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A comprehensive analysis of Türkiye's beaches: spatial distribution, morphometry, and human impacts

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Abstract: The classification and morphometric characteristics of beaches is crucial for understanding coastal dynamics, evaluating natural and anthropogenic pressures, and supporting effective coastal management and conservation strategies. This is particularly important for countries like Türkiye, where extensive and diverse coastlines play a key role in tourism, the economy, and ecological sustainability. This study presents the first comprehensive, nationwide inventory and characterisation of Türkiye's beaches, encompassing its 8483 km coastline. Using satellite imagery, 6110 beaches were identified and classified according to environmental conditions, with analyses conducted on their morphological characteristics, sea boundaries, and provincial distributions. The results show that rocky coast and river-mouth beaches constitute 81% of the total beaches but only 46% of the total beach length. Conversely, deltaic and low-lying beaches represent just 2.6% of the total number but comprise 37% of the total length, highlighting their significance despite their scarcity. Along the Mediterranean and Black Sea coasts, where mountain ranges extend parallel to the shoreline, beaches are fewer in number yet tend to be longer and broader. In contrast, the tectonically active and highly indented Aegean Sea coastline, with numerous bays, gulfs, and peninsulas, has the highest beach density, though these beaches are generally shorter. These findings underscore the role of coastal morphology and geological processes in shaping beach characteristics. In addition to natural factors, anthropogenic activities strongly influence Türkiye's coasts: while coastal engineering structures have reshaped many Black Sea beaches, construction and tourism pressures are most evident along the Aegean coast, with Mediterranean beaches showing the highest proportion of human impact relative to their total number. This comprehensive analysis provides essential data to guide sustainable coastal management and conservation strategies in Türkiye.

Key words: Beach, satellite imagery, morphology, classification, human effect

1. Introduction

Coastlines are dynamic interfaces where marine and terrestrial systems converge, making them both ecologically significant and susceptible to natural processes and anthropogenic pressures (Halpern et al., 2015). These regions are amongst the most densely populated worldwide, supporting a substantial proportion of the global population (Ramesh et al., 2015; Luijendijk et al., 2018; MacManus et al., 2021). Consequently, coastal zone analysis is fundamental for effective coastal management and conservation (Bird 2008; Mishra et al., 2025).

Coastal areas host diverse landforms, including rocky cliffs, tidal flats, and beaches (Davidson-Arnott, 2010). Among these, beaches are significant as they attract tourism activity, thereby intensifying pressures on already sensitive environments. Beaches occur between the interface of the atmosphere, ocean, and land, and are dynamic landforms composed of loose, unconsolidated sediments such as sand, gravel, or cobbles, deposited and reshaped by waves, currents, and tides (Wright and Short, 1984; Daniels, 1999; Anthony, 2005; Bird, 2008; Davidson-Arnott, 2010). These dynamic systems undergo continuous change across temporal and spatial scales (Larson and Kraus, 1994; Burvingt et al., 2017), shaped by the complex interactions among natural processes, local geology and geomorphology, climate change (especially sea-level rise), and anthropogenic activities (Kuleli and Bayazıt, 2022; Monioudi et al., 2023; Zhang et al., 2024).

Beach classification provides an essential framework for understanding the diversity of beach systems. Numerous classification approaches exist, focusing on environmental characteristics such as morphology, sedimentology, and hydrodynamics (Wright and Short, 1984; Jennings and Shulmeister, 2002; Short, 2006; Scott et al., 2011; Klein and

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Short, 2016; Bunicontro et al., 2020). However, a universal classification system remains elusive due to the inherent complexity of coastal dynamics (Wolff et al., 2018). Moreover, many existing classifications often rely on large observational datasets, limiting their applicability beyond the regions where they were developed (Scott et al., 2011).

Advances in remote sensing techniques and geographic information systems (GIS) have significantly enhanced coastal research, enabling the mapping and monitoring of beaches on regional and global scales (Short, 2006; Klein and Short, 2016; Luijendijk et al., 2018; Vousdoukas et al., 2020). High-resolution satellite imagery, particularly from platforms such as Google Earth (GE) Pro, provides powerful tools for identifying beaches, assessing shoreline change, and generating critical data for coastal management (Chettiyam Thodi et al., 2023). GE Pro offers freely accessible imagery with a spatial resolution of 0.5–1 m, facilitating accurate beach detection and morphometric analysis (Luijendijk et al., 2018; Warnasuriya et al., 2020). Additionally, the availability of multitemporal imagery enables the analysis of historical shoreline change (Lesiv et al., 2018).

Despite Türkiye's extensive 8483 km coastline, which constitutes one of the longest and most diverse coastal systems in the Mediterranean and Black Sea region, a comprehensive nationwide assessment of its beaches has been lacking. Previous research has focused mainly on large-scale coastal environments such as deltas, localised shoreline changes, or pollution studies, thus addressing only limited aspects of beaches (Cetin et al., 1999; Karsli et al., 2011; Guneroglu, 2015; Özpolat and Demir, 2019; Aydın et al., 2023; Kılar et al., 2025; Terzi et al., 2025). Broader studies of Türkiye's coastal zone have generally overlooked beaches as distinct geomorphic units, focusing instead on general shoreline characteristics (Erol, 1990; Karaca and Nicholls, 2008; Uzun and Celik, 2014; Kuleli, 2015; Kuleli and Bayazıt, 2022). Consequently, a critical need remains for integrated and comprehensive assessments of beaches at the national scale.

This research addresses this gap by presenting the first nationwide inventory and characterisation of Türkiye's beaches. Using high-resolution satellite imagery from GE Pro, all beaches along the Turkish coastline were identified and their morphometric properties analysed. Beyond simple mapping, this study introduces a novel classification framework incorporating environmental conditions and anthropogenic influences. This integrated approach provides a nuanced understanding of the diverse coastal environments across Türkiye, highlights the key natural and human factors shaping beach morphology and dynamics, and delivers a critical baseline for effective coastal management and conservation strategies.

2. Study area

Located between 36° and 42° north latitude, Türkiye is a large peninsula that serves as a natural bridge between Europe and Asia. The Black Sea borders it to the north, the Mediterranean Sea to the south, the Aegean Sea to the west, and the Sea of Marmara at its centre (Figure 1a). The coastline extends for 8483 km, of which 38.5% lies along the Aegean Sea, 23.9% along the Mediterranean Sea, 20.3% along the Black Sea, and 17.3% along the Sea of Marmara (ONHO, 2008) (Figure 1b). Out of Türkiye's 81 provinces, 28 are coastal, accommodating 55% of the 85.4 million national population (TUİK, 2024).[1] Türkiye is also a major global tourism destination, attracting 56 million international visitors in 2023 (KTB, 2024).[2] In addition, it ranks third globally in the number of Blue Flag-certified beaches, with 567 such designations (Blue Flag, 2024).[3]

The geological evolution of Türkiye, shaped by the interaction of the Anatolian, Eurasian, African, and Arabian tectonic plates (Şengör and Yilmaz, 1981), has created a highly diverse coastal landscape. From the cliffs of the Black Sea to the extensive deltas along the Aegean and Mediterranean, coastal morphology reflects both long-term geological evolution and active tectonic processes (Furlani et al., 2014). The North Anatolian and Taurus mountain ranges and fault systems in the tectonically dynamic Aegean region exert strong controls on coastal morphology (Karaca and Nicholls, 2008). For example, the Northern Anatolian ranges are parallel to the Black Sea coast, creating cliffs and narrow lowlands (Kuzucuoğlu et al., 2019). As a geologically young and tectonically active country, Türkiye has pronounced topographic relief (Şengör and Yilmaz, 1981; Bozkurt, 2001), which has led to the development of numerous river basins. Many beaches form at the mouths of these fluvial systems. Overall, Türkiye's coastline can be categorised into 3 major geomorphological types (Erol 1990): 1) erosional rocky and softer cliff coastlines, which constitute the majority (69%) of the total coastline length; 2) accretional sandy coasts, representing 19% of the coastline; and 3) accretional deltaic coasts, often associated with swampy areas, which account for the remaining 12% of the total length.

[1] TUİK (Turkish Statistical Institute) (2024). National Information Portal (NIP) [online]. Website https://nip.tuik.gov.tr/ [accessed 14 April 2024] (in Turkish)

[2] KTB (Republic of Türkiye Ministry of Culture and Tourism) (2024). 2023 Was a Record Year for Tourism [online]. Website https://basin.ktb.gov.tr/TR-365098/2023-turizmde-rekor-yili-oldu.html [accessed 10 October 2024] (in Turkish).

[3] Blue Flag (2024). All Blue Flag Sites [online]. Website https://www.blueflag.global/all-bf-sites [accessed 13 December 2024].

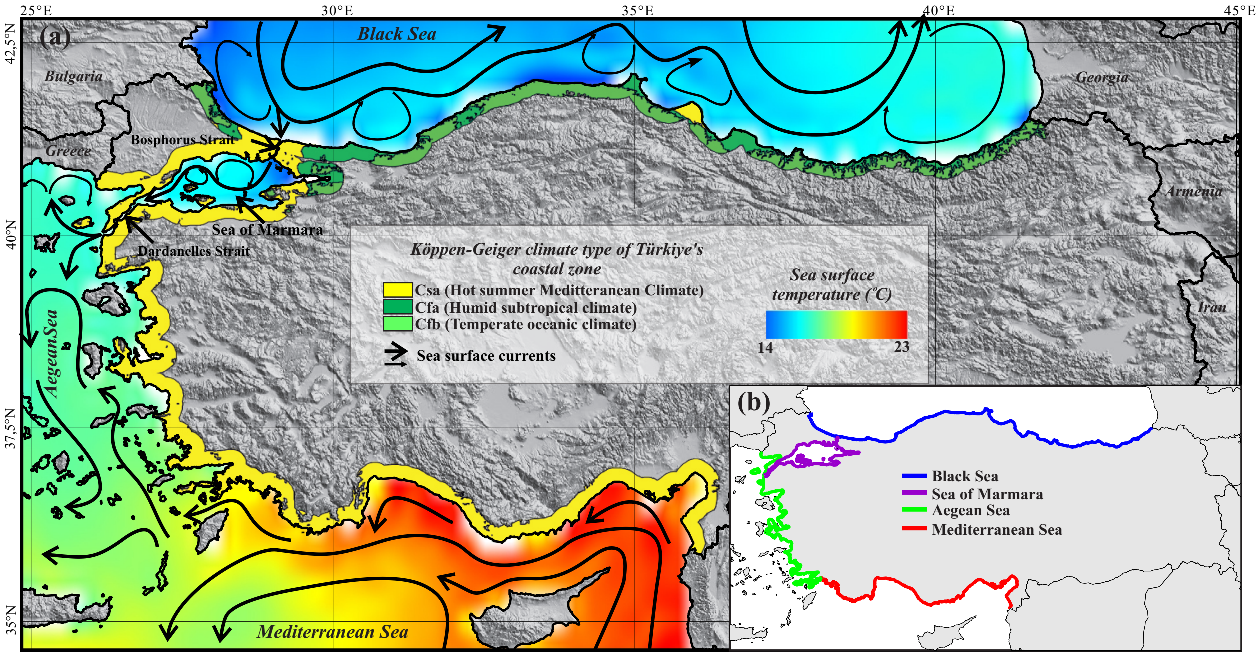

Figure 1. (a) Sea surface currents and SSTs around Türkiye, showing prevailing current directions in the Black Sea, Marmara Sea, Aegean Sea, and Mediterranean Sea (Beşiktepe et al., 1994; Olson et al., 2007; Rio et al., 2007; Tagil et al., 2024), as well as the Köppen–Geiger climate classifications for Türkiye's coastal regions (Taşoğlu et al., 2024). (b) Coastline segments that were used for beach classification in this study.

