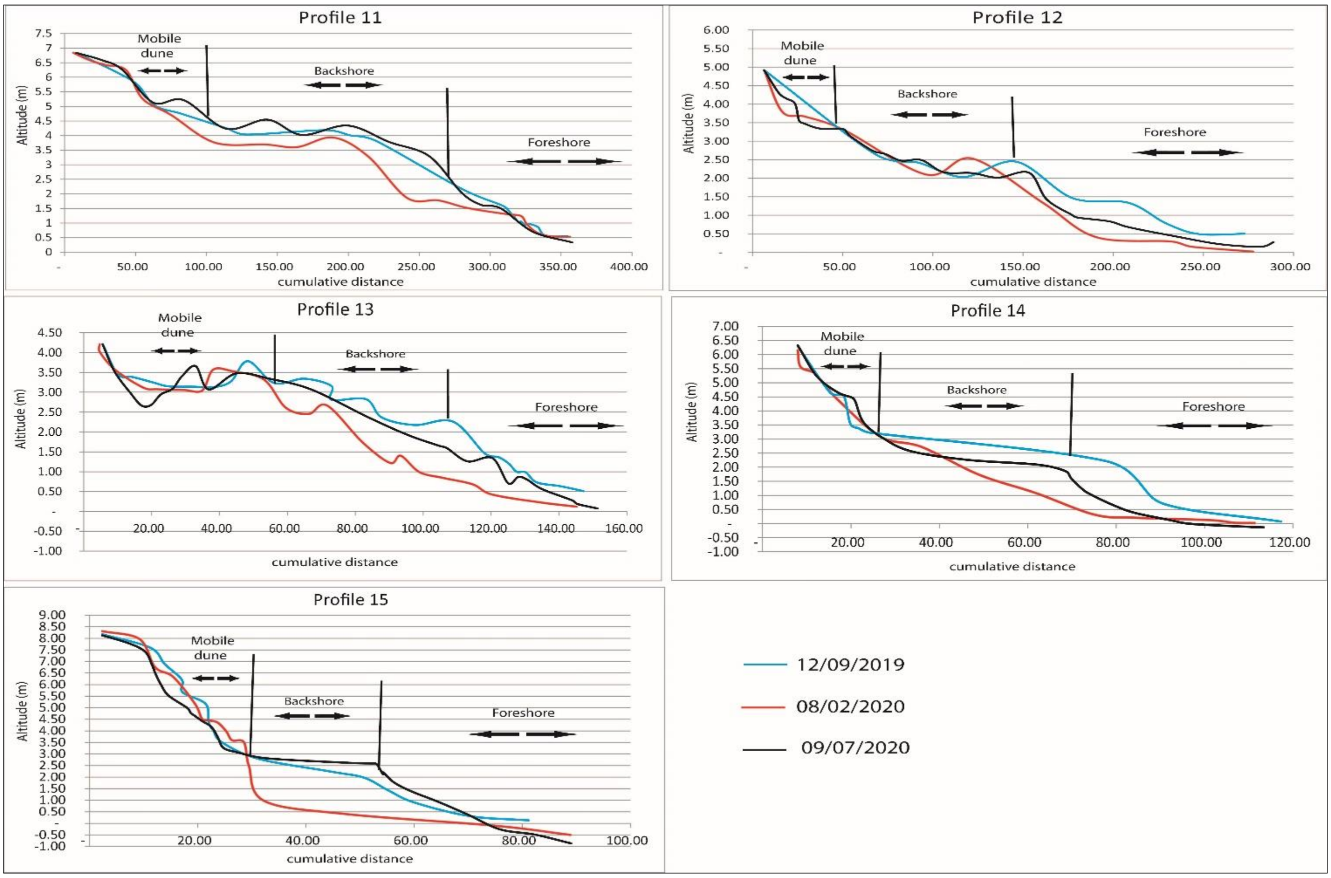

Figure 7. Topographical evolution of the beach profiles of Massa

To understand the seasonal dynamics and current evolution of the Massa coastal cell, it is essential to establish a morphodynamic classification for the beaches within this cell (Sidi Ouassai, Sidi Rbat, and the Massa estuary) through the calculation of the Iribarren number. The parameters measured for this calculation are summarized in Table 3 below. The results show a predominance of intermediate morphology across the beaches. However, some anomalies are noteworthy. These include profiles 3 and 12, surveyed respectively at Sidi Ouassai beach and the Massa estuary, which exhibit dissipative morphology. Additionally, profile 15, surveyed at Sidi Rbat beach, displays a reflective morphology (Table 2).

Having different morphodynamic types within the Massa coastal cell has significant implications for understanding coastal processes. Each morphodynamic type responds differently to hydrodynamic conditions and exhibits distinct characteristics that influence sediment erosion, transport, and deposition processes. In a medium-to-high tidal range zone, such as the study area, Masselink and Short [46] demonstrated that intermediate morphology features a less prominent nearshore bar that appears at low tide. This morphology is also characterized by a unique configuration known as a "low tide bar and channel beach." Here, the upper foreshore is organized around a well-formed bar. Across the surveyed profiles with intermediate morphology, a nearshore bar is observed on the upper foreshore, particularly during the summer season.

