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Article

Evolution of the Shoreline Between the Ports of Valencia and Sagunto (1957-Present)

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Abstract

Coastal areas are increasingly affected by erosion due to climate change and human interventions, threatening the stability of many shorelines. Understanding coastal dynamics is therefore crucial for developing effective conservation and management strategies. This study analyses the evolution of the coastline between the Port of Valencia and the Port of Sagunto from 1957 to the present. Using Geographic Information Systems (GIS), including QGIS and the DSAS extension, five shoreline change indicators (EPR, LRR, NSM, SCE, and WLR) were calculated based on coastlines extracted from orthophotos and satellite images. The analysis was conducted across five distinct zones and three temporal scales (long, medium, and short term) to capture spatial and temporal variations. The results reveal significant heterogeneity: the Arenas–Malvarrosa–Patacona area shows long-term accretion but recent erosion, Port Saplaya shows moderate erosion, Pobla de Farnals is undergoing strong regression, Puzol appears recently stabilized, and Marjal dels Moros, historically stable, now exhibits increasing retreat. Overall, coastal evolution in the study area is influenced by both natural processes and human actions. The data provide valuable insights for medium- and long-term coastal planning and sustainable territorial management.

Keywords: shoreline; geographic information systems (GIS); coastal evolution; coastal management; erosion; accretion; western mediterranean

1. Introduction

The coastline represents a dynamic space of great ecological, economic, and social value [1]. However, it is also one of the most fragile environments on the planet [2], subject to constant interaction between terrestrial, atmospheric and marine processes that shape its morphology [3].

The coastal zone, due to its transitional nature between the terrestrial and marine environments, hosts a wide variety of ecosystems and natural resources. This environmental richness, combined with its accessibility and scenic value, has historically encouraged the concentration of population and economic activities nearby. It is estimated that around 60% of the population is concentrated along the coastline [4]. Over time, this phenomenon has intensified, especially since the late 19th century, when the growth of tourism in Europe solidified the recreational use of beaches [5]. Since then, the coastline has experienced increasing occupation, linked to the expansion of urban infrastructure and the rising demand for tourism services [6,7]. This trend has been particularly pronounced in regions such as the Mediterranean, where the number of residents and visitors has grown significantly in recent decades [8–10]. The growing influx of users has influenced the way beaches are managed. Today, many decisions focus on meeting public needs, prioritizing recreational use over ecological or conservation criteria [11]. Furthermore, to address the risks associated with erosion and to protect urbanized areas near the sea, regenerative measures such as beach nourishment are undertaken, along with the construction of various defense structures like groynes or breakwaters. However, these interventions, far from solving the problem, have disrupted the

natural balance of the coastal system by interrupting sediment transport and promoting erosion processes in other areas of the coastline [12].

On the other hand, the shoreline is one of the most complex elements to delineate within the coastal system due to its dynamic and changing nature [13]. Although it can be basically defined as the meeting point between land, sea, and atmosphere [14], this description is insufficient when attempting to accurately quantify the processes of retreat or advance of the coastal strip. Its exact location is influenced by multiple factors, such as the slope of the beach profile, sea level fluctuations, and wave intensity, which can create ambiguities when interpreting the shoreline at different times [15,16]. In this context, the coastline undergoes changes at different temporal scales. In the short term—ranging from hours to days—the effects of storms, tides, and storms dominate, which can cause significant variations in the profile without indicating a real trend [17]. In the medium and long term—spanning decades to centuries—factors such as changes in sediment balance, sea level rise, and human intervention come into play [18–21]. However, the high short-term variability can obscure underlying trends, so numerous studies recommend using long time series, with records distributed over more than ten years, to more reliably detect the evolutionary behavior of the coastline [17,22].

Finally, among the agents influencing coastal evolution, those induced by human activity can be distinguished from those of natural origin. The main natural factors are sea level fluctuations, wave patterns, currents, and storms. The role of anthropic activity is increasingly decisive, both due to the reduction of sediment supply—through reservoirs, urbanization, or dune destruction—and the installation of infrastructures that modify longitudinal sediment transport, such as ports, groynes, or breakwaters. These types of alterations cause sediment accumulation on the updrift side of the structures and erosive processes downstream [21,23,24]. Furthermore, climate change is intensifying these natural and anthropogenic dynamics. The alteration of hydrodynamics and the sea level rise increase the rate and extent of erosion, as well as a greater risk of coastal erosion [25]. In this regard, the IPCC projections (2007), cited by Maio et al. [26], estimate a possible sea level rise of up to one meter by the end of the century. Although recent predictions are less dramatic, an increase in sea level could worsen coastal retreat, as is currently observed in one-quarter of the coastline of the Valencian Community [1].

In this context, to study these changes, the comparison of shorelines based on historical data has become one of the most widely used methodologies [21]. This approach allows for determining rates of erosion or accretion depending on the mechanisms influencing the coast, thereby projecting possible future changes, which is key for spatial planning [27,28]. However, shoreline analysis can present limitations when based on isolated observations or very short periods. Seasonal variations, run-up, or sea level fluctuations can induce errors if there are not enough records distributed in a representative manner [20]. In recent years, the use of technologies such as satellite imagery, aerial photography, LiDAR sensors, video surveillance, and RTK-GPS has increased the capacity for observation and precision in detecting the shoreline. Despite this, satellite images have spatial resolution limitations that affect erosion rate calculations, though they enable digital processing to enhance shoreline extraction [6,14]. To facilitate analysis, tools such as Geographic Information Systems (GIS) have become essential, as they allow for the comparison of spatial data from different periods and the analysis of the morphological evolution of the coastal strip [6,29]. Finally, the Digital Shoreline Analysis System (DSAS) complement enables quantification of shoreline changes both in the short [30,31] and long term [32].

