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TEMPORAL SHORELINE CHANGES from 1984 to 2022 along BEYMELEK BEACH and BEYMELEK LAGOON, ANTALYA, TÜRKİYE

1984–2022 Yılları Arasında Beymelek Plajı ve Beymelek Lagünü Kıyı Şeridi Değişimleri, Antalya, Türkiye

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ABSTRACT

Coastal zones are important transition zones between land and sea, and the shoreline is subject to dynamic change on both spatial and temporal scales. Accurate measurement and modelling of the shoreline is therefore essential for coastal sustainability and coastal zone management. In this study, the shoreline change of Beymelek Beach and Beymelek Lagoon was analyzed over both short and long periods by using End Point Rate (EPR), Net Shoreline Movement (NSM) and Linear Regression Rate (LRR) statistics from the Digital Shoreline Analyses System (DSAS) tool. The long-term shoreline statistics of the Beymelek Beach indicates that the maximum shoreline accretion was 128.4 m for NSM and 4.3 m/yr for EPR, while the maximum shoreline erosion was -62.6 m for NSM, and -1.8 m/yr for LRR in 1984 and 2022. The maximum shoreline erosion rate of Beymelek Lagoon was -148.5 m for NSM and the maximum shoreline accretion was 5.3 m for NSM between 1984 and 2022. As a result, Beymelek Beach and Beymelek Lagoon have experienced significant shoreline changes over both short and long periods. Therefore, determining the shoreline change in the study area is crucial for making efficient decisions about the coastal zone and contributing to its sustainability.

1. INTRODUCTION

The coastal zone is an area of interaction between the land and the ocean (Nie et al., 2012; Shailesh Nayak, 2002; Yan et al., 2024). In addition, coastal areas are both ecologically and economically important and extremely dynamic (Dai et al., 2019). Historically, people have used coastal areas because of their favorable conditions for industrial, agricultural, recreational, and commercial activities (Ferreira et al., 2021). Today, coastal zones host to 10% of the world's population on 2% of the global land area (Godwyn-Paulson et al., 2021). The global population density in coastal areas within 100 km was 87 people per km^2 in 2000, 99 people per km^2 in 2010, and is projected to be 134 people per km^2 in 2050 (Arun Kumar & Kunte, 2012; Godwyn-Paulson et al., 2021). As a result, coastal areas, which act as a transition between land and sea, have become hotspots for human activities, making them vulnerable and fragile (Cai et al., 2022).

The shoreline is the boundary between land and sea that is constantly changing in shape and position due to dynamic environmental conditions (Kumaravel et al., 2013; Li et al., 2001; Van & Binh, 2008). Analyzing the spatial and temporal dynamics of the shoreline in coastal zones and investigating the drivers of shoreline change is critical to understanding how shoreline respond to natural and anthropogenic influences (Kuleli, 2010; Pardo-Pascual et al., 2012; Qiao et al., 2018). Shoreline changes are influenced by natural factors such as eustatic sea level change, tectonic movement, sediment supply, wind, waves, currents and tides (Aladwani, 2022; Anthony, 2015; Boukhennaf & Mezouar, 2023; Kumar, A. & Jayappa, 2009; Kumar Das et al., 2021) and anthropogenic factors such as the construction of dams, breakwaters, groins and jetties, and sand extraction (Boukhennaf & Mezouar, 2023; Kumar, A. & Jayappa, 2009; Muskananfola & Febrianto, 2020).

Shorelines have been extracted from various datasets such as aerial photographs, field surveys, Synthetic Aperture Radar (SAR) imagery and Light Detection and Ranging (LiDAR) technology, but these datasets are expensive, time consuming and labor intensive (Esmail et al., 2019; Godwyn-Paulson et al., 2021). Landsat imagery is one of the most widely used datasets in shoreline detection methods because it is freely available, allows for large-scale shoreline monitoring, and can be integrated into Geographic Information Systems (GIS) (Boukhennaf & Mezouar, 2023; Esmail et al., 2019; Godwyn-Paulson et al., 2021; Kuleli et al., 2011; Ozturk & Sesli, 2015; Viaña-Borja & Ortega-Sánchez, 2019).

Türkiye has an extensive shoreline of approximately 8.337 km, including 1.542 km along the Mediterranean coast, 2.600 km along the Aegean coast, 2.510 km along the Marmara coast, and 1.685 km along the Black Sea coast (Ilkiliç & Aydin, 2015). Researchers are investigating significant shoreline changes on the Turkish coasts using satellite images and the Digital Shoreline Analyze (DSAS) tool (Ataol et al., 2019; Ataol & Kale, 2022; Duru, 2017; Görmüş et al., 2021; Kılar, 2023; Kılar & Çiçek, 2019; Kuleli et al., 2011; Özpolat & Demir, 2019; Ozturk & Sesli, 2015; Uzun, 2023). This study aims to fill the gap by analyzing the shoreline changes of Beymelek Beach and Lagoon between 1984 and 2022, both spatially and temporally. Using multi-temporal Landsat images and Digital Shoreline Analysis System (DSAS), a comprehensive assessment of the shoreline change in both short (1984–1990, 1990–2000, 2000–2010, 2010–2022) and long periods (1984–2022) is investigated. The results of this study are critical for understanding the effects of both natural processes and human activities on shoreline changes and for developing strategies to ensure the sustainability of this valuable coastal ecosystem.