In winter, this bar undergoes significant erosion, which is reflected in the topographical profiles of the beaches. Dissipative morphology, on the other hand, is characterized by its ability to dissipate and absorb wave energy. It typically has a gentle slope, with waves breaking over long distances. Dissipative morphology is defined by a series of low-relief bars structuring the intertidal and subtidal zones, where waves break repeatedly. Dissipative profiles 3 and 12 exhibit these characteristics of multiple bars at the upper, middle, and lower foreshore levels. Finally, reflective morphology is distinguished by a steep slope. Wave energy is not absorbed but rather reflected by the steep upper intertidal beach. While the upper beach is steep, the lower beach has a gentler slope. This feature is clearly visible in profile 15.

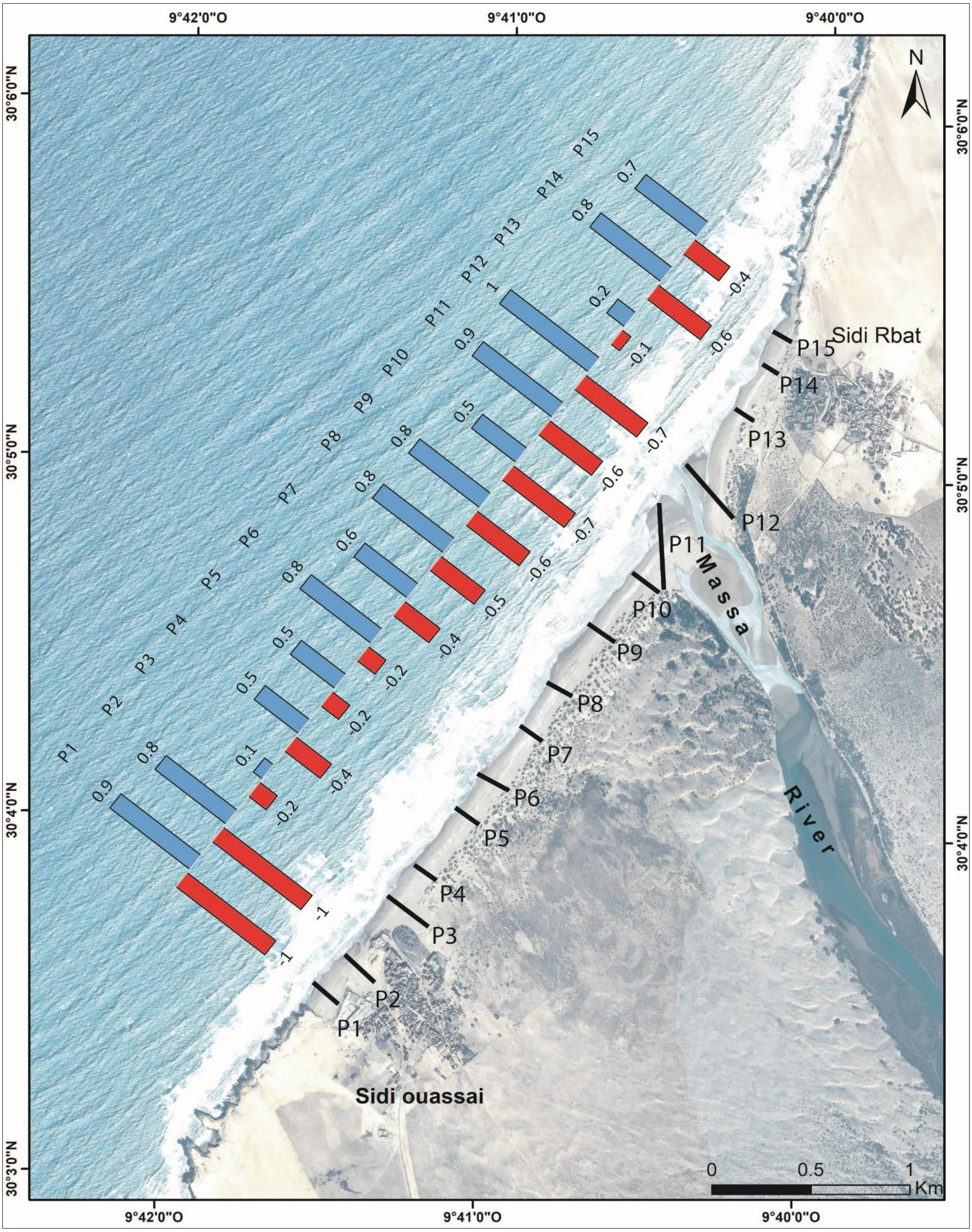

Figure 8. Sediment budget calculated using Profiler 3.1 software on the Massa beaches.

Table 2. Measured or estimated data used in the calculation of the Iribarren number (ξb) for Massa beaches.