This study focuses on analyzing the evolution of the coastline between the Port of Valencia and the Port of Sagunto from 1957 to the present day. The aim is to quantify changes in the shoreline over time through the application of Geographic Information System (GIS) tools and the calculation of key quantitative indicators, including the End Point Rate (EPR), Linear Regression Rate (LRR), Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), and Weighted Linear Regression (WLR). The objective of the research is to identify areas affected by predominant erosion or accretion processes, the interpretation of which will be related to both anthropogenic and natural factors. The results obtained will be an important contribution to coastal management, environmental

conservation, and land-use planning in vulnerable coastal regions. This research constitutes an important contribution to our understanding of the coast, as until now, no comprehensive analyses of coastal evolution have been conducted for the coastal section in this area, except for regional studies or isolated geomorphological observations.

2. Study Area

The study area covers approximately 20 km of coastline and is located in the province of Valencia (Valencian Community, Spain), specifically in the coastal section between the Port of Valencia and the Port of Sagunto (Figure 1). This area is characterized geomorphologically by the presence of beaches, fossil dunes, and alluvial plains [33].

From an oceanographic perspective, a microtidal regime is observed, with a range of less than 30 cm and an astronomical component of about 8–10 cm, typical of the western Mediterranean [4]. However, meteorological storm surges constitute the main factor causing sea level variations, which can reach up to 45 cm during extreme events, such as Storm Gloria in 2020. These surges are associated with sudden drops in atmospheric pressure, with an average response estimated between 2 and 3 cm per hectopascal (hPa) in the Mediterranean, whose sensitivity is greater than that recorded in the Atlantic (around 1.5 cm/hPa) due to the semi-enclosed nature of the Mediterranean Sea [34].

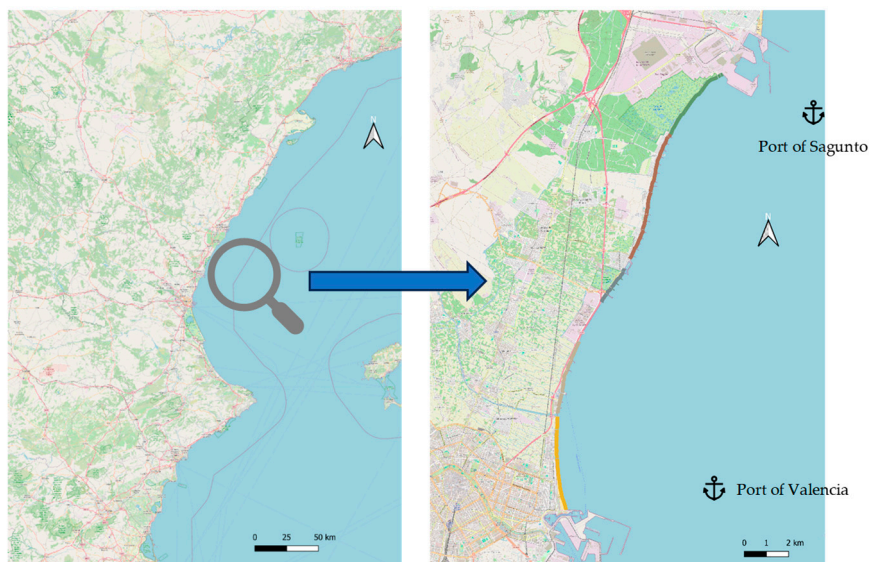


Figure 1. Study area between the Port of Sagunto and the Port of Valencia. Source: OpenStreetMap (2024). Software used: QGIS.

From a climatic perspective, the Valencian coastline experiences average temperatures of approximately 24.6 °C in July and 10.3 °C in January, with average annual precipitation ranging between 500 and 750 mm. Additionally, the prevailing winds in the area have a direct influence on the direction of incoming waves, which affects the formation of coastal currents and the transport of sediments along the shore [4]. The coastal currents in the area have a net southward direction, mainly driven by the prevailing east and northeast winds [34,35].

To characterize the marine dynamics and wave conditions in the stretch between the Port of Valencia and the Port of Sagunto, as shown in Figure 2, data from satellite SIMAR 2081115, managed by Puertos del Estado [35], have been used. This buoy was selected for its proximity to the studied coast, allowing for representative recordings of the oceanographic conditions along the coastline under study. Although no significant trend has been detected in the increase of storm surges (1993–2022), the frequency of extreme events appears to be rising; this is the case in Valencia, where the annual hours with storm surges (SS) greater than 20 cm have increased by +1.5 mm/year [34]. Global

studies such as those by Griggs and Reguero [36] warn that rising sea levels and increased storm intensity will heighten flood risks in coastal wetlands, affecting vulnerable areas like Marjal dels Moros, due to its lower topography.