2. METHOD

2.1. Study area

Beymelek Beach and Beymelek Lagoon are situated in the western part of Antalya, Türkiye. The coast of Beymelek extends for approximately 9 km between 36°15'35.00"N - 30° 4'18.09"E and 36°13'10.91"N - 29°59'10.83"E (Figure 1). Furthermore, the study area is located at the Demre, district of Antalya, which is an important agricultural and tourism hub in Türkiye. The vast greenhouses begin almost 40 meters from the coast, which is very close to the beach. Demre is an ancient city known as Myra during the Roman Empire period and an important tourist destination because it is where St Nicholas or Santa Claus lived in the 4th century. The study area has Mediterranean climate which is hot and dry in summer and warm and wet in winter. The average annual temperature from 1981 to 2014 was 18.4 °C, and the average annual precipitation from 1969 to 2014 was 790.5 mm (Avcı et al., 2021). Demre Stream is an important hydrographical resource that flows into the Mediterranean Sea and affects the coastal morphology of Beymelek Beach.

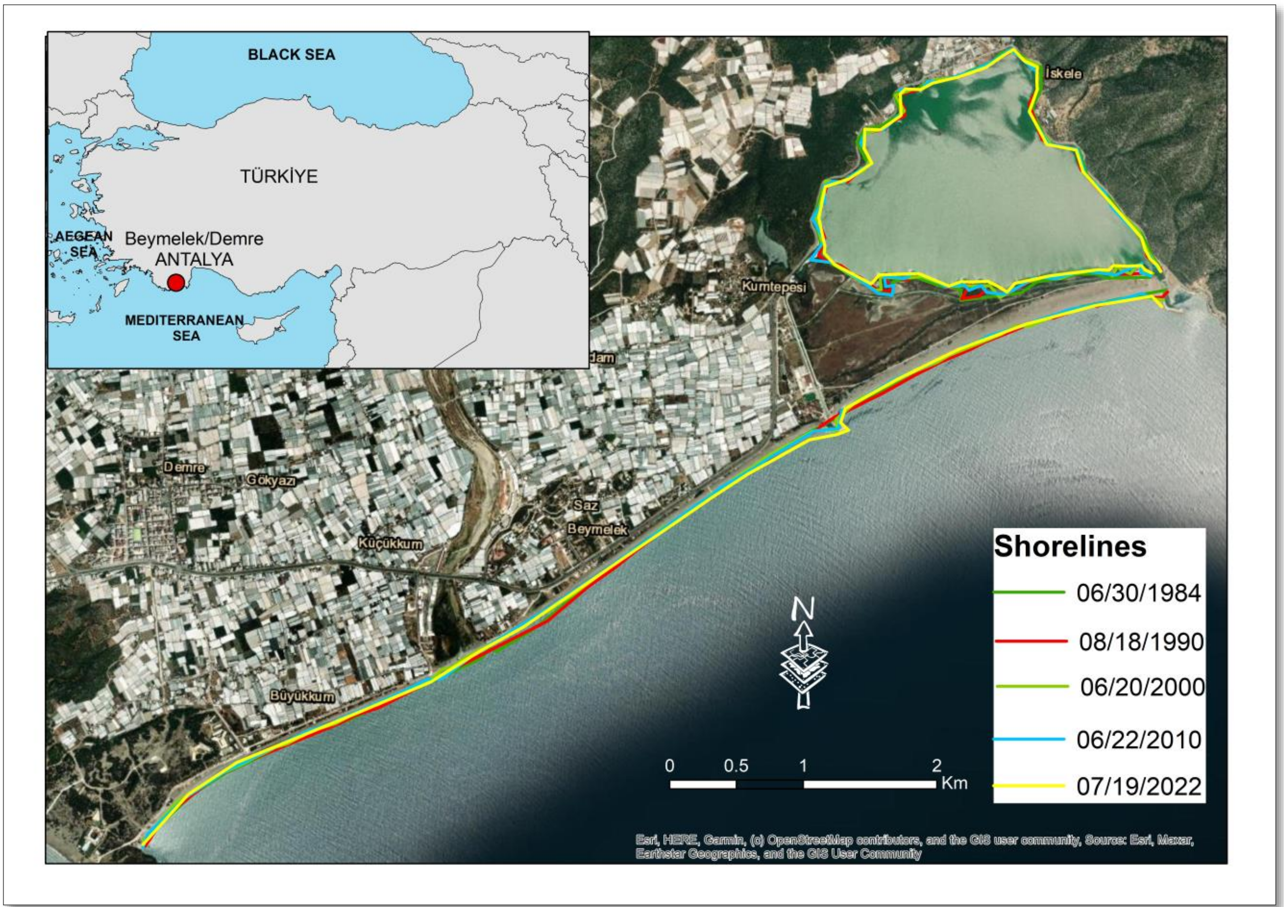

Figure 1: Study area.