Türkiye's coastline is characterised by a temperate climate with notable regional variations. According to the Köppen-Geiger climate classification system (Taşoğlu et al., 2024), the Mediterranean, Aegean, and much of the Marmara coasts are dominated by a hot-summer Mediterranean climate (Csa). In contrast, the Black Sea coast experiences a humid subtropical climate (Cfa) and a temperate oceanic climate (Cfb) (Figure 1a). These climatic differences influence weathering processes, vegetation cover, and ultimately, sediment supply to coastal environments.

The surrounding seas also display diverse hydrodynamic characteristics. The Turkish Straits system, comprising the Bosphorus and the Dardanelles, connects the Black Sea, the Sea of Marmara, and the Aegean Sea, representing one of the most significant waterways in the world. Current directions vary considerably among regions (Figure 1a). Surface currents generally flow west to east in the Black Sea, while along the Mediterranean coast, they flow east to west (Rio et al., 2007). In the Sea of Marmara, surface currents flow from the Black Sea towards the Aegean Sea (Beşiktepe et al., 1994). In the Aegean Sea, circulation is more complex, with a predominantly north–south flow in the north and a south–north flow in the southern section (Olson et al., 2007). These current systems strongly affect the spatial distribution of sea surface temperatures (SSTs). The average SST ranges between 20 and 24 °C in the Mediterranean Sea, 16–20 °C in the Aegean Sea, and 14–18 °C in the Black Sea (Tagil et al., 2024). Projections from time-series analysis indicate that SSTs along Türkiye's coasts will increase by an average of 1.5 °C by 2050 (Bilgili et al., 2024). Such changes will likely influence coastal ecosystems, impacting beach morphology and stability.

3. Data and methods

3.1. Delination of beaches

This study manually identified and vectorised beaches using high-resolution GE Pro imagery captured between 2020 and 2023. Since GE Pro imagery does not provide uniform coastline-wide datasets for a single date, the most recent images available for each region were used (Luijendijk et al., 2018). This ensured the delineation of beaches in their most up-to-date condition. Beach boundaries were mapped by tracing the extent of unconsolidated sediments between the visible landward limit and the seaward shoreline (Figure 2a).

For each beach, morphometric parameters including length, width, and area were calculated using GIS tools (Figure 2a). The length and width of each beach were determined by measuring the maximum extent of the beach (i.e. the widest and longest sections). The same measurement protocol was applied consistently across all sites to ensure comparability. Beyond morphometry, beaches were classified based on environmental conditions, including geomorphological settings, and visible signs of anthropogenic influence (Figure 2b). To assess long-term anthropogenic impacts, historical GE Pro imagery (2000–2019) was compared with the most recent imagery (2020–2023), enabling the detection of beach changes associated with construction and tourism activities (Figure 2c). The results were visualised through scatter plots, bar and pie charts, and thematic maps (Figure 2d), which facilitated the identification of regional patterns and hotspots of beach change or human influence.

In addition to satellite images, supplementary sources such as user-contributed photographs from GE Pro and aerial photographs available through TRIPinVIEW were consulted to support classification. The study also incorporated ground-truth observations collected during extensive fieldwork campaigns along various sections of Türkiye's coasts since 2005. Field photographs and observations served as supplementary data, enriching the analysis and critically validating satellite-derived results. Integrating remote sensing with field-based evidence significantly enhanced the reliability and robustness of the beach inventory and its subsequent characterisation.

Once beaches were delineated and morphometric parameters were extracted, descriptive statistics (e.g., totals and means) and correlation analyses were performed across seas, provinces, and morphological types to explore spatial distribution and interrelationships. Correlation analysis was used to assess relationships among morphometric parameters and to better understand how beach characteristics vary across coastal settings.

3.2. Classification of beaches

This study used a dual-criteria classification system based on geographical setting and the degree of human influence. The framework was developed specifically for Türkiye's coasts, synthesising geomorphological, oceanographic, and geological characteristics with direct field observations and visible anthropogenic pressures. Unlike earlier global or regional classifications, this system is tailored to reflect the diversity of Türkiye's beaches while acknowledging the interplay between natural and human-driven processes. This typology recognises natural morphogenetic environments and the increasingly significant role of human activities in reshaping Türkiye's coasts.

In this study, 7 distinct beach categories were identified. Schematic representations of these categories are shown in Figure 3, field photographs in Figure 4, and satellite images in Figures 5 and 6.

(1) **River-mouth beaches:** located at the river outlets, shaped by sediment transported and deposited at the mouth (Figures 3a, 4a, and 4b).

(2) **Rocky coast or rocky shore beaches:** narrow beaches formed along rocky shorelines or cliff bases with coarse sediments (Figures 3b, 4c, and 4d).

(3) **Low-lying coast beaches:** situated on broad valleys and low plateaus, typically without forming deltas (Figures 3c, 4e, and 4f).

(4) **Deltaic beaches:** extensive beaches composed of fine sediments within delta regions (Figures 3d and 4g).

(5) **Tombolo and coastal spit beaches:** depositional features created by longshore sediment transport extending into the sea (Figures 3e, 4h, and 4i). These two beach types were considered together in the classification due to their similar formation mechanisms and comparable morphological dynamics.

(6) **Human-structure beaches:** beaches developed with coastal engineering works such as breakwaters, spurs, or harbours (Figures 3f and 5a–5d).

(7) **Mixed (or compound) beaches:** environments where natural and anthropogenic processes are inseparably integrated, e.g., river-mouth beaches merging with engineered structures (Figures 3f and 5e–5f). This category recognises the complex interplay between natural and anthropogenic forces in shaping many coastal environments.

Human impacts on Türkiye's beaches were evaluated using satellite imagery and field evidence. Two primary

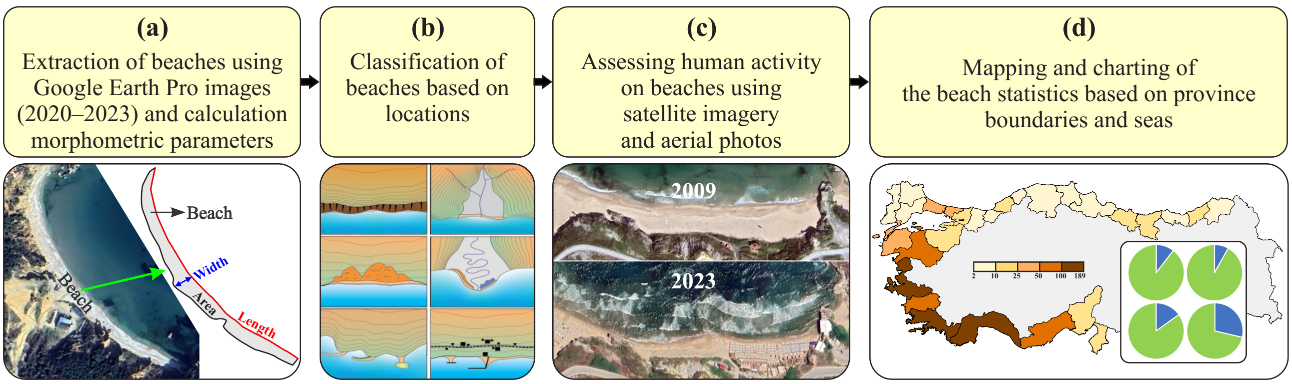

Figure 2. Workflow diagram illustrating beach mapping and analysis methodology.

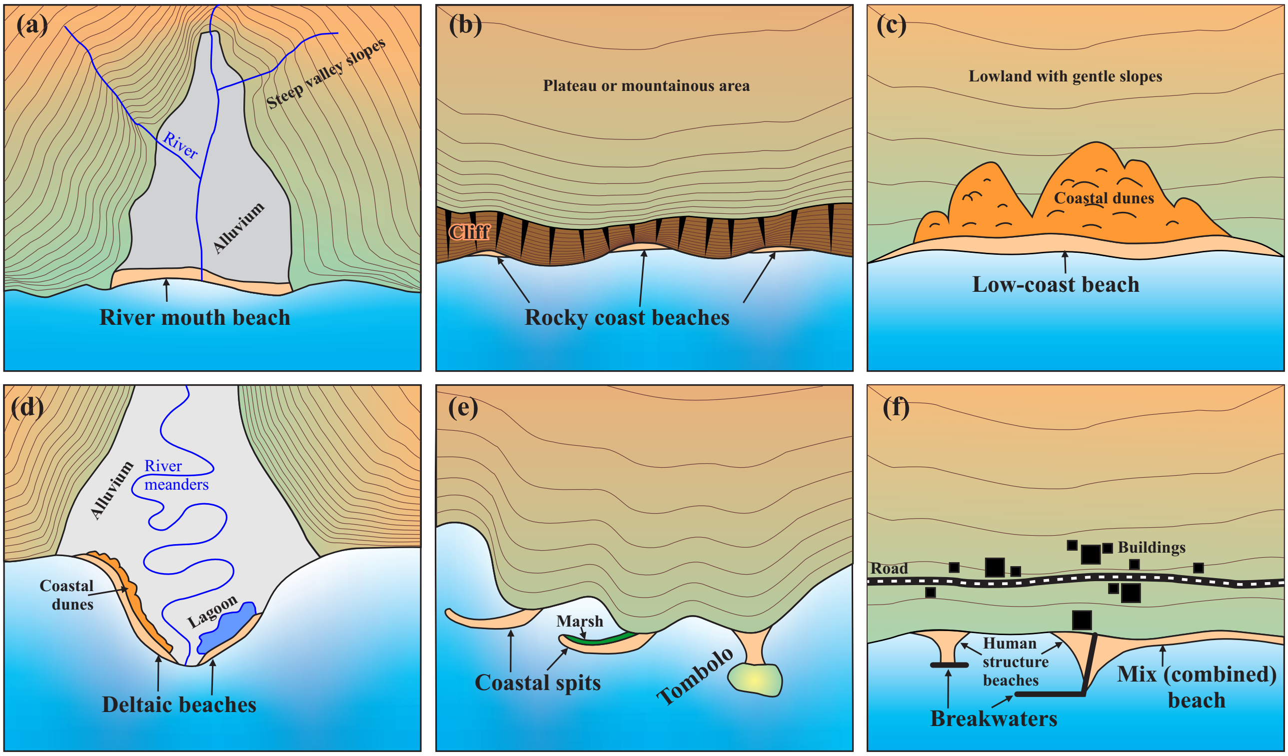

Figure 3. Schematic representation of the beach classifications used in this study.

indicators were used: 1) the expansion of construction into beach areas over time (Figure 6a–6b), and 2) visible tourism-related activities, such as beach clubs, sunbeds, and recreational facilities (Figure 6c). By comparing historical and recent imagery, construction encroachment was identified, while field photographs provided evidence of tourism pressures. This combined approach enabled a comprehensive assessment of the spatial distribution, intensity, and nature of human impacts across Türkiye's beaches, highlighting areas where anthropogenic pressures are most pronounced.