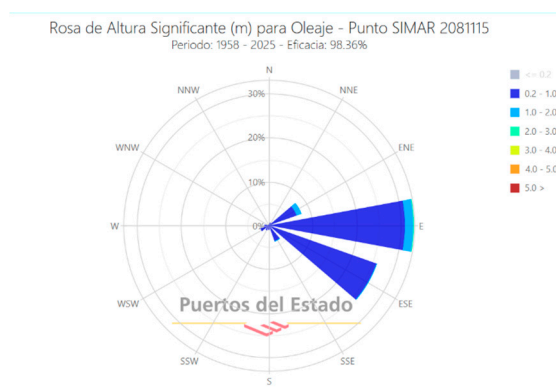


Figure 2. Significant Wave Height Rose (m) from 1958 to 2025 for the study area. Source: Puertos del Estado (2024).

The area as a whole is considerably anthropized and features a wide variety of coastal infrastructures that modify the coastal dynamics and shoreline. This stretch is bounded to the south by the Port of Valencia and to the north by the Port of Sagunto, two port infrastructures that act as barriers to the north-south longitudinal sediment transport. Additionally, throughout the studied sector, a large number of groynes, breakwaters, dikes, and promenades are distributed, which interfere with the coastline and alter accumulation and erosion patterns, limiting the natural processes of beach regeneration. The distribution of these structures is greater in urbanized areas compared to more natural zones.

Finally, in some sectors of the study area, regenerative measures were carried out to restore ecosystems and protect the coastline against erosive processes. On one hand, a volunteer action coordinated by Acció Ecologista-Agró Horta Nord, in collaboration with the Sagunto City Council, restored the flora of the dunes at Puzol Beach [37]. This measure, in addition to contributing to the conservation of native flora, also increased the area's resistance to erosion by protecting the dune system. On the other hand, in Marjal dels Moros, the coastline was replenished with external sandy material as a soft measure to preserve it against storms [38]. These types of regenerative actions help restore environments and mitigate erosion.

3. Materials and Methods

To carry out the study of the coastline evolution in the stretch between the Port of Valencia and the Port of Sagunto from 1956 to 2024, a series of satellite images and orthophotos of the area within that time frame were obtained. These images were downloaded from the data sources of the official websites of the National Geographic Institute (IGN) and the Valencian Cartographic Institute (ICV) (Table 1) and were projected to the UTM Zone 30N coordinate system (EPSG: 25830) in order to work with more precise and reliable data. Once the images were obtained, they were added to the QGIS software (version 3.40). Then, each shoreline was manually digitized using a polyline composed of multiple points, following a consistent criterion for each one of them (Figure 3).

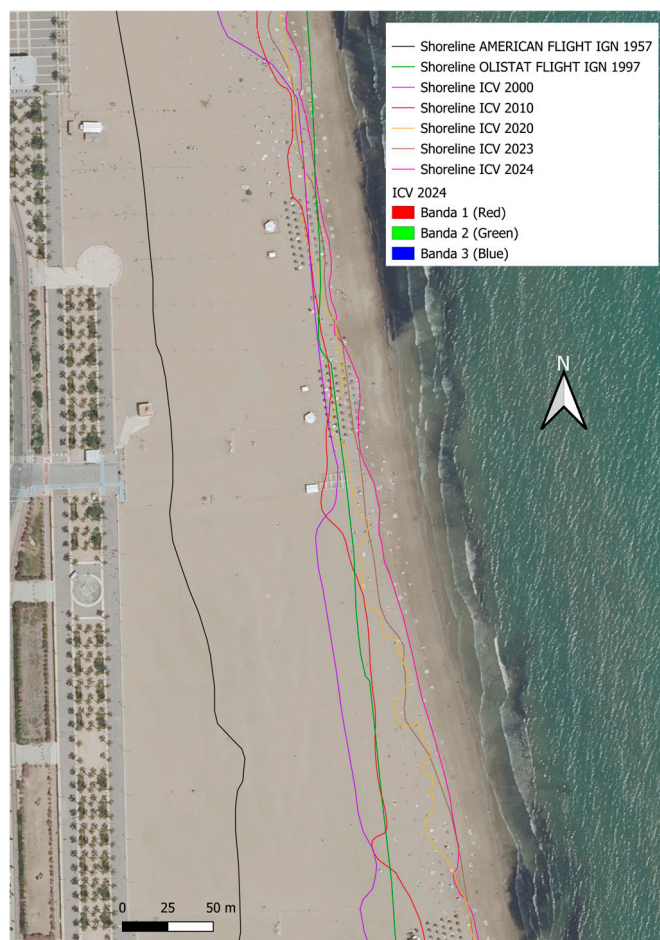


Figure 3. Digitalization of the shoreline of the coastline located in the study zone by QGIS, applying the wet-dry boundary (Shoreline 1957, 2000, 2010, 2020, 2023 and 2024).

To delineate the shoreline, the visual criterion of the transition between the dry zone and the wet part of the beach was used, that is, the wet-dry boundary, which marks the usual reach of the water [39]. Since this is a microtidal area, this criterion aligns with the study's objective [17]. Moreover, this widely used and recognized criterion allows for clear distinction of the shoreline in aerial photographs and shows relative stability against momentary variations in waves or tides, making it a good indicator of the coastal position [16]. Once the shorelines from each of the obtained images were digitized, the DSAS extension [40] was used to calculate the distances between them, enabling a more precise analysis. This tool generates perpendicular profiles, called transects, from a baseline and calculates various metrics that quantify the changes in the shoreline over time.