Massa Beaches	Profils	Pente moyenne (β)	Tan β	L0	H b	Indice d'iribarren (ξb)	Morphological Classification of Beaches
	P 1	1.5°	0.02618	270	3	0.2505	
	P 2	2.25°	0.03929	270	3	0.3759	Intermediate
	P 3	1.19°	0.02077	270	3	0.1987	Dissipative
	P 4	1.85°	0.03229	270	3	0.3089	
Sidi Ouassai	P 5	2.8°	0.04890	270	3	0.4679	
	P 6	2.84°	0.04960	270	3	0.4746	
	P 7	2.39°	0.04173	270	3	0.3993	
	P 8	1.63°	0.02845	270	3	0.2722	Intermediate
	P 9	2.4°	0.04191	270	3	0.4010	
	P 10	1.69°	0.02950	270	3	0.2822	
Mouth of	P 11	1.41°	0.02461	270	3	0.2355	
Massa	P 12	0.89°	0.01553	270	3	0.1486	dissipative
	P 13	1.44°	0.02513	270	3	0.2404	
Sidi Rbat	P 14	3.2°	0.05590	270	3	0.5349	Intermediate
	P 15	6.22	0.01898	270	3	1.0421	reflective

3.2 Seasonal grain Size distribution

During the winter season (February 2020), the predominant sandy materials consist of fine to medium sands. Median values range between 194 µm and 375 µm (Figure 9), indicating a transverse evolution characterized by a decrease in average grain size from the foreshore to the foredune, although some anomalies reveal an inversion of this trend in certain samples. At the mouth of the Massa River, medium sands dominate, likely due to sediment inputs from the river itself, which are the source of these sands. Additionally, these estuarine zone channels northwesterly winds, which have the capacity to transport finer materials inland, leaving coarser elements behind. At the northern and southern extremities of the Massa coastal cell, the median grain size increases significantly due to the presence of rocky outcrops on the foreshore, which enhance wave energy and turbulence in these areas. Simultaneously, a southward decrease in average grain size is observed, consistent with the dominant north-to-south longshore drift and the local northwest-to-southeast wind direction. This trend is accompanied by an increase in grain sorting (Figure 9). However, anomalies are to be noted. These anomalies are probably linked to partial enrichment by shell fragments. They may also be due to a mixture of materials.

During the summer season, hydrodynamic conditions influence the distribution of sediments on the beaches. Median values range between 215 µm and 444 µm (Figure 10). The distribution of these values reveals a spatial evolution of the median across the beaches, from the foreshore to the foredune. The longitudinal distribution of sediments highlights partially coarser areas at the mouth of the Massa River and to the south of Sidi Ouassai beach, as well as relatively finer areas at Sidi Rbat beach and to the south of the mouth (Figure 10). This situation reflects the impact of marine and wind-driven hydrodynamics on the distribution of sediments on the beaches.

The sorting coefficient (SO index) indicates well-sorted sands for all the samples, with values ranging between 1.183 µm and 1.479 µm. The predominance of well-sorted sands, uniformly distributed across the beaches of the Massa estuary, reflects both the existence of a similar hydrodynamic process on all the beaches and a mechanical sorting of sands through longshore drift, coastal currents, and a relatively strong wind dynamic.

