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Multi-decadal Assessment of Shoreline Changes Along the Ksar Esghir Coast, Morocco: Implications for Coastal Management

Ahlam Amara Zenati[1,2], Miriam Wahbi[2], Mohammed Bouchkara[3,4*], Khalid El Khalidi[3,4], Mustapha Maatouk[2], Bouchta Elmoumni [2], Mohamed El Bidaoui[5]

[1] Tanger Med Engineering, Tangier, Morocco

[2] Research and Development in Applied Geosciences Laboratory, Faculty of Sciences and Techniques, Abdelmalek Essaadi University, Tetouan, Morocco

[3] Marine Geosciences and Soil Science Laboratory (URAC-45), Earth Sciences Department, Faculty of Sciences, Chouaib Doukkali University, El Jadida, Morocco

[4] Center of Coastal and Sea, Chouaib Doukkali University, El Jadida, Morocco

[5] Geoscience Laboratory, Earth Sciences department, Faculty of Sciences, Moulay Ismail University, Meknes, Morocco

[*] Corresponding author's e-mail: m.bouchkara@yahoo.com

ABSTRACT

Coastal zones, as highly dynamic and complex environments, have substantial ecological and territorial implications for both government authorities and coastal managers. This research study investigated the impacts of port construction on shoreline dynamics along the coastal region of Ksar Esghir, located on the northern coast of Morocco, over a 19-year period (2002–2021). This study aimed to characterize the evolution of the coastline using high-resolution satellite images in a geographic information system (GIS) environment. Coastline evolution was assessed using GIS tools, particularly the digital shoreline analysis system (DSAS). Statistical approaches were used to determine the net rates of shoreline change, namely the end point rate (EPR) and net shoreline movement (NSM). Three main sectors were defined for the study area: The Eddallya sector, the western sector of Ksar Esghir and the port sector. As a result, two distinct zones have been identified in the Eddallya sector. Zone I shows an average accretion of +1.46 m/year, while zone II shows an erosion of -0.80 m/year. Analysis of the western sector of Oued Ksar Sghir revealed both erosion and accretion sites. Furthermore, the port sector showed positive values for shoreline evolution, with an average of +9.44 m and a rate of +0.49 m/year, signifying significant shoreline expansion over the study period. These findings highlight the dynamic and highly complex processes involved in coastal development in the study area. The results suggest that sediment dynamics, tidal regimes and potential anthropogenic influences have a significant impact on shoreline evolution, especially where port construction is concerned. The outcomes of this study provide helpful information for better and sustainable coastal management along the coastal area of Ksar Sghir.

Keywords: coastal dynamics, shoreline evolution, DSAS, Ksar Sghir, Morocco.

INTRODUCTION

Coastlines are situated within dynamic environments characterized by frequent interactions between the ocean, atmosphere, and human activities. This dynamic interplay results in a continuous movement of the shoreline, both landward and seaward. The driving forces behind these shoreline changes can be classified into three main factors: internal factors, external factors, and human interventions (Thoai et al., 2019). Internal factors encompass a range of natural processes, including nearshore currents, wave energy, tidal fluctuations, and alterations in sediment distribution (Williams et al., 2018).

Coastal areas play a crucial role in providing valuable ecosystem services as well as supporting high levels of ecological and biological productivity.

However, these regions are often targeted for the development of tourist accommodations and infrastructure, as exemplified by the studies conducted by (Benkhattab et al., 2020a; El Khalidi et al., 2021; Hakkou et al., 2018; Maanan et al., 2018). Notably, a significant portion of the global population, approximately 44%, resides within 150 kilometers of a coastline, underscoring the importance of coastal environments (Syvitski et al., 2005).

To understand natural and anthropogenic changes in natural ecosystems and to plan successful remediation projects, the deposition and erosion processes need to be understood (Bouchkara et al., 2022; Jaffe et al., 2007). Shoreline dynamics can be categorized into three primary states: erosion (retreat toward land), equilibrium (stability), and accretion (seaward extension) (Salghuna and Bharathvaj, 2015). These states are intricately linked to such factors as the availability of sediment for beach formation, sea-level fluctuations, and the development of landforms (Salghuna and Bharathvaj, 2015). Both natural processes and human activities significantly influence shoreline erosion and accretion, leading to changes in the surrounding ecosystems (Saranathan et al., 2011; To and Thao, 2008).

The study of shoreline changes has been the focus of numerous investigations worldwide (Addo et al., 2011; Maiti and Bhattacharya, 2009; Moussaid et al., 2015; Ozturk and Sesli, 2015; Zuzek et al., 2003). To extract valuable information about shorelines and water bodies, various methods are employed, serving diverse purposes, including the detection of coastline alterations, coastal zone management, watershed delineation, and flood prediction (El Mrini et al., 2012).

In this research, geospatial techniques, geographic information systems (GIS), and the digital shoreline analysis system (DSAS) were applied to analyze the shoreline changes along the Ksar Esghir coast during 19 years from 2002 to 2021. The study utilized a range of statistical methods, with a particular focus on the net shoreline movement (NSM) and end point rate (EPR) (Moussaid et al., 2015; Thieler et al., 2009, 2005; Thieler and Danforth, 1994).

The primary objectives of this study encompassed three key aspects: (1) quantifying the areas experiencing erosion and accretion, (2) evaluating long-term shoreline change rates, and (3) assessing the impact of human activities, with a specific emphasis on the influence of port construction and the evolution of the coastal environment.

MATERIALS AND METHODS

Study area

The study area spans the municipalities of Ksar Sghir, Ksar El Majaz, and Taghramt, within the province of Fahs-Anjra, in the Tangier-Tetouan-Al Hoceïma region, located in the northern part of Morocco. Geographically, the studied coastline is situated between the city of Tangier to the west and the city of Ceuta to the east. It is bordered to the north by the Strait of Gibraltar and to the south by the geological formations of the external Rif mountain range. The study area represents a small section of Morocco's northern coastline, specifically within the Strait of Gibraltar region. It extends between geographical coordinates $X_1 = 470529$, $X_2 = 498297$, $Y_1 = 580153$, $Y_2 = 589565$, with an east-west orientation, covering a length of approximately 40 km.

Data collection

In this research work, satellite images from Landsat 7 ETM+ (Enhanced Thematic Mapper Plus) and Landsat 8 OLI (Operational Land Imager), with a spatial resolution of 30 meters, were used.

The study of coastal evolution in the Ksar Sghir region covered a 19-year period, from 2002 to 2021. This study is mainly based on the analysis of coastal positions extracted from satellite images acquired over the various years. These data were collected by accessing multi-temporal Landsat satellite images, including both ETM+ and OLI data, from the USGS website (https://earthexplorer.usgs.gov/) for the following milestone years: 2002, 2009, 2010, 2014, 2017 and 2021. The images captured during the summer months (May, June, July, August and September) were chosen to minimize the presence of clouds and thus improve data clarity. In addition, image acquisition was meticulously timed to coincide with low tide conditions in the study area, as illustrated in Table 1, to mitigate potential atmospheric distortions. Moreover, a comprehensive correction process was applied to refine the imaging data. This included both atmospheric and radiometric correction, using the fast line-of-sight atmospheric analysis of spectral hypercubes (FLAASH) module in ENVI software version 5.3. These corrections have improved the accuracy and reliability of the studied image data, facilitating a more robust analysis of coastal evolution.