2.2. Satellite images

The shorelines of Beymelek Beach and Beymelek Lagoon were extracted from Landsat 4-5 TM (30/06/1984, 18/08/1990, 26/06/2000, 22/06/2010) and Landsat 9 OLI-TIRS (19/07/2022)(http://www.earthexplorer.usgs.gov) (Table 1). Landsat images are an important source for medium spatial resolution earth observations and are widely used in determining shoreline changes (Abou Samra & Ali, 2021; Boukhennaf & Mezouar, 2023; Godwyn-Paulson et al., 2021; Özpolat & Demir, 2019; Rahbani & Ghaderi, 2024; Siyal et al., 2022). Additionally, the Landsat images utilized in this study were captured in June and July, months characterized by reduced cloud cover and lower wave amplitudes. It's essential to note that several factors can impact the accuracy of satellite imagery, such as spatial resolution, tidal beach slope, wave amplitude, and cloud cover (Ferreira et al., 2021).

2.3. Shoreline extraction and analysis

The shoreline of Beymelek Beach and Beymelek Lagoon was extracted from multi-temporal Landsat images using the modified normalized difference water index (MNDWI). This index provides optimal results for shoreline extraction due to the short wavelength infrared (SWIR) and green bands. Furthermore, the MNDWI utilizes the mid-infrared (MIR) and green bands to enhance results and reduce noise along coastal zones (Darwish & Smith, 2023; Özpolat & Demir, 2019). The MNDWI formula is given below:

$$(MNDWI)\ (\mathrm{Xu}, 2006) = Green - MIR\ /\ Green + MIR$$

Shoreline change of the Beymelek Beach and Lagoon was analyzed over both in short (1984–1990, 1990–2000, 2000–2010, 2010–2022) and long (1984–2022) periods by using DSAS. DSAS is a software extension for ArcGIS that allows users to compute shoreline rate of change statistics from multiple historical shoreline positions (Thieler & Danforth, 2016). The DSAS tool has been widely used to investigate temporal and spatial shoreline change (Bera, 2019; Bheeroo et al., 2016; Kumar Das et al., 2021; Nassar et al., 2019; Özpolat & Demir, 2019; Sam & Balasubramanian, 2022; Siyal et al., 2022). The short-term shoreline change at Beymelek Beach and Beymelek

Lagoon was analyzed using End Poind Rate (EPR) and Net Shoreline Movement (NSM) statistics, whereas long-term shoreline statistics were analyzed using EPR, NSM, and Linear Regression Rate (LRR) statistics from the DSAS tool. Table 2 provides a description of the DSAS statistics.

Table 1: The characteristics of Landsat images obtained from the United States Geological Survey (USGS) to analyze the spatial and temporal shoreline change of Beymelek Beach and Beymelek Lagoon.

Acquisition date	Image type	Path/Row	Bands	Wavelengths (µm)	Spatial resolution (m)
30/06/1984	Landsat 4-5 TM	178/35	Band 1-Blue	0.45-0.52	30
18/08/1990	Landsat 4-5 TM	178/35	Band 2-Green	0.52-0.60	30
26/06/2000	Landsat 4-5 TM	178/35	Band 3-Red	0.63-0.69	30
			Band 4-NIR	0.76-0.90	30
			Band 5-SWIR 1	1.55-1.75	30
22/06/2010	Landsat 4-5 TM	178/35	Band 6-TIR	10.4-12.5	60
			Band 7-SWIR 2	2.08-2.35	30
			Band 1-Coastal aerosol	0.43-0.45	30
			Band 2-Blue	0.45-0.51	30
			Band 3-Green	0.53-0.59	30
			Band 4-Red	0.64-0.67	30
19/07/2022	Landsat 9 OLI-TIRS	178/35	Band 5-NIR	0.85-0.88	30
			Band 6-SWIRR 1	1.57-1.65	30
			Band 7-SWIRR 2	2.11-2.29	30
			Band 8-Panchromatic	0.50-0.68	15
			Band 9-Cirrus	1.36-1.38	30

Table 2: The rate of change statistics used in this study (Himmelstoss et al., 2021).