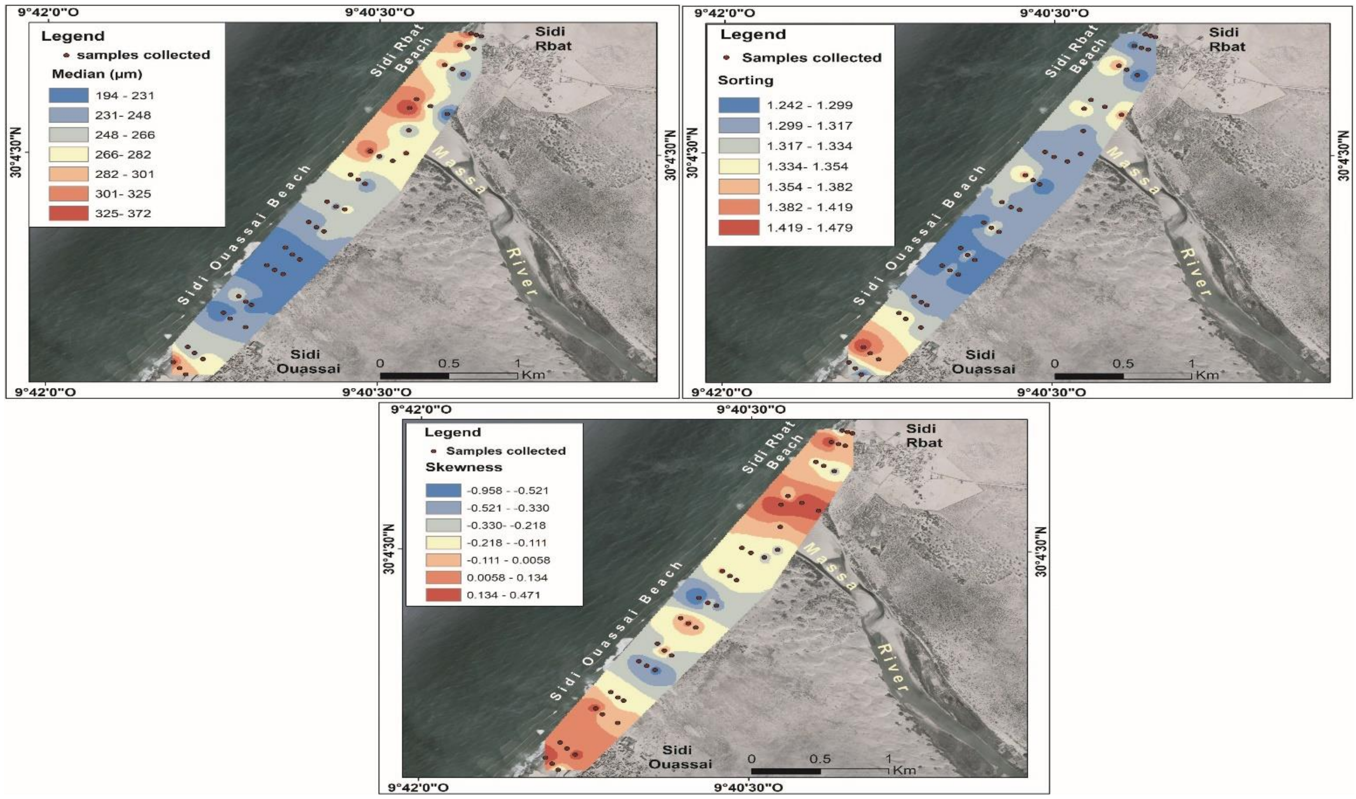

Figure 9. Spatial evolution of granulometric indices (median, sorting index, skewness) during the winter season on the Massa beaches.

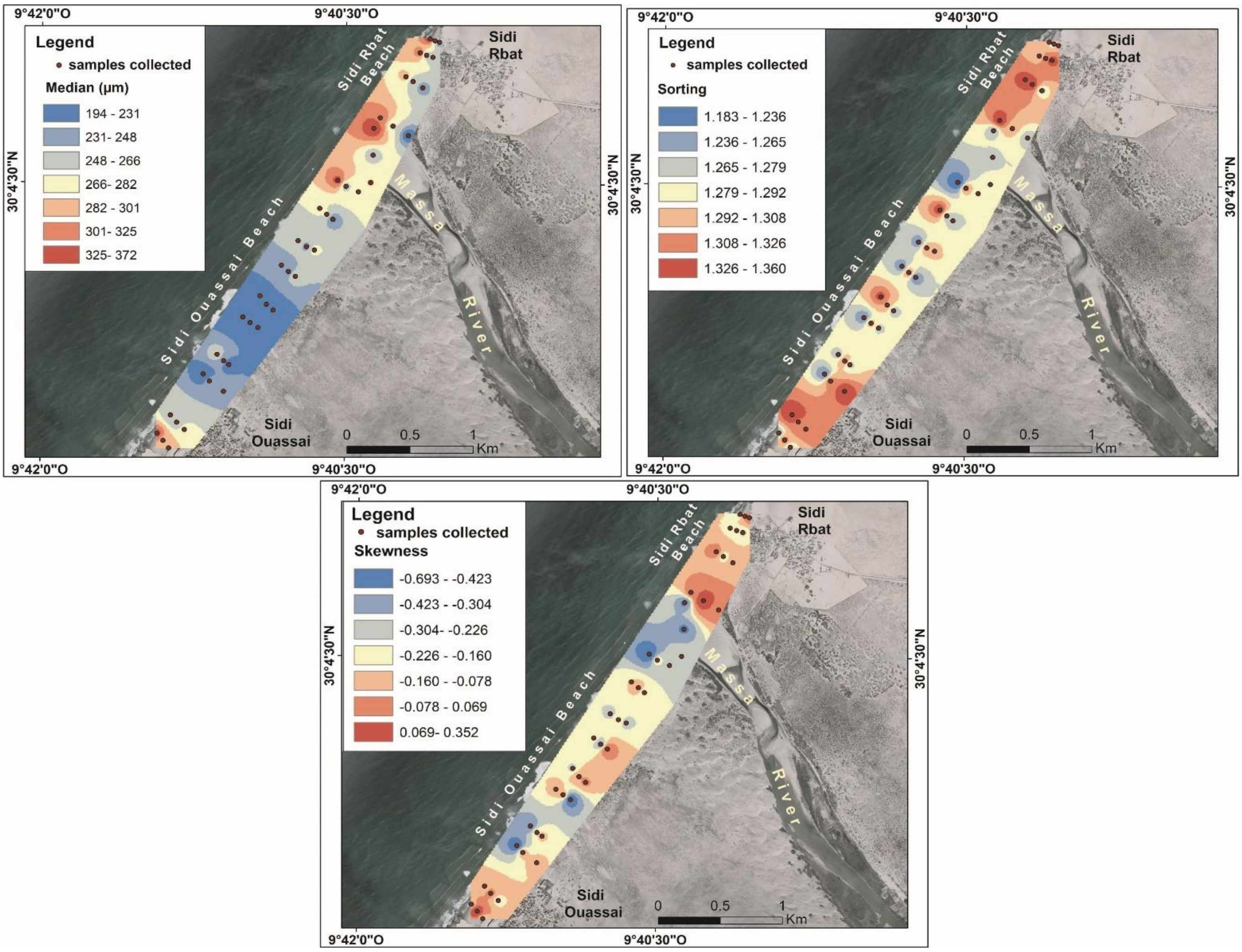

Figure 10. Spatial evolution of granulometric indices (median, sorting index, skewness) during the summer season on the Massa beaches.