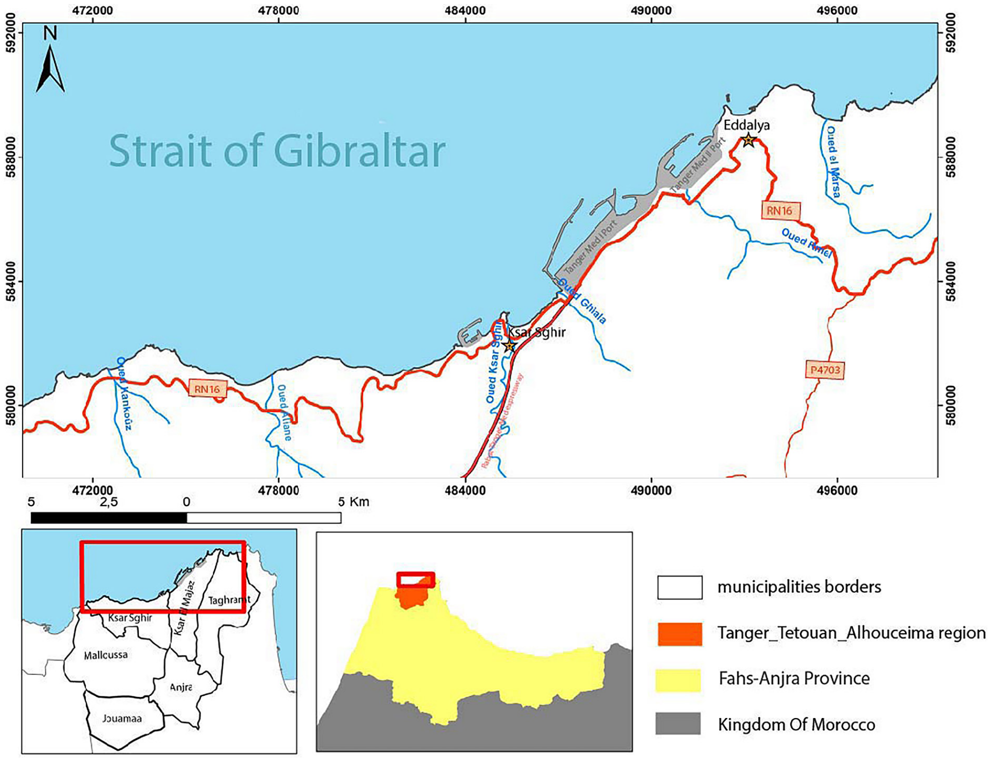

Figure 1. Study area location

Table 1. Characteristics of the collected data

Satellite/captor	Resolution (m)	Spectral band	Acquisition period (hh: mm/jj/mm/a)	Ksar Sghir (Morocco)	
				Low tides	Low tides
Landsat 7 (ETM+)	30	8	10 :44/11/07/2002	8:34 AM	2:19AM
Landsat 7 (ETM+)	30	8	10 :45/30/07/2009	9:08 AM	2:29 AM
Landsat 7 (ETM+)	30	8	10 :55/30/05/2010	9:30 AM	3:19 AM
Landsat 8 (OLI)	30	9	10 :46/21/08/2014	5:41 AM	12:32 PM
Landsat 8 (OLI)	30	9	10 :55/26/06/2017	9:40 AM	3:22 AM
Landsat 8 (OLI)	30	9	10 :55/08/08/2021	7:10 AM	12:47 PM

Shoreline extraction

The selection of indicators from which to extract the shoreline represents the second step in the process. It is crucial to define these indicators based on the specific environment. In the considered case, water was chosen as the indicator for shoreline identification. The shoreline and its evolution, be it erosion or accretion, irrespective of the definition used, serve as representative indicators of the land-sea boundary (Hapke et al., 2006). The shoreline was extracted using the non-normalized difference water index (DWI), the near-infrared (NIR) band, and principal component analysis (PCA). These methods, combined with thresholding techniques, have produced results better than other water index methods.

Moreover, thresholding provided reliable outcomes, primarily by identifying water and non-water pixels. While thresholding involves using a fixed value, it can pose challenges in the presence of shadows, hills, forests, and urban areas. It is a complex and time-consuming task since threshold values can vary based on the location and timing of image acquisition.

The comparative study of water surface extraction methods aimed to devise the most accurate approach that consistently improves water extraction precision in the presence of various environmental noise sources while maintaining a relatively stable threshold value (Liu et al., 2011).

Following the comparison of results, it becomes evident that the thresholding approach using principal component analysis (PCA) provides the sharpest and most reliable results. This

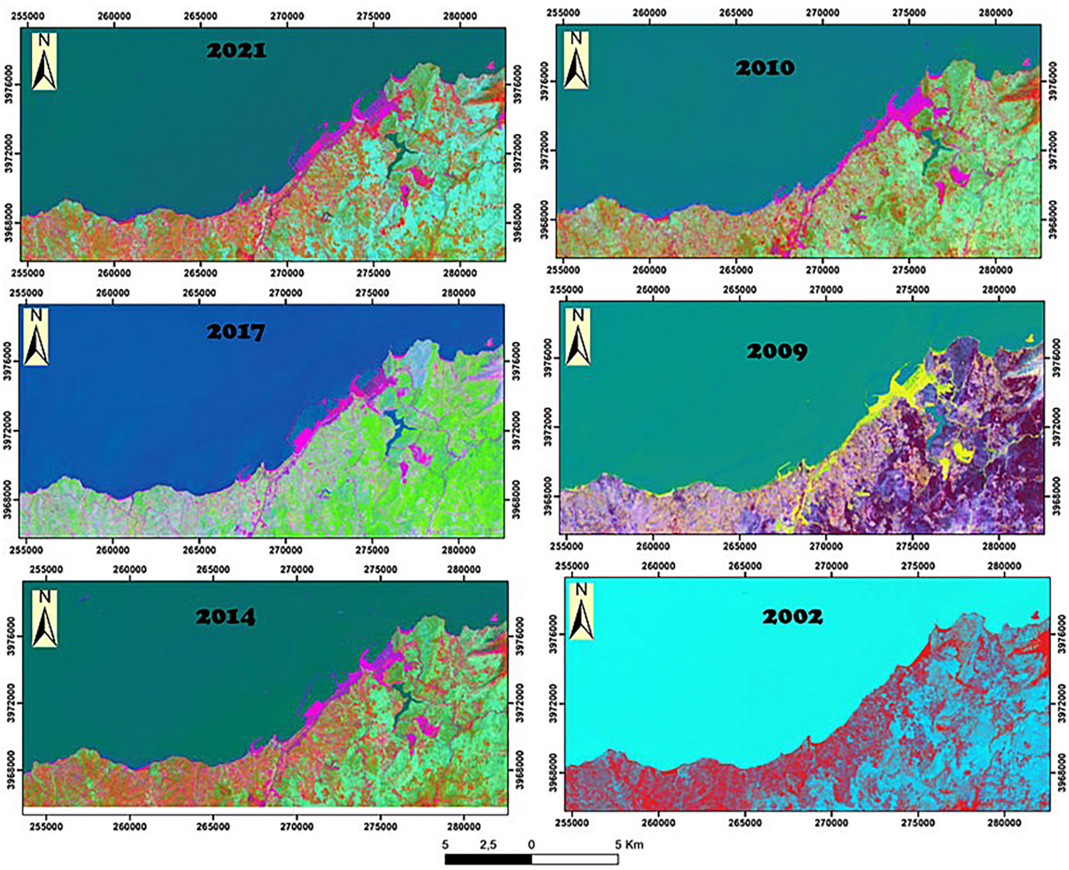

Figure 2. Water surface extraction from Landsat-7 ETM+ and Landsat-8 OLI images using PCA

