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COASTAL HABITAT CHANGES IN THE SOUTHEAST BLACK SEA, TURKIYE

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Abstract. Coastal areas provide a variety of natural resources and ecosystem services ranging from sources of protein and livelihood to coastal and climate stability. In the last decades, the coastal ecosystem of the Black Sea has been subjected to intense anthropogenic pressures such as overfishing, pollution, coastal reclamation, and warfare. The main reason why coastal reclamation is the preferred option for area development is due to the region's unique geographical structures consisting of towering mountains and valleys with narrow coastal areas. This geographical condition also formed a narrow continental shelf which is important for the coastal community in the region and provides sanctuary habitats for local and migratory species from neighboring seas. Trabzon coasts which are situated in the Southeast Black Sea of Turkiye have undergone human intervention in this regard coastal reclamation over a long period of time causing the coasts to lose most of their original shape. Most of Trabzon population occupied the coastal areas and riverbanks consequently most of the settlements and public facilities are focused in this area. The main objectives of the present study were to assess the coastline changes in the Trabzon coasts, Southeast Black Sea, Turkiye. Moreover, coastal habitat changes and patterns in the consequences of coastal reclamation in the area were investigated. In this study remotely sensed data in the form of satellite images and Geographic Information System (GIS) methods were utilized. Sentinel-2 multi-temporal satellite images were used in order to assess changes in the coastline in terms of spatial and temporal. Modified Normalized Difference Water Index (MNDWI) formula was applied for coastal extraction. All operations of the satellite image analysis from images correction and coastline extraction were done using the QGIS open sources software. The results of the present study show that during the period of six years from 2016 to 2022, Trabzon coastline has changed progressively towards the sea in some sites. In this period, Trabzon coasts have gained a new area up to 38 ha m through coastal reclamation activities. Based on ground checking results, the new coastal areas have been transformed into construction areas, to widen seaport area and seaside parks. On the contrary, the same amount of coastal habitats area has been lost. The ecological factor of coastal reclamation should be considered to realize sustainable development. This effort to reduce coastal degradation in the future. This study will support scientific evidence for coastal habitat observation in the region.
Keywords: coastal habitat, coastline change, coastal reclamation, GIS, Black Sea

1 INTRODUCTION

Coastal ecosystems play a vital role in supporting both the environment and human communities by providing a wide range of important services. These services include the benefits that humans derive from the existence of coastal and marine ecosystems (Barbier et al., 2011; Lakshmi, 2021). Estuaries, salt marshes, mangrove forests, seagrass meadows, coral reefs, sandy beaches, and rocky coasts are all important habitats that provide shelter for feeding grounds, nesting sites, breeding areas, and nursing habitats for a wide range of marine organisms (M. Brander et al., 2012). At least one-fourth of global primary productivity occurs within these ecosystems. Moreover, coastal regions support a large proportion of global marine fisheries, global

carbonate production, and global sediment mineralization processes (Agardy et al., 2005). Due to the abundance and diversity of marine life in coastal habitats, these habitats are essential for sustaining food chains, supporting biodiversity and maintaining ecological balance on a global scale (Barbier et al., 2011; Lotze, 2021).

Human activities in coastal areas have a significant impact on coastal ecosystems, with considerable environmental repercussions. Coastal regions are particularly appealing for human settlements and economic activities because of their closeness to water bodies, transit routes and numerous natural resources. However, increased population, urbanization, and industrialization have resulted in a wide range of activities that pose serious challenges to these fragile ecosystems (Halpern et al., 2008; Lotze et al., 2006). Among the various human activities, coastal development appears as a significant driver of change and disruption in coastal habitats. The construction of residential and commercial buildings, ports, marinas, and infrastructure frequently demands extensive land reclamation and modification to the natural landscape. Natural barriers, such as sand dunes and wetlands, which protect against coastal erosion and storm surge, are removed, or modified to accommodate construction projects ((Hu et al., 2018; Ma et al., 2019)).

Coastal development has an impact beyond physical changes and increased coastal vulnerability. Studies reported that human intervention in coastal area have led to ecological degradation in the coastal area (Hu et al., 2018; Tay et al., 2018; Yu et al., 2017). The changes alter the natural flow of water, affect sediment patterns and intrude on the habitats of marine organisms. As a result, the fragile balance of coastal ecosystems is disrupted, putting their resilience and functionality at risk. The loss and fragmentation of habitats, including vital wetlands, estuaries, and salt marshes, disrupt the intricate web of interactions among species. This disruption will have an impact on the breeding, feeding and migrating patterns of numerous plant and animal species, leading to declines in biodiversity and ecological imbalances (Ge & Zhang, 2011).