4. Discussion

4.1 A well-defined seasonal morphological cycle

The analysis and processing of the various topographic data obtained during the different field missions allowed us to extract relevant information about the evolving pattern of the Massa beaches (2019-2020) and to calculate the seasonal volumetric variations. The results highlight the different phases of seasonal evolution of the studied beaches (Sidi Ouassai, Sidi Rbat, Massa estuary) and their morphological response to winter and summer energy variations. Indeed, the dominant weather-marine conditions during the various measurement campaigns had a major influence on the evolution and dynamics of these beaches. During the winter seasons, waves from the north and northwest are regularly rough, reaching heights ranging from 2 to 3 meters, with periods exceeding 10 seconds. However, waves exceeding 4 meters are also present, but they occur in less than 20% of the cases, corresponding to high-energy weather-marine events (storms). In contrast, during the summer seasons, waves with heights of less than 2 meters account for more than 60% of the cases, with periods shorter than 8 seconds.

These weather-marine conditions directly influence the morphological variations observed in the topographical profiles. For all the surveyed topographic profiles, the morphological response of the Massa beaches to seasonal hydrodynamic variations is reflected by erosion in winter and accumulation in summer. However, it is important to note that this normal evolutionary pattern, which characterizes nearly all mesotidal beaches along the Moroccan Atlantic coast[30,35-38], presents variations from one coastal sector to another, even when exposed to identical hydrodynamic characteristics. This is mainly attributed to the physical behavior of the beaches and the local morphological configuration of each area.

The topographic measurements taken during the winter seasons reveal pronounced erosion in all morphological compartments of the beaches (foreshore, backshore, and foredune), with a negative sediment budget. This is primarily manifested by the formation of more or less deep rills and microcliffs in the intertidal zone (foreshore), attesting to the high energy of the waves. This situation is caused by the winter hydrodynamic conditions, which generate powerful waves capable of eroding the beaches. Under the effect of these waves, sediments are carried offshore, resulting in remarkable changes in the topographic profile configuration. The eroded sediments in the intertidal zone are stored in the form of offshore bars that form parallel to the coastline.

The summer measurement campaigns show an increasingly significant accretion, associated with a positive sediment budget for all the Massa beaches. During the calmer hydrodynamic periods of summer, waves tend to be less powerful, and as a result, sediments accumulated in the offshore bars are moved back toward the foreshore, promoting beach thickening. Morphologically, this accretion is manifested by the formation of littoral bars in the foreshore, with a notable thickening of the backshore and foredune. In fact, the beaches' ability to recover their sediment stock lost during the winter seasons shows that there is always a supply of sediments over time. The morphodynamic balance characterizing the beaches in the study area results from the interaction and interference of several hydrodynamic, geomorphological, and wind factors.

When examining the profiles of all the beaches, it is generally observed that they exhibit an intermediate to dissipative type. This physical behavior plays a crucial role in their equilibrium state and their ability to regenerate naturally during the summer seasons. Indeed, the studied beaches are characterized by an extended wave breaking zone, meaning that waves break over a series of bars multiple times. This results in less concentrated energy on the beach, reducing erosion and promoting sediment accumulation.

The presence of foredunes at the upper part of the beach also facilitates the natural replenishment of sediments during the summer seasons. They act as a potential source of sand to nourish the beaches during times of sediment shortage [47]. The relationship between the beaches in the study area and their foredunes is complex and strongly controlled by aerodynamic processes. First, the sand reserves deposited on the foreshore must be abundant. Then, winds from the north and northwest, blowing inland, must be strong enough to dry the sand, mobilize it, and transport it via rolling, saltation, or suspension towards the upper beach. Finally, the presence of vegetation cover in this part of the beach promotes sand accumulation, thereby contributing to the formation of foredunes. These dunes are connected to the beaches through reciprocal sediment exchanges.

4.2 Seasonal grain Size distrubition

Beach sediments are strongly influenced by seasonal hydrodynamic variability, including marine, wind, and fluvial factors on one hand, and the granulometry of source sediments on the other. The spatial evolution of granulometric indices across the different beaches of Massa cannot be attributed solely to the seasonal energy variability between winter and summer. Other geomorphological and hydrodynamic factors have also played a role in the distribution and evolution of sediments.

The transverse distribution of different granulometric indices from 90 samples highlights a noticeable evolution from the foreshore to the foredune. During the winter season, the longitudinal evolution of various textural parameters (Md, SO, SK) reveals significant spatiotemporal variability at the beaches of Massa. The results show an increase in the average grain size at the mouth of the Massa River, a source area for the materials. The median size ranges from 194 µm to 372 µm, accompanied by an increase in sorting index (SO) and skewness index (SK). A decreasing dynamic gradient is observed from north to south, reflecting a progressive reduction in the median size in the direction of the dominant littoral drift (194 µm). Additionally, at the northern and southern ends of the beaches, the median size increases, with values of 343 µm and 324 µm, respectively. This increase results from several geomorphological and hydrodynamic factors. The presence of lithified dunes at the northern and southern ends of Sidi Ouassai and Sidi Rbat beaches may provide a source of sediment supply [28]. Moreover, the high wave energy during winter at the rocky promontory zones can cause significant wave agitation, explaining the increase in the median size.

During the summer season, median values remain high at the mouth of the Massa River and the center of Sidi Ouassai Beach. This may be due to the significant impact of aeolian deflation, which moves fine particles inland. Another possible explanation for this evolution is the predominant action of the receding groundwater table in the central parts of the beaches, which often transports the finest materials offshore. Additionally, the increase in the median size could be partially explained by the enrichment of sediments with shell fragments.