Table 1. Satellite images and orthophotos used for the study, along with their respective dates, spatial resolution, and source of origin.

Name	Date	Spatial resolution	Origin
American flight	01/01/1957	0.5 m	IGN
OLISTAT flight	15/10/1997	1 m	IGN
2000	15/08/2000	0.5 m	ICV
2004	22/06/2004	0.5 m	ICV
2006	25/07/2006	0.5 m	ICV
2008	03/09/2008	0.5 m	ICV
2010	29/11/2010	0.25 m	ICV
2012	07/07/2012	0.5 m	ICV
2015	19/06/2015	0.25 m	ICV

2017	16/07/2017	0.25 m	ICV
2018	19/07/2018	0.25 m	ICV
2019	06/06/2019	0.25 m	ICV
2020	16/05/2020	0.25 m	ICV
2021	15/06/2021	0.25 m	IGN
2022	25/05/2022	0.25 m	ICV
2023	11/06/2023	0.25 m	ICV
2024	11/07/2024	0.25 m	ICV

To perform the calculations in DSAS, a baseline parallel to the most stable shoreline was created to serve as a reference for generating the transects. The transects were generated perpendicular to this baseline, with a length of 150 meters, a spacing of 20 meters, and a smoothing distance of 200 meters. Using the transects and shorelines from different years, and applying the statistics tool included in DSAS, a series of parameters were obtained:

- a) End Point Rate (EPR): Calculates the total change in the shoreline by dividing the net shoreline movement (NSM) by the number of years between the first and last dates of the analysis, expressed in meters per year. Its main strength lies in its simplicity of calculation. However, since it is based only on two time points, it does not consider the available intermediate data, which can limit its ability to adequately reflect changes or trends over time. For this reason, it is common to compare its results with more robust methods, such as linear regression or weighted regression, which take multiple observations into account [41].
- b) Linear Regression Rate (LRR): Estimates the overall trend of coastal change by fitting a linear regression line to all available shoreline positions. In this calculation, the linear regression is derived from the intersection points of each transect, and the slope represents the rate of change expressed in meters per year. It is a useful tool for predicting how the coastline may evolve in the future and allows for assessing whether there is a clear relationship between the passage of time and shoreline movement. However, it can be affected by outliers that skew the results and, in some cases, tends to produce a lower rate of change compared to other methods [17].
- c) Net Shoreline Movement (NSM): Represents the distance (m) between the oldest and most recent shoreline positions, without considering the time elapsed [32].
- d) Shoreline Change Envelope (SCE): Indicates the maximum distance (m) between the most distant shoreline positions, regardless of their temporal order [40].
- e) Weighted Linear Regression (WLR): Similar to LRR, but incorporates the uncertainty of each shoreline position as a weighting factor in the analysis, reducing the impact of less precise data and improving the reliability of the statistical fit [40]. It is used to represent how the shoreline has evolved over time. This method allows identification of areas that have changed more rapidly, helping to highlight zones that may be more vulnerable to erosion [17,42].

These indicators allow for a detailed analysis of erosion and accretion processes along the coast, as well as the detection of potential spatial or temporal behavior patterns. Positive values of the parameters indicate a seaward movement of the shoreline (accretion), while negative values indicate a landward movement (erosion). To conduct a more detailed analysis and more clearly identify the shoreline behavior patterns, the study area was divided into five distinct sections based on the geomorphological, sedimentary, and anthropogenic characteristics of the coast.: Arenas - Malvarrosa - Patacona, Port Saplaya, Pobla de Farnals, Puzol, and Marjal dels Moros (Table 2).

At the sedimentary level, beaches composed of sand and pebbles dominate all five zones [33], especially in zones 1, 3, and 4. From an anthropogenic perspective, all areas are characterized by a significant presence of coastal defense structures (groynes and breakwaters), which alter the coastal dynamics, in addition to existing port infrastructures. In zone 5, slag deposits resulting from the industrial activity of the Altos Hornos de Sagunto stand out, acting as a barrier against erosion [24].

Table 2. Study areas, distributed from South to North, with their respective number of transects, names, extent, and main characteristics of the beaches.

Nº	Transects	Name of the zone	Extension (m)	Limits	Sediment	Main anthropic structures
1	1-215	Arenas - Malvarrosa - Patacona	4.280	39° 27' 47.16" N 0° 19' 11.76" W 39° 30' 4.43" N 0° 19' 22.70" W	Fine sands and pebbles	Port of Valencia 1 breakwater Seafront promenade
2	216-386	Port Saplaya	3.400	39° 30' 8.67" N 0° 19' 22.27" W 39° 31' 33.48" N 0° 18' 50.16" W	Fine sands and gravels	4 transversal groynes 2 breakwaters Seafront promenade
3	387-481	Pobla de Farnals	1.920	39° 32' 52.76" N 0° 17' 52.55" W 39° 33' 37.87" N 0° 17' 5.84" W	Fine sands and pebbles	Marina 4 groynes 3 breakwaters Seafront promenade
4	482-787	Puzol	6.220	39° 33' 51.84" N 0° 16' 55.12" W 39° 36' 55.03" N 0° 15' 31.08" W	Fine sands and pebbles	18 groynes 1 breakwater Seafront promenade
5	788-1000	Marjal dels Moros	3.580	39° 36' 55.03" N 0° 15' 31.08" W 39° 38' 18.85" N 0° 13' 54.07" W	Fine sands	Port of Sagunto 1 embankment

It is important to consider the limitations of this study, as it is based on images with varying resolutions and temporal coverages, whose characteristics may influence the manual digitization of the shorelines. Additionally, the study area contains a large number of anthropogenic structures that alter the shoreline and sediment balance.