The Black Sea marine ecosystems are influenced by a combination of variables, including the inflow of major rivers, morphological patterns, regional climate, and anthropogenic activities. The Black Sea is known for its unique water characteristics, particularly the presence of a permanent halocline that separates the upper, oxygenated layer from the anoxic layer at the bottom. This stratification affects the distribution of marine organisms and contributes to the establishment of various habitats. As a result, only ten percent of the Black Sea can support life in terms of biology. The Black Sea provide a range of habitats, including coastal marshes, rocky coastlines, sandy and muddy bottoms, and submerged plant regions which provide essential feeding, breeding, and nursery grounds for native and migratory species from neighbor seas. These habitats are incredibly productive as statistical reports show that the Black Sea provides higher biomass in compared to the Mediterranean Sea (Yilmaz & Yilmaz, 2009). The Southern Black Sea is noted for key geographical features such as rising mountains parallel to the coastline, sudden dip of continental shelves. This condition has resulted in a narrow coastal habitat along the Southern Black Sea where fishing activities are mainly carried out in the littoral zone, sublittoral zone and epipelagic zone in the region where marine organisms are commonly found. These zones are depending on the natural structure, it includes the area from the shore to a depth of up to 15-20 m. The width of this region can reach up to 100 - 150 m in very short and shallow areas. As a result, marine organisms richness decreases as depth increases (Zaitsev, 2006).

The Black Sea on the other hand, has become the subject of human activities and has had a significant impact on marine ecosystems, affecting both the environment and the livelihoods of coastal communities. Overfishing, marine transportation, pollution, war, and other human pressures have all contributed to the degradation of the Black Sea coastal ecosystems over the course of decades (Oguz et al., 2012). Among the various human pressures, coastal development is appearing as a major driver of change and disturbance in coastal habitats. The coastal parts of the Black Sea are the most densely populated and urbanized area. Most of settlements and public facilities were built in the coastal area and riverbanks. Rapid urbanization and coastal infrastructure development have resulted in habitat loss, the destruction of vital costal ecosystems such as marshes and dunes, and alterations to coastal natural landscapes.

In recent decades, the Southeast Black Sea coasts particularly in Turkiye have seen extensive coastal reclamation. Coastal reclamation in Trabzon and certain provinces in the Southeastern Black Sea region since the 1960s has resulted in significant transformations of the shoreline (Sesli et al., 2009). The alterations to the shoreline have diverse effects, both positive and negative. The purposes are to develop new land to accommodate expanding populations, promote tourism and facilitate economic activities. While coastal reclamation may provide economic benefits and potential for development, it also has significant environmental and coastal ecosystem implications (AlQahtany et al., 2022). The artificial shoreline built in Trabzon disrupts the natural hydrodynamic process, causing erosion and sedimentation in certain areas. In addition, the shoreline changes that occur with coastal reclamation also led to the change of existing coastal habitats.

Monitoring and assessment of changes in coastal areas and habitats are important for understanding the dynamics, assessing the effects of human activities, identifying coastal hazards and directing effort towards sustainable management and conservation. The objective of the present study is to better understand the historical changes in coastal habitats in order to improve management and development activities in the studied area. The study used remotely sensed images recorded at two different times over a period of time and the Geography Information System (GIS) technique to monitor and assess the coastal habitat change in the Trabzon coast, Southeast Black Sea, Turkiye. As a result of this investigation, how much/to what extent the coasts have changed over time and space, as well as the habitat implications as the consequences of physical change on the coast, have been determined.

2 METHODOLOGY

2.1 Study area

The study area of the Trabzon coasts, located in the Southeast Black Sea region of Turkiye, serves as the focus of investigation in the present study (Figure 1). Trabzon region is situated between the sea and the mountains and notable for its unique feature in the form of its rocky and irregular geomorphology. The mountains align closely with the coastline, resulting in an immediate and steep hinterland adjacent to the coast. This geographical configuration prompts the development of linier settlements along the coasts rendering the cities extremely vulnerable to the negative impacts of the marine environment. Trabzon coasts characterized by a diverse range of coastal habitats including sandy beaches, rocky cliffs, and estuaries.