The predominance of fine to medium sands, along with the good sorting quality (SO index ranging from 1.183 µm to 1.479 µm) observed during both the winter and summer seasons, suggests a relatively stable beach where hydrodynamic processes promote efficient mechanical sediment sorting. However, the decrease in grain size toward the foredune may make this area more vulnerable to wind erosion, as fine sands are more easily transported by wind, particularly under the influence of the dominant northwesterly winds. In contrast, at the northern and southern ends of the Massa coastal cell, the presence of rocky outcrops on the foreshore increases wave energy and turbulence, which can lead to greater erosion of adjacent beaches. These areas are therefore less stable due to more intense hydrodynamic activity, which limits the deposition of fine sediments and favors coarser grain sizes.

5. Conclusion

The study of the morphological evolution of the Massa beaches using an electronic total station allowed us to track the seasonal dynamics of the beaches and their morphodynamic response to winter and summer hydrodynamic variations. This study is complemented by a granulometric analysis of the predominant sandy materials during the different measurement campaigns. The spatialization of various sorting parameters (Median, Sorting, Skewness) using a Geographic Information System (GIS) also provided a global view of sediment distribution on the beaches during the winter and summer seasons. The results obtained from this work indicate a normal morphological cycle for the Massa beaches, characterized by erosion in winter and accumulation in summer. This morphological cycle reflects the beaches' significant ability to restore their sediment stock lost during the winter seasons. This result is primarily explained by the intermediate to dissipative physical behavior that predominates on these beaches, as well as the presence of a well-developed foredune that helps maintain the morphodynamic equilibrium of the beaches on a seasonal scale. Additionally, the spatialization of the different granulometric indices from the samples collected simultaneously with the topographic surveys shows an increase in average grain size at the mouth of the Massa River and at the northern and southern ends of the beaches. Furthermore, the grain size decreases progressively from north to south and from the foreshore to the foredune, in the direction of the prevailing winds. The observed grain size distribution has significant implications for the morphodynamic balance and erosion of the studied beaches. This study could serve as a critical platform for understanding the dynamics of the Massa beaches on a seasonal scale, particularly in a global context marked by climate change and rising sea levels.

Acknowledgement

The authors express their gratitude to the local authorities who allowed us to carry out measurements on beaches located within an integral protection zone in the Souss Massa National Park. A special thanks also goes to the Dean of the Faculty of Letters and Humanities, who permitted us to conduct granulometric analyses at the Geomorphology Laboratory.

Author contributions

M'hamed Nmiss, Mhamed Amyay and abderrahmane Ouammou: Conceptualization, Methodology, Field study, Writing-Original draft preparation, Data Analysis. **Mahjoub benbih, Hassan Nait-si and Nadia Atiki**: Data collection Data analysis, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Luijendijk, A., Hagenaars, G., Ranasinghe, R., Baart, F., Donchyts, G., & Aarninkhof, S. (2018). The state of the World's beaches. Scientific Report 8, 1-11 https://doi.org/10.1038/s41598-018-24630-6
2. Aouiche, I., Daoudi, L., El mimouni, A, Ihbach, f., Sedrati,M., & Ouahmane, B. (2016). Dynamique morpho-sédimentaire de la baie d'Agadir: Caractérisation sédimentologique et évolution des petits fonds. Revue Marocaine de Géomorphologie,1, 31- 46.
3. Coco, G., Senechal, N., Rejas, A., Bryan, K.R., Capo, S., Parisot, J.P., Brown, J.A., & MacMahan, J.H.M. (2014). Beach response to a sequence of extreme storms. Geomorphology, 204, 493-501. https://doi.org/10.1016/j.geomorph.2013.08.028
4. Scott, T., Masselink, G., O'Hare, T., Saulter, A., Poate, T., Russell, P., Davidson, M., & Conley, D. (2016). The

extreme 2013/2014 winter storms: Beach recovery along the southwest coast of England. Marine Geology, 382, 224-241. https://doi.org/10.1016/j.margeo.2016.10.011