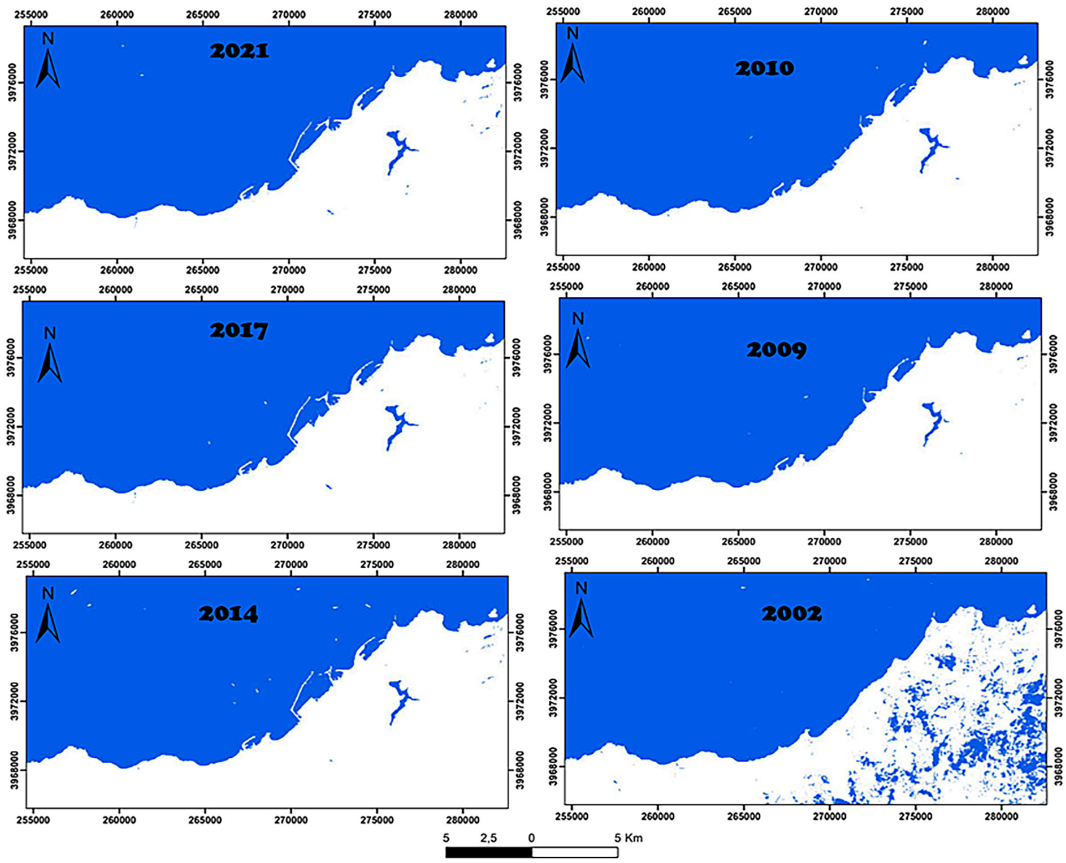

Figure 3. Results of PCA

method was utilized for shoreline digitization, ensuring high-quality results.

The shoreline extraction was carried out through manual digitization of the processed images for each year. The resulting polyline files were saved in a geodatabase within ArcGIS 10.6. These polyline shapefiles served as input data for the DSAS v.5 (Digital Shoreline Analysis System) software (Thieler et al., 2009, 2005).

DSAS model

In this research study, the DSAS (Digital Shoreline Analysis System) software was used to analyze the evolution of the shoreline in the Ksar Sghir region. DSAS is a plugin developed by the United States Geological Survey (USGS), available for free, and it operates within the Environmental Systems Research Institute's (ESRI) ArcGIS Geographic Information System (GIS) software. DSAS calculates rate-of-change statistics for a chronological series of vector shoreline data. This tool has been employed in various studies to measure and monitor coastline dynamics worldwide (Benkhattab et al., 2020a, 2020b; El Khalidi et al., 2021; Hakkou et al., 2018; Miranda et al., 2019; Moussaid et al., 2015; Nassar et al., 2019; Quang et al., 2021; Thieler et al., 2005, 2009; Thieler and Danforth, 1994; Zagórski et al., 2020).

DSAS version 4.3 within ArcGIS 10.3 was utilized to automatically measure changes in reference lines for comparison. These reference lines were spaced 100 meters apart and were generated from a baseline.

DSAS measures the distances between the intersection points of transects and coastlines, calculates change rates along each transect, and presents the results in tabular form. The software provides various statistics to assess coastline dynamics.

This process began with the creation of transects, followed by index calculation and the graphical representation of attribute tables of the calculated indices as per their relevance. Statistical calculations involved the automatic analysis of all transects to define the areas of change and calculate their average values (Faye, 2010; Thieler et al., 2009).

After calculation, the attribute table of transects contains various indices considered during configuration, with the most relevant ones in this study being the end point rate (EPR) and net shoreline movement (NSM).

End point rate – is the ratio of the distance between the oldest and most recent coastline positions over the time (number of years) elapsed between the two dates. Expressed in meters per year (Thieler et al., 2005). The end point rate method uses only two known positions of the reference line (the oldest and most recent positions). The distance (in meters) measured between these extreme shoreline locations during the study period is divided by the number of years to obtain the annual shoreline change rate. The advantage of this method lies in its simplicity. However, when intermediate positions between the two extreme dates of the study period are available, the rates estimated by this technique will not account for potential temporal variations in shoreline change (Sagne et al., 2021).

Net shoreline movement – indicates the distance between the oldest and most recent coastlines for each transect, with units expressed in meters (Thieler et al., 2009).

RESULTS

The study of the historical evolution of the coastline in the coastal area encompassing the three municipalities of Ksar Sghir, Ksar El Majaz, and Taghramt was conducted using the Landsat satellite images during the period from 2002 to 2021. Over these 19 years, the analysis focused on three distinct sectors due to significant variations in shoreline change rates across different parts of the study area. These sectors include the following:

- Western sector of Ksar Sghir: This sector covers the western portion of Ksar Sghir and constitutes the first area of interest in the analysis.
- Port sector of Ksar Sghir: The second sector of interest is the port area of Ksar Sghir, which may have experienced unique shoreline dynamics attributed to the construction and operation of the Mediterranean Ports (Tanger Med I and Tanger Med II).
- Eddallya sector: The third sector encompasses the Eddallya region, serving as another focal point for shoreline analysis.

Throughout the study period, various anthropogenic modifications were introduced in terms of coastal structures within the study area. These modifications could include the construction of coastal protection structures, such as breakwaters, groins, or seawalls. Additionally, the study

Table 2. Sector numbers and transects delimiting each sector using DSAS

N°	Studied sectors	Transects numbers	Sector extension (Km)
1	West sector of Ksar Sghir	1_148	21.52
2	Port zone	148_266	10.40
3	Eddallya sector	266_328	8.22

might consider changes before and after the establishment of the Mediterranean Ports (Tanger Med I and Tanger Med II).

The selection of these sectors and the consideration of specific timeframes for analysis (pre and post-construction of coastal structures or ports) aim to capture the diverse impacts of human activities and engineering interventions on the coastal environment. These modifications can significantly influence shoreline dynamics, erosion rates, and sediment transport patterns.

By focusing on these distinct sectors and timeframes, the study aimed to provide a comprehensive understanding of the historical evolution of the coastline in this region, taking into account the complex interplay between natural processes and human-induced changes.