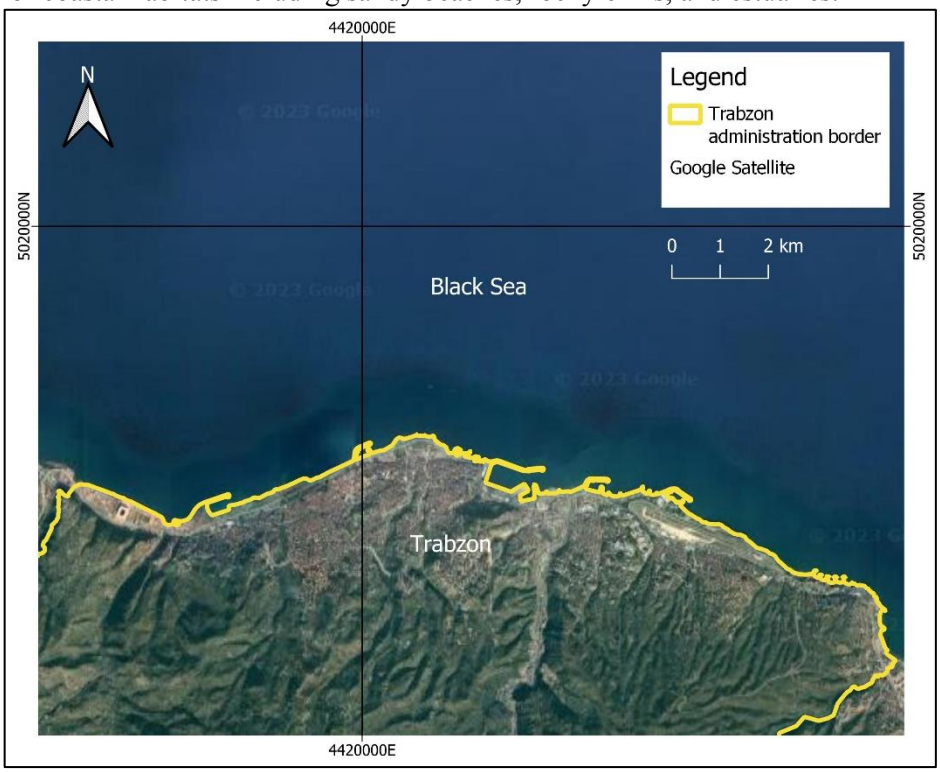

Figure 1. Study area in Trabzon coasts, Southeast Black Sea

Trabzon is namely the largest city in the Southeast Back Sea Region of Turkiye. With a land area of approximately 4.865 square kilometers, Trabzon has a growing population of 335.628 people, making it the third most populous city in the region (*Trabzon Nüfusu 2022*, n.d.). The region holds significant social and economic importance, with tourism, fishing and maritime activities developing as important economic drivers. The sea serves as a major link for trade and transportation, influencing the region's history and socio-economy. Trabzon is renowned as an important seaport in the region, playing a crucial role in connecting various seaports and coastal cities within the Black Sea region. Trabzon is significant because it has been the key major port along the Eastern Black Sea for centuries. In addition, Trabzon possesses a wide-reaching hinterland supported by a robust network of roads that extent deep into inner Anatolia and stretch as far as the Caucasus and Iran via Eastern Anatolian.

The majority of the population of the Southeast Black Sea region occupied the coastal area and along riverbanks. Consequently, settlements and public infrastructure are concentrated in these regions. In response to the growing need for urban and industrial expansion, Trabzon has undergone extensive coastal reclamation activities over the last decades. This has been particularly evident in areas experiencing high demand due to the province's status as a top tourism destination in the region. The reclamation projects primarily involve the construction of residential and commercial buildings, infrastructural developments, ports, marinas, and tourism-related facilities. Driven by economic development and urban development demand, coastal reclamation has become the preferred approach adopted by the local government (Guneroglu, 2015).

2.2 Datasets

In order to assess changes in the coastal area, remotely sensed data in the form of satellite images datasets and GIS techniques were engaged in the present study. A multi-temporal analysis was performed using a series of images datasets acquired at different time intervals. The main objective was to assess the alteration in the coastal boundary over a certain period of time. By comparing and analyzing these images, changes in land cover, coastline position, and coastal features can be derived ().

The present study used multi-temporal Sentinel-2 satellite image datasets to assess the coastline change for a six-year period. An image with acquisition data on April 23rd, 2016, was used as the initial condition, while image with acquisition data on September 9th, 2022, was used as the current condition. All images were analyzed using the WGS84 datum and UTM Zone 37 North projections. Satellite images datasets information is given in Table 1. In the present study tides effect on coastline were neglected due to small variability of tides in the study area.

Table 1. Specification of the used satellite datasets

Year	Acquisition Date	Path/Row	Spatial Resolution (m)
2016	April 23rd 2016	L1C_T37TEF	10
2022	September 9th 2022		

The European Space Agency's (ESA) Sentinel-2 satellite images are widely utilized for monitoring and assessing various aspects of the Earth's surface, including marine and coastal habitats. Sentinel-2 satellites, orbiting the Earth, capture high-resolution images in various spectral bands, providing essential information on land cover, vegetation health, water quality and coastal dynamics. These images are particularly valuable for monitoring changes in coastal ecosystems such as coastline changes, coastal erosion, vegetation diversity, and water clarity.

Sentinel-2 satellite imagery has proven to be highly valuable for monitoring and assessing marine and coastal resources due to their regular visits and accessibility. Sentinel-2 images have been used to classify and map coastal land cover types, including beaches, rocky shores, and urban areas. By comparing images acquired at different times, changes in coastal land cover due to natural process or human activities over time can be detected and quantified (). Sentinel-2 satellite images were obtained from United States Geological Survey (USGS).