Statistic	**Description**	**Unit**
NSM	The distance between the oldest and the youngest shorelines for each transect.	m
EPR	Calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline	m/yr
LRR	Determined by fitting a least-squars regression line to all shoreline points for a transect.	m/yr

3. RESULTS

3.1. Short-term shoreline analyses

The short periods of shoreline change in Beymelek Beach and Beymelek Lagoon were analyzed by using EPR and NSM statistics of the DSAS tool (Figure 2, 3, and 4). The statistical results indicate that the maximum shoreline in Beymelek Beach was detected between 2010 and 2022, with an NSM value of 115.1 m and an EPR rate of 9.5 m/yr. However, the maximum shoreline regression in Beymelek Beach was observed in 1990 and 2000 with the NSM value of -67.5 m and with the EPR rate of 9.8 m/yr (Table 3). Furthermore, the maximum shoreline progression in Beymelek Lagoon was observed in 2010 and 2022 with the NSM value of 143.9 m and with the EPR rate of 11.9 m/yr, whereas the maximum shoreline recession was observed in 2000 and 2010 with the NSM value of -126.9 m and with the EPR rate of -12.6 m/yr (Table 4). As a result, the maximum shoreline progression was observed in both Beymelek Beach and Beymelek Lagoon between 2010 and 2022, while the maximum shoreline recession occurred in Beymelek Beach between 1990 and 2000 and in Beymelek Lagoon between 2000 and 2010. Additionally, it is important to note that between 1990 and 2000, Beymelek Beach and Beymelek Lagoon experienced their largest shoreline recessions (Figure 2, 3, and 4).

3.2. Long-term shoreline analyses

The long-term shoreline analyses in Beymelek Beach and Beymelek Lagoon were evaluated by using EPR, NSM and LRR statistics from the DSAS tool (Table 5, 6). The statistical results show that between 1984 and 2022, the maximum shoreline progression in Beymelek Beach was 128.4 m for NSM, 4.3 m/yr for EPR and 4.1 m/yr for LRR, while the maximum shoreline regression was -62.6 m for NSM and -1.6 m/yr for EPR and -1.8 m/yr for LRR (Table 5).

In Beymelek Lagoon, the maximum shoreline progression in 1984 and 2022 was 5.2 m for NSM, 0.1 m/yr for EPR and 0.4 m/yr for LRR, while the maximum shoreline recession was -148.4 m for NSM, -3.9 m/yr for EPR and -3.9 for LRR (Table 6). Moreover, over a period of 38 years, the maximum shoreline recession in Beymelek Beach occurred along the Demre stream, while the maximum shoreline progression occurred along antropogenically constructed coastal structures (Figure 5). In Beymelek Lagoon, the maximum shoreline recession was observed along the seaside of the Lagoon during the 38 years (Figure 6).

Table 3: Shoreline change statistics for Beymelek Beach.

Statistic	1984-90	1990-00	2000-10	2010-22
EPR				
Average	0.7	-1.7	-0.2	0.8
Max.	8.08	**9.8**	5.8	**9.5**
Min.	-4.8	-6.8	-2.9	-2.02
NSM				
Average	4.7	-17.3	-2.1	9.9
Max.	49.5	96.7	58.1	**115.1**
Min.	-29.5	**-67.5**	-29.4	-24.4

Table 4: Shoreline change statistics for Beymelek Lagoon.

Statistic	1984-90	1990-00	2000-10	2010-22
EPR				
Average	3.4	-0.5	0.05	1.05
Max.	20.4	10.2	5.9	**11.9**
Min.	-7.5	-9.2	**-12.6**	-2.45
NSM				
Average	20.9	-4.9	0.5	12.6
Max.	125.3	100.9	59.1	**143.9**
Min.	-46.4	-90.9	**-126.9**	-29.6

Table 5: Shoreline change statistics of Beymelek Beach from 1984 to 2022.

Statistic	1984–2022
EPR	
Average	-0.1
Max.	4.3
Min.	-1.6
NSM	
Average	-4.8
Max.	128.4
Min.	-62.6
LRR	
Average	-0.2
Max.	4.1
Min.	-1.8

Table 6: Shoreline change statistics of Beymelek lagoon from 1984 to 2022.

Statistic	1984–2022
EPR	
Average	-0.8
Max.	0.1
Min.	-3.9
NSM	
Average	-30.4
Max.	5.2
Min.	-148.4
LRR	
Average	-0.5
Max.	0.4
Min.	-3.9

