

Article

Assessment of Shoreline Change in Southeast Ireland Using Geospatial Techniques

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Abstract

This study presents a comprehensive 35-year (1990–2025) shoreline change assessment along the southeast coast of Ireland, integrating multi-decadal Landsat satellite archives with GIS-based Digital Shoreline Analysis System (DSAS) metrics to quantify both spatial and temporal coastal dynamics. Unlike previous studies that focus on shorter timeframes or localized sectors, this research provides a regional-scale, orientation-specific comparison between the eastern-facing (SE1; County Wexford) and southern-facing (SE2; County Waterford) shorelines. Shoreline evolution was quantified using four complementary DSAS indicators—Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR), allowing robust discrimination between short-term variability and multi-decadal trends. The results reveal noticeable spatial variability in shoreline behavior with 57% accretion and 42% erosion across the eastern-facing coast (SE1) in County Wexford and the southern-facing coast (SE2) in County Waterford. SCE values ranging from 2.26 m to 663.83 m indicate considerable short-term shoreline variability, particularly within dynamic barrier and embayed systems. NSM values between −216.65 m and +663.83 m indicate erosional hotspots, particularly along soft-sediment coasts and exposed southern-facing sectors, whereas accretion is limited to embayments, sandy beaches, and zones of effective sediment trapping. Rate-based analyses show EPR values between −14.82 and +20.38 m/yr and LRR values between −5.27 and +20 m/yr, with LRR providing more reliable estimates of multi-decadal trends in highly dynamic environments. The findings highlight the strong influence of coastal orientation, sediment availability, geological controls, and human activities on shoreline change in southeastern Ireland. These findings provide valuable evidence to support coastal management, hazard mitigation, and climate adaptation planning, with the assistance of policymakers, to develop effective strategies that enhance the resilience and quality of life of coastal communities.



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Keywords: coastal erosion and accretion; digital shoreline analysis system (DSAS); remote sensing; shoreline change; Southeast Ireland

1. Introduction

Coastal areas are highly dynamic environments that continually change through interactions between terrestrial and marine processes [1]. Shoreline changes, particularly erosion and accretion, are a global issue affecting 70% of the coastline and posing serious threats to low-lying areas, coastal ecosystems, infrastructure, and nearby communities [2]. While coastal erosion is a natural and important geomorphological process, it becomes problematic when human infrastructure and settlements occupy the coastal zone, limiting the natural movement and recovery of coastal habitats [3,4]. It is driven by sea-level rise, storms, changes in wave energy and direction, tides, and sediment transport, as well as by human activities such as urban development, sand mining, harbor construction, and the use of coastal protection structures [5–7]. Current projections suggested that nearly 50% of the world's sandy beaches may be affected by severe erosion by the end of this century if these present trends continue [8]. Therefore, analyzing shoreline changes across different time periods is essential for understanding coastal behavior and supporting effective coastal management planning.

The effects of coastal change extend beyond landform changes, particularly for people, ecosystems, and economic activities [9]. Coastal erosion leads to land loss, flooding, habitat destruction, and damage to transport routes and civil infrastructure, while threatening biodiversity and the valuable ecosystem services provided by beaches, dunes, wetlands, and estuaries [5,6,10]. Globally, 15% to 40% of the population lives in coastal areas, making these areas particularly vulnerable to shoreline retreat and sea level rise [2]. In addition, coastal changes threaten cultural heritage and archaeological sites, particularly shoreline retreat and the loss of natural buffer zones such as beaches and dunes, which can increase the exposure of coastal infrastructure, communities, and ecosystems to flooding and wave inundation associated with sea-level rise and storm surges [11,12].

Coastal erosion is becoming more severe across Europe, particularly along Atlantic-facing coastlines, as 50% of the world's sandy beaches may be at risk of significant erosion by 2100 under current trends, according to the source projection. Approximately 17% of the UK coastline and 20% of the Irish coast are currently affected by erosion, although rates vary with the location. In England and Wales, approximately 28% of the coastline is eroding at rates exceeding 0.1 m/year, despite extensive coastal protection, including seawalls and groynes [3]. Ireland (the whole island) has a long coast estimated at approximately 7500 km, and erosion affects roughly one-fifth of it, while only a small portion is protected by engineered coastal defenses [13]. On the other hand, economic studies estimate that coastal erosion currently costs the UK approximately £15 million per year, and this could rise to over £120 million per year by 2080 under severe climate change scenarios. Similar environmental and economic impacts are expected in Ireland if sea levels rise and storm intensity increases [3]. The situation in the Republic of Ireland is not much different from that in the UK.

Sea-level rise is widely recognized as the primary driver of coastal erosion, and short-term processes, where shoreline changes observed over a few years to about a decade such as storms and variations in wave conditions play a key role in controlling shoreline stability [14]. Satellite measurements show that global sea level has been rising at approximately 3.5 mm per year since the early 1990s [7]. Climate projections estimate a global sea-level rise of 18–59 cm by 2100, and some studies suggest it could be 0.5–2 m under a high-emission scenario [3,15]. Ireland is often considered less vulnerable because much of its coastline consists of cliffs and exhibits large tidal ranges [3,16]. However, some studies indicate that up to 30% of Irish coastal wetlands could be lost if the sea level rises by 1 m [13]. In addition, intensifying storm activity and shifting wave patterns are expected to exert greater pressure on sandy beaches, dunes, and low-lying coastal areas [17,18].

Globally, some studies [6,10,19] have focused on analyzing shoreline dynamics, but detailed, location-specific measurements of multi-decadal shoreline change along the Irish coast remain limited, particularly in Southeast Ireland. Some early studies from the 1980s to the early 2000s provided essential insights into erosion trends, sediment movement, and barrier behavior along parts of Northern, Eastern, Western, and Southern Ireland, highlighting the influence of glacial sediments, offshore sandbanks, and harbor development [20–22]. In assessing coastal change, most recent studies have examined coastal vulnerability, which shows the likelihood of a coastal area experiencing damage or change due to coastal hazards such as erosion, flooding, and sea-level rise, depending on both its exposure to these hazards and its physical and socio-economic characteristics at both national and regional scales, relying on qualitative approaches rather than focusing on implementing detailed, multi-decadal shoreline measurements [14,23,24]. While previous studies have identified erosion-prone areas and dynamic barrier systems, systematic multi-decadal quantification of shoreline change along the southeast Irish coast using consistent statistical methods remains limited. Also, shoreline change analyses using modern satellite imagery remain scarce, particularly those that employ multiple statistical indicators to capture both multi-decadal trends and short-term variability. This has created a clear gap in understanding how erosion and accretion patterns have evolved in response to changing wave conditions, sea-level rise, and increasing human influence.

The shoreline forms the boundary between land and sea and responds quickly to natural forces such as waves and storms, as well as to human activities [25,26]. Traditional field-based monitoring methods are often costly, time-consuming, and limited in spatial coverage, making them less suitable for analyzing long coastlines. As a result, advances in remote sensing (RS) and geographic information systems (GIS) have significantly improved shoreline monitoring by enabling repeated, large-scale, and cost-effective observations over the past decades. Multi-temporal satellite data from platforms such as Landsat and SPOT have been widely used to map shoreline positions and to measure patterns of erosion and accretion with reliable accuracy [1,6,27]. To quantify these changes consistently, the Digital Shoreline Analysis System (DSAS) is commonly used, as it provides a robust statistical framework for calculating shoreline change [28–32]. Together, RS, GIS, and DSAS offer a practical approach for analyzing multi-decadal shoreline dynamics, supporting improved understanding of coastal behavior and more informed coastal management decisions [29,30].

Despite a growing international literature on satellite-based shoreline monitoring [8,19,33], systematic multi-decadal quantification of shoreline dynamics along the southeast Irish coast using multiple complementary DSAS statistics is absent from the peer-reviewed literature. This study addresses the research question of what the spatial pattern of shoreline changes along the eastern-facing (SE1, County Wexford) and southern-facing (SE2, County Waterford) coasts over the period 1990–2025 is, by filling the gap by analyzing shoreline change along the southeast coast of Ireland using satellite imagery from multiple time periods and DSAS statistical methods. The shoreline is defined as the instantaneous land–water interface derived from the NDWI-zero contour, following the waterline method described by Liu et al. (2017) [1]. This positional proxy captures the wet-dry boundary at the time of image acquisition and is commonly used in Landsat-based DSAS analyses [34]. The positional shoreline change does not directly reflect sediment loss or gain; rather, it indicates the horizontal movement of the waterline over time. Therefore, this study aims to capture shoreline variability, quantify net movement, estimate rates of change, and characterize the magnitude and direction of shoreline change across eastern- and southern-facing coastal sectors using DSAS statistics. The study identified erosion and accretion hotspots and differences between episodic and continuous trends, and provides

an improved understanding of spatial variation in coastal response. The findings provide quantitative evidence to support coastal zone management, hazard mitigation planning, and multi-decadal climate adaptation strategies, and can contribute to providing updated, region-specific insights currently lacking for the southeastern coast of Ireland.

2. Materials and Methods

2.1. Study Area

The Republic of Ireland has a total area of 70,273 km² which shares a long coastline of approximately 7400 km ($\pm 5\%$) with Northern Ireland [35]. Upland areas on the island are mainly coastal, reaching elevations of roughly 1000 m. Ireland's topography includes several upland regions reaching elevations of approximately 1000 m, many of which occur relatively close to the coastline, reflecting the strong interaction between the island's relief and its surrounding marine environment [36]. Topography, together with associated geological controls, has produced extensive (3000 km) rock-dominated coasts with a maritime climate significantly influenced by the North Atlantic Ocean in the northern region [37]. Prevailing southwesterly winds and frequent Atlantic storm systems generate high-energy wave conditions along the western and southern coasts of Ireland. The eastern and southeastern regions consist of unconsolidated quaternary glaciogenic sediments and have fewer rock exposures [3]. This coastal environment supports a wide range of ecosystems, such as cliffs, beaches, and barriers, including different sand and gravel types, lagoons, dunes, and salt marshes, mudflats and other wetlands, which provide services like coastal protection, habitat generation, and socio-economic benefits like tourism, fisheries, and recreation [16,22,23]. The North Atlantic Ocean strongly influences Ireland's mild climate [14]. Coastal changes, particularly coastal erosion with sea-level rise, are low in Ireland due to its cliffed coastline and low population density in coastal areas; 20% of the coastline is currently experiencing erosion. Also, the southeast Irish coast is classified as a macro-tidal to meso-tidal environment. The mean spring tidal range at Dunmore East is approximately 3.8 m, making tidal influence on waterline position substantial on low-gradient beaches. This information is now included in the study area description [3,9,13].