West sector of Ksar Sghir

This sector has been divided into three distinct zones to capture the varying rates of shoreline change (Figure 4). Importantly, these changes are considered in light of the construction and operation of the Mediterranean Ports (Tanger Med I and Tanger Med II) and their potential influence on coastal areas and shoreline dynamics.

Zone I, encompassing the first transect to the 70th transect, exhibits a significant degree of erosion. The average shoreline changes within this zone measure approximately -5.97 m, with an overall erosion rate of roughly -0.32 m/year. Zone II presents a more intricate shoreline change pattern. While there is an overarching trend of accretion, intermittent areas are exhibiting slight erosion. The average shoreline change in this zone stands at approximately 5.30 m, with an average variation rate of around 0.27 m/year. The construction of coastal structures associated with the ports may have influenced sediment deposition in this area, contributing to the observed accretion.

The third zone, spanning from the 121st transect to the 148th transect, showcases a substantial accretion trend. Here, the shoreline has expanded

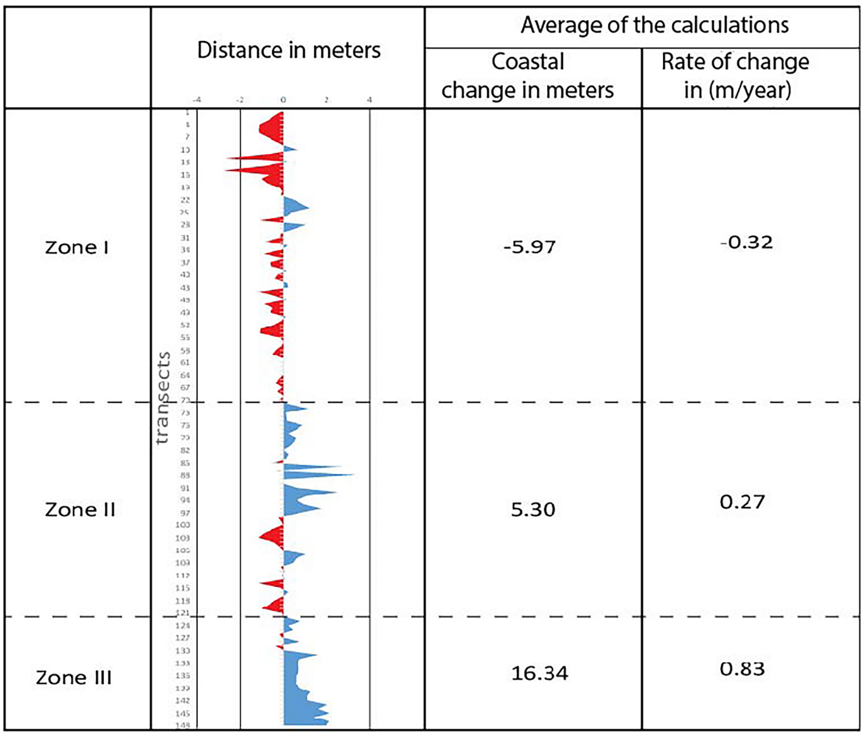

Figure 4. Evolution of the shoreline in the littoral part of West Ksar during the period 2002–2021

by an average of approximately +16.38 m, with a rapid accretion rate of approximately +0.86 m/year. The coastal protection measures associated with the ports could have played a pivotal role in enhancing sediment deposition and fostering accretion in this area. The maximum net evolution observed at the 88th transect, where a significant accretion of approximately +62.54 m has occurred, equivalent to an annual accretion rate of about +3.23 m/year. This remarkable accretion may be a result of sediment deposition influenced by the nearby port infrastructure.

The evolution of the shoreline along the western coast of Ksar Sghir from 2002 to 2021 exhibits diverse patterns of erosion and accretion across different zones. These patterns are likely influenced by the construction and operation of the Mediterranean Ports (Tanger Med I and Tanger Med II) and the associated coastal protection measures. The ports can significantly alter sediment transport dynamics, resulting in both erosion and accretion, as observed in the various zones.

Figure 5 presents a map illustrating the variation of End Point Rate (EPR) and Net Shoreline

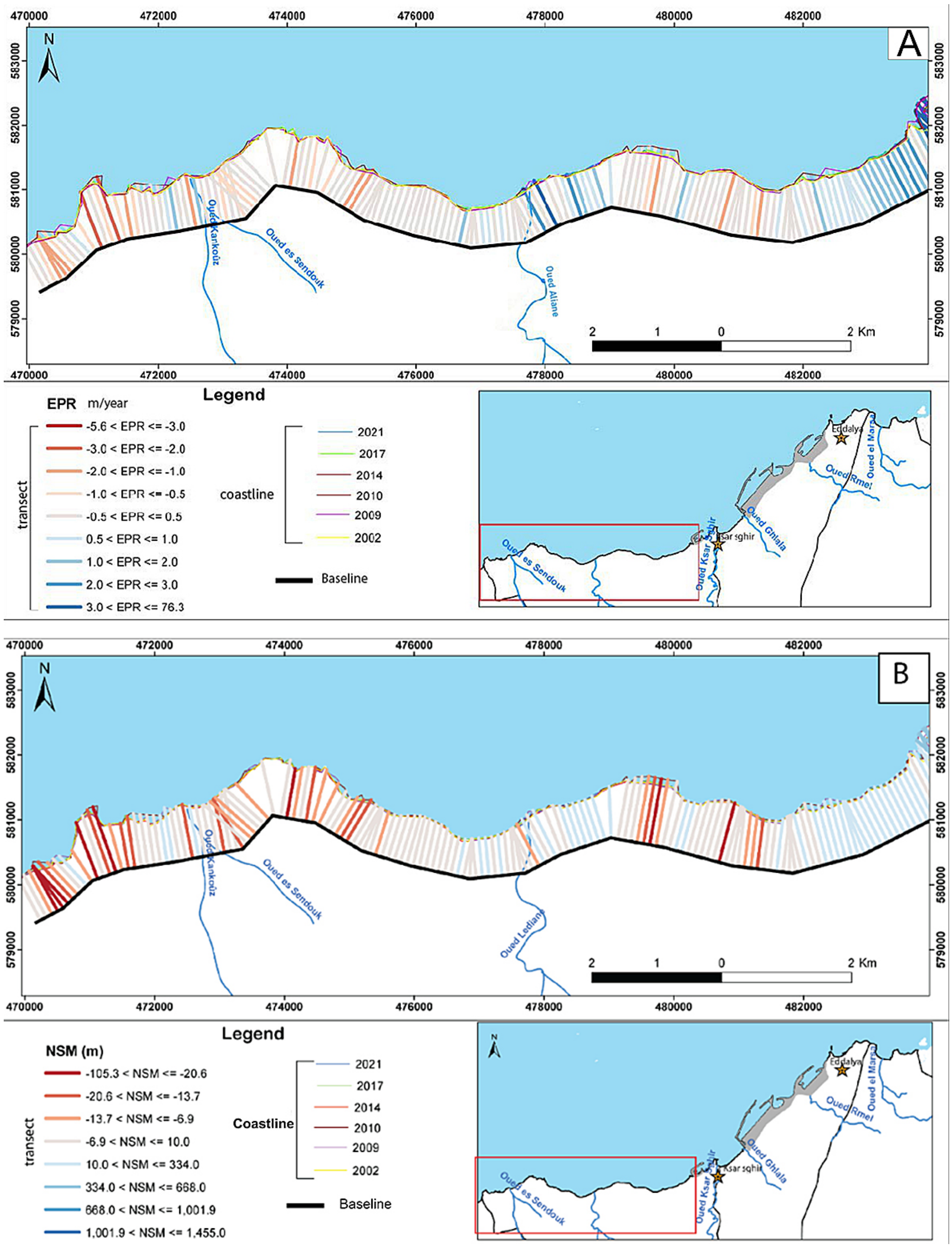

Figure 5. Classification map of shoreline changes using the EPR method (A) and the NSM method (B)

Movement (NSM) by transect along the designated sector. This map highlights notable fluctuations in EPR and NSM values calculated using the DSAS tool.