4. Result

4.1. Total number and size of beaches

This study identified a total of 6110 beaches along the coastline of Türkiye. Their distribution by sea is as follows: 19% (1156) are located along the Black Sea, 20% (1213) along the Sea of Marmara, 46% (2836) along the Aegean Sea, and 15% (935) along the Mediterranean coast (Figure 7a, Table 1). This distribution reflects the contrasting geomorphology settings and coastal processes across Türkiye's different sea regions.

The combined total beach length in Türkiye is 2890 km, corresponding to 34% of the national coastline. The average beach length is 473 m, though considerable regional variation exists. Despite hosting the most beaches, the Aegean Sea is characterised by relatively short and narrow beaches, with an average length of 315 m and a width of 18 m (Figure 7b–7d, Table 1). This pattern is linked to the highly indented and tectonically active coastline, dominated by bays, gulfs, and peninsulas. In contrast, the Mediterranean and Black Sea coasts, where mountain ranges run parallel to the shoreline, host fewer beaches but with much greater dimensions. Mediterranean beaches are on average 2.4 times longer than Aegean beaches, while Black Sea beaches are about twice as wide. As a result, the mean beach area in both regions is 4 times larger than in the Aegean and Marmara Seas. Although relatively rich in the number of beaches, the Sea of Marmara has modest dimensions in both length and width.

At the provincial level, variations are more pronounced (Figures 8a–8d). Muğla has the most beaches (1342), followed by İzmir, Çanakkale, and Balıkesir, each with more than 500 beaches (Figure 8a, Table 1). These provinces highlight the concentration of short, small-scale beaches typical of the Aegean coast (Figure 8b). By contrast, Sakarya Province on the Black Sea hosts the longest beaches, including 3 deltaic beaches with an average length of 18 km. Other provinces with considerable average beach lengths (>900 m) include Adana, Antalya, Edirne, Düzce, and Sinop. This reflects the dominance of vast coastal plains and deltaic settings in these regions.

After excluding extreme values to focus on the representative 98% of beaches, beach lengths range from 13 to 6587 m, width from 3 to 144 m, and area from 55

Figure 4. Examples of naturally formed beaches. (a and b) River-mouth beaches at Butterfly Valley (Muğla) and Marmara Island (Balıkesir), respectively; (c and d) rocky coast beaches at Anamur (Mersin) and Bozcaada Island (Çanakkale), respectively; (e and f) low-lying coastal beaches at Şile (İstanbul) and Anamur (Mersin), respectively; (g) deltaic beach at Karacabey Delta (Bursa); (h) tombolo beach at Anamur (Mersin); and (i) coastal spit beach at Ölüdeniz (Muğla).

Figure 5. Examples of human-structure beaches. (a and b) Beaches in Giresun Province, (c and d) beaches in Fatsa (Ordu Province), and (e and f) mixed beaches in Giresun and Rize Provinces.

Figure 6. (a and b) Construction on Geyikli Beach (Çanakkale) and (c) an example of a tourism beach from the Şile coast (İstanbul).

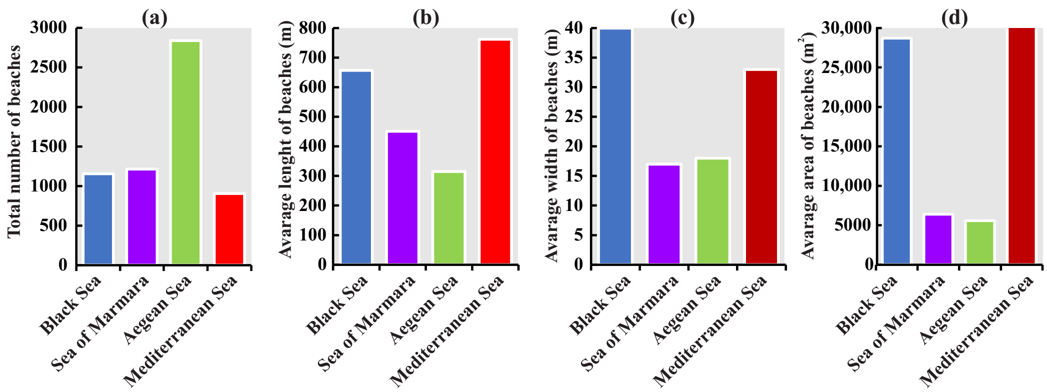

Figure 7. Beach characteristics by sea. (a) Total number, (b) average length, (c) average width, and (d) average area.

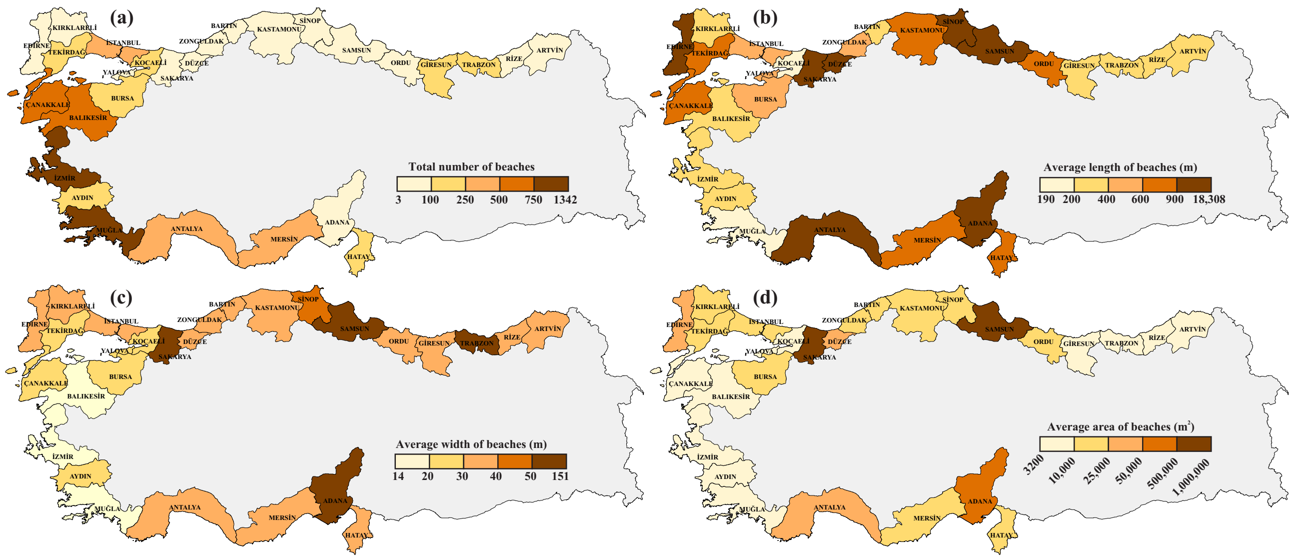

Figure 8. Spatial distribution of beach characteristics by province. (a) Total number, (b) average length, (c) average width, and (d) average area.

Table 1. Beach statistics by province and sea (TNB: total number of beaches, AvL: average length, AvA: average area, AvW: average width, Rck: total number of rocky coast beaches, RvrM: total number of river-mouth beaches, Delta: total number of deltaic beaches, Spit: total number of coastal spit and tombolo beaches, LowL: total number of low-lying coastal beaches, Str: total number of human-structure beaches, Mix: total number of natural and human-structure beaches, Cnst: total number of beaches with construction, and Trzm: total number of beaches with tourism activities).

	TNB	AvL	AvA	AvW	Rck	RvrM	Str	Mix	Delta	LowL	Spit	Cnst	Trzm
Adana	50	2413	91,591	72	18	8	14	2	4	4	0	17	21
Antalya	257	1001	47,321	37	144	52	25	10	5	20	1	59	105
Artvin	23	293	7759	34	7	10	6	0	0	0	0	3	2
Aydın	200	330	6906	21	130	38	23	3	3	1	2	32	55
Balıkesir	575	378	6070	16	403	105	44	11	7	1	4	106	60
Bursa	127	505	11,903	23	81	13	26	3	2	2	0	21	21
Çanakkale	605	620	9936	24	379	139	51	11	16	4	5	84	38
Edirne	47	1269	34,588	35	34	3	3	1	4	2	0	7	2
Giresun	108	309	8498	38	33	10	48	17	0	0	0	19	11
Hatay	146	726	22,601	32	41	26	52	23	2	2	0	33	22
Mersin	253	617	22,356	32	163	48	17	8	5	10	2	45	80
İstanbul	347	512	15,396	34	234	57	46	3	1	4	2	66	42
İzmir	933	255	4562	16	650	166	86	8	8	5	10	157	148
Kastamonu	96	604	12,199	30	69	10	14	3	0	0	0	16	4
Kırklareli	83	395	11,460	36	61	18	2	1	0	1	0	5	4
Kocaeli	206	190	4407	21	144	34	26	1	0	1	0	16	13
Muğla	1342	191	3278	14	870	339	91	12	14	8	8	176	189
Ordu	98	607	14,518	37	46	20	18	14	0	0	0	26	11

Table 1. (Continued).

Rize	65	260	5912	39	12	17	30	6	0	0	0	18	11
Sakarya	3	18,308	999,699	151	0	0	0	0	3	0	0	1	2
Samsun	26	7057	617,052	96	4	6	9	3	4	0	0	12	5
Sinop	77	983	16,300	43	43	17	13	3	0	1	0	16	8
Tekirdağ	114	773	10,339	21	68	17	19	8	0	2	0	40	8
Trabzon	101	270	7491	52	10	6	72	13	0	0	0	12	8
Zonguldak	67	476	13,496	38	36	15	10	5	1	0	0	17	11
Bartın	54	351	10,950	38	39	7	5	2	0	0	1	11	7
Yalova	87	576	7340	22	36	8	30	3	10	0	0	25	18
Düzce	20	970	26,390	34	11	7	1	0	1	0	0	4	2
Black Sea	1156	657	28,732	40	633	199	236	68	9	8	3	199	121
Sea of Marmara	1213	451	6412	17	764	178	207	29	26	5	4	230	99
Aegean Sea	2836	315	5577	18	1878	628	218	34	38	18	22	426	429
Mediterranean Sea	905	762	30,643	33	491	191	120	43	17	37	6	189	259

to 204,000 m^2 (Table 1). Correlation analysis highlights strong interdependencies among these parameters. A strong positive correlation is observed between length and area (r = 0.87) (Figure 9a), indicating that longer beaches tend to have larger areas. In contrast, the relationship between length and width (r = 0.3) (Figure 9b) and width and area (r = 0.29) (Figure 9c) is weak, suggesting that width is a more variable parameter influenced by local geomorphology and wave dynamics rather than scaling directly with length.

4.2. Beach types

Building on the general distribution and morphometric characteristics of beaches presented in Section 4.1, this section examines the diversity of beach types along Türkiye's coasts. Classification by geomorphology and human influence shows pronounced contrasts between the abundance of certain beach types and the spatial dominance of others (Figures 10–12)

Rocky coast beaches are the most prevalent beach type in Türkiye, comprising 61.6% (3766 beaches) of the total (Figure 10a). Despite their high number, rocky coast beaches are the smallest in size, averaging 172 m in length, 14 m in width, and 2000 m^2 in area (Table 2, Figures 10b and 10d). Their total length (649 km) represents 22% of the national total, ranking them as the third longest beach type. This highlights a contrast between abundance and spatial extent: while numerically dominant, rocky beaches contribute relatively little to the overall coastal length.