This study focuses on the southeastern coast of Ireland, extending along the eastern and southern-facing shorelines of Counties Wexford and Waterford, between 51°56'–52°44' N and 6°11'–7°47' W. The area is partially exposed to the Irish Sea from the northeast and more energetic Atlantic Ocean coastline from the south as a transitional coastal zone, resulting in substantial spatial variability in coastal geomorphology and shoreline dynamics as it supports different coastal settlements, transport infrastructure, and ecologically critical coastal environments, enhancing the societal and environmental relevance of shoreline change assessment in the region for coastal management and climate adaptation [20,38,39]. The study area was divided into two sections to provide a detailed analysis of changes. Sandy beaches, with some dunes, cliffs, and engineered structures, such as harbors at Wexford and Kilmore Quay, dominate the eastern-facing southeast coast [39]. The County Wexford is exposed to Irish Sea swell and wind waves approaching predominantly from the northeast and east, with mean significant wave heights of 1.5–2.5 m and peak periods of 6–10 s based on ERA5 reanalysis data. Net longshore drift along this coast is predominantly southward [21]. On the other hand, the southeastern coast, facing south, comprises bays, cliffs and headlands, and beaches, with a mixed bedrock–sediment coast and some anthropogenic features such as harbors, seawalls, and coastal roads in County Waterford [39].

The division of the study area into SE1 and SE2 follows the natural geomorphological boundary at Hook Head, which marks a transition from the Irish Sea-dominated, predominantly eastward-facing shorelines of County Wexford to the Atlantic-influenced,

southward-facing embayed and headland coast of County Waterford. While the boundary coincides with the county administrative limit, the primary basis for this subdivision is the distinct change in coastal orientation (east-facing versus south-facing), wave exposure regime, and dominant sediment transport processes across the two sectors, rather than administrative convention.

The County Waterford receives Atlantic swells from the southwest, which are more energetic, with significant wave heights commonly exceeding 3 m during winter storms [14]. The southeast coast of Ireland is subject to a maritime climate with prevailing south-westerly winds. The eastern-facing coast (SE1) is sheltered from Atlantic swell and is primarily influenced by wind waves and moderate swells from the Irish Sea approaching from the northeast to east-northeast. Significant wave heights typically range from 0.5–2.5 m during fair-weather periods, increasing to over 4 m during winter storm events [15]. The southern-facing coast (SE2) is more energetic, receiving Atlantic swell and storm waves predominantly from the south-southwest. Seasonal variability is significant, with the highest wave energy and storm activity concentrated between October and March. These contrasting wave regimes drive the differing shoreline behaviors described in the Results.

The sediment budget of the southeast coast is strongly influenced by the legacy of Quaternary glaciation. In County Wexford (SE1), unconsolidated glaciogenic till and outwash deposits provide the primary sediment source for beaches and barrier systems, with net longshore transport directed southward under Irish Sea wave forcing [21,40]. Key sediment sinks include Wexford Harbour, Rosslare Harbour, and Kilmore Quay, where harbor structures impede continuity of alongshore transport. In County Waterford (SE2), the mixed bedrock–sediment coast has a more limited sediment budget, with most beaches dependent on cliff erosion of glaciogenic bluffs and episodic cross-shore supply from the inner shelf [13,38]. The limited sediment availability renders SE2 beaches more susceptible to erosion and less able to recover after storm events.

The tidal regime in the study area is semi-diurnal. The tidal range at Wexford Harbour varies from approximately 0.8 m (neap) to 2.1 m (mean spring), and at Dunmore East (County Waterford) from approximately 1.0 m (neap) to 3.8 m (mean spring), based on the Irish National Tide Gauge Network data. These tidal variations affect the positional accuracy of NDWI-derived shorelines.

The study area is shown in Figure 1.

2.2. Data

The USGS (United States Geological Survey) Earth Explorer was used to acquire Landsat images of the southeast coast of Ireland. These Landsat images have a spatial resolution of 30 m by 30 m and are available in raster format. Images were extracted for the period 1990–2025 from Landsat 5 (Thematic Mapper) TM and Landsat 8 (Operational Land Imager with Thermal Infrared Sensor) OLI/TIRS remote-sensing data (refer to Table 1). These images were cloudless or had less than 10% cloud cover.

Table 1. Satellite data information, including sensors and bands.

Year	Satellite Name	Sensor ID	Path/Row	Acquisition Date	Band
1992	Landsat 5	TM	206/023	30 October 1992	Band 2
			206/024	30 October 1992	Band 4
1999	Landsat 5	TM	206/023	19 November 1999	Band 2
			206/024	19 November 1999	Band 4
2010	Landsat 5	TM	206/023	16 October 2010	Band 2
			206/024	16 October 2010	Band 4
2025	Landsat 8	OLI/TIRS	206/023	18 May 2025	Band 3
			206/024	18 May 2025	Band 5

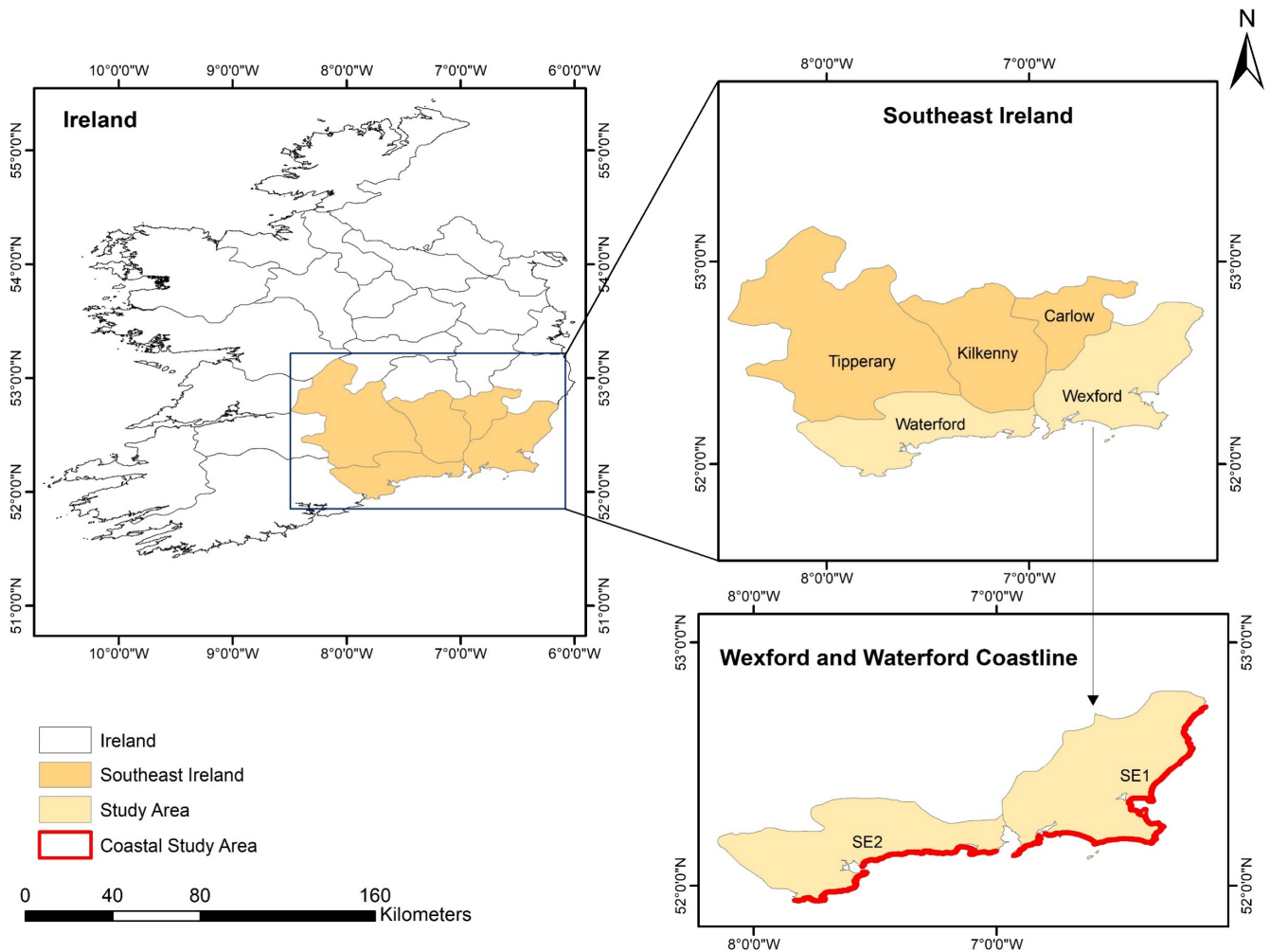


Figure 1. Locations of the coastal study area in Southeast Ireland (SE1—southeast coast in county Wexford; SE2—southeast coast in county Waterford).

Shorelines were retrieved manually using the Normalized Difference Water Index (NDWI). Equation (1) determines the Normalized Difference Water Index (NDWI) from the Near-Infrared (NIR) and Green (G) channels.

$$\text{NDWI} = \frac{\text{Green} - \text{Near Infrared (NIR)}}{\text{Green} + \text{Near Infrared (NIR)}}$$

For Landsat 5;

$$\text{NDWI} = \frac{\text{Band 2} - \text{Band 4}}{\text{Band 2} + \text{Band 4}} \quad (1)$$

For Landsat 8;

$$\text{NDWI} = \frac{\text{Band 3} - \text{Band 5}}{\text{Band 3} + \text{Band 5}}$$

2.3. DSAS Statistical Tools

The Digital Shoreline Analysis System (DSAS) is a Geographic Information System (GIS)-based tool widely used in historical trend analysis to quantify shoreline position change through time. This is developed by the United States Geological Survey (USGS) as a freely available extension for Environmental Systems Research Institute (ESRI) ArcGIS software [32]. In this study, DSAS (version 6) was used because it can compute multiple rate-of-change statistics from a time series of shoreline positions, enabling the objective evaluation of both the magnitude and direction of shoreline movement [28–31].

DSAS calculates shoreline change statistics by measuring the spatial differences between shoreline positions derived for specific time periods along shore-normal transects

generated from a defined baseline [6,31]. These statistics enable a quantitative assessment of shoreline variability, net displacement, and multi-decadal long-term change. In this study, the following DSAS statistical indicators were employed [29].