2.3 Coastline extraction

The MNDWI (Modified Normalized Difference Water Index) is the improved version of McFeeter's NDWI (Normalized Difference Water Index) developed for coastal areas and water body extraction. It is widely used to identify and delineate various coastal features such as coastlines, marshes, and tidal zones (Wicaksono & Wicaksono, 2019). The MNDWI can effectively differentiate between water and non-water pixels by examining specific spectral bands, often the green and mid-infrared bands. Water bodies have positive values, whereas land features have zero or negative values Because of its sensitivity to minor variation in water reflectance, the MNDWI is ideal for mapping and monitoring coastal zones, including changes in coastline and vegetation (Wicaksono & Wicaksono, 2019).

The MNDWI is calculated using a formula that involves the green and shortwave infrared (SWIR) spectral bands. In terms of Sentine-2 data, the MNDWI formula is calculated using the green band (B3) and the shortwave infrared band 1 (SWIR1, B11) (). The calculation results in an index value that ranges from –1 to 1. Higher positive numbers indicate the existence of water, whereas lower positive values or zero indicate the presence of land or non-water areas. Negative values are usually associated with dense vegetations (). Coastline extractions were done using the MNDWI formula as follows:

$$\text{MNDWI} = \frac{\rho_{green} - \rho_{SWIR}}{\rho_{green} + \rho_{SWIR}}$$

2.4 Coastal change analysis

The analysis of coastline changes was conducted through the overlay method, which involved method comparing the initial coastline from 2016 with the current coastline from 2022. The overlay methods allow the identification of areas where the coastline has shifted towards the sea, indicating sedimentation, or towards the land, indicating sediment loss due to erosion or abrasion in this study case mostly due to human activities particularly extensive coastal reclamation in the study area. The displacement of the coastline was quantified and calculated as the rate of coastal change. The flowchart of the present study is given in Figure 2.

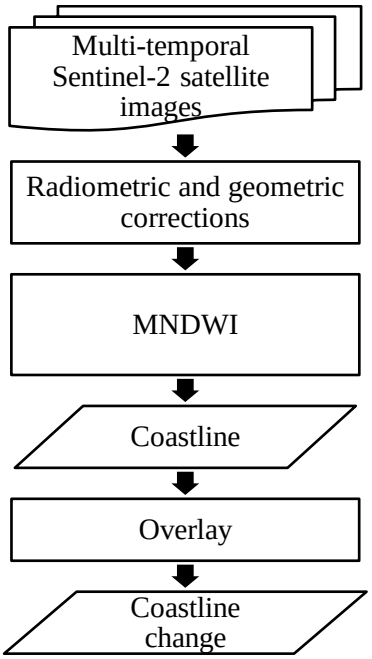

Figure 2. Flowchart of coastline extraction in this study

In order to determine coastal habitat, change in the study area, a comprehensive assessment was conducted. Historical data from various sources including literature, maps, reports, archives, and other relevant information from experts were gathered to observe the previous/original and current/new habitat types and condition in the study area. Statistical analysis and geospatial tools were employed to detect significant changes and measure the extent of habitat change in the study area.

In this study, the conversion of natural coastal habitats into human-made structures that took place in the study area was identified as the loss of coastal ecosystems. In terms of coastal habitat types, the coastal reclamation process in Trabzon has converted the initial coasts into rocky shores habitat.

In addition, the current investigation also focuses on examining the historical alteration in water distribution across the coastal area over a span of thirty-seven years, specifically from 1984 to 2021. To identify changes in coastal aquatic habitats, the study utilized satellite images captured at various intervals, enabling the monitoring of the presences and shifts of coastal water bodies over the study period.

The dataset utilized in this study was generated by the European Commission's Joint Research Centre as part of the Copernicus Programme. The dataset was derived from Landsat imagery provided by the USGS and NASA. It is particularly designed for monitoring water resources and conserving biodiversity (*Global Surface Water Explorer*, n.d.). The datasets used in this study were recorded at the 40E, 50N. The dataset is publicly accessible, and can be accessed online through the web map address:

All image processing, geospatial analysis, and data visualization were carried out using the open - source software tool of QGIS 3.30.2 (*Download QGIS*, n.d.).

3RESULTS AND DISCUSSIONS

Coastline change

The primary objective of the study was to explore the morphological and ecological shifts that occurred within the coastal habitats of Trabzon, Southeast Black Sea of Turkiye over a span of six years, specifically from 2016 to 2022. The study studied the changes in the physical and the associated ecological aspects of these habitats. To accomplish this, objective advanced techniques including the utilization of high-resolution remote sensing datasets and GIS were employed to investigate the spatial and temporal variations along an extensive segment of approximately 20 m along the Trabzon coastline. This advanced technology facilitates the acquisition of comprehensive insight into the constantly changing characteristics of the coastal area, and its evolution over the specified timeframe.