River-mouth beaches, the second most common type, account for 19.6% (1196 beaches) of the total (Figure 10a). Although larger than rocky coast beaches, they remain relatively short, averaging 565 m in length and 35 m in width (Figures 10b and 10c). Their cumulative length (675 km) makes them the second longest beach type. Nearly half of both rocky coast and river-mouth beaches are concentrated along the Aegean Sea coast (Figures 11a and 11b), particularly in Muğla and İzmir provinces (Figure 12b). This concentration reflects the rugged peninsulas, karstic formations, and numerous short valleys characteristic of these regions.

Human-influenced beaches constitute a substantial share of Türkiye's coastline. Human-structured beaches, shaped by coastal engineering, comprise 12% of the total (781). In contrast, mixed (or compound) beaches, which combine natural processes with artificial structures, represent 2.8% (174 beaches) (Figure 10a). Human-structure beaches are small, averaging 262 m in length and 29 m in width, making them the second smallest type after rocky coasts. Mixed beaches, however, are significantly larger, averaging 1353 m in length and 59 m in width. This makes them 5 times longer and twice as wide as human-structured beaches.

Geographically, human-structure beaches are common along the Black Sea, Aegean Sea, and Sea of Marmara coasts, whereas mixed beaches are particularly prevalent along the Black Sea (Figures 11c and 11d). Provinces such as Muğla, İzmir, and Trabzon have the highest number of structured beaches, while Hatay and Giresun stand out for mixed beaches (Figure 12c and 12d). On average, 34 beaches per province are directly linked to human construction, underscoring the scale of anthropogenic modification along Türkiye's coasts.

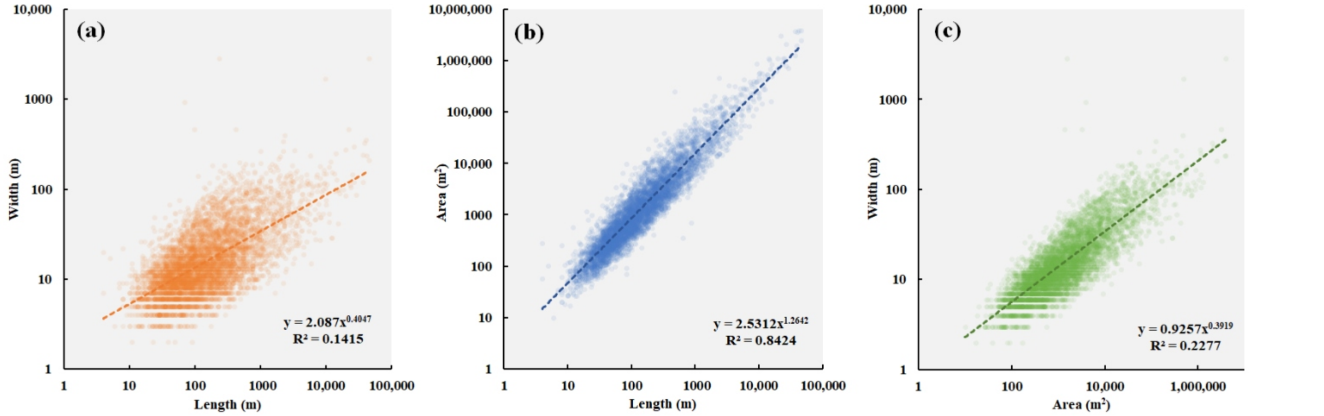

Figure 9. Relationship between beach parameters. (a) Length vs width, (b) length vs area, and (c) area vs width (axes labelled on logarithmic scales).

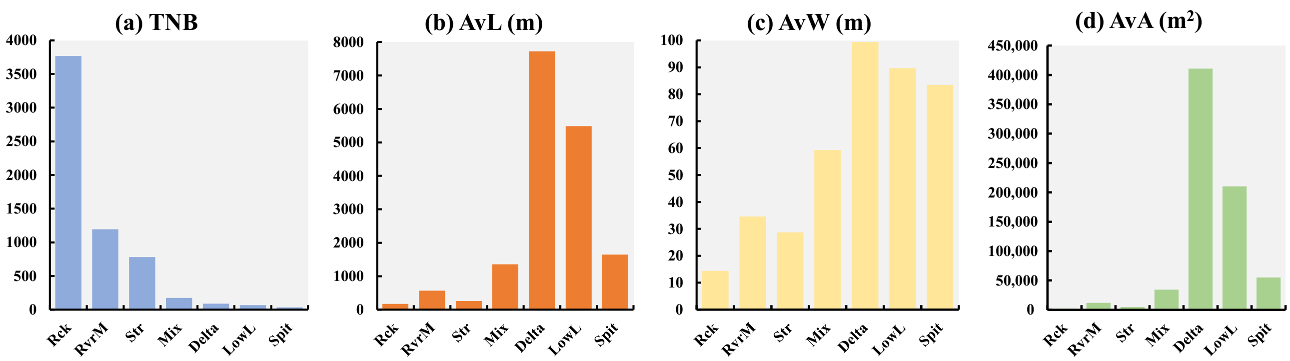

Figure 10. Beach statistics by type (TNB: total number of beaches, AvL: average length, AvA: average area, AvW: average width, Rck: rocky coastline beaches, RvrM: river-mouth beaches, Str: beaches with human structures, Mix: beaches with a combination of natural and human structures, Delta: deltaic beaches, LowL: low-lying coastal beaches, and Spit: coastal spit and tombolo beaches).

Table 2. Beach statistics according to beach types (Y: yes, N: none; for other abbreviations, please refer to Table 1).

	Rck	RvrM	Str	Mix	Delta	LowL	Spit	Cnst (Y)	Cnst (N)	Trzm (Y)	Trzm (N)
TNB	3766	1196	781	174	90	68	35	1044	5066	908	5202
AvL	172	565	262	1353	7722	5488	1648	1515	258	1640	269
AvW	14	35	29	59	99	90	83	46	19	49	20
AvA	2006	11,822	4713	34,403	410,720	210,078	55,098	54,750	5405	64,223	5042

Among the natural types, deltaic beaches, low-lying coastal beaches, and spit–tombolo systems form a smaller share of the total. Deltaic beaches represent 1.5% (90 beaches), low-lying beaches 1.1% (68 beaches), and spit–tombolo beaches only 0.6% (35 beaches). Despite their rarity, these beach types dominate in terms of size. Deltaic beaches are by far the largest, with an average length of 7722 m and a width of 99 m, resulting in a cumulative length of 694 km. Low-lying beaches average 5488 m in length, contributing 373 km in total (Figures 10b–10d). Together, these two categories account for 87% of Türkiye's 33 beaches longer than 10 km, showing their disproportionate contribution to coastal length and area. Spit and tombolo beaches, while limited in number, also have above-average sizes, averaging 1648 m in length and 83 m in width.

Regional comparisons further emphasise these differences. Rocky and river-mouth beaches dominate the Aegean coast (Figures 12a and 12b). At the same time, the Black Sea, despite its steep topography and numerous valleys, has fewer natural rocky and river-mouth beaches due to extensive coastal engineering. Instead, structure and mixed beaches are more common in the Black Sea and Marmara regions (Figures 12c and 12d). Conversely,

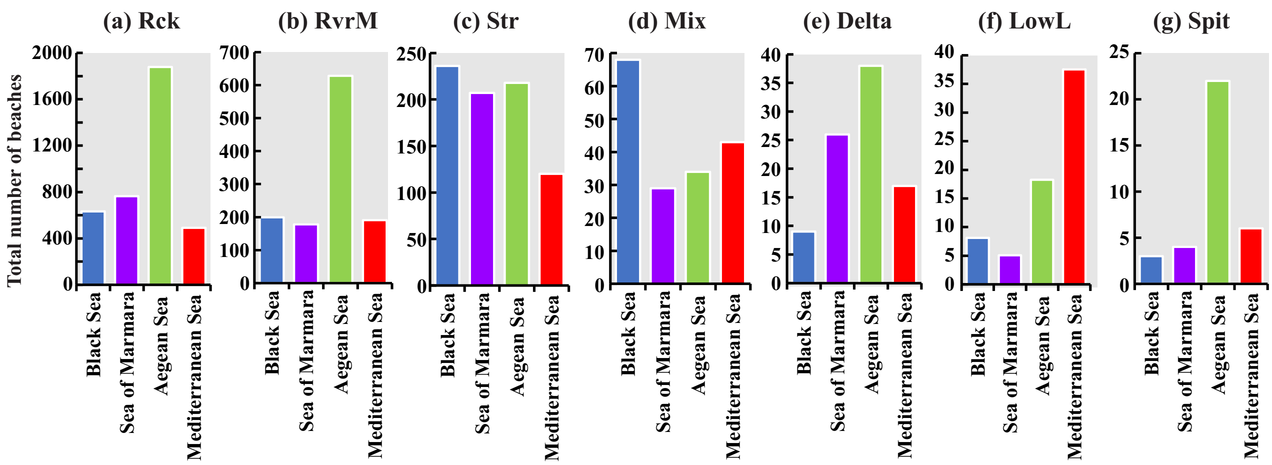

Figure 11. Total number of beach types by sea (for the abbreviations, see Table 1 and Figure 10).