Landsat images were obtained as USGS Level-2 surface reflectance products, which are systematically orthorectified using the Global Land Survey ground control point database, with a reported root-mean-square error (RMSE) of less than 12 m [41]. No additional co-registration was performed as all products were confirmed to align within one pixel across acquisition dates. In DSAS, an offshore baseline was digitised parallel to the general coastline orientation at a fixed seaward offset of 200 m, following standard DSAS protocols [32]. Shore-normal transects were cast at 50 m spacing, yielding 2117 transects across SE1 and SE2 combined. Transect length was set to 1500 m to ensure all extracted shoreline positions were intersected.

2.3.1. Shoreline Change Envelope (SCE)

SCE measures the total range of shoreline movement by calculating the distance between the most landward and most seaward shoreline positions at each transect, irrespective of their time. SCE indicates overall shoreline variability.

2.3.2. Net Shoreline Movement (NSM)

NSM represents the distance between the oldest and the most recent shoreline positions, indicating the net direction and magnitude of shoreline displacement over the analysis period.

2.3.3. End Point Rate (EPR)

Calculates the rate of shoreline change by dividing the NSM by the elapsed time between the oldest and youngest shoreline positions. EPR provides a straightforward estimate of the average rate of change but is sensitive to the choice of shoreline dates.

2.3.4. Linear Regression Rate (LRR)

LRR estimates the multi-decadal rate of shoreline change by fitting a least-squares regression line through all available shoreline positions at each transect. LRR incorporates all shoreline data and is less sensitive to short-term variability.

In the present study, DSAS was applied to analyze shoreline evolution along the south-east coast of Ireland using multi-temporal shoreline datasets extracted for the years 1992, 1999, 2010, and 2025, covering the period from 1990 to 2025. This temporal range and interval spacing were selected based on the availability of cloud-based image-processing techniques and of high-quality, consistent satellite imagery. Given the 30 m spatial resolution of Landsat imagery, longer temporal intervals were selected to capture meaningful shoreline changes while minimizing uncertainty associated with manual shoreline extraction.

To enhance interpretability and reduce analytical complexity, the study area was subdivided into two geomorphologically and orientationally distinct sections: the eastern-facing coast (SE1), covering County Wexford, and the southern-facing coast (SE2), covering County Waterford in southeastern Ireland (refer to Figure 1). This subdivision enables more precise comparison of shoreline change patterns across differing wave exposure and coastal process regimes, using the four DSAS statistical tools mentioned above to characterize shoreline dynamics and identify erosion and accretion trends. The overall methodology carried out in this research is shown in Figure 2.

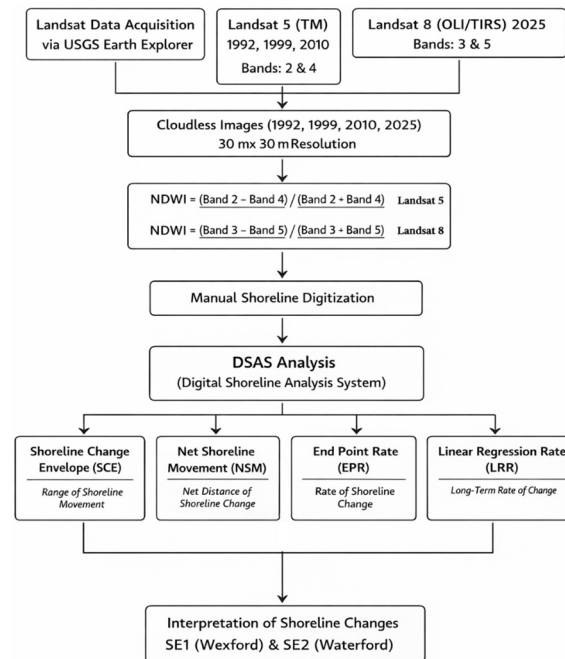


Figure 2. Overall methodology.

2.4. Uncertainty Assessment

Tidal normalisation was not applied in this study due to the absence of beach cross-sectional profile data at all transect locations, which would be required to calculate tidal swash excursion distances. However, the potential horizontal displacement of the NDWI-derived waterline due to tidal variability was estimated at representative sites. Assuming a mean beach gradient of approximately 1:50, which is typical for sandy beaches in southeast Ireland [21], and a maximum inter-image tidal stage difference of approximately 2 m, the potential horizontal displacement of the waterline may reach approximately 100 m. This estimate represents a maximum theoretical displacement under unfavorable tidal conditions. Consequently, shoreline change values smaller than this magnitude should be interpreted cautiously, as they may fall within the potential positional uncertainty associated with tidal variability.

3. Results

3.1. Overview of Shoreline Change Patterns in Southeast Ireland

The shoreline change analysis was conducted along the southeast coast of Ireland using four shoreline positions extracted for 1992, 1999, 2010, and 2025, covering the overall period considered from 1990 to 2025 (refer to Figure 3). A total of 2117 transects were generated using DSAS at a spacing of 50 m, representing approximately 216 km of coastline. The results indicate that shoreline changes vary across the different locations, with both erosion and accretion observed. In general, shoreline accretion predominates in the study area, accounting for approximately 57%, whereas 42% exhibit net erosion, with less than 1% showing a relatively stable shoreline position. In addition, noticeable differences in shoreline behavior have been identified between the two coastal sectors, the eastern-facing coast (SE1) in County Wexford and the southern-facing coast (SE2) in County Waterford, with higher variability and more pronounced patterns of erosion and accretion.

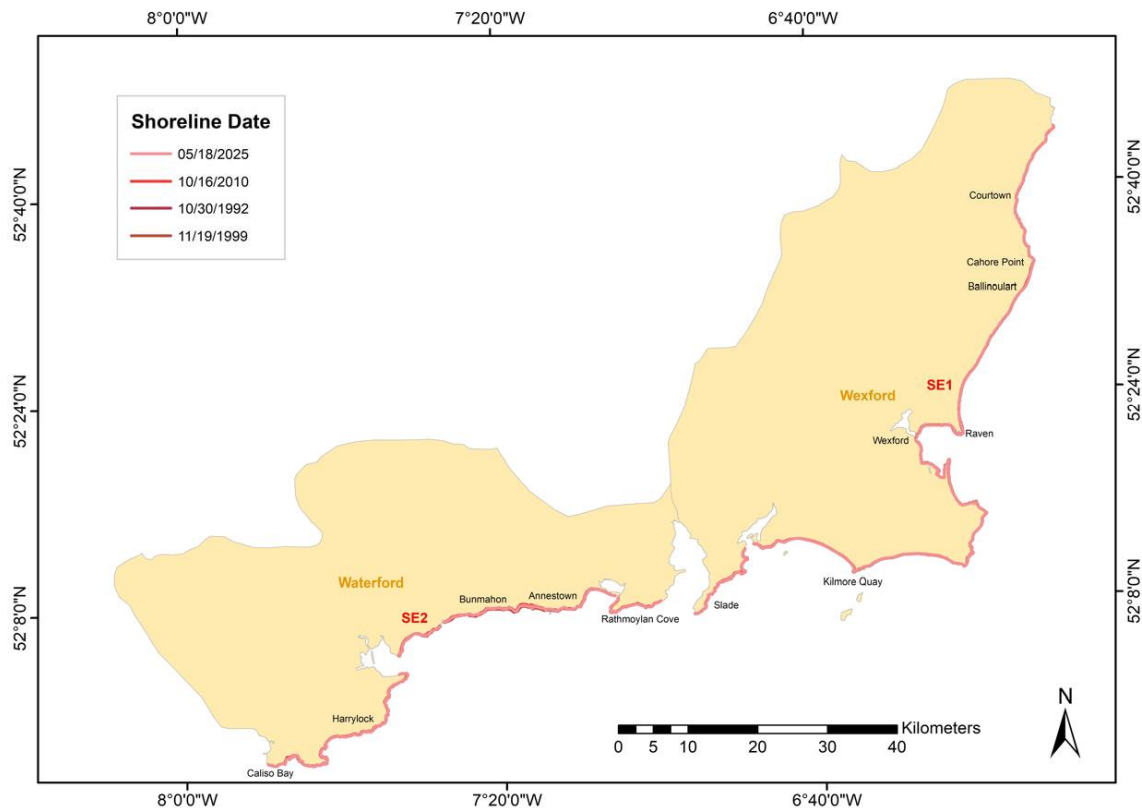


Figure 3. Manually extracted coastline in southeast Ireland from 1990 to 2025 based on Landsat images (1992, 1999, 2010 and 2025). (SE1—southeast coast in county Wexford; SE2—southeast coast in county Waterford).