5. Holman, R. A., & Stanley, J. (2007). The history and technical capabilities of Argus. Coastal engineering, 54, 477-491. https://doi.org/10.1016/j.coastaleng.2007.01.003
6. Pianca, C., Holman, R., & Siegle, E. (2015). Shoreline variability from days to decades: Results of longterm video imaging. Journal of Geophysical Research: Oceans, 120, 2159-2178.
7. Hagenaars, G., de Vries, S., Luijendijk, A.P., de Boer, W.P., & Reniers, A.J.H.M. (2018). On the accuracy of automated shoreline detection derived from satellite imagery: A case study of the sand motor mega-scale nourishment. Coastal Engineering, 133, 113–125.
8. Elsner, P., Dornbusch, U., Thomas, I., Amos, D., Bovington, J., & Horn, D. (2018). Coincident beach surveys using UAS, vehicle mounted and airborne laser scanner: Point cloud intercomparison and effects of surface type heterogeneity on elevation accuracies. Remote Sensing of Environment, 208, 15-
9. Maras, E.M., & Karafazli, K.N. (2024). Monitoring coastal erosion and sediment accumulation in the Kızılırmak Delta using UAVs and photogrammetry. Advanced UAV,4 (1), 42-52. DOI:10.53093/mephoj.1176847
10. Pathak, S., Acharya, S., Bk, S., Karn, G., & Thapa, U. (2024). UAV-based topographical mapping and accuracy assessment of orthophoto using GCP. Mersin Photogrammetry Journal, 6 (1), 01-08. DOI:10.53093/mephoj.1350426
11. Yakar, M.; Yılmaz, H.M.; Mutluoğlu, Ö. Comparative evaluation of excavation volume by TLS and total topographic station based methods. Lasers Eng. 2010, 19, 331–345
12. Smithers, S. G., & Hoeke, R. K. (2014). Geomorphological impacts of high-latitude storm waves on low-latitude reef islands observations of the December 2008 event on Nukutoa, Takuu, Papua New Guinea. Geomorphology, 222,106-121. https://doi.org/10.1016/j.geomorph.2014.06.017
13. Sahu, B.K. (1964). Depositional mechanisms from the size analysis of clastic sediments. Journal of sedimentary petrology, 34,1,73-83.
14. Pinot, M., & Jaramillo, E. (1992). Morphology, Texture and Mineralogical Composition of Sandy Beaches in the South of Chile. Journal of Coastal Research, 8 (3), 593-602. DOI: 10.2112/1551-5036-8.3.593
15. Abuodha, J.O.Z. (2003). Grain size distribution and composition of modern dune and beach sediments, Malindi Bay coast, Kenya. Journal of African Earth Sciences 36, 41–54. DOI: 10.1016/S1464-343X(03)00007-0.
16. Nmiss, M., Amyay, M., Atiki, N., Benbih, M., & Nait-Si, H. (2024). Quantifying sediment flux under moderate wave energy on beaches south of Agadir, Morocco. Ecological Engineering and Environmental Technology, 26 (1), 78-91. DOI: 78-91. 10.12912/27197050/157497.
17. Matin, N., & Jahid, H. (2021). A quantitative analysis of shoreline changes along the coast of Bangladesh using remote sensing and GIS techniques. CATENA, 201,1-17. DOI:10.1016/j.catena.2021.105185.
18. Mbezi, J., Mango, J., Lubida, A., Valerian, R., & Kato, L. (2024).Exploring shoreline changes and their implications in coastal communities using GIS and remote sensing techniques: The case of eastern beaches of Unguja island, Tanzania. Regional Studies in Marine Science, 75, 1-15. https://doi.org/10.1016/j.rsma.2024.103566
19. Nmiss, M., Amyay, M., & Ouammou, A. (2020). Apport des SIG et de la télédétection dans la détermination et le suivi de la dynamique de ligne de rivage: application sur le littoral de la baie d'agadir et des Chtouka ouest (Maroc). Revue Géomagherb. 16, 34-43.
20. Nmiss, M., Amyay, M., Atiki, N., & Irifi H. (2019).Apport du SIG et de la télédétection au suivi de la dynamique des espaces côtiers: Application sur le littoral de la baie d'Agadir (Maroc). Publications de la faculté des Lettres et Sciences Humaines,Oujda, 51-62
21. Clarke, K.C. (1986). Advances in geographic information systems. Computers, environment and urban systems, 10 (3),175-18. https://doi.org/10.1016/0198-9715(86)90006-2
22. Jonuzi, E., Alkan,T., Durduran,S.S., & Selvi, H.Z. (2024). Using GIS-supported MCDA method for appropriate site selection of parking lots: the case study of the city of tetovo, North Macedonia. International journal of Engineering and Geosciences, 9 (1),86-98. https://doi.org/10.26833/ijeg.1319605
23. Paul, S. (2022). Change detection and future change prediction in habra I and II block using remote sensing and GIS- A case study. International journal of Engineering and Geosciences,2022, 7(2),191-207. https://doi.org/10.26833/ijeg.975222
24. Rahman, S.A., Islam,Md.M., Salman,Md.A., & Rafiq, M,R. (2022). Evaluating bank erosion and identifying possible anthropogenic causative factors of Kirtankhola River in Barishal, Bangladesh: an integrated GIS and Remote Sensing approaches. International journal of Engineering and Geosciences,7(2),179-190. DOI: 10.26833/ijeg.947493
25. Eminoğlu, Y., & Tarhan, Ç. (2024). Decadal evolution of GIS in disaster management and risk assessment. International Journal of Engineering and Geosciences, 10 (2), 173-196. https://doi.org/10.26833/ijeg.1544048
26. Khasanov, k., & Bakiev, M. (2025). GIS-Based Geostatistical Techniques for Sedimentation Assessment Using USV Data: Case study Tuplang Reservoir, Uzbekistan. International Journal of Engineering and Geosciences, 10 (2), 231-234. https://doi.org/10.26833/ijeg.1567019
27. Yakar, M., Yilmaz, H. M., & Mutluoglu, O. (2014). Performance of photogrammetric and terrestrial laser scanning methods in volume computing of excavtion and filling areas. Arabian Journal for Science and Engineering, 39, 387-394