Starting from the western shoreline near Oued Aliane and extending eastward, there is a significant range of variation in both EPR and NSM, ranging from -105.3 (-5.6 m/year) to 10 meters (0.5 m/year). The majority of this region is characterized by erosion, particularly evident in the western part near Oued Kenkouz. Here, several transects exhibit substantial shoreline retreat, with EPR values ranging between -105.3 m (5.6 m/year) and -20.6 m (3 m/year).

Moving towards Ksar Sghir in the eastern part of Oued Aliane, there is a prevalence of positive EPR and NSM values indicating accretion. These values range from +10 m (+0.5 m/year) to +334 m (+2 m/year). Additionally, certain transects in this area show intermittent negative values, suggesting localized erosion, with EPR values ranging from -6.9 m (-1 m/year) to -105.3 m (-3 m/year).

The evolution of the shoreline in the port sector

This sector is divided into three zones; I, II and III (Figure 6). The analysis of the results has revealed significant variations in the non-port areas, specifically in Zone 2. However, Zones 1 and III, where the ports are situated, were excluded from the calculations due to their engineered and modified nature, which may not yield reliable results when analyzed using the DSAS software (Figure 6).

In Zone II, characterized as the non-port area, the analysis indicates a prevailing trend of accretion with minimal erosion. This is evident from the positive values of shoreline evolution, with an average of approximately +9.44 m and an average rate of change of about +0.49 m/year.

The positive values of shoreline evolution in Zone II signify that, on average, this area has experienced net accretion over the study period from 2002 to 2021. Accretion suggests an increase in the landward extent of the shoreline, which can be influenced by various natural processes and sediment dynamics.

Overall, this area stands out as an area of net shoreline accretion with limited erosion, indicating a positive trend in shoreline evolution.

The shoreline dynamics within Zone 2 are primarily characterized by a prevailing trend of accretion, which is evident when examining the classification of transects using the EPR and NSM methods. This classification reveals the following shoreline change patterns:

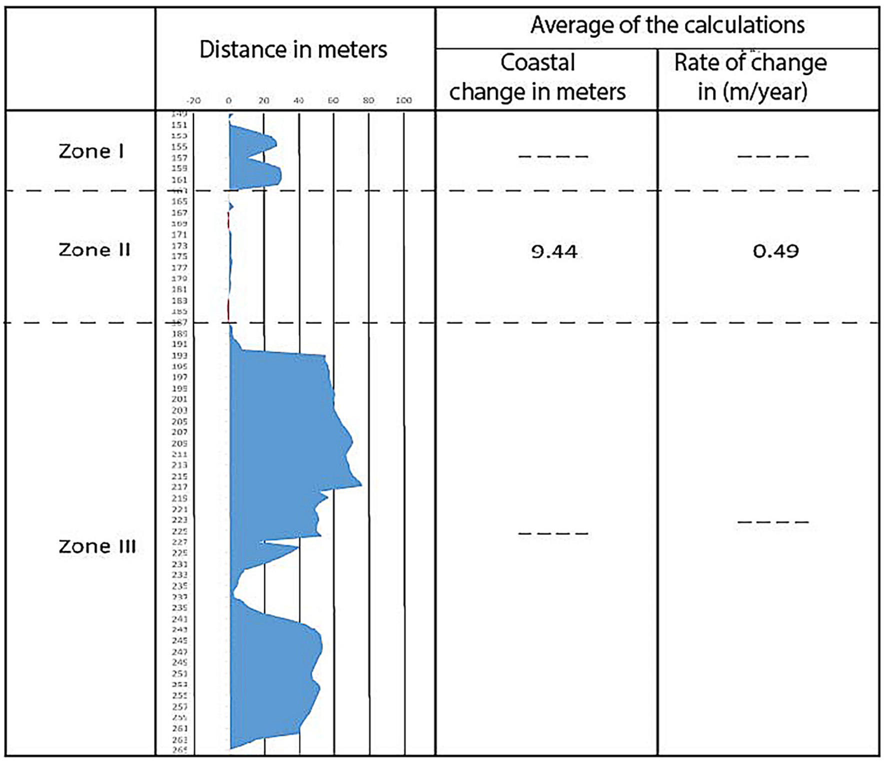

Figure 6. Evolution of the shoreline in the coastal part of the port area of Ksar Sghir over the period 2002–2021

To the west of Oued Ksar Sghir, the EPR and NSM values range from -6.9 m (-0.5 m/year) to 10 meters (0.5 m/year). This indicates a mix of slight erosion and accretion along different transects within this segment. Some transects exhibit values between -13.7 m (-1 m/year) and 20.6 m (3 m/year), signifying more pronounced variations in shoreline position. These fluctuations can be attributed to the complex interactions between erosional and depositional processes, sediment availability, and local coastal conditions.

Moving towards Ksar Sghir Beach in the eastern part of Zone II, a notable stability of positive values is observed. These values fall within the range of +10 m (1 m/year) to +334 m (3 m/year), indicating a relatively stable shoreline with consistent accretion tendencies. This suggests that this portion of the coastline has experienced a consistent landward expansion over the study period.

The stability and positive values of EPR and NSM in this eastern segment suggest that sediment deposition processes, sediment transport patterns, or natural shoreline dynamics may have contributed to the observed accretion. Understanding these processes is essential for informed coastal management and planning in this region.

It is worth noting that the observed shoreline dynamics can be influenced by a variety of factors, including sediment availability, wave and tidal patterns, as well as potential anthropogenic interventions or coastal protection measures.