Through the analysis of satellite imagery datasets, it is evident that the coastal morphology of Trabzon underwent substantial alterations over a span of six years, particularly from 2016 to 2022. These findings were derived from analysis of the 2022 coastline, representing the current state, overlaid onto the 2016 coastline, which signifies the initial condition. The 2016 coastline is depicted by yellow line while the 2022 coastline is illustrated by green line. The red area on the map represents the coastal areas alteration over this timeframe.

The comparison between the two coastlines provided insightful information. When the coastline had landward displacement compared to the current coastline, it indicated sediment loss or erosion. Conversely, when the coastline exhibited seaward displacement, it signified accretion or sedimentation accumulation. In this study, areas of the coastline in 2016 that were situated in front of the 2022 coastline suggested a shift characterized by coastline retreating towards the land or abrasion. On the other hand, areas of the coastline in 2022 that extended beyond the coastline in 2016 indicated a change signifying the coastline advancing toward the sea or accretion. Areas that underwent major coastal alterations over the study timeframe are depicted in Figure 2 and Figure 3 for Beşirli district and Değirmendere district, respectively.

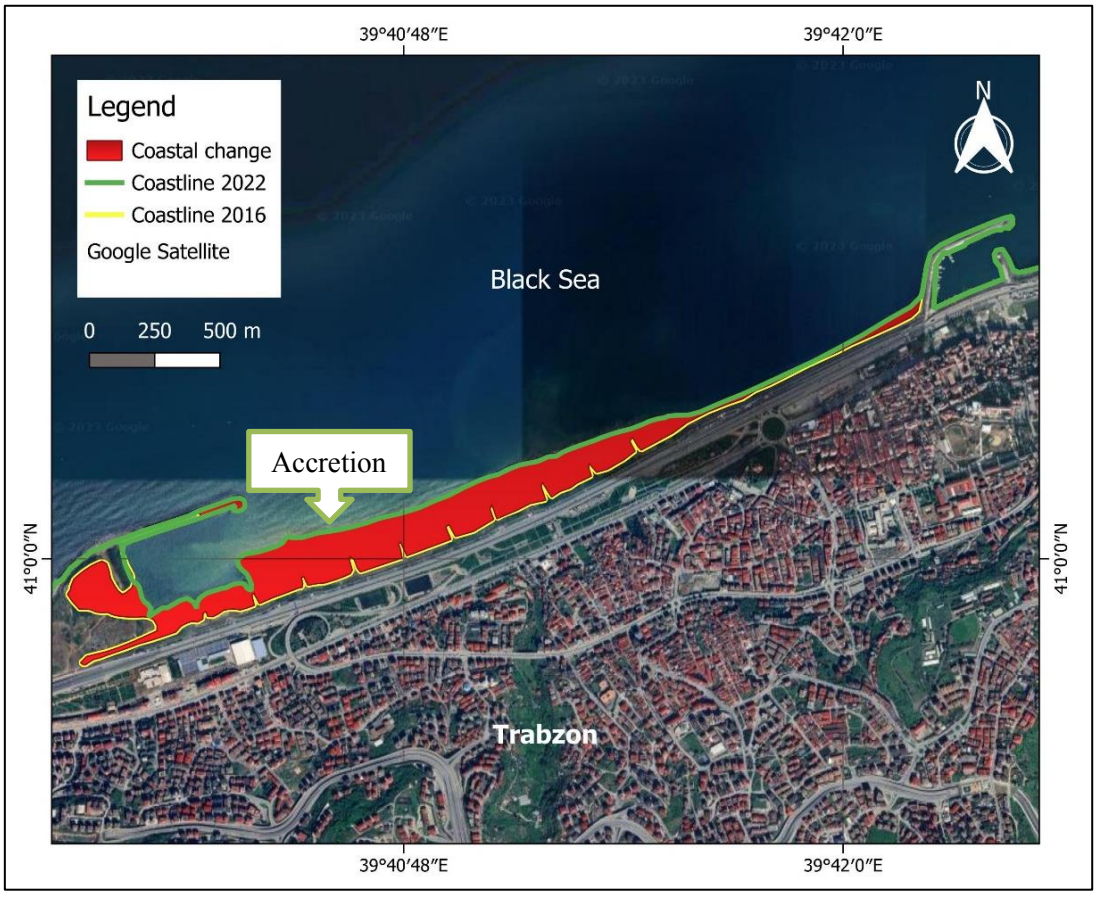

Figure 2. An example of coastal changes in Trabzon Beşirli coast

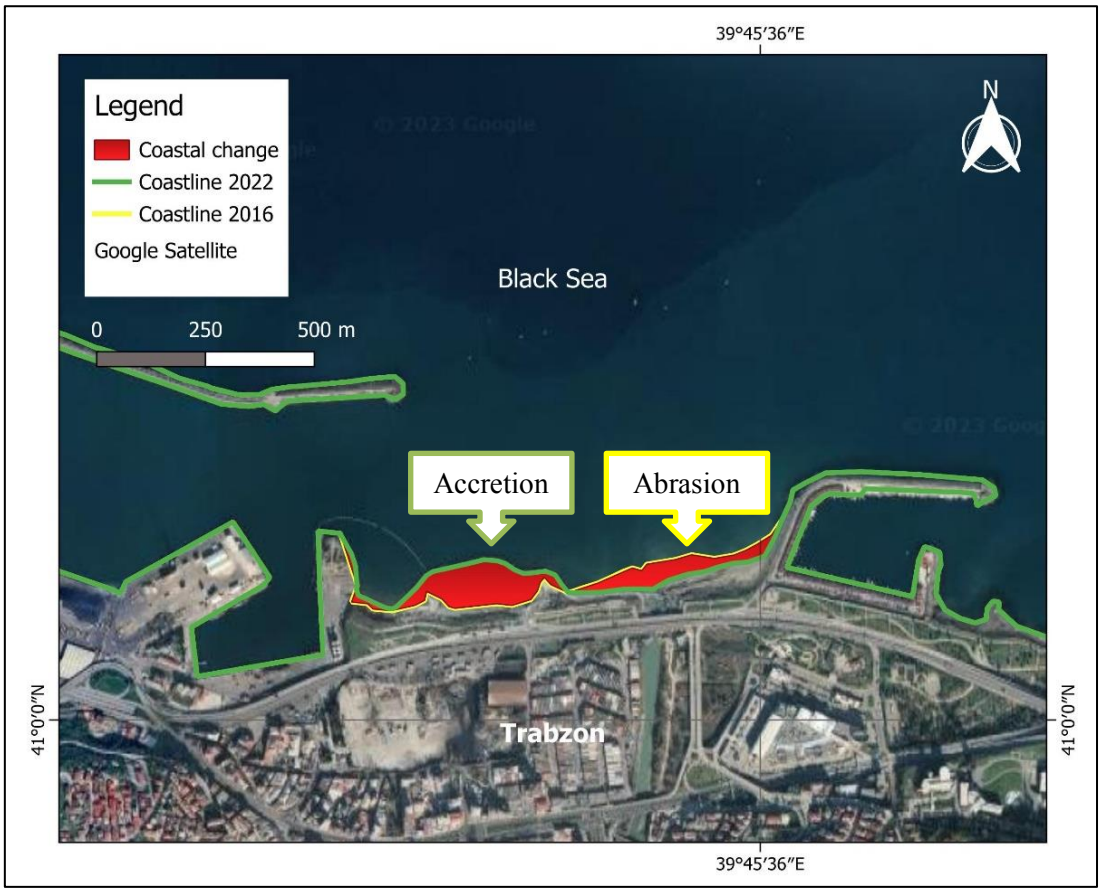

Figure 3. An example of coastal changes in Trabzon Değirmendere coast