28. Nait-Si, H., Ouammou, A., & Nmiss, M. (2022). Apport du SIG dans l'analyse physique et hydrographique dans un bassin versant anti-atlasique. Cas du bassin versant de l'oued Adoudou. Publication de la faculté des Lettres et des Sciences Humaines-Oujda,53-58.
29. Tifratine, S., Taj-Eddine, K., Algouti, A., & Cunha, P.P. (2020). Sedimentological, mineralogical and geochemical investigation of Essaouira's coastal dune system: potential origin and provenance. Arabian Journal of Geoscience, 13, 1-16.
30. Nmiss M, Anthony, E, Amyay, M, & Ouammou, A. (2022). Multi-decadal shoreline change, inherited coastal morphology and sediment supply in the Souss-Massa littoral cell (Morocco), and a prognosis with sea-level rise. Journal of African Earth science,196, 1-12.
31. Naji, E., Aberkan, M., Saadane, A., & Nmiss, M. (2025). Erosion and shoreline retreat indicators in the Rabat-Salé littoral and their impact on coastal planning. Journal of African Earth Sciences, 223, 1-
32. Unel, F. B., Kusak, L., & Yakar, M. (2023). GeoValueIndex map of public property assets generating via Analytic Hierarchy Process and Geographic Information System for Mass Appraisal: GeoValueIndex. Aestimum, 82, 51-69
33. Nmiss, M., Amyay, M., Atiki, N., & Tnourji, H. (2021). The morphological consequences of the storm of 1 March 2018 on a highly anthropized beach: the case of Agadir bay. Publication de la faculté des Lettres et des Sciences Humaines-Oujda, 27-33.
34. Mhammdi, N., Medina, F., Belkhayat, Z., El Aoula, R., Geawahri, M.A., Chiguer, A. (2020). Marine storms along the Moroccan Atlantic coast: an underrated natural hazard? Journal of African Earth Science. 163, 1-15. https://doi.org/10.1016/j.jafrearsci.2019.103730
35. Aouiche, I., Daoudi, L., Anthony, E. J., Sedrati, M., Ziane, E., Harti, A., & Dussouillez, P. (2016). Anthropogenic effects on shoreface and shoreline changes. Input from a multi-method analysis, Agadir Bay, Morocco. Geomorphology, 254,16-31. https://doi.org/10.1016/j.geomorph.2015.11.013
36. Bourhili, A., El Khalidi, K., Minoubi, A., Maanan, M., & Zourarah, B. (2023). Periodical Morphodynamic Changes of Sand Movements at El Jadida Beach. Ecological Engineering & Environmental Technology, 24 (4),15–26, DOI: 10.12912/27197050/162253.
37. Aangri, A., Hakkou, M., Krien, Y., Chtioui, T., & Benmohammadi, A. (2024). Risk Assessment of Marine Flooding along the Agadir and Taghazout Coasts (Moroccan Atlantic). Journal of coastal Research,40,179-192. DOI: 10.2112/JCOASTRES-D-23-00033.1
38. Lharti, S., Florb, G., El kasmi, S., Flor-Blanco, G., El Janati, M., Marcelli, M., Piazzolla, D., Scanu, S., Della Venturae, G., Boukili, B., & El Moutaoukkil, N. (2024). Multi-decadal evolution of the Moroccan Atlantic shoreline: A case study from the Essaouira coastal sector. Journal of African Earth Science,212,1-24. https://doi.org/10.1016/j.jafrearsci.2024.105191.
39. Nmiss, M. (2023). Morphologie et dynamique actuelle du littoral atlantique marocain entre oued Massa et oued Souss. [Thèse de doctorat, Université Sidi Mohamed Ben Abdellah-Fès].
40. Atiki, N., Tnourji, H., Nmiss, M., & Ouammou, A. (2021). Dynamique des vents et leurs implication dans la répartition des dunes dans la plaine de Souss Massa (centre ouest du Maroc). Publication de la faculté des Lettres et des Sciences Humaines-Oujda,103-109.
41. Yakar, M., Yilmaz, H. M. & Mutluoglu, O. (2010). Close range photogrammetry and robotic total station in volume calculation. International Journal of the Physical Sciences. 5(2), 086-096.
42. Cohen, O. (2014).Profiler 3.1 XL, un logiciel gratuit pour la construction et l'analyse de profils topographiques dans Microsoft Excel©. XIIIèmes Journées Nationales Génie Côtier – Génie Civil, 557-564. DOI : 10.5150/jngcgc.2014.061
43. Battjes, J. (1974). Surf similarity. Proceedings of 14th Coastal Engineering Conference, Copenhagen, Denmark. American Society of Civil Engineers, New York, 466-480. https://doi.org/10.1061/9780872621138.029
44. Folk R, L., Ward W, C. (1957). Brazos River bar: a study in the significance of grain size parameters. Journal of sedimentary petrology, 27 (1) 3-26. https://doi.org/10.1306/74D70646-2B21-11D7-8648000102C1865D
45. Blott, S,J ., Pye, K. (2001). GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface. Process and Landforms, 26, 1237-1248. https://doi.org/10.1002/esp.261
46. Masselink, G., Short, A.D. (1993). The effect of tide range on beach morphodynamics and morphology: a conceptual beach model. Journal of Coastal Research. 9 (3), 785-800. https://www.jstor.org/stable/4298129
47. Nmiss, M., Amyay, M., & Ouammou, A. (2021). Dynamique du trait de côte d'une plage peu anthropisée cas de la plage Sidi Ouassai, Massa (Maroc Atlantique). Publication de la faculté des lettres et des sciences humaines-Oujda, 249-256.