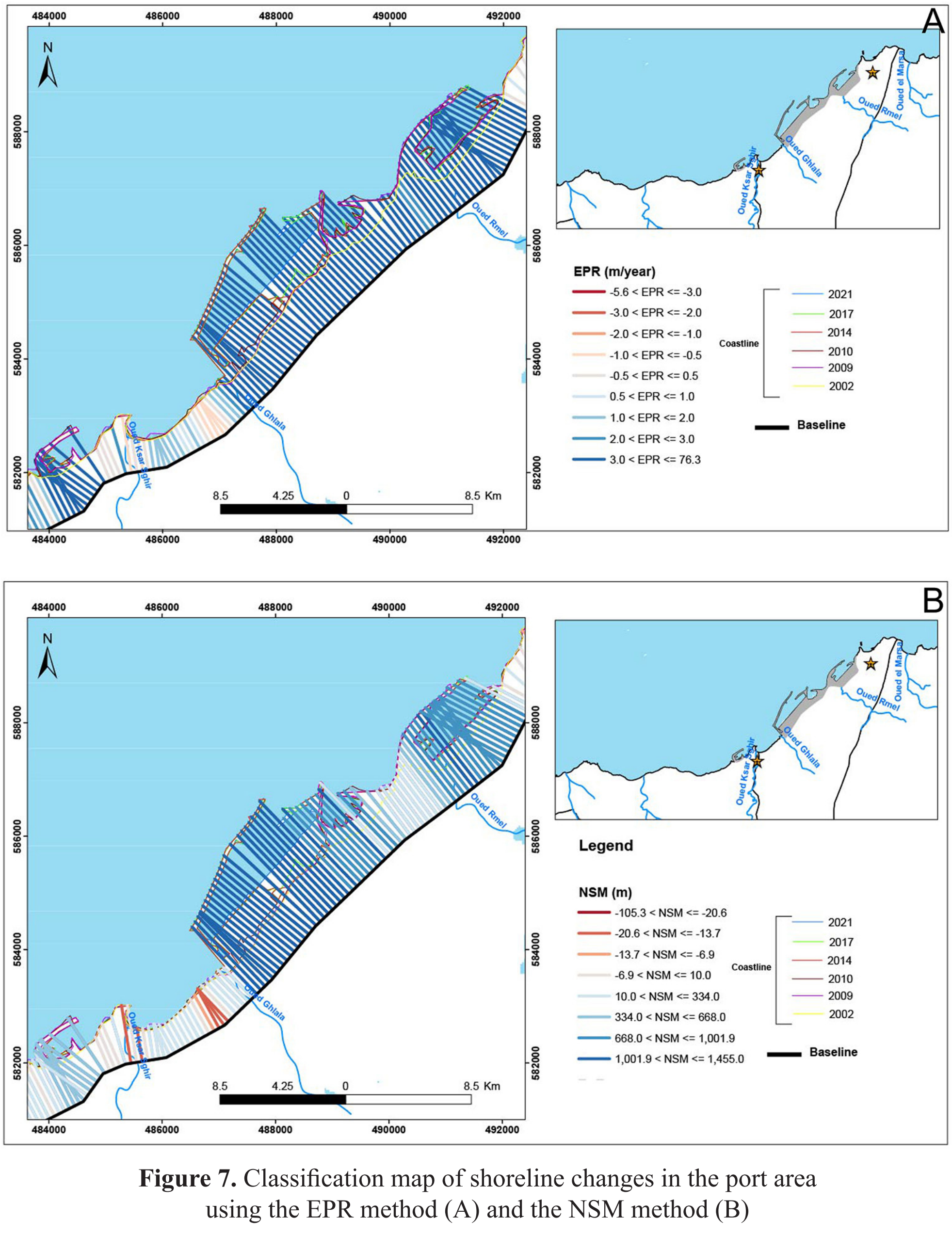

Figure 7. Classification map of shoreline changes in the port area using the EPR method (A) and the NSM method (B)

The evolution of shoreline in the Eddallya sector

The shoreline evolution graph for the Eddallya sector illustrates two distinct zones with differing shoreline dynamics (Figure 8):

In Zone I, there is a notable positive shoreline evolution trend, indicating accretion. The average variation in distance observed in this zone is approximately +26.63 m, with a relatively high accretion rate of about +1.46 m/year. This suggests that, on average, the shoreline in this area has been advancing seaward, potentially due to sediment deposition and natural processes favoring accretion.

Conversely, Zone II exhibits a significant impact of erosion. The shoreline in this zone has been experiencing erosion at an average rate of approximately -0.80 m/year. This corresponds to an average variation in distance of approximately -26.3 m. The negative values signify a landward retreat of the shoreline, which may be attributed to erosional forces such as wave action, sediment loss, or other environmental factors contributing to shoreline erosion.

The stark contrast in shoreline dynamics between Zone I and Zone II underscores the complex nature of coastal processes within the Eddallya sector. While Zone I is characterized by accretion and shoreline advancement, Zone II is marked by erosion and shoreline retreat.

These observations emphasize the importance of understanding the specific drivers and mechanisms influencing the shoreline changes in each zone. Factors such as sediment availability, wave and tide patterns, as well as potential anthropogenic impacts, can play a significant role in shaping shoreline dynamics.

The Eddallya sector, particularly in the vicinity of the coastal zone near Oued El Marsa, is significantly affected by erosion. This area exhibits pronounced shoreline retreat, with values ranging from -20.5 m to -105.3 m. These erosion rates correspond to an average annual rate of coastal retreat ranging from -3 m/year to -5.6 m/year (Figure 9). The substantial erosion observed in this sector signifies a landward movement of the shoreline over time, reflecting the dynamic interplay of erosional forces. Such forces may include wave action, sediment loss, and other environmental factors contributing to shoreline retreat.

DISCUSSION

Within the scope of this study, two highly effective methods were employed, namely the End Point Rate (EPR) and Net Shoreline Movement (NSM), as proposed by the DSAS software (Thieler et al., 2009). These methods provide a

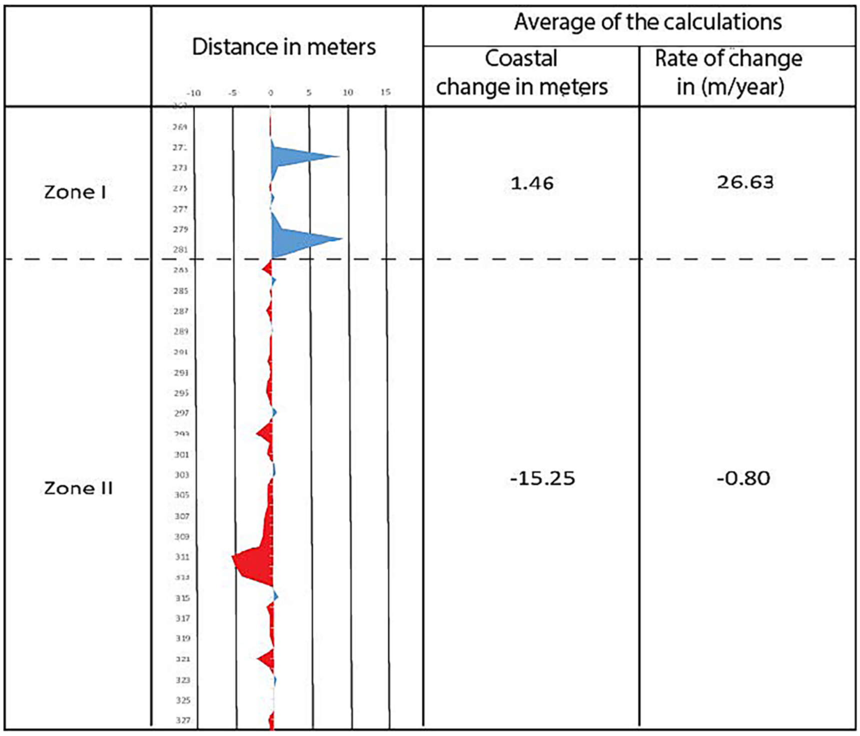

Figure 8. Evolution of the shoreline at the Eddallya sector over the period 2002–2021