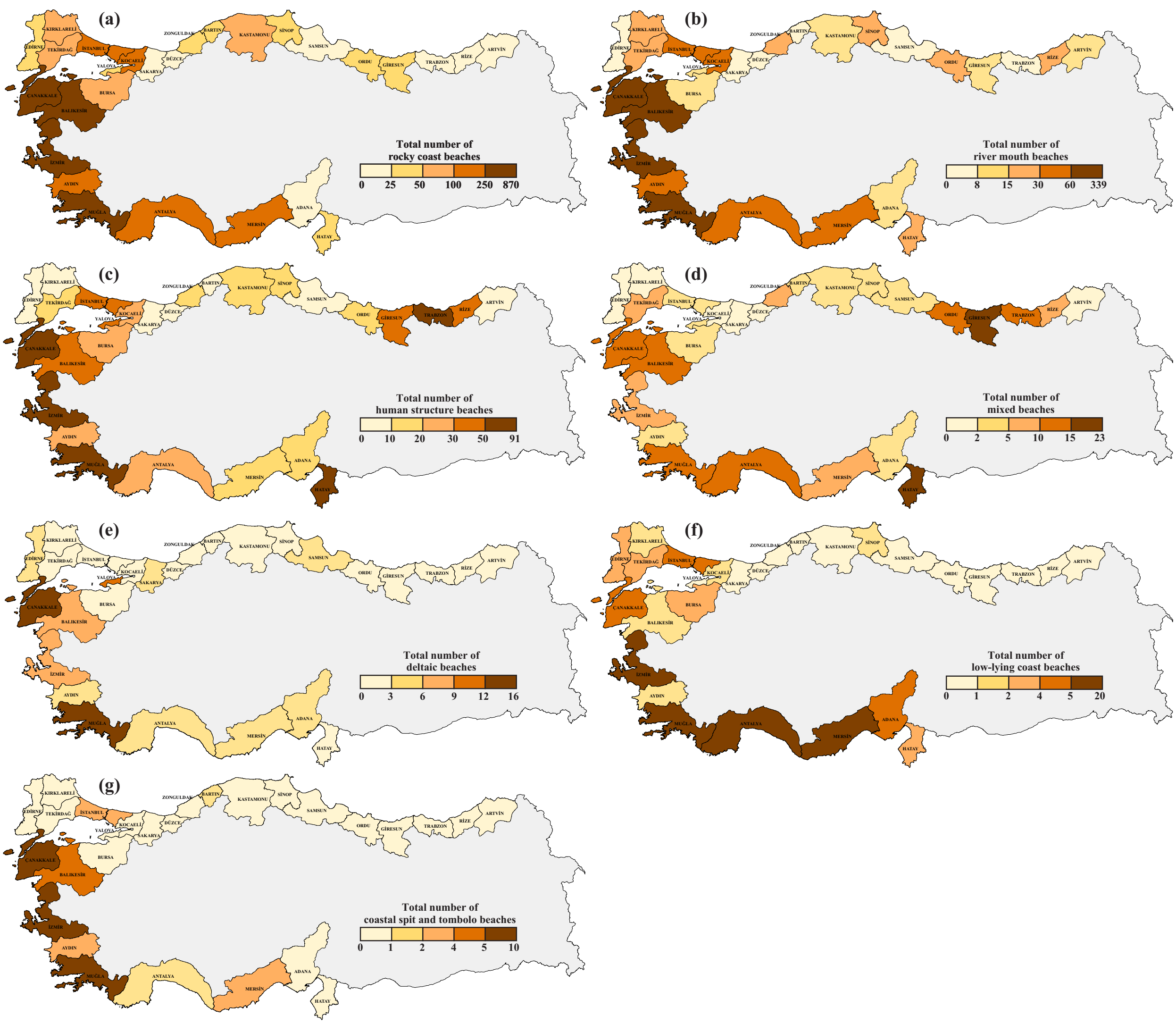

Figure 12. Spatial distribution of beach types by province. (a) Rocky coast, (b) river mouth, (c) human structure, (d) mixed, (e) deltaic, (f) low-lying coastal, and (g) coastal spit and tombolo.

deltaic and low-lying beaches are concentrated in the Mediterranean, where vast coastal plains and major river deltas (e.g., Çukurova, Göksu, and Asi) provide favourable settings (Figures 12e and 12f). Spit and tombolo beaches are particularly associated with western Anatolia, notably in the Aegean region (Figure 12g).

Overall, small beaches (rocky, river-mouth, and human-structure) are the most abundant, while longer beaches that cover a larger area (deltaic, low-lying, and spit–tombolo) are rarer. This contrast underscores the interplay of geomorphological, hydrological, and human factors shaping Türkiye's diverse coastal environments.

4.3. Human impact on beaches

Human activities, particularly tourism and coastal construction, significantly influence the spatial distribution and characteristics of Türkiye's beaches. Of the 6110 beaches identified in this study, 908 (~15%) are directly associated with tourism (Figure 13a). The Sea of Marmara has the fewest tourism-related beaches (99). The Aegean Sea has the highest total number of beaches (429). However, the Mediterranean Sea has the highest proportion of tourism-related beaches, with nearly one-third (28.6%) linked to tourism (Figure 13a). At the provincial scale, Muğla (189), Antalya (105), and İzmir (148), located along the Aegean and Mediterranean coasts are the primary tourism centres, consistent with their role as Türkiye's leading coastal destinations. In contrast, most provinces along the Black Sea host fewer than 10 tourism-related beaches (Figure 13b).

Construction pressures are similarly widespread. Satellite imagery analysis showed that 1044 beaches (17.1% of the national total) show signs of coastal construction in the past 20–30 years (Figure 13c). Muğla (176 beaches), İzmir (157 beaches), Balıkesir (106 beaches), and Çanakkale (84 beaches), all located along the Aegean and Marmara coasts, have the highest concentrations of constructed beaches (Figure 13d). These patterns align geographically with the regions of most significant tourism development. Indeed, a strong positive correlation (r = 0.9) between the number of tourism-related beaches and the number of human-structure beaches shows that tourism is a key driver of coastal modification (Figure 13e).

The morphometric characteristics of impacted beaches further underline this trend. Beaches with tourism activities average 1640 m in length and 49 m in width, making them approximately 6 times longer and 2.5 times wider than

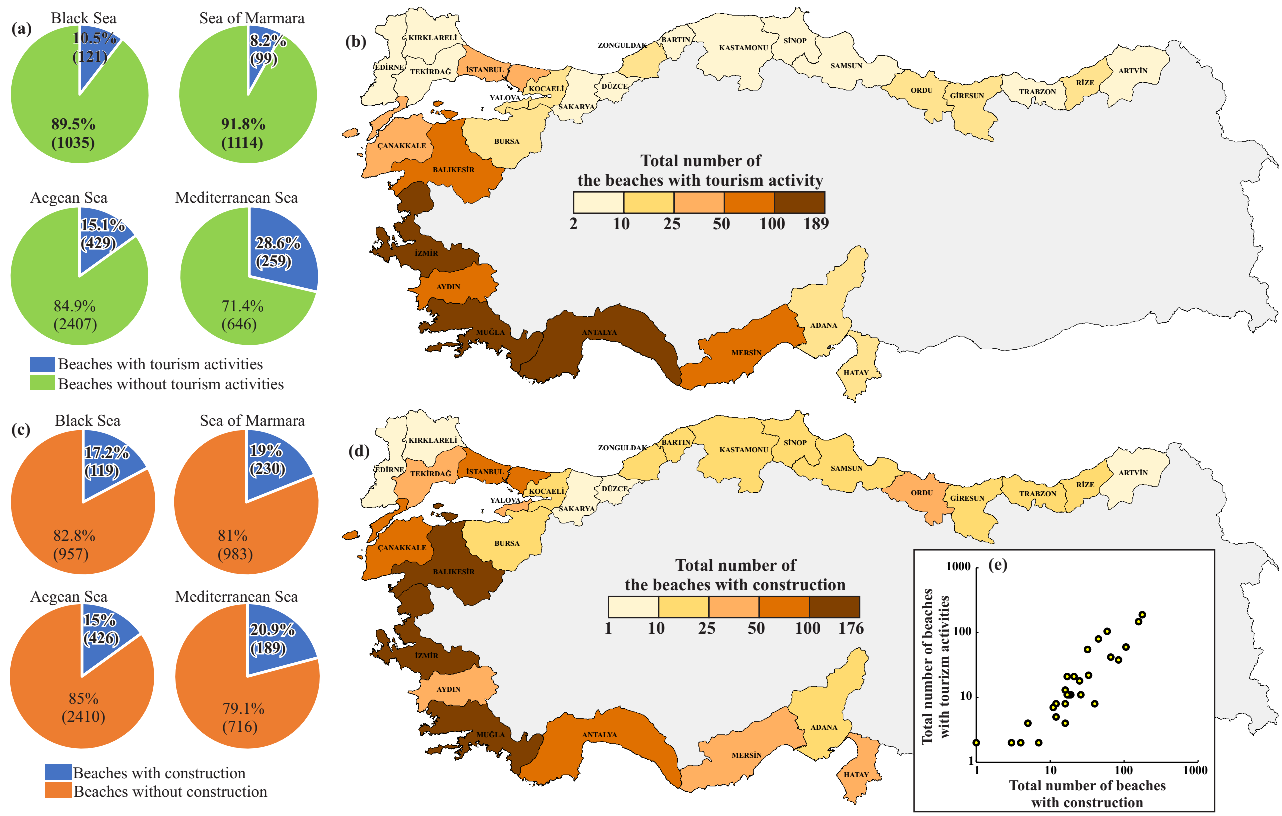

Figure 13. Tourism and construction impacts on beaches. (a) Proportion and total number of beaches with tourism activity by sea, (b) number of tourism-related beaches by province, (c) proportion and total number of beaches with construction by sea, (d) number of beaches with construction by province, and (e) correlation between tourism activity and construction (logarithmic scales).

beaches without tourism (Table 2). Similarly, beaches with construction are 5.8 times longer and 2.3 times wider than unconstructed ones. These results suggest a preference for larger, more accessible beaches for tourism development and construction projects.

This means that tourism is spatially concentrated along the Aegean and Mediterranean coasts and increases pressure through associated construction. These processes disproportionately transform the country's longest and most expansive beaches, reshaping natural coastal dynamics and intensifying management challenges.

5. Discussion

5.1. Limitations in beach delineation

In recent years, numerous studies have relied on automated or semiautomated shoreline extraction techniques applied to satellite imagery (Mentaschi et al., 2018; Vousdoukas et al., 2020; Mao et al., 2022). These approaches enable efficient, long-term monitoring but often struggle with capturing small-scale features or differentiating beaches from adjacent coastal landforms. The present study used manual digitisation based on recent high-resolution imagery to overcome this limitation, prioritising local accuracy over processing speed. Although manual delineation is labour-intensive and subject to interpreter bias, it has been widely adopted in coastal research when fine-scale detail is required (Boak and Turner, 2005; Sesli et al., 2009; Kılar et al., 2025). This method does not ensure consistency and reproducibility across interpreters (Goodchild, 2011). Nevertheless, manual delineation remains a robust and appropriate approach for a baseline national-scale inventory.

Although this study provides the first comprehensive inventory of Türkiye's beaches using satellite imagery, several limitations must be acknowledged, particularly regarding accurately representing sedimentary and morphological characteristics. One major challenge was the influence of atmospheric tides, which can distort apparent beach width in satellite images. While astronomical tidal amplitudes are typically low in Türkiye (approximately 10 cm for the M2 component) (Arabelos et al., 2011), wind-driven and pressure-induced tides can temporarily widen or narrow visible beaches, leading to under- or overestimation of their true extent (Figure 14a).

Challenges were also pronounced in dynamic coastal environments, particularly lowlands, dune systems, and deltas, as in other parts of the world (Figure 14b) (Boak and Turner, 2005; Harley et al., 2019). Türkiye hosts at least 75 dune systems (Erinç, 2001), alongside extensive deltaic coasts, both of which are highly sensitive to wind, storms, and wave action (Figure 14c) (Kılar et al., 2025). These dynamic processes, often accelerated by climate change and human activity, can rapidly shift shoreline positions, complicating the accurate monitoring of beach formation and erosion (Ekercin, 2007; Ranasinghe, 2016; Ataol et al., 2019; Özpolat and Demir, 2019; Monioudi et al., 2023). Consequently, some coastal features such as spits were not reliably detected, as also noted by (Kazancı et al., 2022).