3.2. Shoreline Variability Based on Shoreline Change Envelope (SCE)

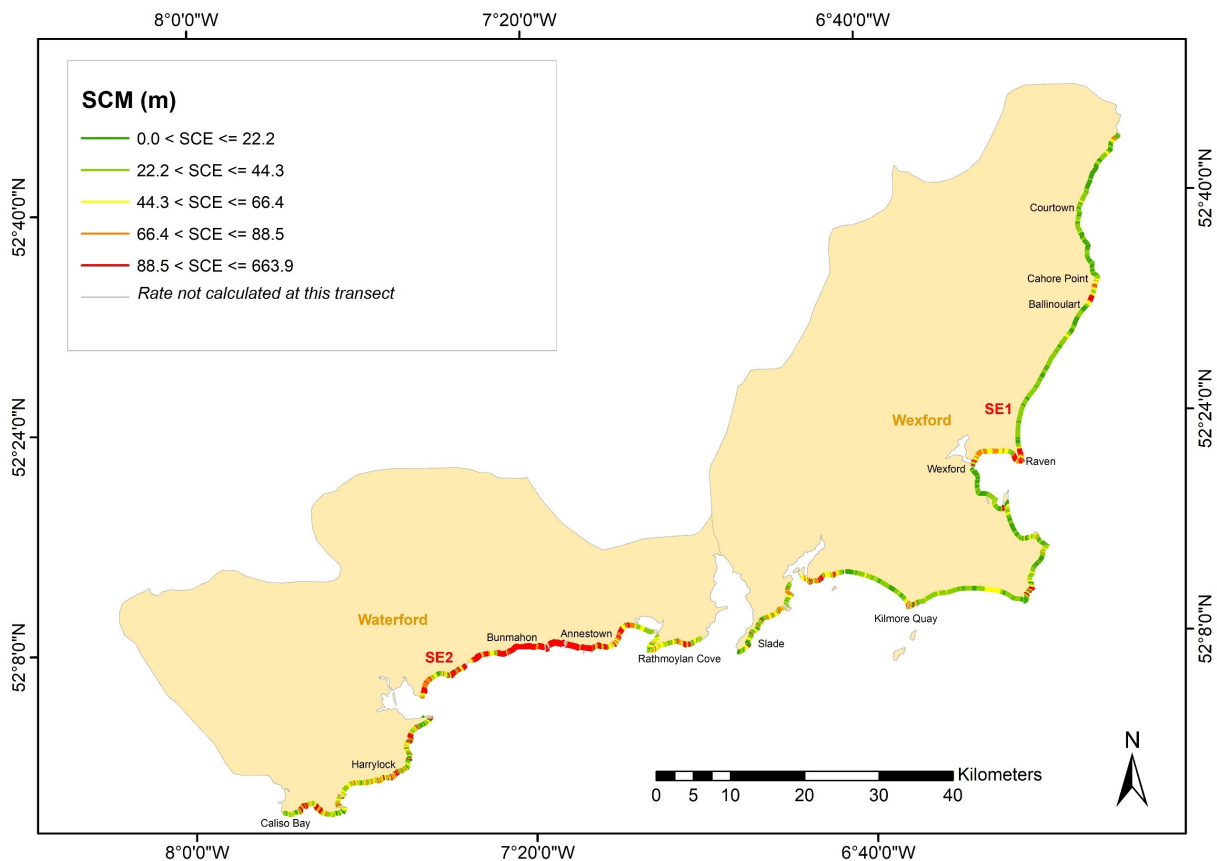
The Shoreline Change Envelope (SCE) shows the maximum total distance, independent of time, between the most distant landward and seaward points. The SCE from 1990 to 2025, based on DSAS results and an illustration of the location where significant change has occurred during 1990 and 2025 on the southeast coast of Ireland, is shown in Figure 4. Across the study area, SCE ranges from 2.26 m to 663.83 m, with a mean SCE of 53.73 m, indicating substantial variability in shoreline behavior. The distribution of SCE values indicates that most transects exhibit low to moderate variability, whereas some show large fluctuations with highly dynamic, unstable variation in both SE1 and SE2.

According to the spatial analysis of SCE, a clear regional contrast is evident between the two coastal sections. Although SE1 (County Wexford) is characterized by relatively low SCE values, compared with higher values recorded elsewhere, such as 663.83 m in SE2 (County Waterford) of the southeast coast, some locations in SE1, such as Cahore point, Ballinoulart, Raven Point, Wexford, Rosslare harbor, Nethertown beach near to Shilmore, Kilmore Quay, and Bannow Bay showed some larger fluctuations in shoreline position with a SCE value of 115.52 m, 128.35 m, 116.7 m, 162.79 m, 175.55 m, 185.61 m, and 118.76 m (Figure 4b–d). SE2 showed greater fluctuations in areas such as Annestown, Bunmahon, Ringville, and Caliso Bay with SCE values of 242.16 m, 245.72 m, 179.46 m, and 200.17 m (Figure 4e) respectively. Moreover, areas such as Slade exhibited unusual variations, with SCE values exceeding 500 m (663.83 m), indicating significant shoreline fluctuation throughout the period.

3.3. Net Shoreline Movement (NSM) Analysis

The Net Shoreline Movement (NSM) indicates the total horizontal displacement of the shoreline between the oldest and the most recent shoreline position along each DSAS transect. In this study, positive NSM values indicate accretion with seaward shoreline movement. In contrast, negative values indicate erosion with landward shoreline movement, consistent with the transect orientation in which land is to the left and sea to the right. The NSM for 1990 to 2025, based on DSAS results along the southeastern coastline, is shown in Figure 5.

Along the southeastern coast, NSM values ranged from -216.65 m to $+663.83$ m, indicating substantial spatial variability in shoreline behavior over the period. From the eastern-facing southeast coast, the Slade shoreline in Wexford moved seaward, while from the southern-facing southeast coast, the Benvoy beach shoreline moved landward. Further, in the eastern face of the southeast coast, NSM mostly ranges between 0 and ± 100 m from both positive and negative sides. However, some unusual values, such as -115.52 m, -113.72 m, -150.25 m, and $+663.83$ m, were observed at Cahore Point, Ballinoulart, Kilmore Quay, and Slade, respectively. On the other hand, along the southern-facing southeast coast, the shoreline moved seaward in areas such as Annestown and Ballyvoyle Cove, with accretion of $+238.43$ m and $+228$ m, respectively. The shoreline moved landward from regions such as Tramore and Maytown, with erosion recorded at -216.65 m and -173.67 m, as shown in Figure 6.



(a)

Figure 4. Cont.



Figure 4. Coastal change from 1990 to 2025 for SE1 and SE2 with Google map examples (<https://earth.google.com/web/>, accessed on 22 March 2026). (a) Shoreline Change Envelope (SCE) based on DSAS results. (b) Ballinoulart Bay Beach in 1990 (LHS) and 2025 (RHS) (52.5262 N, 6.2233 W). (c) Raven Point in 1990 (LHS) and 2025 (RHS) (52.4053 N, 6.3434 W). (d) Slade Harbor in 2005 (LHS) and 2025 (RHS) (52.1368 N, 6.9088 W). (e) Annestown and Bunmahon in 1985 (LHS) and 2025 (RHS) (52.1393 N, 7.2719 W). (White boxes—Original capture, Green boxes—if there is an accretion, Red boxes—if there is an erosion).

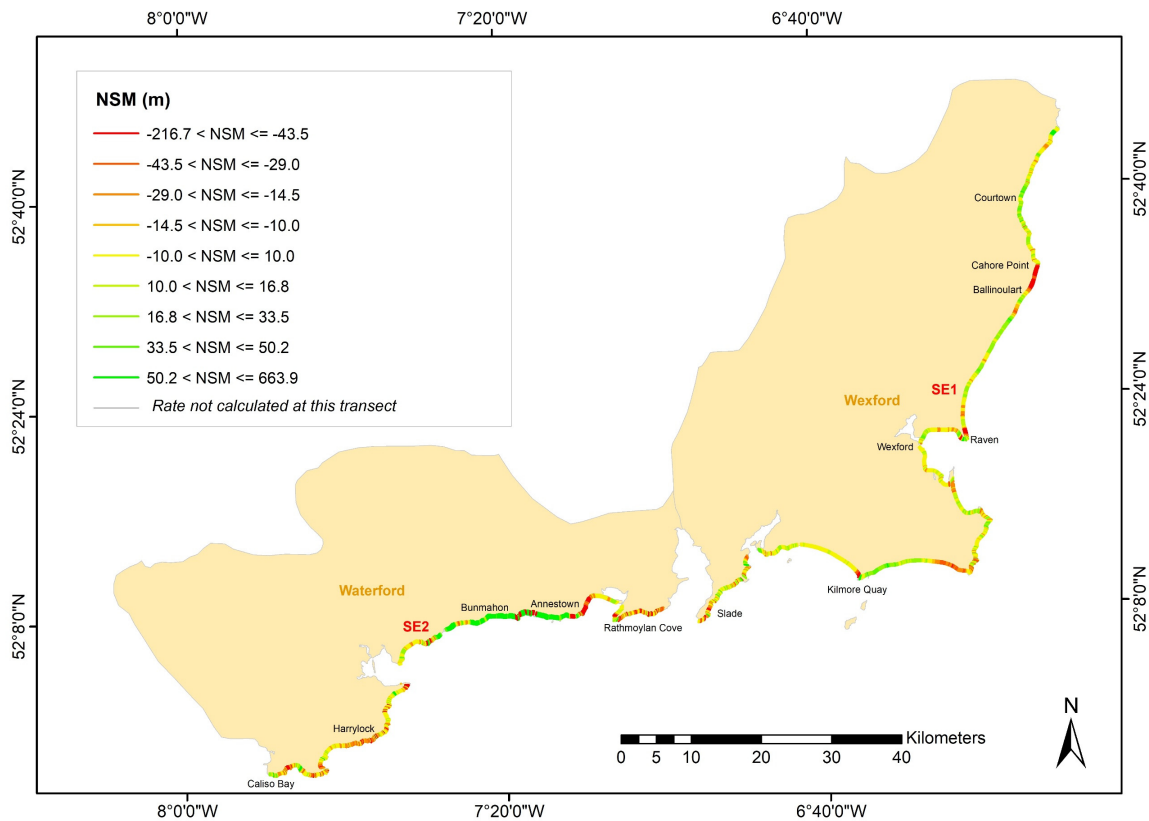


Figure 5. Net Shoreline Movement (NSM) from 1990 to 2025 based on DSAS results in the southeast coastline of Ireland (SE1—southeast coast in county Wexford; SE2—southeast coast in county Waterford).

3.4. Rate of Shoreline Change Using End Point Rate (EPR)

The End Point Rate (EPR) was used to estimate the average annual rate of shoreline change by dividing the net shoreline displacement between the oldest and most recent shoreline positions by the time interval. The positive ERP values indicate the annual accretion rate, and the negative ERP values indicate the annual erosion rate. The EPR from 1990 to 2025, based on DSAS analysis results for the southeastern coast, is illustrated in Figure 7.

The EPR values along the southeast coast ranged from -14.82 m/year to 20.38 m/year, indicating pronounced spatial variability in short- and medium-term shoreline change rates rather than rapid change. The mean EPR of $+0.18$ m/year in the study area suggests an overall tendency toward accretion, as indicated by the average across all transects. At locations close to Annestown, Bunmahon, and Ballydwan beach, accretion rates were recorded as high as 5.58 m/year, 7.32 m/year, and 12.3 m/year. Furthermore, erosion rates were observed in different sections of the coastline. Notably high erosion rates of -11.08 m/year and -13.84 m/year were observed at locations such as Harrylock and Benvoy Beach.

Moreover, in SE1, accretion and erosion rates ranged from 0 m/year to ± 5 m/year at most locations, except at Slade, where the highest accretion rate was $+20.38$ m/year. On the other hand, in SE2, EPR values fluctuated between roughly -15 m/year and $+15$ m/year, as shown in Figure 8. The highest erosion rate of -14.82 m/year was recorded at Tramore, and the highest accretion rate of $+12.3$ m/year was observed at Annestown.