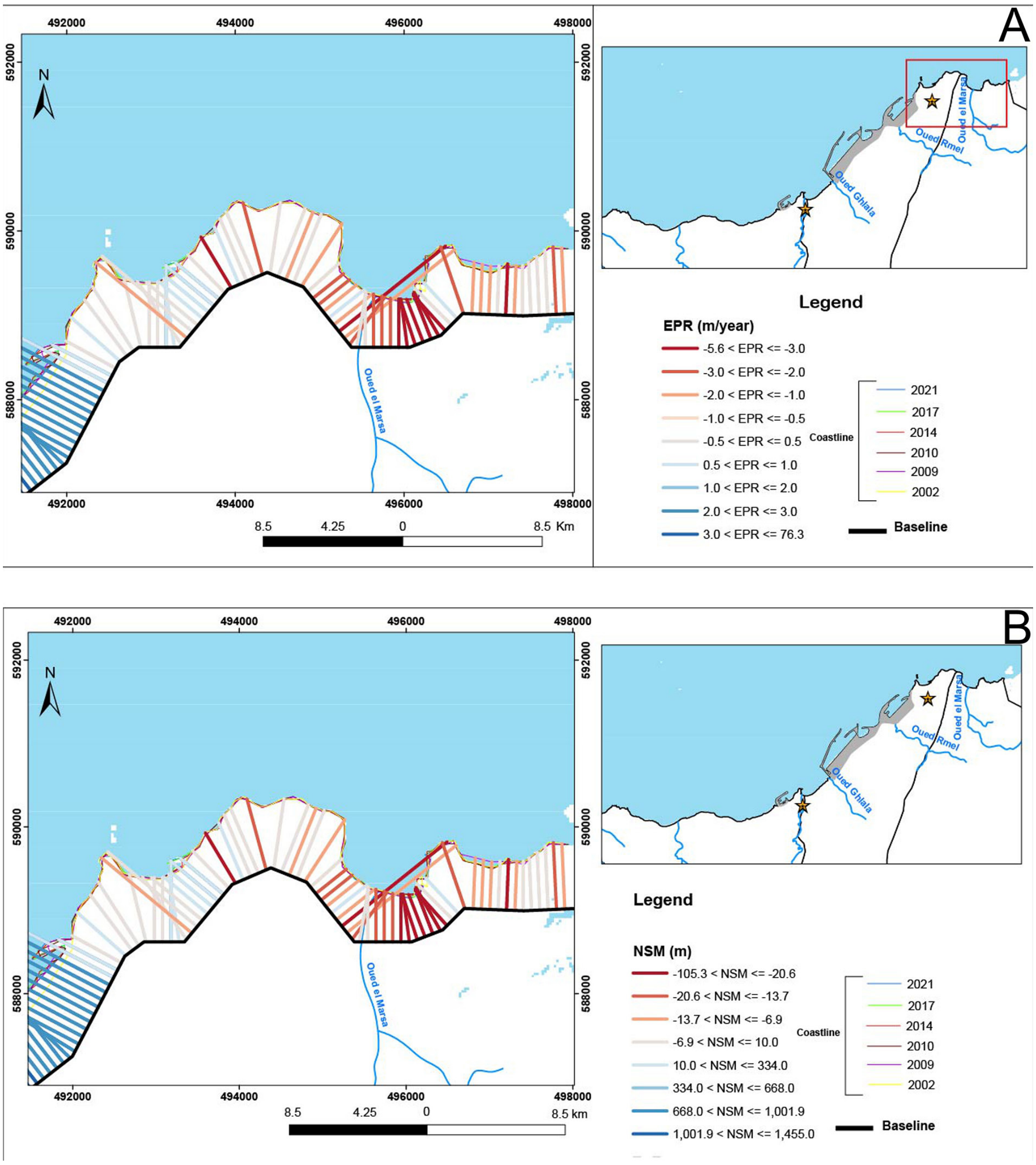

Figure 9. Classification maps of shoreline changes in the Eddallya sector using the EPR method (A) and the NSM method (B)

comprehensive assessment of shoreline variation at specific points.

The results indicate a dynamic interplay between erosion and accretion along the three sectors studied during the period from 2002 to 2021. Notably, a significant erosion trend was observed in the west part of the Oued Kankouz estuary. Additionally, the region around the Oued El Marsa estuary exhibited significant erosion, with erosion rates reaching up to -2 m/year.

Utilizing the EPR and NSM methods, substantial accretion was identified in two distinct coastal segments. An advancement of the shoreline, with an average rate of +2 m/year, was observed between the Oued Aliane estuary and the military port. Furthermore, a more pronounced accretion was identified beyond this region, with erosion rates exceeding +1 m/year and shoreline advancement exceeding +10 m. These areas are characterized by sediments that become trapped near the estuaries, unable to discharge into the sea, resulting in a sediment deficit caused by sediment transport patterns.

Moreover, the conducted analysis reveals that the studied coastline is characterized by fragility, featuring both unstable and relatively stable zones. The evolutionary trend indicates a seaward advance, signifying erosion with rates exceeding -2 m/year, particularly evident at the Oued El Marsa estuary and the western section of Oued Kenkouz.

A temporal analysis demonstrates that the years 2002, 2009, 2010, 2014, 2017, and 2021 experienced erosion, with an average rate of approximately -0.69 m/year, and accretion, with an average rate of approximately +0.89 m/year, across the entire study area.

These findings underscore the complex and dynamic nature of coastal processes in the study region. They suggest that sediment dynamics, tidal patterns, and potential anthropogenic influences play significant roles in shaping shoreline evolution. The presence of sediment trapping near estuaries emphasizes the need for careful management and monitoring of sediment transport in these areas to mitigate erosion and promote coastal stability.

This study provides valuable insights into the multifaceted coastal dynamics of the Ksar Sghir region, highlighting the importance of understanding these processes for informed coastal management and planning. Further research, including field studies and sediment analyses, is essential to unravel the specific mechanisms driving shoreline changes in this coastal area and to determine sustainable coastal management practices.

CONCLUSIONS

The comprehensive analysis of the historical evolution of the coastline in the Ksar Sghir coastal area over the period of 2002 to 2021 reveals intricate patterns of shoreline dynamics. The study focused on three distinct sectors, namely the western sector of Ksar Sghir, the port sector of Ksar Sghir, and the Eddallya sector. Significant variations in shoreline change rates were observed, influenced by anthropogenic modifications, including the construction and operation of Mediterranean Ports (Tanger Med I and Tanger Med II), and the implementation of coastal protection structures. In the western sector of Ksar Sghir, three distinct zones were identified with varying rates of shoreline change. Zone I exhibited an average erosion of approximately -5.97 m/year, Zone II showed an average accretion of approximately +5.30 m/year, and Zone III demonstrated substantial accretion with an average rate of approximately +16.38 m/year, reaching a maximum accretion of +62.54 m. The port sector of Ksar Sghir, divided into Zones I, II, and III, revealed noteworthy variations. In Zone II, the non-port area, an average accretion of approximately +9.44 m/year was observed, indicating a positive trend in shoreline evolution. However, Zones I and III, where the ports are situated, were excluded from calculations due to their engineered and modified nature. The Eddallya sector exhibited two distinct zones with differing dynamics. Zone I showed a positive shoreline evolution, indicating accretion at an average rate of approximately +1.46 m/year. In contrast, Zone II experienced erosion at an average rate of approximately -0.80 m/year.

These findings underscore the importance of understanding local characteristics and specific timeframes in assessing coastal evolution. The observed patterns suggest that sediment dynamics, tidal patterns, and human-induced changes play crucial roles in shaping shoreline dynamics. Such insights are essential for informed coastal management, emphasizing the need for tailored strategies that consider the multifaceted interactions between natural forces and human interventions.