5.2. Beach classification

The classification of coasts and beaches has long been a central focus in coastal geomorphology (Fairbridge, 2004; Finkl, 2004), with studies in this field extending over a century (Johnson, 1919). Over time, various classification systems have been developed, each tailored to specific objectives and regional contexts (Wright and Short, 1984; Anthony, 1998; Jennings and Shulmeister, 2002; Finkl, 2004; Scott et al., 2011). These systems typically consider multiple factors, including sediment grain size, tidal range, coastal energy regimes, sediment transport processes, morphological attributes, and broader geological development (Fairbridge, 2004; Finkl, 2004)

Regional case studies highlight the diversity of these approaches. In New Zealand, 3 distinct gravel beach types were identified from field observations of 42 sites (Jennings and Shulmeister, 2002). In Australia, a morphodynamic framework categorised beaches into 15 types according to tidal and wave conditions, which was subsequently applied nationwide (Short, 2006). In Brazil, beaches were

Figure 14. Examples of limitations in beach delineation. (a) Kepez Beach (Çanakkale) showing apparent width increase due to atmospheric pressure-induced low sea level, (b) beach backed by a low dune system on Bozcaada (Tenedos Island), and (c) eroded and newly formed beaches along the retreating shore of the Karacabey Delta (Bursa).

classified according to dominant coastal processes and geological and geomorphological settings (Dominguez, 2006; Klein and Short, 2016). Along the southwest coast of England, storm-induced morphological changes were analysed using cluster analysis, resulting in 4 beach groups (Burvingt et al., 2017), while another study in the same region identified 9 beach types based on morphological, sedimentological, and hydrodynamic characteristics (Scott et al., 2011). Similarly, 4 beach types in Argentina were distinguished in the Golfo Nuevo region using sediment grain size, morphology, and morphometric parameters (Bunicontro et al., 2020). At the global scale, coastlines were recently categorised into 4 classes based on sediment type, coastal form, and the presence or absence of human-made modifications (Calkoen et al., 2025).

These examples show that beach classification schemes are highly variable, reflecting the aims, methods, and environmental settings of each study. Consequently, the same beach may be classified differently depending on the framework adopted. Furthermore, recent advances in GIS and the availability of high-resolution coastal datasets have enabled more sophisticated, multiparameter approaches (Davidson-Arnott, 2010). Nevertheless, no single system has fully addressed the diverse requirements of researchers working across different spatial and temporal scales (Fairbridge, 2004; Finkl, 2004).

Within this context, the present study introduces a classification of beaches in Türkiye, grounded in field observations, geomorphological characteristics, and human impacts. This framework provides a first step towards understanding the spatial variability of Turkish beaches and offers a valuable baseline for future comparative studies. Further refinement could be achieved by integrating additional parameters such as sediment grain size, wave and tidal dynamics, and more detailed assessments of anthropogenic pressures. Such efforts would enhance classification resolution within Türkiye and contribute to the broader international discourse on coastal and beach classification.

5.3. Coastal morphology and beach characteristics of Türkiye

Variations in beach number and size are strongly linked to the coastal morphology of Türkiye's different sea regions. The tectonic activity of the Aegean Sea coast has produced a highly indented coastline, resulting in many beaches. However, numerous sheltered bays and gulfs, combined with prevailing wind directions, have limited the development of wide beaches in this region. In contrast, the Mediterranean and Black Sea coasts—where mountain ranges run parallel to the shoreline—host fewer beaches. Yet, their exposure to more decisive wave action has facilitated the formation of longer and wider beaches.

Türkiye's coastlines are predominantly wave-dominated with low tidal amplitudes, and rocky shores are widespread. This combination generally results in relatively short and narrow beaches. The average beach length (473 m) and width (24 m) in Türkiye reflect this trend, consistent with observations from other Mediterranean regions. For example, Monioudi et al. (2023) reported that many beaches in Cyprus are narrower than 50 m. In contrast, beach lengths tend to be greater in regions influenced by stronger tidal forces and higher wave energy—such as Australia—and the average beach length tends to be significantly longer (Short, 2006). Thus, while broader oceanic conditions explain part of this variation, local coastal morphology remains a decisive factor shaping individual beach characteristics, as observed worldwide.

The interaction between geomorphological settings and anthropogenic pressures varies considerably across Türkiye's coastal regions. Along the Aegean coast, the highly indented horst and graben morphology produces many small beaches, which are heavily affected by tourism and coastal development due to their accessibility and attractiveness. In contrast, the Mediterranean coast hosts a smaller number of longer and more expansive beaches, where extensive tourism infrastructure exerts intense pressure on natural systems. Along the Black Sea, steep and rugged topography limits the number of natural beaches. At the same time, large-scale engineering projects such as the coastal highway have substantially modified coastal morphology and reduced opportunities for beach formation. The Sea of Marmara has moderate levels of natural diversity and human use, reflecting its mixed geomorphological structure and proximity to major metropolitan areas.

These regional contrasts highlight that, much like in other parts of the world, natural coastal morphology governs the distribution and dimensions of beaches as well as how human pressures manifest across different environments.

5.4. Human impact, pollution, and climate change

Around 40% of the global population lives near coasts, and this proportion continues to rise (Neumann et al., 2015). However, this demographic trend contributes to the rapid degradation of coastal geomorphology and ecosystems. In many countries, coastal populations are growing faster than inland populations. Combined with economic expansion, this shift has intensified pressures on coastal environments (Luijendijk et al., 2018; Robbe et al., 2024) and accelerated coastal erosion driven by anthropogenic influences (Mishra et al., 2025).

Türkiye's coasts have been particularly affected by rapid and often unplanned urbanisation (Guneroglu, 2015). The concentration of urban centres, the construction of an extensive coastal road network, widespread land reclamation projects, and the proliferation of ports and wave-breaking structures (Figure 5) have significantly reduced the formation of natural beaches in Türkiye. The boom in coastal tourism has further accelerated construction, particularly along the Mediterranean and Aegean shores (Kuleli and Bayazıt, 2022; Guneroglu et al., 2024).

One of the most striking examples is the Black Sea Coastal Road, which stretches approximately 540 km across 6 Black Sea provinces—Samsun, Ordu, Giresun, Trabzon, Rize, and Artvin. In particular, the coastal zones of Artvin, Trabzon, Rize, and Giresun have undergone extensive reclamation, with large sections of the highway built on artificially created land, effectively burying the original coastline (Yılmaz, 2008; Guneroglu, 2015). Along the Central and Eastern Black Sea coasts, particularly between Sinop and Artvin, 397 T-shaped groynes have been identified, behind which beach formation processes are still ongoing (Süme et al., 2019). This large-scale coastal engineering has fundamentally altered natural coastal processes and hindered the development of many natural beach types.

Despite Coastal Law number 3621 (Coastal Law, 1990)[4], which prohibits construction within 50 m of the shoreline, development persists. Findings from this study show that construction has occurred on 17% of Türkiye's beaches over the last 20 to 30 years.

Beyond physical infrastructure, plastic waste accumulation poses another major anthropogenic threat (Figure 15) (Güven et al., 2017; Gündoğdu and Çevik, 2019; Aydın et al., 2023; Şener and Yabanlı, 2023; Terzi et al., 2025). Together, intensive construction and pollution jeopardise Türkiye's rich aquatic biodiversity. The country lacks an integrated and comprehensive coastal management framework (Uzun and Celik, 2014).

There is, therefore, a pressing need for an adaptive, science-based management strategy to safeguard these fragile environments in the face of ongoing human pressures and accelerating impacts of climate change.

[4] Coastal Law (1990). Republic of Türkiye, Coastal Law No. 3621 [online]. Website https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=3621&MevzuatTur=1&MevzuatTertip=5 [accessed 10 October 2024] (in Turkish).

Figure 15. Plastic debris on the beaches. (a and b) Karacabey Delta, (c) Avşa Island, and (d) Şile (photo courtesy of Mehmet Korhan Erturaç).

Beyond human interference, climate change poses a significant threat to coastal areas, as sea-level rise and intensified storms alter beach dynamics (Nicholls and Cazenave, 2010; Hinkel et al., 2014; Jiménez et al., 2017; Vousdoukas et al., 2020; Maroukian et al., 2024). Sea-level rise induces hazards such as permanent submersion of beaches, beach erosion, and degradation or loss of beaches (Van De Wal et al., 2024; Vecchio et al., 2024). Over the past 25 years, the global mean sea level has accelerated and is projected to continue increasing (Nerem et al., 2018; Bamber et al., 2019). Along Europe's coastlines, extreme sea levels are expected to rise by an average of 57 cm under the RCP4.5 scenario and up to 81 cm under RCP8.5 by the end of the century (Vousdoukas et al., 2017). In Türkiye, sea-level rise is estimated at 1–2 mm annually. However, in areas such as Antalya—where groundwater extraction is extensive and land subsidence occurs (Simav et al., 2012; Mohamed and Skliris, 2022) —the impacts of sea-level rise are expected to be more severe. These processes significantly threaten sandy beaches, especially in deltaic and low-lying coastal zones (Karaca and Nicholls, 2008; Vousdoukas et al., 2020; Evelpidou 2022; Rizzo et al., 2025).

Beaches serve as natural buffers that absorb wave and storm energy and sustain coastal economies through tourism. According to the IPCC report (IPCC 2023), sandy beaches are among the most vulnerable to sea-level rise and extreme events, with significant implications for sustainable tourism in Mediterranean countries such as Türkiye. In this context, the Mediterranean region has been identified as a climate change hotspot, warming approximately 20% faster than the global average (Giorgi, 2006; Cramer et al., 2020). Loss of beach width and increased erosion threaten coastal protection and the tourism-based economies that rely on these landscapes.

Beaches composed of unconsolidated sediments can, under specific conditions, undergo natural cementation, forming beachrock (Figure 16). These features serve as important indicators of past sea-level fluctuations and provide vital protection against wave energy (Desruelles et al., 2009; Erginal et al., 2013; Avcıoğlu et al., 2016; Öztürk et al., 2016). Beachrock contributes significantly to the stability of the coastal zone (Evelpidou, 2022). Although widespread along Türkiye's coasts (Avşarcan, 1997), human activities, particularly tourism, are increasingly threatening these formations. Their degradation accelerates coastal erosion, particularly on fine-grained beaches.

6. Conclusions

This study provides a comprehensive inventory and characterisation of Türkiye's beaches along its coastlines. The analysis of 6110 beaches showed the complex relationship between their geographical distribution, morphological features, and human interaction. The results show that coastal geomorphology and tectonic activity are the primary determinants of beach occurrence and morphology. The Aegean coast, shaped by horst and graben systems with numerous bays, gulfs, and peninsulas, contains the highest number of beaches. However, these are typically short due to the highly indented shoreline. In

Figure 16. Beachrock on the coast of Gazipaşa Beach (Antalya).

contrast, the Mediterranean and Black Sea coasts, where mountain ranges run parallel to the coast, are characterised by fewer but generally longer and more expansive beaches. Specifically, the average width of Black Sea beaches is approximately double that of Aegean beaches. These differences in size highlight the role of coastal morphology and geological processes in shaping beach characteristics.

Rocky coast beaches are the most common type (61.6%), but these beaches are the smallest in size. Rare types such as deltaic and low-lying coastal beaches only constitute 2.6% of the total number of beaches but they are the longest and most expansive beaches, making up 37% of the total beach length. This finding shows a clear contrast between numerical abundance and contribution to coastline length.

Regarding anthropogenic impacts, 908 beaches (15%) were directly associated with tourism activities, while 1044 beaches (17.1%) showed evidence of coastal construction over the past 20 to 30 years. The regions with the highest tourism and construction pressure are the Aegean and Mediterranean coasts. This is more pronounced in tourism centres such as Muğla, İzmir, Balıkesir, and Çanakkale. A strong positive correlation was found between tourism and construction, which clearly shows the significant impact of tourism on coastal morphology. Consequently, larger and more accessible beaches are preferred for both tourism development and construction projects.

This comprehensive analysis shows the unique nature of beach systems in Türkiye's different coastal regions and provides a vital foundation for sustainable coastal management and conservation strategies.