4. Results

The average values obtained for each parameter in the five delineated zones are shown in Figure 3, broken down into three different temporal scales: long term (1957-2024), medium term (1997-2024), and short term (2015-2024) (Table 3). Statistical values for each of the five analyzed parameters (EPR, LRR, NSM, SCE and WLR) were obtained. The results of this study include: mean, median, standard deviation, total sum, minimum, maximum, range, as well as the values of the first quartile (Q1), third quartile (Q3), and the interquartile range (IQR). These values are shown in the appendix.

Table 3. Mean values of the indicators EPR, LRR, NSM, SCE, and WLR obtained for each of the five zones, divided into three different temporal scales.

1957-2024						
Nº	Zona	\bar{x} EPR	\bar{x} LRR	\bar{x} NSM	\bar{x} SCE	\bar{x} WLR

1	Arenas - Malvarrosa - Patacona	0.963	0.877	58.422	76.313	0.812
2	Port Saplaya	-0.250	-0.274	-16.155	47.633	-0.238
3	Pobla de Farnals	-0.709	-0.570	-43.989	68.882	-0.388
4	Puzol	-0.271	-0.230	-18.361	51.295	-0.194
5	Marjal dels Moros	-0.004	0.031	-2.367	33.948	-0.007
1997-2024						
Nº	Zona	\bar{x} EPR	\bar{x} LRR	\bar{x} NSM	\bar{x} SCE	\bar{x} WLR
1	Arenas - Malvarrosa - Patacona	-0.396	-1.468	-3.670	28.398	-1.468
2	Port Saplaya	-0.084	-0.448	-0.084	-0.084	-0.084
3	Pobla de Farnals	-0.939	-0.134	-8.509	35.490	-0.134
4	Puzol	0.577	0.049	5.206	23.888	0.049
5	Marjal dels Moros	-0.506	-0.522	-4.549	9.211	-0.522
2015-2024						
Nº	Zona	\bar{x} EPR	\bar{x} LRR	\bar{x} NSM	\bar{x} SCE	\bar{x} WLR
1	Arenas - Malvarrosa - Patacona	-0.267	-1.433	-2.416	28.811	-1.433
2	Port Saplaya	-0.087	-0.450	-0.783	21.781	-0.450
3	Pobla de Farnals	-1.047	-0.227	-9.288	36.011	-0.227
4	Puzol	0.605	0.060	5.550	24.496	0.060
5	Marjal dels Moros	-0.510	-0.529	-4.623	9.226	-0.529

With the aim of clearly and comparatively representing the results graphically, the LRR parameter was selected. Unlike other parameters such as NSM or SCE, which can be more influenced by extreme values or isolated changes, LRR offers a more consistent view of coastal behavior over time, allowing for the identification of a general and stable trend in shoreline evolution [17]. Figure 4 shows the evolution of the LRR indicator across the five study zones over three different time periods: 1957–2024 (long term), 1997–2024 (medium term), and 2015–2024 (short term).



Figure 4. Spatial division of the study area into five subzones: Arenas – Malvarrosa – Patacona (Zone 1), Port Saplaya (Zone 2), Pobla de Farnals (Zone 3), Puzol (Zone 4), and Marjal dels Moros (Zone 5).

In Figure 4.1 (1957–2024), gentle fluctuations are observed in most zones, with generally positive values standing out in Zone 1 (Arenas - Malvarrosa - Patacona) and negative values in Zones 2, 3, and 4 (Port Saplaya, Pobla de Farnals, and Puzol). In Zone 5 (Marjal dels Moros), there is a noticeable trend towards positive values in the final section.

The variations in the LRR progressively increase when the 1997-2024 time interval is considered (Figure 4.2). All zones exhibit more pronounced peaks, both positive and negative. Notably, there is a very pronounced minimum value in Zone 5, which did not appear in the longer-term timeframe. Additionally, more intense oscillations are identified in the central zones (Zones 2, 3, and 4).

In the shortest time interval (2015-2024) a general trend toward negative values is observed in most of the sections (Figure 4.3). Zone 5 maintains a graph shape similar to that of the intermediate time interval, with relatively constant low values. Zones 2 and 3 show less variability compared to the longer time frames.