Over this six-year timeframe, the coastal landscape of Trabzon experienced a noteworthy transformation. This is characterized by a significant advancement of approximately 38 hectares towards the sea. The major coastline changes in the Beşirli and Değirmendere districts, which are evident in the appearance of new land transformation in these regions. At least 35 hectares of new land emerged, causing a significant alteration of up to 205 meters in the coastline of Beşirli. Likewise, Değirmendere experienced the formation of a new land area spanning 2.6 hectares, leading to an extension as much as 105 m.

However, alongside these impressive developments, there was also evidence of erosion impacting an area of 1.5 hectares. The erosion caused the coastline to retreat inland by as much as 60 meters. Despite the fact that there was a noticeable coastal expansion, it is important to recognize that some areas also experienced natural erosion process. The dynamic interaction between the advancement and erosion of the coastline serves as an example of the ongoing changes in Trabzon' coastal environment.

The dynamics and significant changes observed in Trabzon's coastline can be largely attributed to human activities, particularly coastal development through coastal reclamation. The findings of various observations indicate that the coastal alteration in the Trabzon area is primarily a result of human interventions in coastal regions, specifically through the practice of coastal reclamation (Aktürk & Güneroğlu, 2021; Guneroglu, 2015; Karsli et al., 2011). Currently, development projects are underway in the Beşirli and Değirmendere districts, involving coastal reclamation, driven by social and economic interests.