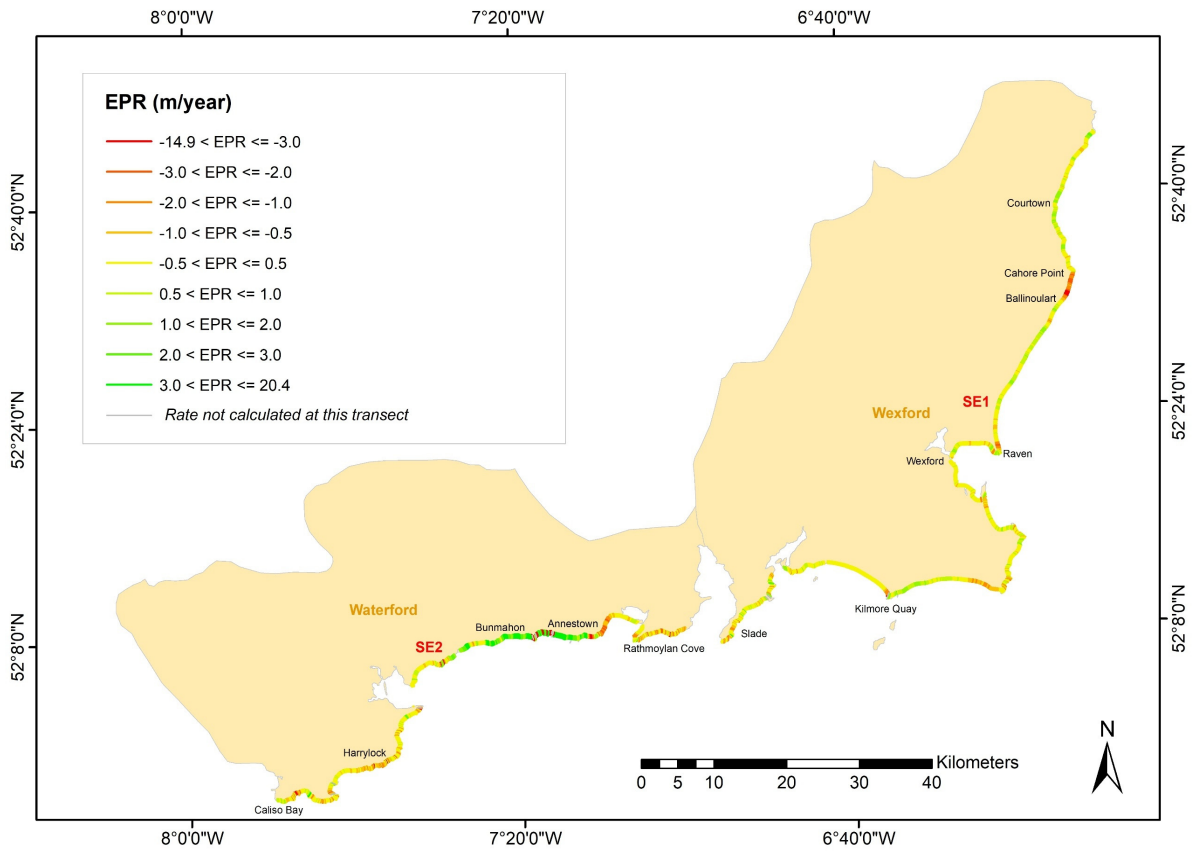


Figure 7. End Point Rate (EPR) from 1990 to 2025 based on DSAS results in the southeast coastline of Ireland SE1—southeast coast in county Wexford; SE2—southeast coast in county Waterford).

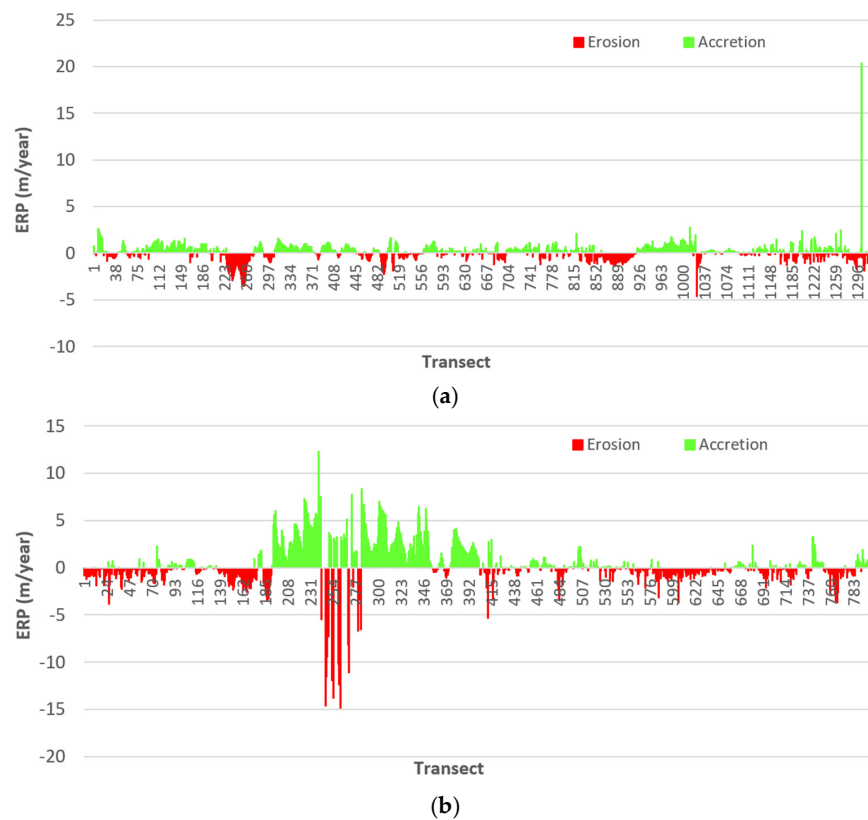


Figure 8. Spatial patterns of EPR during 1990 and 2025. (a) SE1. (b) SE2.

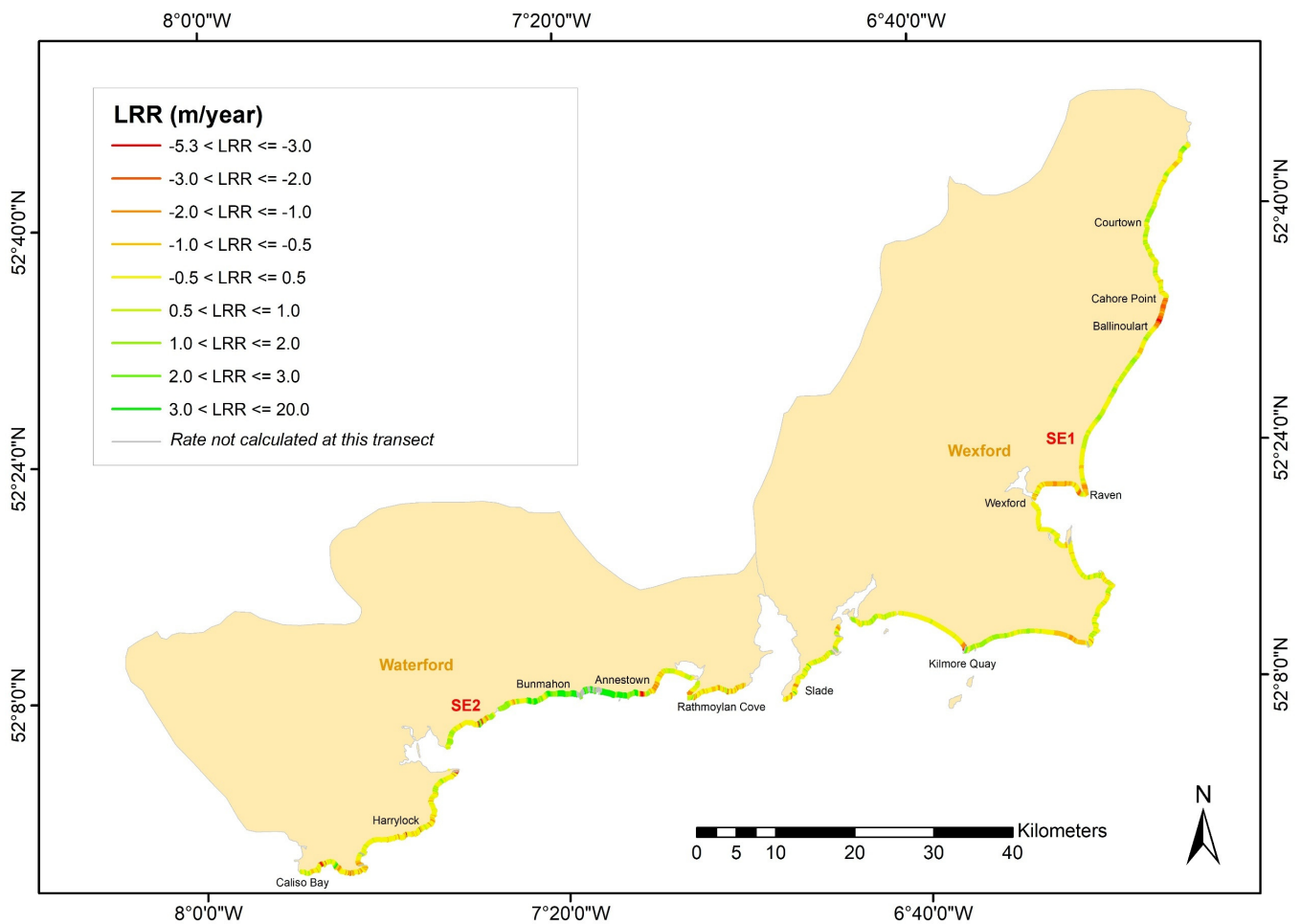
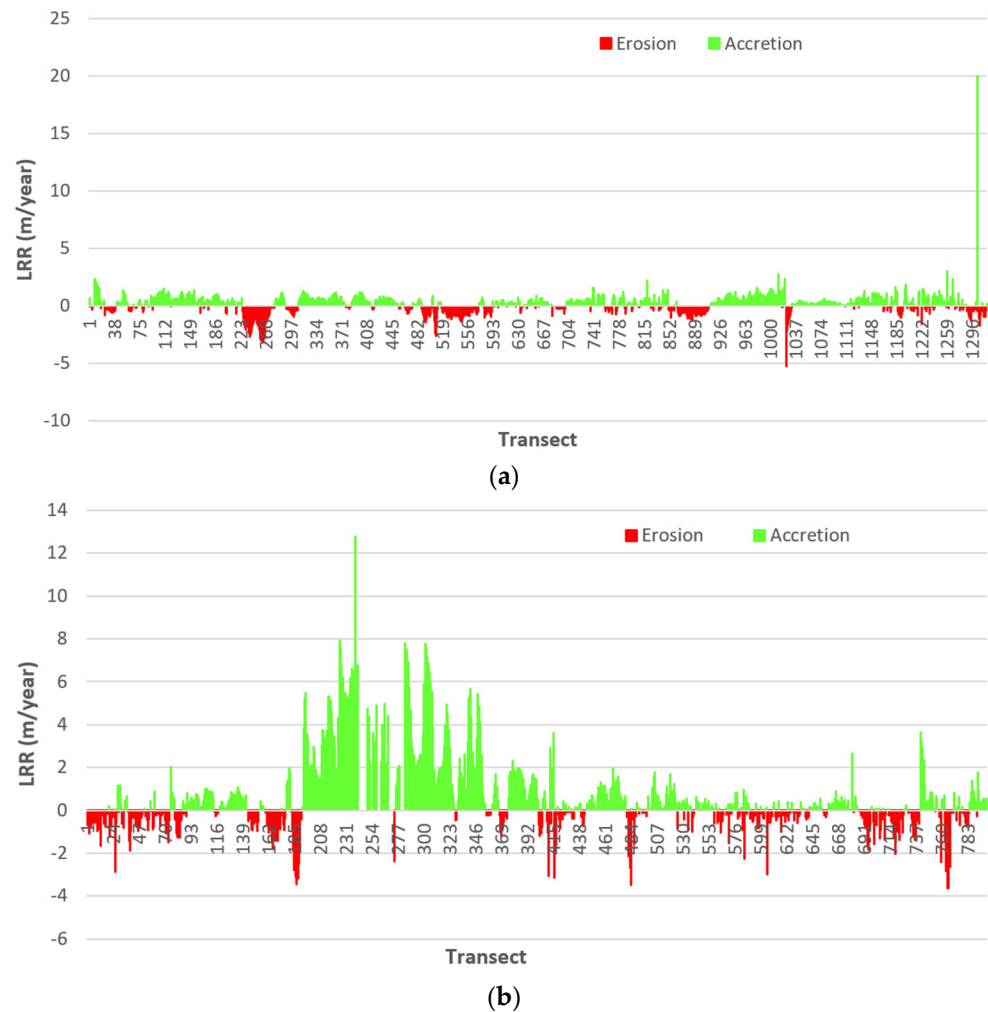