Declaration of competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

The datasets generated and analysed in this study are available from the corresponding author upon reasonable request. The satellite imagery used for beach delineation in this study was obtained from GE Pro. Due to licensing restrictions, raw files cannot be shared directly; however, researchers can access the same imagery via GE Pro by following the methodology outlined in this study. We gratefully acknowledge TRIPinVIEW for providing aerial imagery that supported the analysis. The Köppen–Geiger climate map was obtained from Taşoğlu et al. (2024)[5], and the SST data were accessed from Tagil et al. (2024)[6].

Author contributions

Muhammed Zeynel Öztürk contributed to the conceptualisation, data curation, formal analysis, methodology, resources, supervision, visualisation, writing (original draft, writing review, and editing). Berkay Yılmaz contributed to the data curation, formal analysis, investigation, methodology, and writing (original draft). Abdullah Soykan contributed to the investigation, validation, supervision, and writing (review and editing).

[5] Taşoğlu E, Öztürk MZ, Yazıcı Ö (2024). High Resolution Köppen-Geiger Climate Zones of Türkiye. Website https://doi.org/10.1002/joc.8635 [accessed 12 May 2025]

[6] Tagil S, Danacioglu S, Yurtseven N (2024). Time series clustering of sea surface temperature in the Mediterranean and Black Sea marine system. Website https://doi.org/10.1002/joc.8687 [accessed 10 May 2025]

References

Anthony EJ (1998). Sediment-Wave Parametric Characterization of Beaches. Journal of Coastal Research 14: 347–352

Anthony EJ (2005). Beach Erosion. In: Schwartz M.L. (eds) Encyclopedia of Coastal Science. Springer Netherlands, Dordrecht, pp 140–145

Arabelos DN, Papazachariou DZ, Contadakis ME, Spatalas SD (2011). A new tide model for the Mediterranean Sea based on altimetry and tide gauge assimilation. Ocean Science 7: 429–444 https://doi.org/10.5194/os-7-429-2011

Ataol M, Kale MM, Tekkanat İS (2019). Assessment of the changes in shoreline using digital shoreline analysis system: a case study of Kızılırmak Delta in northern Turkey from 1951 to 2017. *Environmental Earth Sciences* 78: 579 https://doi.org/10.1007/s12665-019-8591-7

Avcıoğlu M, Yiğitbaş E, Erginal AE (2016). Beachrock formation on the coast of Gökçeada Island and its relation to the active tectonics of the region, northern Aegean Sea, Turkey. Quaternary International 401: 141–152 https://doi.org/10.1016/j.quaint.2015.10.108

Avşarcan B (1997). Yalıtaşı oluşumuyla ilgili kuramlar ve Türkiye kıyılarındaki yalıtaşlarının bazı özellikleri. Coğrafya Dergisi 259–282 (in Turkish).

Aydın İ, Terzi Y, Gündoğdu S, Aytan Ü, Öztürk RÇ et al. (2023). Microplastic Pollution in Turkish Aquatic Ecosystems: Sources, Characteristics, Implications, and Mitigation Strategies. Turkish Journal of Fisheries and Aquatic Sciences 23: https://doi.org/10.4194/TRJFAS24773

Bamber JL, Oppenheimer M, Kopp RE, Aspinall WP, Cooke RM (2019). Ice sheet contributions to future sea-level rise from structured expert judgment. Proceedings of the National Academy of Sciences 116: 11195–11200 https://doi.org/10.1073/pnas.1817205116

Beşiktepe ŞT, Sur Hİ, Özsoy E, Latif MA, Oğuz T et al. (1994). The circulation and hydrography of the Marmara Sea. Progress in Oceanography 34: 285–334 https://doi.org/10.1016/0079-6611(94)90018-3

Bilgili M, Durhasan T, Pinar E (2024). Time series analysis of sea surface temperature change in the coastal seas of Türkiye. Journal of Atmospheric and Solar-Terrestrial Physics 263: 106339 https://doi.org/10.1016/j.jastp.2024.106339

Bird ECF (2008). Coastal geomorphology: an introduction. Wiley, Chichester, England Hoboken, NJ

Boak EH, Turner IL (2005). Shoreline Definition and Detection: A Review. Journal of Coastal Research 214: 688–703 https://doi.org/10.2112/03-0071.1

Bozkurt E (2001). Neotectonics of Turkey–a synthesis. Geodinamica Acta 14: 3–30 https://doi.org/10.1080/09853111.2001.11432432

Bunicontro MP, Marcomini SC, López RA (2020). Coastal Morphology and Human Intervention in Golfo Nuevo, Patagonia Argentina. Journal of Coastal Research 36: 780 https://doi.org/10.2112/JCOASTRES-D-19-00070.1

Burvingt O, Masselink G, Russell P, Scott T (2017). Classification of beach response to extreme storms. Geomorphology 295: 722–737 https://doi.org/10.1016/j.geomorph.2017.07.022

Calkoen FR, Luijendijk AP, Hanson S, Nicholls RJ, Moreno-Rodenas A et al. (2025). Mapping the world's coast: a global 100-m coastal typology derived from satellite data using deep learning. https://doi.org/10.5194/essd-2025-388

Cetin H, Bal Y, Demirkol C (1999). Engineering and Environmental Effects of Coastline Changes in Turkey, Northeastern Mediterranean. Environmental & Engineering Geoscience V: 315–330 https://doi.org/10.2113/gseegeosci.V.3.315

Chettiyam Thodi MF, Gopinath G, Surendran UP, Prem P, Al-Ansari N et al. (2023). Using RS and GIS Techniques to Assess and Monitor Coastal Changes of Coastal Islands in the Marine Environment of a Humid Tropical Region. Water 15: 3819 https://doi.org/10.3390/w15213819

Cramer W, Guiot J, Marini K (2020). Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report. https://doi.org/10.5281/ZENODO.7224821

Daniels RC (1999). Beaches. Environmental Geology. Kluwer Academic Publishers, Dordrecht, pp 41–42

Davidson-Arnott R (2010). Introduction to coastal processes and geomorphology. Cambridge University Press, Cambridge

Desruelles S, Fouache É, Ciner A, Dalongeville R, Pavlopoulos K et al. (2009). Beachrocks and sea level changes since Middle Holocene: Comparison between the insular group of Mykonos–Delos–Rhenia (Cyclades, Greece) and the southern coast of Turkey. Global and Planetary Change 66:19–33 https://doi.org/10.1016/j.gloplacha.2008.07.009

Dominguez JML (2006). The Coastal Zone of Brazil: an overview. Journal of Coastal Research 16–20

Ekercin S (2007). Coastline Change Assessment at the Aegean Sea Coasts in Turkey Using Multitemporal Landsat Imagery. Journal of Coastal Research 233: 691–698 https://doi.org/10.2112/04-0398.1

Erginal AE, Ekinci YL, Demirci A, Bozcu M, Öztürk MZ et al. (2013). First record of beachrock on Black Sea coast of Turkey: Implications for Late Holocene sea-level fluctuations. Sedimentary Geology 294: https://doi.org/10.1016/j.sedgeo.2013.06.003

Erinç S (2001). Jeomorfoloji II Güncelleştirenler Ertek, A., Güneysu, C.). Der Yayınları (in Turkish).

Erol O (1990). Impacts of sea-level rise on Turkey. In: Tirus J.G. (eds) Changing Climate and the Coast. U.S. Environmental Protection Agency, Washington, DC, pp 183–200

Evelpidou N (2022). Coastal Erosion: The Future of Sandy Beaches. https://doi.org/10.5281/ZENODO.7298431

Fairbridge RW (2004). Classification of Coasts. Journal of Coastal Research 201: 155–165

Finkl CW (2004). Coastal Classification: Systematic Approaches to Consider in the Development of a Comprehensive Scheme. Journal of Coastal Research 201: 166–213

Furlani S, Pappalardo M, Gómez-Pujol L, Chelli A (2014). The rock coast of the Mediterranean and Black seas. Memoirs 40:89–123 https://doi.org/10.1144/M40.7

Giorgi F (2006). Climate change hot-spots. Geophysical Research Letters 33: 2006GL025734 https://doi.org/10.1029/2006GL025734

Goodchild MF (2011). Scale in GIS: An overview. Geomorphology 130: 5–9 https://doi.org/10.1016/j.geomorph.2010.10.004

Gündoğdu S, Çevik C (2019). Mediterranean dirty edge: High level of meso and macroplastics pollution on the Turkish coast. Environmental Pollution 255: 113351 https://doi.org/10.1016/j.envpol.2019.113351

Guneroglu A (2015). Coastal changes and land use alteration on Northeastern part of Turkey. Ocean & Coastal Management 118: 225–233 https://doi.org/10.1016/j.ocecoaman.2015.06.019

Guneroglu N, Guneroglu A, Dihkan M, Sari D, Onur M et al. (2024). Determining anthropogenic pressure on the Southern Black Sea blue flag beaches. Journal of Coastal Conservation 28: 55 https://doi.org/10.1007/s11852-024-01057-y

Güven O, Gökdağ K, Jovanović B, Kıdeyş AE (2017). Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environmental Pollution 223: 286–294 https://doi.org/10.1016/j.envpol.2017.01.025

Halpern BS, Frazier M, Potapenko J, Casey KS, Koenig K et al. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. Nature Communications 6: 7615 https://doi.org/10.1038/ncomms8615

Harley MD, Kinsela MA, Sánchez-García E, Vos K (2019). Shoreline change mapping using crowd-sourced smartphone images. Coastal Engineering 150: 175–189 https://doi.org/10.1016/j.coastaleng.2019.04.003

Hinkel J, Lincke D, Vafeidis AT, Perrette M, Nicholls RJ et al. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. Proceedings of the National Academy of Sciences 111: 3292–3297 https://doi.org/10.1073/pnas.1222469111

IPCC (2023). Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jennings R, Shulmeister J (2002). A field based classification scheme for gravel beaches. Marine Geology 186: 211–228 https://doi.org/10.1016/S0025-3227(02)00314-6

Jiménez JA, Valdemoro HI, Bosom E, Sánchez-Arcilla A, Nicholls RJ (2017). Impacts of sea-level rise-induced erosion on the Catalan coast. Reg Environ Change 17: 593–603 https://doi.org/10.1007/s10113-016-1052-x

Johnson DW (1919). Shore processes and shoreline development. John Wiley & Sons Ltd.