Due to the growing demand for land expansion to accommodate social and economic activities, coupled with the limited availability of land and the rising demand for land expansion to support social and economic activities, governments frequently turn to coastal reclamation as a development strategy. Such development approaches, however, frequently stray from the fundamentals of coastal dynamics process, creating new difficulties, most notably erosion problems on the opposite side of the coastline (Sesli et al., 2009). The coastal reclamation conducted at the mouth of the Değirmendere river has altered the sedimentation pattern in the surrounding area. The natural movement of substance along the coastal area, which typically flows from west to east, has been interrupted due to the implementation of construction projects along the coast (). Consequently, sediment accumulation occurred in the western part of the area, while other areas experienced a depletion of sediment. This disruption in substance movement disturbs the hydrodynamic balance, resulting in the erosion of the coast.

The identification and delineation of the coastline were accomplished through the implementation of the MNDWI (Modified Normalized Difference Water Index) methods. The outcomes of this study present compelling scientific evidence supporting that substantiates the efficacy of utilizing high resolution remotely sensed datasets and GIS techniques in the monitoring and evaluation of the coastline and coastal habitat alterations. In addition, the integration of high-resolution datasets such as Sentinel-2 with the MNDWI methods, serving as a proficient tool for automated coastal detection, proved to be beneficial for the analysis and monitoring of land-sea changes. By employing this collaborative methodology, researchers and stakeholders can obtained valuable insight into the complex mechanisms that shape coastal environments. This, in turn, assists in making well-informed decisions regarding efficient coastal management and preservation initiatives.

Coastal habitat change

The morphological changes occurring in Trabzon's coastal area have direct implication for the ecological state of coastal habitats in the region. These changes are primarily a result of human activities, particularly coastal development through coastal reclamation. Coastal reclamation, which involves enclosing coastal land, directly impacts, and diminishes the extent of coastal habitats in the area. This process alters the natural structure of the coast and fills the beach, thereby affecting the shallow habitat that plays an acritical role in supporting coastal ecosystems.

Over the past few decades, Trabzon's coastline has experienced significant alteration as a consequence of extensive coastal reclamation practices in the region. These prolonged reclamation activities have resulted in the degradation of the natural shape and habitat of Trabzon's coast. The coastal waters of Trabzon are characterized by sandy coastal ecosystems with steep contours. The shallow water habitat plays a crucial role for the coastal communities, providing them with shelters and food sources for native and migratory species in the region. Moreover, the shallow water habitat is particularly significant due to the nature of the Black Sea waters at certain depths.

Furthermore, the materials used in coastal reclamation are often non-permeable, limiting the natural sedimentation process in deeper waters and disrupting the usual patterns of coastal dynamics. Additionally, the reclamation process carries the risks of introducing chemical pollutants from the soil materials used for reclamation. Sedimentary material spread around the construction area also potentially creating an opaque and anoxic environment that disrupt natural processes beneath the surface. The cumulative impacts of these changes, arising from coastal reclamation, poses significant challenges to the coastal ecosystems in Trabzon.

In order to evaluate the long-term changes in coastal habitats along Trabzon's coast, an analysis of historical data pertaining to water occurrence in the region was conducted. The observation of data from 1984 to 2021 revealed a significant transformation in the coastal landscape, resulting in the permanent alteration or loss of coastal habitats within the area. This observation is supported by the notable reduction or disappearance of water occurrences, as indicated by the highlighted red area on the map. Long term Trabzon coastal habitat change can be observed through water occurrence change intensity given in Figure 4.

Research findings reveal that coastal reclamation activities driven by urbanization and development pressures significantly alter the coastline and cause changes in coastal habitats in the study area. This observation highlights the conversion of natural coastal habitats into human-made structures, leading to the loss of vital coastal ecosystems. The cumulative effects of human activities have resulted in a decline in biodiversity, habitat loss, depleted fish stocks, deteriorating water quality, and ecological imbalances in the Black Sea. These impacts not only affect the environment but also have economic and social consequences, particularly for coastal communities relying on fishing and tourism.

Trabzon is known for depending on the marine transportation fishery and tourism sector. The Black Sea fisheries sector, in particular, significantly contributes to the national economy (Yilmaz & Yilmaz, 2009). However, due to overfishing, pollution, and ecosystem degradation in the Black Sea, this sector has faced numerous challenges in recent decades (Oguz et al., 2012). These challenges have affected the sustainability of fish populations and disturbed the balance of the marine ecosystem.

Moreover, the tourism sector in Trabzon heavily relies on the preservation and sustainability of its ecological resources. The natural beauty of Trabzon coastal areas, including its diverse marine structure and pristine beaches blends with the green landscape attracts visitors from domestic and international (Acar & Uzunali, 2020). However, any loss or degradation of the coastal ecosystems over the long term can have direct and adverse effects on the livelihood of the local communities that are dependent on tourism.