Figure 9. Linear Regression Rate (LRR) from 1990 to 2025 based on DSAS results in the southeast coast-line of Ireland SE1—southeast coast in county Wexford; SE2—southeast coast in county Waterford).

3.6. Case Studies of Extreme Shoreline Change Sectors

Three sectors exhibiting the highest magnitudes of shoreline change were selected for detailed analysis. At Slade (SE1), the exceptionally high SCE (663.83 m) and positive NSM (+663.83 m) are interpreted as reflecting progressive southward extension of a sand flat and beach ridge system, facilitated by sediment accumulation in the sheltered embayment behind Hook Head. This pattern is consistent with the accretionary behaviour observed in similar harbour-proximal embayments in Ireland [42]. At Tramore (SE2), the large negative NSM (−216.65 m) reflects long-term landward movement of the beach face, driven by exposure to Atlantic swell and the erosion of glaciogenic sediment bluffs [13,38]. At Raven Point (SE1), the high SCE (116.7 m) reflects rotational oscillation of the spit tip under varying wave approach, rather than a unidirectional trend, as indicated by the relatively low LRR magnitude at this transect.



erosional and accretionary zones along the eastern-facing coast [40]. Higher accretions along the eastern coastline are observed in areas such as Courtown, Ardamine, Ballyvalden, Ballinesker, the Ballyhealy beach area, Hookless village, etc. However, these locations lie mainly between the harbors on both sides. Therefore, interruptions caused by sediment movement from these harbors or by the orientation of the coastline allow sand to accumulate, thereby recording these accretions in these locations [39,44]. In the southern-facing coast, both accretion and erosion have been highlighted. Locations such as Rathmoylan Cove, Brownstown Head, Tramore, Harrylock, Maytown, Ardmore, and Caliso Bay experienced erosion because these areas are mainly exposed to Atlantic waves and have limited sediment supply [44,45]. In contrast, the locations such as Kilfarrasy Beach, Boatstrand, Rathinure, Ringuille, and Cappagh Bay Beach (Transect ID's: 1532, 1533, 1593, and 2057) undergo lower wave energy, allowing sediment to settle and beaches to remain stable [44,45]. These mixed shoreline behaviors indicate the erosion along headlands due to strong waves and accretion in bays behind headlands due to weaker waves. While certain DSAS transects adjacent to Courtown Harbour record net accretion due to sediment trapping on the updrift side of the harbour structure, field observations from February 2026 (Figure 11) show the captured photographs of coastal erosion in Courtown Beach ($52^{\circ}39'14.0''$ N $6^{\circ}13'21.2''$ W), active dune-scarp recession indicative of recent storm-driven erosion, consistent with the episodic nature of shoreline change in barrier and dune systems [3].



Figure 11. Coastal erosion and its impact on the environment at Courtown Beach (Photo courtesy of Mr. Md Imtiaz Islam, Dublin City University, Ireland).

Figure 11 shows the captured photographs of coastal erosion in Courtown Beach ($52^{\circ}39'14.0''$ N $6^{\circ}13'21.2''$ W) in County Wexford. These photos were captured on the 7th of February 2026. They illustrate significant shoreline retreat and the formation of a recession scarp along a forested coastline. This process can be driven by high-energy

wave action and storm surges, which undercut the primary dune or soil layer, leading to the destabilization of the vegetative canopy and the eventual recruitment of large woody debris into the intertidal zone.

4.2. Shoreline Change Rates and Statistical Indicators

The higher SCE values on the southern-facing coast reflect larger short-term shoreline oscillations associated with episodic storm-driven wave action, even in areas where the rocky geological framework limits multi-decadal net displacement. However, the eastern face of the southeast coastline generally shows lower values because longshore sediment distribution exerts more gradual control, resulting in more minor variability in shoreline change, although an unusually high value was observed at locations such as Cahore point, Ballinoulart, Raven, Wexford, Rosslare harbour, Nethertown beach, Kilmore Quay, Bannow Bay, etc. [21,43].

Locations such as Raven and Ballymacaw Cove recorded larger negative NSM values, reflecting multi-decadal shoreline retreat and landward movement, driven by the continuous erosion of soft sediments, including beaches supported by dunes, barrier systems, and erodible glacial deposits, which are removed by waves and storms [13]. In addition, most multi-decadal erosion has been widely documented along Tramore, Helvick, Harrylock, Ardmore, and other locations in County Waterford, where storms that erode weak coastal materials drive shoreline change [38]. Additionally, at Ballyhealy Beach, Ringbaun in Wexford and Kilfarrasy Beach, and Boatstrand in Waterford, large positive NSM values indicate net shoreline growth, with sediment accumulating over time. These areas are exposed to bays and barrier systems, which reduce wave energy and allow sand to accumulate [44–46]. Further, this indicates that this accretion is controlled mainly by coastline shape and periodic sediment supply through alongshore transport, rather than by sustained shoreline advance. This accretionary behavior is consistent with the general pattern identified by Burningham and French (2017) [25] and Murray et al. (2023) [34], in which accretion in embayed and barrier-proximal settings is primarily controlled by coastline shape and periodic sediment supply via alongshore transport, rather than by sustained shoreline advance. Following this, locations such as Rathmoylan Cove and Ballydwan Beach, with higher SCE values and lower NSM values, indicate that the shoreline experiences significant back-and-forth movement over time but does not exhibit a notable multi-decadal shift landward or seaward [34]. Also, locations where SCE and NSM values are both high and of the same sign, such as accreting sections like Nemestown or erosional stretches near Helvick, indicate consistent directional change and therefore higher multi-decadal significance.

By showing similar variations as Chalencon et al. (2025) [24] and Zorlu and Kusak (2025) [47], mainly along the eastern-facing coast, EPR values show short-term changes in shoreline position and highlight event-based responses. On the other hand, LRR values provide a smooth multi-decadal shoreline trend, limiting the influence of extreme events in several locations, such as Courtown and Ringbaun. EPR values were higher than LRR values, reflecting that short-term storm erosion strongly affects the shoreline, but does not always lead to multi-decadal retreat.

Because shoreline position is strongly influenced by short-term processes rather than by steady multi-decadal change, some shoreline transects exhibit inconsistent multi-decadal trends, as indicated by low LRR values [34,47]. The storm events can cause rapid erosion or accretion over short periods along southern-facing embayments [44]. However, recovery after a storm often occurs, resulting in little overall shoreline advance or retreat when averaged through time [48]. This results in low LRR values. In bays with headlands, beach rotation causes sediment to move along the beach from one end to the other as

wave directions change [14]. In embayed settings with headland control, beach rotation redistributes sediment within the embayment in response to changing wave approach direction, producing alternating advance and retreat at different transect locations. As a result, the net multi-decadal shoreline displacement, as captured by NSM and LRR, tends to be small, because the oscillatory movements partially cancel over time [3].

4.3. Impacts of Natural Processes and Human Interventions

Human interventions, such as harbor construction and coastal protection works, further disrupt sediment transport, introducing irregular and localized shoreline responses [2]. Both natural processes and human activities affect shoreline change along the southeast coast of Ireland, and the influence of these factors varies with coastline orientation [48]. The southern-facing coast is directly exposed to Atlantic waves, generating high-energy waves that cause erosion, particularly in open bays [14]. In contrast, the eastern-facing coast is primarily influenced by Irish Sea waves, with longshore sediment transport controlling the formation of alternating areas of erosion and accretion, depending on sediment availability and coastal structure [21]. Winter storms can drive rapid and significant shoreline erosion, strongly influencing short-term coastal change despite limited multi-decadal movement [15]. Tides and nearshore currents, particularly near estuaries and harbors, transport sediment and influence shoreline position over time [48]. Human activities also alter natural coastal processes. Harbor structures at Kilmore Quay and Rosslare impede sediment transport, resulting in sediment accumulation on the updrift side and erosion on the downdrift side [44]. Coastal protection works can stabilize certain shoreline sections but may increase erosion in nearby areas by blocking sediment transport. Likewise, land reclamation and beach nourishment can cause local accretion, but these effects are often short-lived and may not be sustainable in the long term. Shoreline change patterns help identify coastal vulnerability across the region [43,44,48].