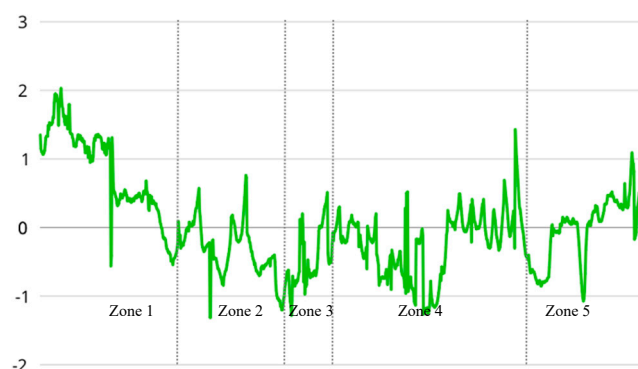


Figure 5. 1. Linear Change Rate (LRR) by study zones for the period 1957-2024. Zone 1: Arenas – Malvarrosa – Patacona, zone 2: Port Saplaya, zone 3: Pobla de Farnals, zone 4: Puzol, zone 5: Marjal dels Moros. Mean values of the indicators EPR, LRR, NSM, SCE, and WLR obtained for each of the five zones, divided into three different temporal scales.

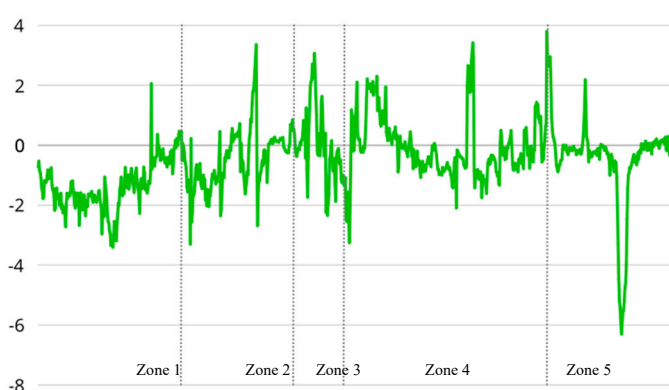


Figure 5. 2. Linear Change Rate (LRR) by study zones for the period 1997-2024. Zone 1: Arenas – Malvarrosa – Patacona, zone 2: Port Saplaya, zone 3: Pobla de Farnals, zone 4: Puzol, zone 5: Marjal dels Moros. Mean values of the indicators EPR, LRR, NSM, SCE, and WLR obtained for each of the five zones, divided into three different temporal scales.

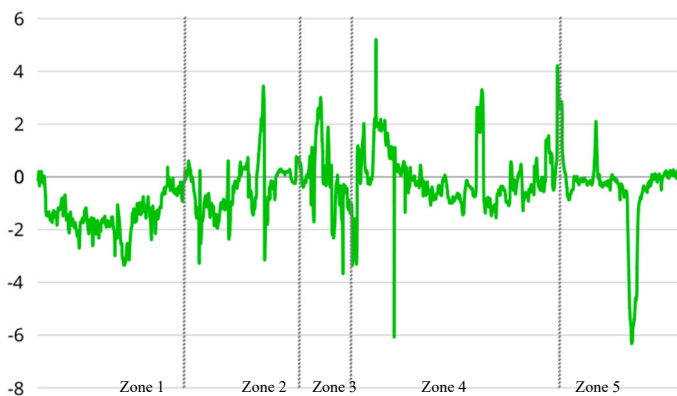


Figure 5.3. Linear Change Rate (LRR) by study zones for the period 2015-2024. Zone 1: Arenas – Malvarrosa – Patacona, zone 2: Port Saplaya, zone 3: Pobla de Farnals, zone 4: Puzol, zone 5: Marjal dels Moros. Mean values of the indicators EPR, LRR, NSM, SCE, and WLR obtained for each of the five zones, divided into three different temporal scales.

5. Discussion

5.1. Comparative Analysis of Average Values by Areas and Time Scales

The analysis of the obtained results has made it possible to identify significant spatial and temporal patterns in the evolution of the coastline. To strengthen the analysis and validate the findings, this information was compared with a recent study conducted by the Geoenvironmental Cartography and Remote Sensing Group (CGAT) of the Polytechnic University of Valencia (UPV), in collaboration with the Valencian Cartographic Institute (ICV), which provides a detailed and up-to-date view of the coastal dynamics in the Valencian region.

Zone 1: Arenas - Malvarrosa – Patacona

In the long term (1957-2024), this zone shows a clear trend of shoreline accretion, as observed in the LRR graph, with an average of 0.88 m/year. Additionally, it presents positive average values for each of the other parameters: NSM of 58.42 m; SCE of 76.31 m; and WLR of 0.81 m/year. This accretion dynamic could be linked to the influence of the Port of Valencia, which since its construction acts as a barrier to the north-south sediment transport, favoring sediment accumulation on the updrift side of the breakwater [21,23,25].

Recent studies, such as the one of Conesa et al. [28], confirm this accretion trend in the area. Specifically, the Malvarrosa Beach width has increased from 48 m to 240 m between 1957 and the present day, in response to the port's effect as a sedimentary barrier.

Despite this trend, the positive evolution has shifted in recent decades. In the medium term (1997-2024), an inversion in the trend is observed, with negative values for EPR (-0.40 m/year) and LRR (-1.47 m/year), suggesting the onset of an erosive phase, which is also confirmed in the 2015-2024 period (mean LRR: -1.43 m/year). This transition has been highlighted in studies such as those by CGAT-UPV, which emphasize the increasing vulnerability of sections not protected by anthropic structures.