REFERENCES

1. Addo, K.A., Jayson-Quashigah, P.N., Kufogbe, K.S., 2011. Quantitative analysis of shoreline change using medium resolution satellite imagery in Keta, Ghana. Mar. Sci. 1, 1–9.
2. Benkhattab, F.Z., Hakkou, M., Bagdanavičiūtė, I., Mrini, A. El, Zagaoui, H., Rhinane, H., Maanan, M., 2020a. Spatial-temporal analysis of the shoreline change rate using automatic computation and geospatial tools along the Tetouan coast in Morocco. Nat. Hazards 104, 519–536.
3. Benkhattab, F.Z., Hakkou, M., Bagdanavičiūtė, I., Mrini, A., El, Zagaoui, H., Rhinane, H., Maanan, M., 2020b. Spatial-temporal analysis of the shoreline change rate using automatic computation and geospatial tools along the Tetouan coast in Morocco. Nat. Hazards 104, 519–536. https://doi.org/10.1007/s11069-020-04179-2
4. Bouchkara, M., El Khalidi, K., Benazzouz, A., Erraji Chahid, N., Joudar, I., Zourarah, B., Maanan, M., 2022. Study of morphodynamic and sedimentological changes in the Oualidia Lagoon (Morocco) using bathymetric data: First investigations after the sediment trap dredging. Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLVI-4/W3-, 53–63. https://doi.org/10.5194/isprs-archives-xlvi-4-w3-2021-53-2022
5. El Khalidi, K., Bourhili, A., Bagdanavičiūtė, I., Minoubi, A., Hakkou, M., Zourarah, B., Maanan, M., 2021. Coastal land use and shoreline evolution along the Nador lagoon Coast in Morocco. Geocarto Int. 0, 1–17. https://doi.org/10.1080/10106049.2021.1974958
6. El Mrini, A., Anthony, E.J., Maanan, M., Taaouati, M., Nachite, D., 2012. Beach-dune degradation in a Mediterranean context of strong development

pressures, and the missing integrated management perspective. Ocean Coast. Manag. 69, 299–306.

7. Faye, I.B.N., 2010. Dynamique du trait de côte sur les littoraux sableux de la Mauritanie a la Guinée-Bissau (Afrique de l'Ouest): Approches régionale et locale par photo-interprétation, traitement d'images et analyse de cartes anciennes.
8. Hakkou, M., Maanan, M., Belrhaba, T., El Ouai, D., Benmohammadi, A., 2018. Multi-decadal assessment of shoreline changes using geospatial tools and automatic computation in Kenitra coast, Morocco. Ocean Coast. Manag. 163, 232–239.
9. Hapke, C., Reid, D., Richmond, B.M., Ruggiero, P., List, J., 2006. National assessment of shoreline change Part 3: Historical shoreline change and associated coastal land loss along sandy shorelines of the California Coast.
10. Jaffe, B.E., Smith, R.E., Foxgrover, A.C., 2007. Anthropogenic influence on sedimentation and intertidal mudflat change in San Pablo Bay, California: 1856–1983. Estuar. Coast. Shelf Sci. 73, 175–187. https://doi.org/10.1016/j.ecss.2007.02.017
11. Liu, W., Liu, G., Zhang, Q., 2011. Influence of vegetation characteristics on soil denitrification in shoreline wetlands of the Danjiangkou Reservoir in China. Clean–Soil, Air, Water 39, 109–115.
12. Maanan, Mehdi, El Barjy, M., Hassou, N., Zidane, H., Zourarah, B., Maanan, Mohamed, 2018. Origin and potential ecological risk assessment of trace elements in the watershed topsoil and coastal sediment of the Oualidia lagoon, Morocco. Hum. Ecol. Risk Assess. 24, 602–614. https://doi.org/10.1080/10807039.2017.1394176
13. Maiti, S., Bhattacharya, A.K., 2009. Shoreline change analysis and its application to prediction: A remote sensing and statistics based approach. Mar. Geol. 257, 11–23.
14. Miranda, I.M., Toldo, E.E., Da Fontoura Klein, A.H., Da Silva, G.V., 2019. Shoreline evolution of lagoon sandy spits and adjacent beaches, Lagoa dos Patos, Brazil. J. Coast. Res. 35, 1010–1023. https://doi.org/10.2112/JCOASTRES-D-18-00092.1
15. Moussaid, J., Fora, A.A., Zourarah, B., Maanan, Mehdi, Maanan, Mohamed, 2015. Using automatic computation to analyze the rate of shoreline change on the Kenitra coast, Morocco. Ocean Eng. 102, 71–77.
16. Nassar, K., Mahmod, W.E., Fath, H., Masria, A., Nadaoka, K., Negm, A., 2019. Shoreline change detection using DSAS technique: Case of North Sinai coast, Egypt. Mar. Georesources Geotechnol. 37, 81–95. https://doi.org/10.1080/1064119X.2018.1448912
17. Ozturk, D., Sesli, F.A., 2015. Shoreline change analysis of the Kizilirmak Lagoon Series. Ocean Coast. Manag. 118, 290–308. https://doi.org/10.1016/j.ocecoaman.2015.03.009
18. Quang, D.N., Ngan, V.H., Tam, H.S., Viet, N.T., Tinh, N.X., Tanaka, H., 2021. Long-term shoreline evolution using dsas technique: A case study of Quang Nam province, Vietnam. J. Mar. Sci. Eng. 9, 1–18. https://doi.org/10.3390/jmse9101124
19. Sagne, P., Ba, K., Fall, B., Youm, J.P.M., Faye, G., Sarr, J.P.G., Sow, E.H., 2021. Cartographie De La Dynamique Historique Du Trait De Côte Des Plages De Guédiawaye Et Malika (Dakar, Sénégal). Eur. Sci. J 17, 214.
20. Salghuna, N.N., Bharathvaj, S.A., 2015. Shoreline change analysis for northern part of the coromandel coast. Aquat. Procedia 4, 317–324.
21. Saranathan, E., Chandrasekaran, R., Soosai Manickaraj, D., Kannan, M., 2011. Shoreline Changes in Tharangampadi Village, Nagapattinam District, Tamil Nadu, India—A Case Study. J. Indian Soc. Remote Sens. 39, 107–115.
22. Syvitski, J.P.M., Harvey, N., Wolanski, E., Burnett, W.C., Perillo, G.M.E., Gornitz, V., Arthurton, R.K., Bokuniewicz, H., Campbell, J.W., Cooper, L., 2005. Dynamics of the coastal zone, in: Coastal Fluxes in the Anthropocene: The Land-Ocean Interactions in the Coastal Zone Project of the International Geosphere-Biosphere Programme. Springer, pp. 39–94.
23. Thieler, E.R., Danforth, W.W., 1994. Historical shoreline mapping (II): application of the digital shoreline mapping and analysis systems (DSMS/DSAS) to shoreline change mapping in Puerto Rico. J. Coast. Res. 600–620.
24. Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., Ergul, A., 2009. The Digital Shoreline Analysis System (DSAS) version 4.0-an ArcGIS extension for calculating shoreline change. US Geological Survey.
25. Thieler, E.R., Himmelstoss, E.A., Zichichi, J.L., Miller, T.L., 2005. The Digital Shoreline Analysis System (DSAS) version 3.0, an ArcGIS extension for calculating historic shoreline cange. US Geological Survey.
26. Thoai, D.T., Dang, A.N., Oanh, N.T.K., 2019. Analysis of coastline change in relation to meteorological conditions and human activities in Ca mau cape, Viet Nam. Ocean Coast. Manag. 171, 56–65.
27. To, D. Van, Thao, P.T.P., 2008. A Shoreline Analysis using DSAS in Nam Dinh Coastal Area. Int. J. Geoinformatics 4.
28. Williams, A.T., Rangel-Buitrago, N., Pranzini, E., Anfuso, G., 2018. The management of coastal erosion. Ocean Coast. Manag. 156, 4–20.
29. Zagórski, P., Jarosz, K., Superson, J., 2020. Integrated assessment of shoreline change along the Calypsostranda (Svalbard) from remote sensing, Field survey and GIS. Mar. Geod. 43, 433–471. https://doi.org/10.1080/01490419.2020.1715516
30. Zuzek, P.J., Nairn, R.B., Thieme, S.J., 2003. Spatial and temporal considerations for calculating shoreline change rates in the Great Lakes Basin. J. Coast. Res. 125–146.