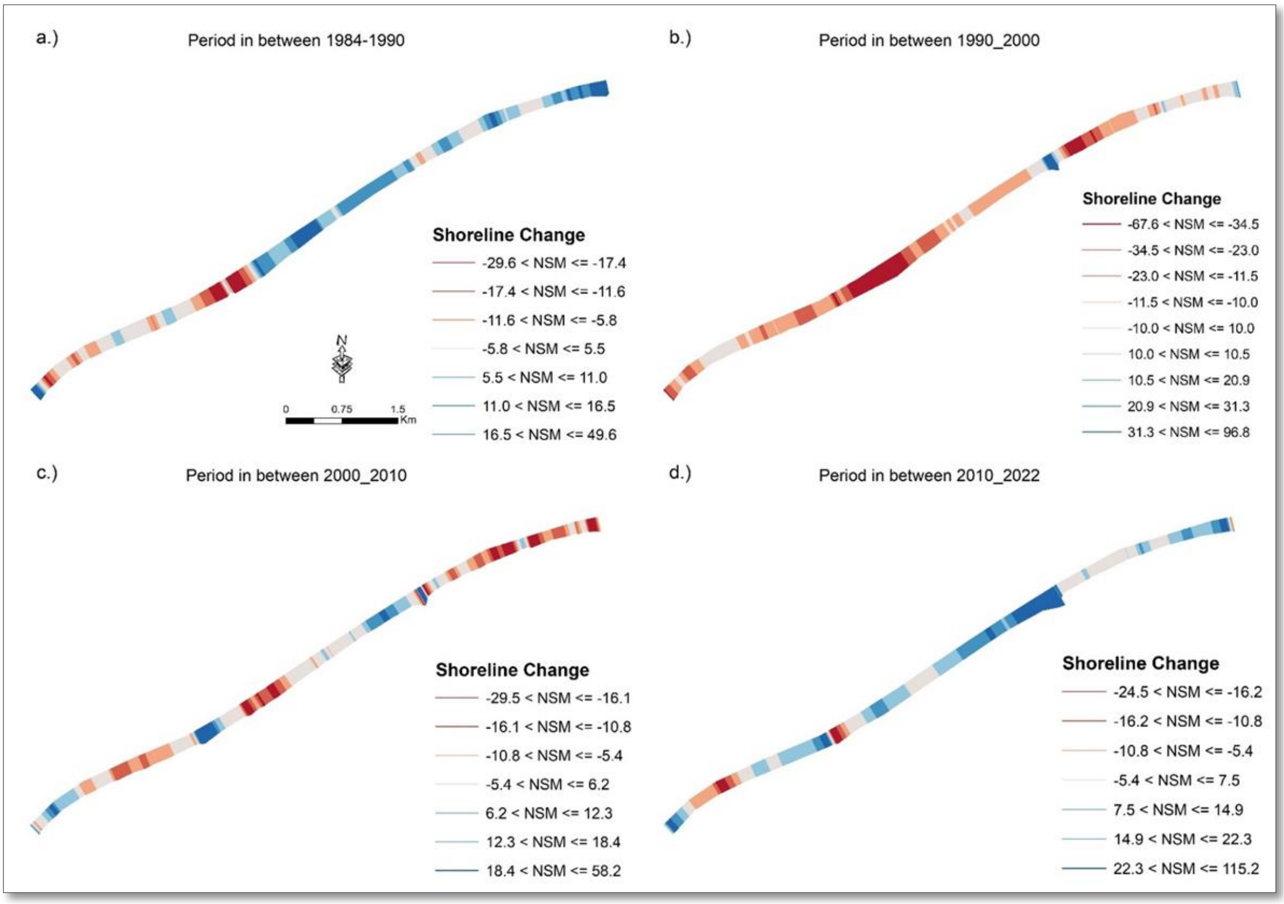

Figure 3: The Net Shoreline Movement (NSM) for Beymelek Beach was calculated for four different periods: (a) 1984–1990, (b) 1990–2000, (c) 2000–2010, and (d) 2010–2022.