4.4. Management Implications and Study Limitations

Shorelines experiencing high erosion are highly dynamic and therefore more exposed to coastal risk [23]. This is clear in barrier and dune systems along the eastern-facing coast, which are sensitive to wave and sediment changes, and in exposed southern-facing bays where storm energy is strongest. These environments are particularly vulnerable to future sea-level rise and to stronger storms projected under climate change [3,49]. Therefore, shoreline change metrics help identify high-risk coastal areas and prioritize management actions [45]. The results highlight the need for coastal management strategies that consider shoreline orientation, as eastern- and southern-facing coasts respond differently to environmental forces.

Nature-based solutions (NbS) and sediment-based interventions, such as beach nourishment and dune restoration, are generally considered more sustainable than hard engineering structures (e.g., seawalls, groynes) because they work with natural coastal processes rather than interrupting them. Hard structures can disrupt longshore sediment transport, accelerating erosion downdrift of the structure and reducing the coastal system's overall sediment budget. In contrast, NbS approaches maintain sediment connectivity, support ecological function, and can adapt more flexibly to changing conditions, including projected sea-level rise. Coastal planning should also employ adaptive management that accounts for storm-driven, short-term shoreline changes, rather than relying solely on multi-decadal average trends. Uncertainty in the shoreline change results arises from several sources. Minor errors can occur during shoreline extraction, and differences in tidal level at the time satellite images are captured can shift the apparent shoreline position. In addition, the temporal gaps between available satellite images may not fully capture short-term changes

driven by storms or seasonal variability. The use of linear trend methods also assumes steady shoreline behavior, which can oversimplify the complex and non-linear nature of coastal processes. These factors should be considered when interpreting the results and applying them to coastal management decisions.

In addition, a potential source of positional uncertainty in this study arises from differences in tidal stage at the time of satellite image acquisition. Because NDWI-derived shorelines represent the instantaneous land–water boundary, variations in tidal level can influence the horizontal position of the extracted shoreline, particularly on gently sloping beaches. Although efforts were made to select images with minimal cloud cover to ensure reliable shoreline extraction, strict control of tidal stage was not possible due to the limited availability of cloud-free Landsat imagery in Ireland’s maritime climate. Consequently, some positional variability in shoreline location may reflect tidal differences rather than true shoreline movement. This limitation is widely recognised in optical satellite-based shoreline monitoring studies, particularly in temperate regions where cloud cover restricts image availability [33,50,51]. Therefore, the reported shoreline change rates should be interpreted as indicative of broader long-term trends rather than precise measurements of short-term shoreline displacement.

Further, one methodological limitation of this study is the absence of a formal quantitative uncertainty assessment for the extracted shoreline positions. Several factors may introduce positional uncertainty in satellite-derived shorelines, including the spatial resolution of Landsat imagery (30 m), georeferencing accuracy, differences in tidal stage at the time of image acquisition, and manual digitisation of the shoreline proxy. Although a consistent shoreline extraction method and geospatial framework were applied across all images to minimise interpretation differences, these factors may influence the precise magnitude of the calculated shoreline change rates.

Another limitation concerns the number of shoreline observations used to calculate shoreline change rates. The Linear Regression Rate (LRR) in this study is derived from four shoreline positions, potentially increasing sensitivity to short-term shoreline fluctuations driven by episodic events such as storms. As a result, individual shoreline positions may exert a stronger influence on the calculated regression trend. To reduce potential misinterpretation associated with relying on a single indicator, shoreline behaviour in this study was interpreted using multiple DSAS metrics, including Net Shoreline Movement (NSM) and End Point Rate (EPR). The use of complementary indicators allows a more balanced assessment of shoreline change patterns and helps distinguish persistent long-term trends from short-term variability.

Although the SE1 and SE2 sectors exhibit contrasting shoreline behaviour, the comparison presented in this study is primarily descriptive. Formal statistical testing of differences in shoreline change rates between sectors was not undertaken because shoreline trends are derived from a limited number of shoreline observations and may be influenced by local geomorphic controls. Future studies incorporating higher-temporal-resolution datasets could apply statistical methods to more robustly evaluate regional differences in shoreline change rates. In addition, studies should incorporate sediment grain size measurements to better characterize the morphodynamic state of individual beach systems and their sensitivity to the contrasting wave regimes of the two coastal sectors.

4.5. Recommendations

The following recommendations are based on the research work carried out.

- Instead of adopting a uniform coastal defense approach, coastal management strategies should be tailored to local coastal conditions and the spatial variability in shoreline change identified by DSAS indicators (e.g., NSM, EPR, LRR, and SCE).

- By allowing natural coastal processes to operate effectively, locations where accretion occurs, particularly within barrier and embayed systems in the SE1 sector, should prioritise nature-based solutions such as dune restoration and sediment nourishment.
- New development and redevelopment should be avoided in erosion-prone areas, particularly at locations where high negative NSM and EPR values were observed (e.g., Tramore, Kilmore Quay, and Cahore Point).
- Shoreline observations should be conducted regularly to monitor ongoing changes and identify emerging trends, particularly where sea-level rise and increased storm activity are occurring.
- Coastal vulnerability maps should incorporate the full range of DSAS-derived indicators (e.g., NSM, SCE, EPR, and LRR) to capture both short-term variability and long-term shoreline change trends.
- Locations with harbors and coastal defenses that exhibit both erosion and accretion patterns in nearby areas require further examination to identify changes in sediment movement, thereby informing future structural design or modification.
- Effective coastal management requires collaboration among planners, engineers, and local stakeholders to ensure that evidence of shoreline change is translated into practical and socially acceptable actions.

5. Conclusions

This study documents spatial variability in shoreline changes along the southeast coast of Ireland over the period 1992–2025 using multi-temporal satellite imagery and DSAS-based metrics. While sea-level rise and storm intensification are projected to exacerbate coastal erosion in the region under future climate scenarios, the observed patterns in this study reflect the integrated influence of wave exposure, sediment availability, geological controls, and human interventions rather than being directly attributed to climate change within the study period. SCE, NSM, EPR, and LRR have been used as metrics in DSAS. Our findings showed considerable spatial variability, with some high-erosion locations along the coasts of Wexford and Waterford. However, accretion predominates along large sections of the coastline, with embayments, sandy beaches, and areas of sediment trapping. Large negative NSM values with consistently negative EPR and LRR identified erosion hotspots such as Cahore point, Ballinoulart, Wexford harbour, Raven, Rosslare harbour, Slade, etc., in SE1 in the County Wexford coastline, and Rathmaylon cove, Brownstown head, Tramore, Newtown, Annestown, Helvick, Ardmore, and Caliso bay, etc., in SE2 in County Waterford. In contrast, positive NSM values highlighted localised zones of shoreline advance in areas such as Courtown, Annestown, and Bunmahon. A comparison of these indicators confirms that LRR yields more multi-decadal trends in dynamic coastal environments, whereas SCE shows short-term variability that is concealed when considered in isolation. However, the interpretation of small-magnitude shoreline change rates remains constrained by the absence of a formal quantitative uncertainty analysis, and such values should therefore be treated with caution. Nevertheless, these findings highlight that coastal orientation, sediment availability, geological controls, and human interactions significantly affect shoreline change, and this evidence supports coastal management, hazard mitigation, and future measure planning in the region. Additionally, it is highly recommended to expand the work along the entire Irish shoreline and then utilize state-of-the-art artificial intelligence to predict the future shoreline.

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References

1. Liu, Y.; Wang, X.; Ling, F.; Xu, S.; Wang, C. Analysis of Coastline Extraction from Landsat-8 OLI Imagery. *Water* **2017**, *9*, 816. [[CrossRef](#)]
2. Pang, T.; Wang, X.; Nawaz, R.A.; Keefe, G.; Adekanmbi, T. Coastal erosion and climate change: A review on coastal-change process and modeling. *AMBIO* **2023**, *52*, 2034–2052. [[CrossRef](#)] [[PubMed](#)]
3. Masselink, G.; Russell, P. Impacts of climate change on coastal erosion. *MCCIP Sci. Rev.* **2013**, *2013*, 71–86. [[CrossRef](#)]
4. Defeo, O.; McLachlan, A.; Schoeman, D.S.; Schlacher, T.A.; Dugan, J.; Jones, A.; Lastra, M.; Scapini, F. Threats to sandy beach ecosystems: A review. *Estuar. Coast. Shelf Sci.* **2009**, *81*, 1–12. [[CrossRef](#)]
5. Gopinath, G.; Thodi, M.F.C.; Surendran, U.P.; Prem, P.; Parambil, J.N.; Alataway, A.; Al-Othman, A.A.; Dewidar, A.Z.; Mattar, M.A. Long-Term Shoreline and Islands Change Detection with Digital Shoreline Analysis Using RS Data and GIS. *Water* **2023**, *15*, 244. [[CrossRef](#)]
6. Chettiyam Thodi, M.F.; Gopinath, G.; Surendran, U.P.; Prem, P.; Al-Ansari, N.; Mattar, M.A. Using RS and GIS Techniques to Assess and Monitor Coastal Changes of Coastal Islands in the Marine Environment of a Huid Tropical Region. *Water* **2023**, *15*, 3819. [[CrossRef](#)]
7. Gao, W.; Liu, J.; Xu, Y.; Li, P. Evolution of sandy shores under the combined impact of global climate change and anthropogenic activities in Shandong Peninsula, East China. *J. Asian Earth Sci.* **2024**, *259*, 105887. [[CrossRef](#)]
8. Mentaschi, L.; Voudoukas, M.I.; Pekel, J.F.; Voukouvalas, E.; Feyen, L. Global long-term observations of coastal erosion and accretion. *Sci. Rep.* **2018**, *8*, 12876. [[CrossRef](#)]
9. Phillips, C.; Murphy, C.; Bresnihan, P. The impacts of and responses to place loss in a coastal community in Ireland. *Local Environ.* **2022**, *27*, 879–896. [[CrossRef](#)]
10. Samarasekara, R.S.M.; Sasaki, J.; Jayaratne, R.; Suzuki, T.; Ranawaka, R.A.S.; Pathmasiri, S.D. Historical changes in the shoreline and management of Marawila Beach, Sri Lanka, from 1980 to 2017. *Ocean Coast. Manag.* **2018**, *165*, 370–384. [[CrossRef](#)]
11. Westley, K.; McNeary, R. Assessing the Impact of Coastal Erosion on Archaeological Sites: A Case Study from Northern Ireland. *Conserv. Manag. Archaeol. Sites* **2014**, *16*, 185–211. [[CrossRef](#)]
12. Westley, K. Refining Broad-Scale Vulnerability Assessment of Coastal Archaeological Resources, Lough Foyle, Northern Ireland. *J. Isl. Coast. Archaeol.* **2019**, *14*, 226–246. [[CrossRef](#)]
13. Devoy, R.J.N. Coastal vulnerability and the implications of sea-level rise for Ireland. *J. Coast. Res.* **2008**, *24*, 325–341. [[CrossRef](#)]
14. Egon, A.; Farrell, E.; Iglesias, G.; Nash, S. Measurement and Modelling of Beach Response to Storm Waves: A Case Study of Brandon Bay, Ireland. *Coasts* **2025**, *5*, 32. [[CrossRef](#)]
15. Fealy, R.; Murphy, C.; Maynooth, N.U.I. *IPCC Sixth Assessment Report; Intergovernmental Panel on Climate Change (IPCC): Geneva, Switzerland, 2021; Chapter 4.*
16. McKenna, J.; Carter, R.W.G.; Bartlett, D. Coast Erosion in Northeast Ireland—Part II: Cliffs and Shore Platforms. *Ir. Geogr.* **1992**, *25*, 111–128. [[CrossRef](#)]
17. Vallarino Castillo, R.; Negro Valdecantos, V.; del Campo, J.M. Understanding the impact of hydrodynamics on coastal erosion in Latin America: A systematic review. *Front. Environ. Sci.* **2023**, *11*, 1267402. [[CrossRef](#)]
18. Romão, F.; Lima, M.; Coelho, C. A State-of-the-Art Review on Storm Events, Overtopping and Morphological Changes in Front of Coastal Structures. *J. Mar. Sci. Eng.* **2024**, *13*, 40. [[CrossRef](#)]
19. Bishop-Taylor, R.; Nanson, R.; Sagar, S.; Lymburner, L. Mapping Australia’s dynamic coastline at mean sea level using three decades of Landsat imagery. *Remote Sens. Environ.* **2021**, *267*, 112734. [[CrossRef](#)]
20. Carter, R.W.G. Sea-level changes in Northern Ireland. *Proc. Geol. Assoc.* **1982**, *93*, 7–23. [[CrossRef](#)]