The intensification of erosion could be related to the increase in the intensity and frequency of storms, due to the consequences of climate change observed throughout the 19th century, which adds to the sediment scarcity associated with anthropogenic activities (dams, destruction of dune systems, etc.).

Zone 2: Port Saplaya

In the long term (1957-2024), Port Saplaya shows a moderate but steady erosive trend, with average negative values of EPR (-0.25 m/year) and LRR (-0.27 m/year), accompanied by a net coastline loss of -16.15 m (NSM) and a similar rate of shoreline retreat in WLR (-0.23 m/year). This erosive dynamic persists in the medium and short term, with LRR values around -0.44 m/year, suggesting a continuous presence of regressive coastline processes across all time scales.

Despite this, the relatively low NSM and SCE values reflect an apparent stability. According to CGAT-UPV, this may be due to the strong anthropogenic control exerted over this area and the presence of defensive structures, such as groynes, which slow down erosive processes—albeit at the cost of interrupting coastal sediment transport and hindering the natural regeneration of the system.

Zone 3: Pobla de Farnals

In the long term (1957–2024), Pobla de Farnals is characterized by a strong erosive trend, with notably negative values across all analyzed indicators: EPR (-0.71 m/year), LRR (-0.57 m/year), NSM (-43.99 m), and WLR (-0.39 m/year). These data reflect a significant accumulated loss of shoreline in recent decades, making this area one of the most vulnerable stretches of the Valencian coast.

In the medium term (1997–2024), a temporary change in trend is observed, with a positive LRR value (0.13 m/year), suggesting some stabilization or partial recovery of the system during this period. This improvement could be attributed to various factors, such as milder hydrodynamic conditions, targeted interventions, or variations in sediment transport [5]. However, this recovery is not sustained in the short term (2015–2024), as a pronounced negative EPR (-1.05 m/year) is recorded again, indicating that the vulnerability persists and that positive fluctuations may not be sustainable without structural measures or regeneration efforts.

According to Sánchez-Arcilla et al. [42], erosion in the Mediterranean has intensified as a result of the sharp reduction in riverine sediment supply, caused by basin regulation, reforestation, and the construction of dams. This sediment scarcity, worsened by retention in rivers, is one of the key factors identified by CGAT-UPV in their assessment of Pobla de Farnals, classifying it as one of the areas most affected by erosive processes. Additional factors are the intensive urbanization of the coastline and the lack of effective interventions, such as coastal defense structures or regeneration projects, which have left the coast especially exposed to storms, facilitating a progressive retreat of the shoreline.

In this context, Pobla de Farnals represents a clear case of sedimentary imbalance and anthropogenic pressure, where the natural dynamics have been profoundly altered without an effective adaptive response. Erosion not only affects the coastal profile but also threatens infrastructures, urban areas, and nearby ecosystems, highlighting the urgent need for integrated planning and specific protective measures.

Zone 4: Puzol

In the overall analysis (1957–2024), this area shows moderate negative values, with an EPR of -0.27 m/year, an LRR of -0.23 m/year, and an NSM of -18.36 m. However, at the medium scale (1997–2024), the EPR becomes positive (0.58 m/year) and the LRR remains stable at 0.04 m/year, suggesting a possible recovery or phase of stability. In the short term (2015–2024), this period of stability persists, with an EPR of 0.65 m/year and an LRR of 0.06 m/year.

These negative values could be attributed to the influence of the Port of Sagunto and the associated urban developments, which disrupt the coastal drift and cause erosive processes in adjacent sectors such as the stretch between Puzol and Massalfassar [4]. However, stabilization is observed in the medium and short term, which may be related to the strong anthropization of the area, due to the construction of numerous defensive structures and the implementation of regenerative measures that help mitigate erosion, such as the one carried out in 2023 by the Ajuntament de Puçol.

The CGAT-UPV study also recognizes this recent stabilization, although it warns that the defensive works have induced erosion in other stretches, especially towards the south, which highlights the need to plan coastal interventions in an integral manner and not in a sectorial way.

Zone 5: Marjal dels Moros

In the long term (1957–2024), it presents very stable values of EPR (-0.004 m/yr) and LRR (0.03 m/yr), suggesting a relatively balanced coastline, although the values of NSM (-2.37 m) and SCE (33.95 m) indicate some mobility in the coastline. As the period shortens, the dynamics become more regressive, with negative LRR values, both in the medium (-0.52 m/yr) and in the short term (-0.53 m/yr), and similar WLR values, suggesting an increase in coastline regression.

This regression is mainly influenced by the interruption of the coastal drift generated by the Port of Sagunto. This situation is aggravated by the reduction of fluvial sedimentary contributions, due to the construction of the Regajo reservoir in 1959, which has contributed to the sedimentary imbalance and increased regression on the southern coast of the port [43].

In addition, the absence of defensive structures directly on the coastline leaves the marsh particularly exposed to natural erosion processes. However, the presence of slag from the historical dumping of the Altos Hornos de Sagunto, which encrusts the sediment, and the anthropic regeneration interventions carried out by the Ajuntament de Sagunto in 2023, mitigated the effects of erosion in this coastal stretch in the medium and short term. Also noteworthy is the action carried out in 2017 to reinforce the protection of the marsh, with the repair of about 50 meters of the defense mote and the restitution of the protective platform by pouring 850 m³ of boulders from accumulations in nearby breakwaters. Although this intervention did not directly modify the position of the coastline, it did increase the resilience of the system against extreme events [44].