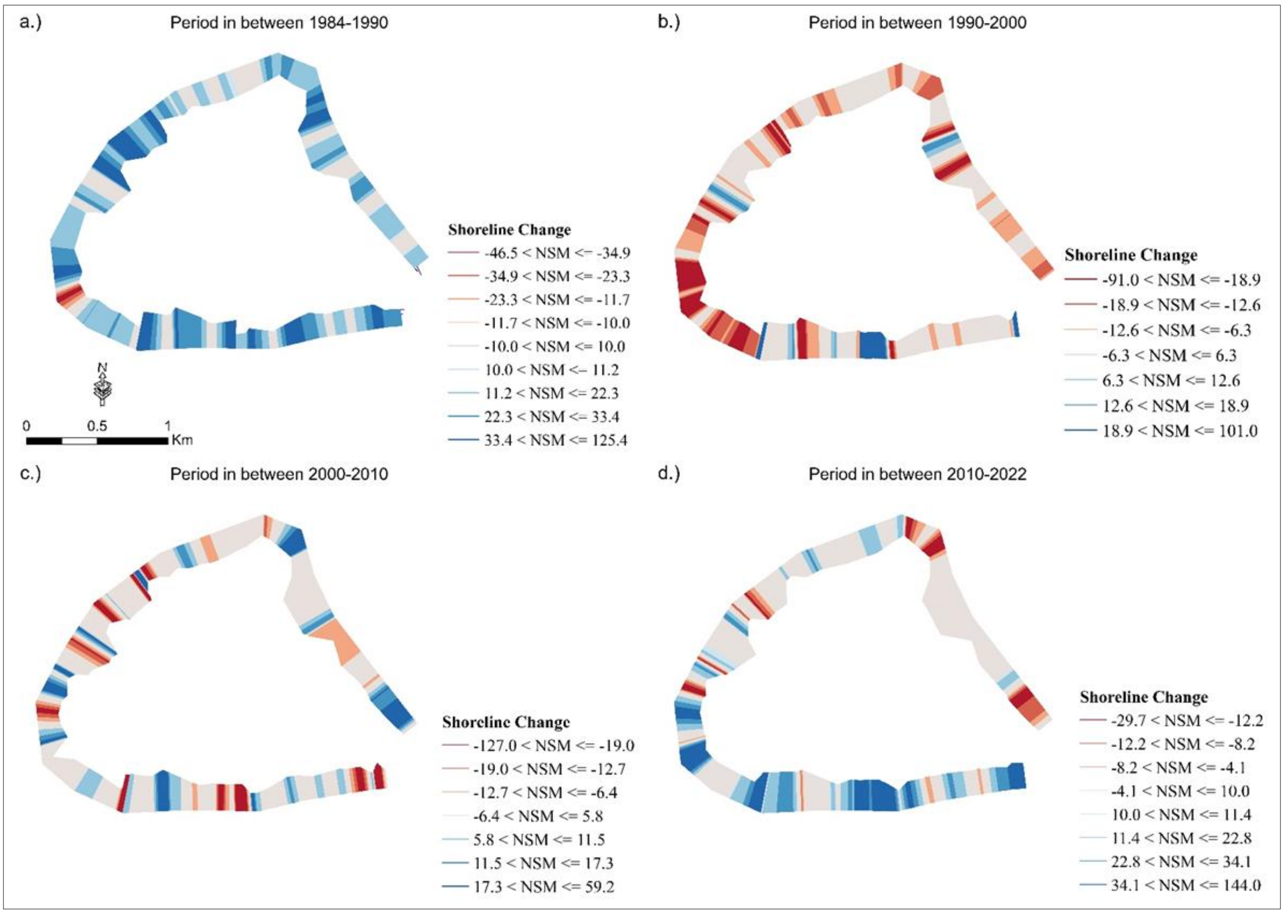

Figure 4: The Net Shoreline Movement (NSM) for Beymelek Lagoon was calculated for four different periods: (a) 1984–1990, (b) 1990–2000, (c) 2000–2010, and (d) 2010–2022.

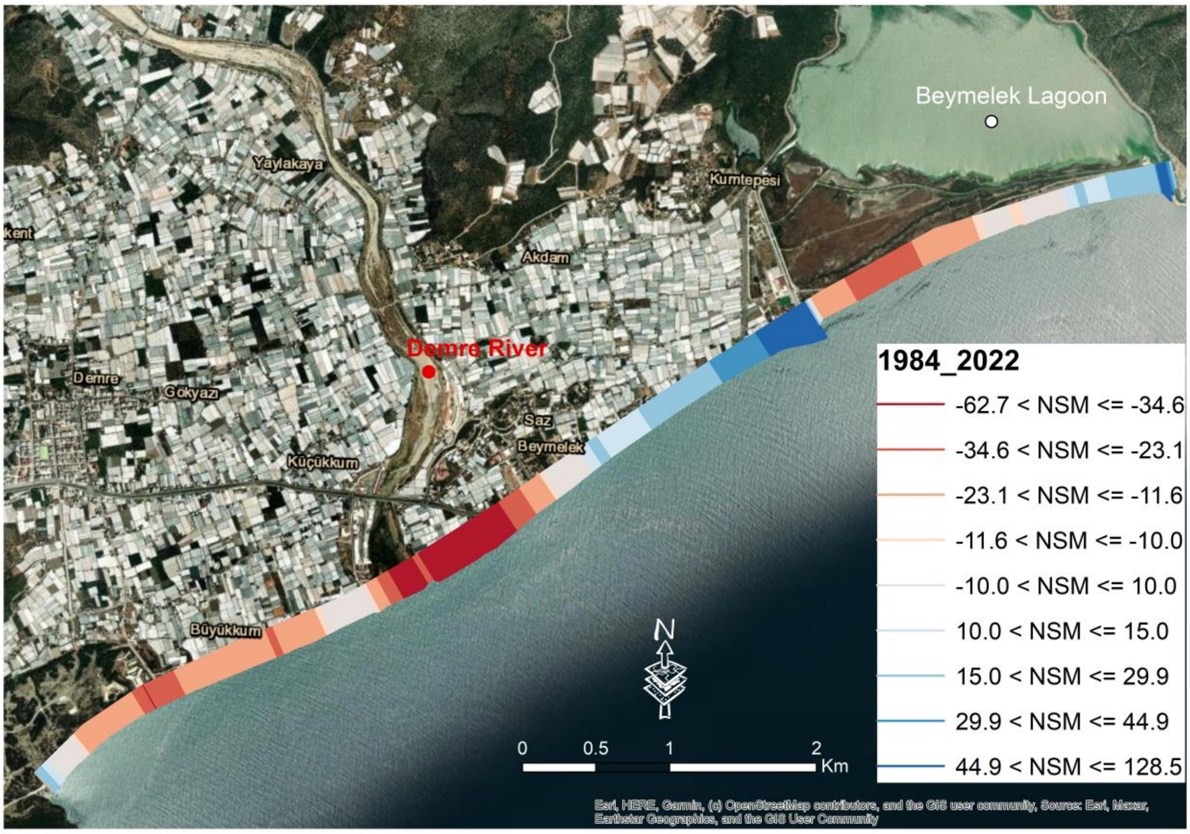

Figure 5: The Net Shoreline Movement (NSM) statistic for Beymelek Beach between 1984 and 2022.