21. Carter, R.W.G.; Johnston, T.W.; McKenna, J.; Orford, J.D. Sea-level, sediment supply and coastal changes: Examples from the coast of Ireland. *Prog. Oceanogr.* **1987**, *18*, 79–101. [[CrossRef](#)]
22. Carter, R.W.G.; Bartlett, D.J. Coastal Erosion in Northeast Ireland—Part I: Sand beaches, dunes and river mouths. *Ir. Geogr.* **1990**, *23*, 1–16. [[CrossRef](#)]
23. Grotoli, E.; Biauxque, M.; Jackson, D.W.T.; Cooper, J.A.G. Long-term drivers of shoreline change over two centuries on a headland-embayment beach. *Earth Surf. Process. Landf.* **2023**, *48*, 2500–2520. [[CrossRef](#)]
24. Chalénçon, E.; Cawkwell, F.; O’Shea, M.; Murphy, J. Automating the quantification of coastal change using historical aerial photography: A case study along the coastline of county Cork, Ireland. *Camb. Prisms Coast. Futures* **2025**, *3*, e1. [[CrossRef](#)] [[PubMed](#)]
25. Burningham, H.; French, J. Understanding coastal change using shoreline trend analysis supported by cluster-based segmentation. *Geomorphology* **2017**, *282*, 131–149. [[CrossRef](#)]
26. Nidhinarangkoon, P.; Ritphring, S.; Kino, K.; Oki, T. Shoreline Changes from Erosion and Sea Level Rise with Coastal Management in Phuket, Thailand. *J. Mar. Sci. Eng.* **2023**, *11*, 969. [[CrossRef](#)]
27. Apostolopoulos, D.N.; Nikolakopoulos, K.G. SPOT vs Landsat satellite images for the evolution of the north Peloponnese coastline, Greece. *Reg. Stud. Mar. Sci.* **2022**, *56*, 102691. [[CrossRef](#)]
28. Albuquerque, M.; Espinoza, J.; Teixeira, P.; de Oliveira, A.; Corrêa, I.; Calliari, L. Erosion or Coastal Variability: An Evaluation of the DSAS and the Change Polygon Methods for the Determination of Erosive Processes on Sandy Beaches. *J. Coast. Res.* **2013**, *165*, 1710–1714. [[CrossRef](#)]
29. Oyedotun, T.D.T. Shoreline Geometry: DSAS as a Tool for Historical Trend Analysis. *Geomorphol. Tech.* **2014**, *3*, 1–12.
30. Kaliraj, S.; Chandrasekar, N.; Magesh, N.S. Impacts of wave energy and littoral currents on shoreline erosion/accretion along the south-west coast of Kanyakumari, Tamil Nadu using DSAS and geospatial technology. *Environ. Earth Sci.* **2014**, *71*, 4523–4542. [[CrossRef](#)]
31. Bheeroo, R.A.; Chandrasekar, N.; Kaliraj, S.; Magesh, N.S. Shoreline change rate and erosion risk assessment along the Trou Aux Biches–Mont Choisy beach on the northwest coast of Mauritius using GIS-DSAS technique. *Environ. Earth Sci.* **2016**, *75*, 444. [[CrossRef](#)]
32. Himmelstoss, E.A.; Henderson, R.E.; Kratzmann, M.G.; Farris, A.S. *Digital Shoreline Analysis System (DSAS) Version 5.1 User Guide*; U.S. Geological Survey: Reston, VA, USA, 2021.
33. Luijendijk, A.; Hagenaars, G.; Ranasinghe, R.; Baart, F.; Donchyts, G.; Aarninkhof, S. The State of the World’s Beaches. *Sci. Rep.* **2018**, *8*, 6641. Correction in *Sci. Rep.* **2018**, *8*, 11381. [[CrossRef](#)]
34. Murray, J.; Adam, E.; Woodborne, S.; Miller, D.; Xulu, S.; Evans, M. Monitoring Shoreline Changes along the Southwestern Coast of South Africa from 1937 to 2020 Using Varied Remote Sensing Data and Approaches. *Remote Sens.* **2023**, *15*, 317. [[CrossRef](#)]
35. Nolan, W. Geography of Ireland. In *Essays on Ireland*; Uploaded 01/04/2008; Government of Ireland: Dublin, Ireland, 2008.
36. Arosio, R.; Wheeler, A.J.; Sacchetti, F.; Guinan, J.; Benetti, S.; O’Keefe, E.; van Landeghem, K.J.J.; Conti, L.A.; Furey, T.; Lim, A. The geomorphology of Ireland’s continental shelf. *J. Maps* **2023**, *19*, 2283192. [[CrossRef](#)]
37. McCullagh, D.; Benetti, S.; Plets, R.; Sacchetti, F.; O’Keefe, E.; Lyons, K. Geomorphology and substrate of Galway Bay, Western Ireland. *J. Maps* **2020**, *16*, 166–178. [[CrossRef](#)]
38. Fitzgerald, C.A. *Climate Change and Shoreline Built Cultural Assets; The Preparation of a Vulnerability Atlas*; The Heritage Council of Ireland: Kilkenny, Ireland, 2010.
39. Waterford City and County Council. Chapter 10: Landscape, Coast/Marine and Blue Green Infrastructure. In *Waterford City & County Development Plan 2022–2028*; Waterford City and County Council: Waterford, Ireland, 2022; pp. 268–280.
40. Orford, J.D.; Carter, R.W.G. Geomorphological Changes on the Barrier Coasts of South Wexford. *Ir. Geogr.* **1982**, *15*, 70–84. [[CrossRef](#)]
41. Roy, D.P.; Wulder, M.A.; Loveland, T.R.; Woodcock, C.E.; Allen, R.G.; Anderson, M.C.; Helder, D.; Irons, J.R.; Johnson, D.M.; Kennedy, R.; et al. Landsat-8: Science and product vision for terrestrial global change research. *Remote Sens. Environ.* **2014**, *145*, 154–172. [[CrossRef](#)]
42. O’Hagan, A.M.; Cooper, J.A.G. Spatial variability in approaches to coastal protection in Ireland. *J. Coast. Res.* **2002**, *36*, 544–551. [[CrossRef](#)]
43. Stori, F.T.; O’Hagan, A.M.; O’Mahony, C. National Integrated Coastal Zone Management Frameworks Need to Adapt. In *Climate Change Management*; Springer Nature: Berlin/Heidelberg, Germany, 2023. [[CrossRef](#)]
44. Department of Agriculture, Food and the Marine Agencies & Programmes Division. *Regional Seascape Character Assessment for Ireland 2020*; Ordnance Survey Ireland: Dublin, Ireland, 2020.
45. Policy Research Corporation Ireland. *The Economics of Climate Change Adaptation in EU Coastal Areas*; Policy Research Corporation: Dublin, Ireland, 2015.
46. Hurley, J. *Coastal Erosion at Ballygrangans*; SWC Promotions: Kilmore, Ireland, 2006.

47. Zorlu, O.; Kusak, L. An assessment of the long-term change of the Mersin west coastline using digital shoreline analysis system and detection of pattern similarity using fuzzy C-means clustering. *Front. Mar. Sci.* **2025**, *12*, 1457016. [[CrossRef](#)]
48. Environmental Protection Agency. *National Climate Change Risk Assessment*; The Environmental Protection Agency: Wexford, Ireland, 2025.
49. Paranunzio, R.; Guerrini, M.; Dwyer, E.; Alexander, P.J.; O'Dwyer, B. Assessing Coastal Flood Risk in a Changing Climate for Dublin, Ireland. *J. Mar. Sci. Eng.* **2022**, *10*, 1715. [[CrossRef](#)]
50. Pardo-Pascual, J.E.; Sánchez-García, E.; Almonacid-Caballer, J.; Palomar-Vázquez, J.M.; Santos, E.P.d.L.; Fernández-Sarría, A.; Balaguer-Beser, Á. Assessing the accuracy of automatically extracted shorelines on microtidal beaches from landsat 7, landsat 8 and sentinel-2 imagery. *Remote Sens.* **2018**, *10*, 326. [[CrossRef](#)]
51. Vos, K.; Splinter, K.D.; Harley, M.D.; Simmons, J.A.; Turner, I.L. CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. *Environ. Model. Softw.* **2019**, *122*, 104528. [[CrossRef](#)]

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