The CGAT-UPV study coincides in pointing out this area as particularly vulnerable, constituting a representative case to evaluate the natural response of the coastline in the absence of intensive and permanent interventions.

5.2. Development of the Coastline Between the Ports of Sagunto and Valencia

Overall, the results show a heterogeneous evolution throughout the five analyzed areas, conditioned by both natural and anthropogenic factors. The urbanized areas have a greater presence of infrastructures (breakwaters, dikes or artificial regeneration) that protect and stabilize the coast, while the natural areas are more vulnerable to erosive processes. The comparison of the results obtained with those of the CGAT-UPV study confirms and reinforces the validity of the data obtained, highlighting the importance of carrying out multiscale analyses that allow observing trends in the coastline over several time scales. These observed trends warn about the need to act against this type of processes, carrying out a more effective coastal planning in the context of climate change and sea level rise.

Considering the scarcity of sediments due to anthropogenic causes (reservoirs, destruction of dune systems, port works, breakwaters, jetties), it is found that the greatest positive displacements are usually related to recent regeneration or areas with active sediment supply. On the contrary, the most negative values, especially in Pobla de Farnals and Puzol, seem to be related to erosive episodes, possibly linked to intense storms or to the lack of sediments.

In addition, the results obtained in the present study coincide with other studies that have analyzed the evolution of the coastline in the Mediterranean. In particular, it reinforces the idea that sediment imbalance has been one of the key factors explaining the intensification of erosional processes, especially as a result of the reduction of fluvial inputs. This decrease is mainly due to the construction of reservoirs, reforestation of watersheds and channelization of rivers [4,42].

This must be added to the role played by the port works, which interrupt the coastal drift and directly influence the morphodynamic behavior of the nearby sections [24]. For all these reasons, the changes observed in this stretch should not be understood as a one-off event, but as the result of a set of natural processes and human transformations that have been accumulating for decades. In this context, the use of multiscale analysis tools and Geographic Information Systems, such as those used in this study, is key to be able to detect trends, anticipate possible risks and propose management measures adapted to the current situation, especially considering the impact of climate change and the rise in sea level in recent years [25].

6. Conclusions

The multi-temporal analysis of the evolution of the coastline between the Port of Valencia and the Port of Sagunto has shown a coastal dynamic strongly conditioned by human action and natural processes. In the long term (1957-2024), the results show an alternation of areas with clear accumulation, such as zone 1 (Arenas – Malvarrosa - Patacona), and others markedly erosive, such

as zone 3 (Pobla de Farnals), reflecting the impact of infrastructures such as ports, which interrupt the longitudinal transport of sediments. At this scale, accretionary processes dominate to the north of these structures, while regressive processes affect the southern sections.

At the medium scale (1997-2024), erosion is more influenced by artificial regeneration and other punctual works. Even so, the fact that some areas, such as zone 3 (Pobla de Farnals), remain vulnerable indicates that these interventions do not always work in the medium term. In the short term (2015-2024), erosion is the main process in almost the entire stretch, especially after strong storms such as Gloria, which caused significant setbacks in unprotected areas.

The analyzed indicators (EPR, LRR, NSM, SCE and WLR), obtained using GIS tools such as QGIS and DSAS, have made it possible to quantitatively characterize the evolution of the coastline. The comparison with the CGAT-UPV study reinforces the reliability of the results and demonstrates the validity of the applied methodology. It is confirmed that the sedimentary imbalance combined with the proliferation of rigid structures has profoundly altered the coastal morphodynamics since 1957.

In addition, the analysis confirms that areas with greater urban pressure tend to coincide with sections where artificial accretion is observed. However, this pattern may be more closely related to the presence of infrastructures such as ports, which alter the longshore sediment transport and promote accumulation in certain areas. In contrast, more exposed zones with less direct intervention, such as Marjal dels Moros (zone 5), show higher rates of regression despite having structures like the breakwater from the Altos Hornos, indicating limited protection against erosive processes. These patterns highlight the need to integrate land use and sediment dynamics into coastal planning.

Supplementary Materials: The following supporting information can be downloaded at the website of this paper posted on Preprints.org.

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Abbreviations

CGAT-UPV	Geoenvironmental Cartography and Remote Sensing Group (Universitat Politècnica de València)
DSAS	Digital Shoreline Analysis System
EPR	End Point Rate
EPSG	European Petroleum Survey Group
GIS	Geographic Information Systems
ICV	Valencian Cartographic Institute (Instituto Cartográfico Valenciano)
IGME	Spanish Geological and Mining Institute (Instituto Geológico y Minero de España)
IGN	National Geographic Institute (Instituto Geográfico Nacional, Spain)
IPCC	Intergovernmental Panel on Climate Change
LiDAR	Light Detection and Ranging
LRR	Linear Regression Rate
MTTECO	Ministry for Ecological Transition (Ministerio para la Transición Ecológica, Spain)
NSM	Net Shoreline Movement
QGIS	Quantum Geographic Information System
RTK-GPS	Real-Time Kinematic Global Positioning System
SCE	Shoreline Change Envelope
SS	Storm Surge
UTM	Universal Transverse Mercator
WLR	Weighted Linear Regression

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