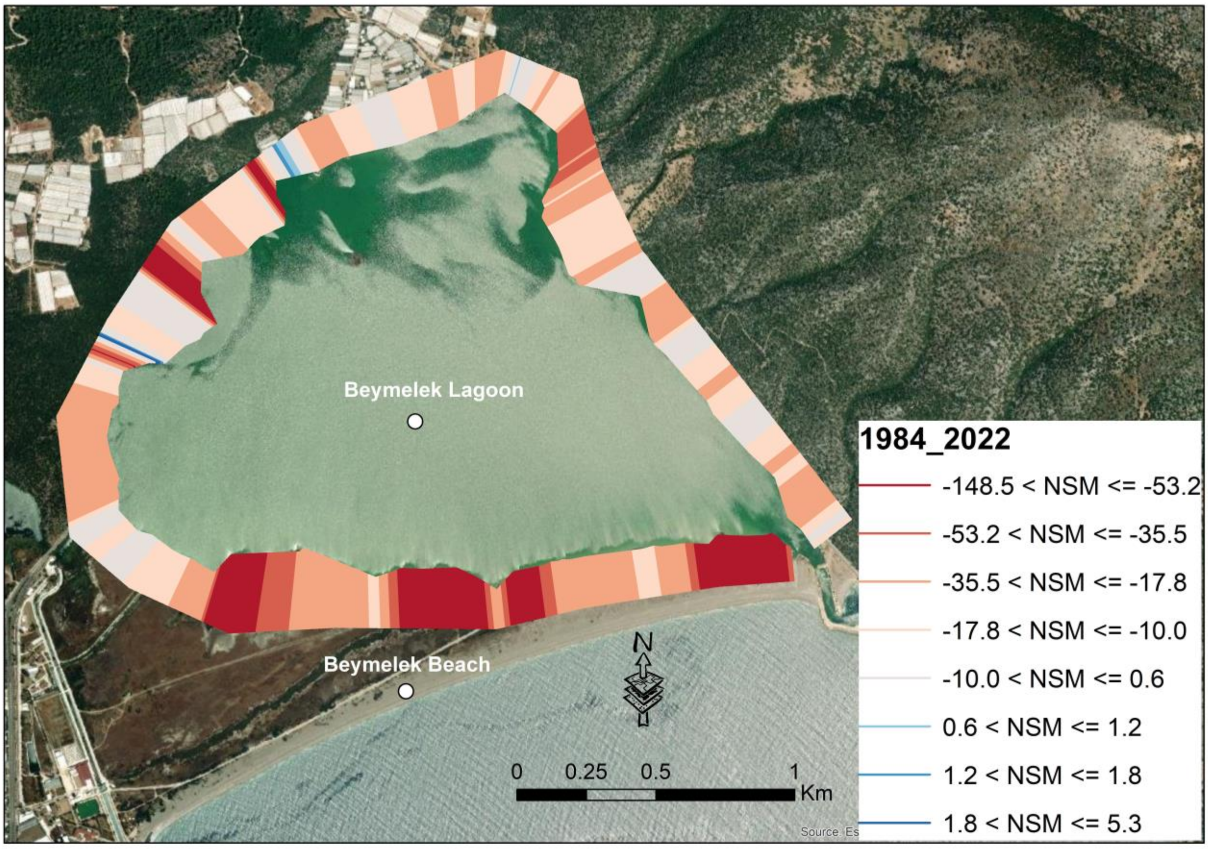

Figure 6: The Net Shoreline Movement (NSM) statistic for Beymelek Lagoon between 1984 and 2022.

4. DISCUSSION

Beymelek Beach and Lagoon, located on Türkiye's Mediterranean coast, are important for tourism, agriculture, and coastal ecology. The region boasts ideal climatic conditions, making it a prime location for recreational activities. Additionally, its proximity to Myra, an ancient Roman city, and the tomb of Saint Nicholas (Santa Claus) draws numerous tourists annually. The area is also surrounded by greenhouses, highlighting its significance for agricultural practices. Consequently, the intense tourism and agricultural activities significantly impact the shoreline dynamics over both short and long-term periods.

Short-term shoreline changes at Beymelek Beach reveal that 2010 and 2022 were recovery years, marked by a maximum shoreline progression of 115.1 m for NSM. In contrast, the maximum shoreline recession of Beymelek Beach was ocurred between 1990 and 2000, with NSM value of -67.5 m and -9.8 m/yr for EPR (Table 3). This situation indicates that the coast of Beymelek experienced significant erosion in earlier periods, while accretion has been observed mostly in recent period. Similarly, Beymelek Lagoon exhibited comparable trends, with the recovery period in 2010 and 2022 showing a maximum shoreline progression of 143.9 m for NSM. In contrast, the maximum shoreline regression occurred between 2000 and 2010, with an NSM value of -126.9 m.