Karaca M, Nicholls RJ (2008). Potential Implications of Accelerated Sea-Level Rise for Turkey. Journal of Coastal Research 242: 288–298 https://doi.org/10.2112/07A-0003.1

Karsli F, Guneroglu A, Dihkan M (2011). Spatio-temporal shoreline changes along the southern Black Sea coastal zone. Journal of Applied Remote Sensing 5: 053545 https://doi.org/10.1117/1.3624520

Kazancı N, Gürbüz E, Özgüneylioğlu A, Gürbüz A, Boyraz-Aslan S et al. (2022). An inventory of coastal spits of the eastern Mediterranean and Black seas. Mediterranean Geoscience Reviews 4 (3): 329-349.https://doi.org/10.1007/s42990-022-00086-9

Kılar H, Amarouche K, Akpınar A (2025). Wave storm impacts on shoreline evolution: A case study of Iztuzu beach. Ocean & Coastal Management 267: 107748 https://doi.org/10.1016/j.ocecoaman.2025.107748

Klein AHDF, Short AD (2016). Brazilian Beach Systems: Introduction. In: Short A.D., Klein A.H.D.F. (eds) Brazilian Beach Systems. Springer International Publishing, Cham, pp 1–35

Kuleli T (2015). The socio-economic significance of the Turkish coastal environment for sustainable development. Environmental Monitoring and Assessment 187: 231 https://doi.org/10.1007/s10661-015-4477-7

Kuleli T, Bayazıt S (2022). Land cover change detection in the Turkish coastal zone based on 28-year (1990–2018) Corine data. Environmental Monitoring and Assessment 194: 846 https://doi.org/10.1007/s10661-022-10509-7

Kuzucuoğlu C, Çiner A, Kazancı N (2019). The Geomorphological Regions of Turkey. In: Kuzucuoğlu C., Çiner A., Kazancı N. (eds) Landscapes and Landforms of Turkey. Springer International Publishing, Cham, pp 41–178

Larson M, Kraus NC (1994). Temporal and spatial scales of beach profile change, Duck, North Carolina. Marine Geology 117: 75–94 https://doi.org/10.1016/0025-3227(94)90007-8

Lesiv M, See L, Laso Bayas JC, Sturn T, Schepaschenko D et al. (2018). Characterizing the Spatial and Temporal Availability of Very High Resolution Satellite Imagery in Google Earth and Microsoft Bing Maps as a Source of Reference Data. Land 7: 118 https://doi.org/10.3390/land7040118

Luijendijk A, Hagenaars G, Ranasinghe R, Baart F, Donchyts G et al. (2018). The State of the World's Beaches. Scientific Reports 8: 6641 https://doi.org/10.1038/s41598-018-24630-6

MacManus K, Balk D, Engin H, McGranahan G, Inman R (2021). Estimating population and urban areas at risk of coastal hazards, 1990–2015: how data choices matter. Earth System Science Data 13: 5747–5801 https://doi.org/10.5194/essd-13-5747-2021

Mao Y, Harris DL, Xie Z, Phinn S (2022). Global coastal geomorphology – integrating earth observation and geospatial data. Remote Sensing of Environment 278: 113082 https://doi.org/10.1016/j.rse.2022.113082

Maroukian H, Spyrou E, Tsiatoura S, Tzouxanioti M, Evelpidou N (2024). Sea Level Rise and the Future of Tombolos: The Case of Greece. Journal of Marine Science and Engineering 12: 1578 https://doi.org/10.3390/jmse12091578

Mentaschi L, Vousdoukas MI, Pekel J-F, Voukouvalas E, Feyen L (2018). Global long-term observations of coastal erosion and accretion. Scientific Reports 8: 12876 https://doi.org/10.1038/s41598-018-30904-w

Mishra M, Sudarsan D, Chand P, Paul S, Dofee AA et al. (2025). Exploring global trends and future research directions in Shoreline Analysis Systems (SAS): a bibliometric analysis. Journal of Coastal Conservation 29: 30 https://doi.org/10.1007/s11852-025-01110-4

Mohamed B, Skliris N (2022). Steric and atmospheric contributions to interannual sea level variability in the eastern mediterranean sea over 1993–2019. Oceanologia 64: 50–62 https://doi.org/10.1016/j.oceano.2021.09.001

Monioudi IN, Velegrakis AF, Chatzistratis D, Vousdoukas MI, Savva C et al. (2023). Climate change- induced hazards on touristic island beaches: Cyprus, Eastern Mediterranean. Frontiers in Marine Science 10: 1188896 https://doi.org/10.3389/fmars.2023.1188896

Nerem RS, Beckley BD, Fasullo JT, Hamlington BD, Masters D et al. (2018). Climate-change–driven accelerated sea-level rise detected in the altimeter era. Proceedings of the National Academy of Sciences 115: 2022–2025 https://doi.org/10.1073/pnas.1717312115

Neumann B, Vafeidis AT, Zimmermann J, Nicholls RJ (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding - A Global Assessment. PLoS ONE 10: e0118571 https://doi.org/10.1371/journal.pone.0118571

Nicholls RJ, Cazenave A (2010). Sea-Level Rise and Its Impact on Coastal Zones. Science 328: 1517–1520 https://doi.org/10.1126/science.1185782

Olson DB, Kourafalou VH, Johns WE, Samuels G, Veneziani M (2007). Aegean Surface Circulation from a Satellite-Tracked Drifter Array. Journal of Physical Oceanography, 37 (7): 1898-1917. https://doi.org/10.1175/JPO3028.1

ONHO (2008). Turkish Naval Forces, Office Of Navigation, Hydrography and Oceanography. Coastal survey information.

Özpolat E, Demir T (2019). The spatiotemporal shoreline dynamics of a delta under natural and anthropogenic conditions from 1950 to 2018: A dramatic case from the Eastern Mediterranean. Ocean & Coastal Management 180: 104910 https://doi.org/10.1016/j.ocecoaman.2019.104910

Öztürk MZ, Erginal AE, Kiyak NG, Ozturk T (2016). Cement fabrics and optical luminescence ages of beachrock, North Cyprus: Implications for Holocene sea-level changes. Quaternary International 401: 132-140 https://doi.org/10.1016/j.quaint.2015.03.024

Ramesh R, Chen Z, Cummins V, Day J, D'Elia C et al. (2015). Land–Ocean Interactions in the Coastal Zone: Past, present & future. Anthropocene 12: 85–98 https://doi.org/10.1016/j.ancene.2016.01.005

Ranasinghe R (2016). Assessing climate change impacts on open sandy coasts: A review. Earth-Science Reviews 160: 320–332 https://doi.org/10.1016/j.earscirev.2016.07.011

Rio M-H, Poulain P-M, Pascual A, Mauri E, Larnicol G et al. (2007). A Mean Dynamic Topography of the Mediterranean Sea computed from altimetric data, in-situ measurements and a general circulation model. Journal of Marine Systems 65: 484–508 https://doi.org/10.1016/j.jmarsys.2005.02.006

Rizzo A, Mattei G, Dumon Steenssens L, Anzidei M, Aucelli PPC et al. (2025). Methodological advances in sea level rise vulnerability assessment: implications for sustainable coastal management in a climate change scenario. Ocean & Coastal Management 268: 107751 https://doi.org/10.1016/j.ocecoaman.2025.107751

Robbe E, Abdallah LB, El Fels L, Chaher NEH, Haseler M et al. (2024). Towards Solving the Beach Litter Problem: Ecosystem Service Assessments at North African Coasts. Sustainability 16: 5911 https://doi.org/10.3390/su16145911

Scott T, Masselink G, Russell P (2011). Morphodynamic characteristics and classification of beaches in England and Wales. Marine Geology 286: 1–20 https://doi.org/10.1016/j.margeo.2011.04.004

Şener İ, Yabanlı M (2023). Macro- and microplastic abundance from recreational beaches along the South Aegean Sea (Türkiye). Marine Pollution Bulletin 194: 115329 https://doi.org/10.1016/j.marpolbul.2023.115329

Şengör AMC, Yilmaz Y (1981). Tethyan evolution of Turkey: A plate tectonic approach. Tectonophysics 75: 181–241 https://doi.org/10.1016/0040-1951(81)90275-4

Sesli FA, Karsli F, Colkesen I, Akyol N (2009). Monitoring the changing position of coastlines using aerial and satellite image data: an example from the eastern coast of Trabzon, Turkey. Environmental Monitoring and Assessment 153: 391–403 https://doi.org/10.1007/s10661-008-0366-7

Short AD (2006). Australian Beach Systems—Nature and Distribution. Journal of Coastal Research 221: 11–27 https://doi.org/10.2112/05A-0002.1

Simav M, Yildiz H, Türkezer A, Lenk O, Özsoy E (2012). Sea level variability at Antalya and Menteş tide gauges in Turkey: atmospheric, steric and land motion contributions. Studia Geophysica et Geodaetica 56: 215–230 https://doi.org/10.1007/s11200-010-0067-x

Süme V, Yüksek T, Kaya A (2019). Trabzon ve Rize kıyılarındaki T-mahmuzların plaj olarak kullanılabilirliği üzerine alan çalışması. Gümüşhane Üniversitesi Fen Bilimleri Enstitüsü Dergisi https://doi.org/10.17714/gumusfenbil.531373 (in Turkish)

Tagil S, Danacioglu S, Yurtseven N (2024). Time series clustering of sea surface temperature in the Mediterranean and Black Sea marine system. International Journal of Climatology 44: 6083-6099. https://doi.org/10.1002/joc.8687

Taşoğlu E, Öztürk MZ, Yazıcı Ö (2024). High Resolution Köppen-Geiger Climate Zones of Türkiye. International Journal of Climatology 44: 5248–5265 https://doi.org/10.1002/joc.8635

Terzi Y, Gündoğdu S, Yandi İ, Altinpinar İ, Öztürk RÇ et al. (2025). Marine litter on the Turkish Black Sea shoreline: Abundance, composition, and sources. Waste Management 205: 115027 https://doi.org/10.1016/j.wasman.2025.115027

Uzun B, Celik N (2014). Sustainable management of coastal lands: A new approach for Turkish coasts. Ocean & Coastal Management 95: 53–62 https://doi.org/10.1016/j.ocecoaman.2014.04.010

Van De Wal R, Melet A, Bellafiore D, Camus P et al. (2024). Sea Level Rise in Europe: Impacts and consequences. State of the Planet Discussions 1-65 https://doi.org/10.5194/sp-3-slre1-5-2024

Vecchio A, Anzidei M, Serpelloni E (2024). Sea level rise projections up to 2150 in the northern Mediterranean coasts. Environmental Research Letters 19: 014050 https://doi.org/10.1088/1748-9326/ad127e

Vousdoukas MI, Mentaschi L, Voukouvalas E, Verlaan M, Feyen L (2017). Extreme sea levels on the rise along Europe's coasts. Earth's Future 5: 304–323 https://doi.org/10.1002/2016EF000505

Vousdoukas MI, Ranasinghe R, Mentaschi L, Plomaritis TA, Athanasiou P et al. (2020). Sandy coastlines under threat of erosion. Nature Climate Change 10: 260–263 https://doi.org/10.1038/s41558-020-0697-0

Warnasuriya TWS, Kumara MP, Gunasekara SS, Gunaalan K, Jayathilaka RMRM (2020). An Improved Method to Detect Shoreline Changes in Small-Scale Beaches Using Google Earth Pro. Marine Geodesy 43: 541–572 https://doi.org/10.1080/01490419.2020.1822478

Wolff C, Vafeidis AT, Muis S, Lincke D, Satta A et al. (2018). A Mediterranean coastal database for assessing the impacts of sea-level rise and associated hazards. Scientific Data 5: 180044 https://doi.org/10.1038/sdata.2018.44

Wright LD, Short AD (1984). Morphodynamic variability of surf zones and beaches: A synthesis. Marine Geology 56: 93–118 https://doi.org/10.1016/0025-3227(84)90008-2

Yılmaz C (2008). Karadeniz sahil yolunun kıyı kentleri üzerine etkileri. TÜCAUM V Coğrafya Sempozyumu 149–159 (in Turkish)

Zhang X, Wu C, Hu R, Xu S, Xu Z et al. (2024). Can Satellite-Derived Beach Images Resolve the Responses to Human Activities? Journal of Geophysical Research: Earth Surface 129: 2 https://doi.org/10.1029/2023JF007339