The long-term shoreline trend analysis of Beymelek Beach from 1984 to 2022 reveals that the mouth of Demre stream is the most significantly affected area by erosion, while the surrounding coastal structures exhibit the highest rates of accretion. Over the past 38 years, nearly the entire shoreline of Beymelek Lagoon has experienced erosion. The statistical findings of the study indicate that the shorelines of Beymelek Beach and Beymelek Lagoon are highly dynamic, undergoing substantial changes over both short and long-term periods. These findings are consistent with other shoreline change studies conducted along the Mediterranean coast (Ciritci & Türk, 2019; Kazı & Karabulut, 2023; Kılar & Çiçek, 2018; Kuleli et al., 2011; Özpolat & Demir, 2019; Yiğit et al., 2022). For example, Yiğit et al. (2022) assessed the short and long-term shoreline changes of Konyaaltı Beach, located within the borders of Antalya on the Mediterranean coast. The statistical results indicated that Konyaaltı Beach experienced approximately 20 meters of erosion and 10 meters of accretion over both the 35-year and 5-year periods. Another significant study focused on the Göksu Delta Delta (Ciritci & Türk, 2019; Kazı & Karabulut, 2023; Kılar & Çiçek, 2018). Shoreline analyses of these studies revealed that the areas with the highest erosion in the Göksu Delta are Altınkum, the mouth of the Göksu River, and the end parts of İncekum, while accumulation is concentrated on the east and west coasts of İncekum (İnceburun) Cape. Additionally, Özpolat and Demir (2019) evaluated the spatio-temporal shoreline changes of the Seyhan Delta along Turkey's Eastern Mediterranean coast. Their study estimated coastal erosion of the Seyhan Delta at -4,039,251 m² from 1956 to 2018, primarily due to the construction of the Seyhan Dam in 1956.

As a result, many coastal regions along the Mediterranean coast have experienced erosion over both short and long periods. Beymelek Beach and Lagoon, which are ecologically sensitive areas, are among those significantly impacted by shoreline changes due to the combined effects of natural hydrodynamic forces and human activities that disrupt sediment transport and deposition. Coastal structures, in particular, play a significant role in altering the wave and sediment dynamics along the shoreline. Additionally, sediment input from the Demre River, as well as tourism and agricultural activities implemented along the coast and lagoon, have substantial impacts on shoreline changes. These factors contribute to the dynamic nature of the coastal environment, leading to both erosion and accretion over time. Understanding the interplay between these natural and anthropogenic influences is crucial for effective coastal management and mitigation strategies. Additionally, ongoing monitoring and research are essential to understand the evolving dynamics of the shoreline and to develop adaptive strategies that can respond to changing conditions. Collaboration between local authorities, researchers, and stakeholders is crucial to ensure the long-term sustainability of Beymelek Beach and Lagoon. In conclusion, the dynamic and significant changes observed in the shorelines of Beymelek Beach and Lagoon highlight the complex interplay between natural processes and human activities. Effective management and conservation efforts are necessary to protect these valuable coastal resources.

5. CONCLUSION

This study provides a comprehensive analysis of the temporal shoreline changes from 1984 to 2022 along Beymelek Beach and Beymelek Lagoon in Antalya, Türkiye. Using DSAS tool and multi-temporal Landsat imagery, we have quantified both short-term and long-term shoreline dynamics in this critical coastal zone.

- Short-term shoreline statistic indicates that Beymelek Beach and Beymelek Lagoon experienced maximum shoreline progression between 2010 and 2022. In this period, they both underwent a recovery process. Short-term shoreline statistics show that Beymelek Beach experienced the maximum shoreline recession between 1990 and 2000, with an NSM value of -67.5 m, followed by Beymelek Lagoon in 2000 and 2010, with an NSM value of -126.9 m (Table 3 and Table 4).
- The long-term shoreline change statistic for Beymelek Beach indicates that the maximum shoreline regression was observed at the mouth of Demre River, with an NSM value of -62.6 m. In contrast, the maximum shoreline accretion was observed along the coastal structures, with an NSM value of 128.4 m. Additionally, the long term shoreline change of Beymelek Lagoon indicates that the maximum shoreline erosion was -148.4 m for NSM, whearese the maximum shoreline accretion was 5.2 m for NSM (Table 5 and Table 6).

The study highlights the influence of natural processes and human activities on shoreline dynamics. While natural factors such as sediment supply, wind, waves, and currents have played significant roles, anthropogenic activities, including coastal construction, tourism and agricultural practices, have markedly impacted the shoreline evolution.

Understanding these temporal shoreline changes is crucial for effective coastal zone management and sustainability. The insights gained from this study can inform the development of localized strategies to mitigate erosion, manage sediment transport, and protect the ecological and economic value of Beymelek Beach and Beymelek Lagoon. Future research should focus on integrating more detailed hydrodynamic models and higher-resolution satellite imagery to further enhance the precision of shoreline change analyses and support adaptive management strategies in response to ongoing and future coastal changes.

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