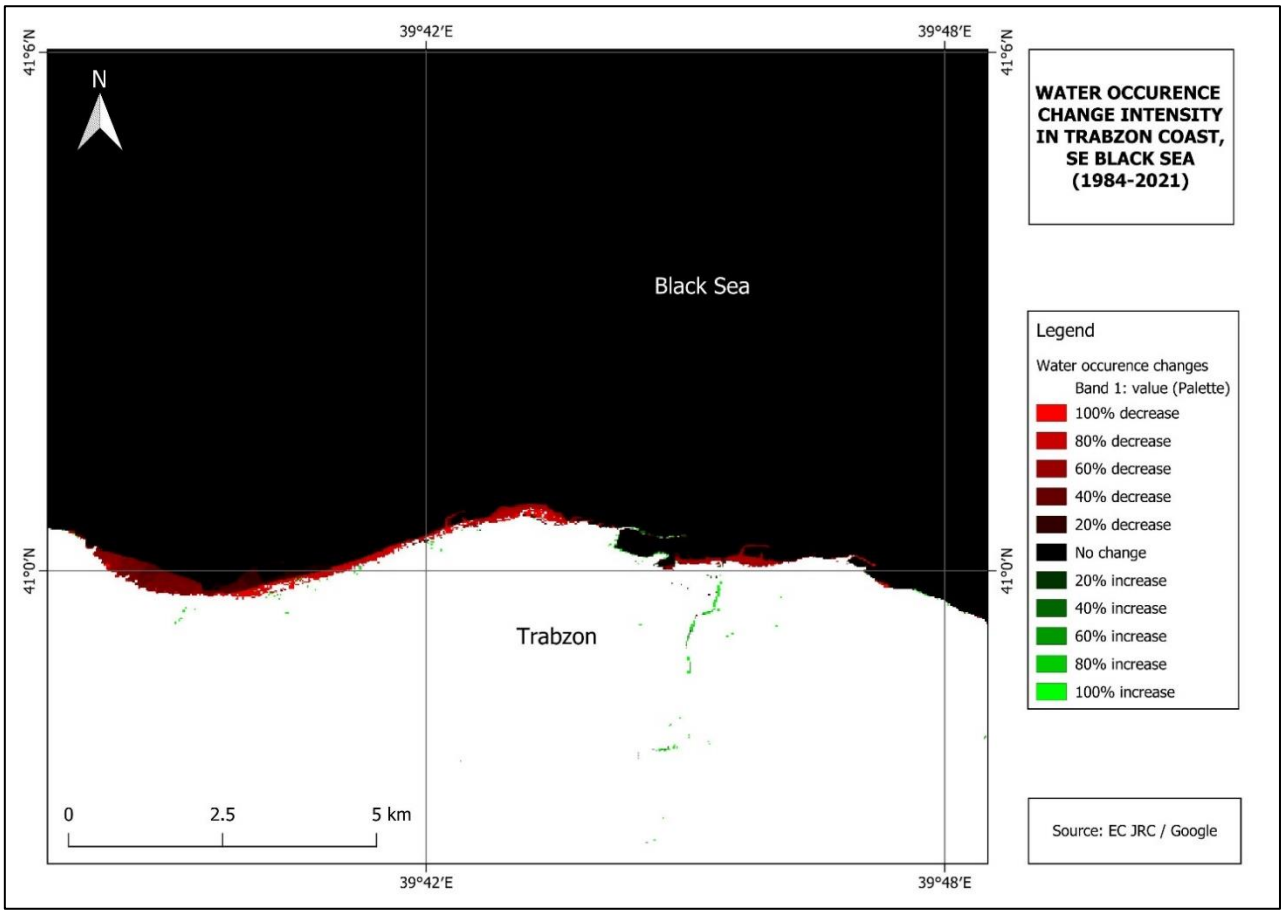

Figure 3. Long-term water occurrences change intensity in the study area (red color indicating permanent loss/change of aquatic habitat)

It is essential to monitor the coastal resources through costal change monitoring to protect these ecosystem services for the sake of the environment and the human community that depend on coastal ecosystems. The region's coastal habitats require effective management and conservation measures. The long-term ecological effects must be taken into account, and sustainable practices must be used to balance coastal development with the preservation and restoration of coastal habitats.

4 CONCLUSIONS

This study focuses on the investigation of morphological and ecological transformation in Trabzon coastal habitat spanning a period of six years. The research utilized advanced techniques such as high-resolution satellite imagery datasets and GIS to analyze physical changes occurring in coastal regions the findings unveiled the formation of a new area spanning 38 hectares and a shoreline advancement of up to 205 meters due to coastal reclamation activities, resulting in permanent loss of coastal habitat. Conversely, the study documented erosion spanning 1.5 hectares and a coastal retreat of 60 meters during the study timeframe. The coastal environment of Trabzon has been adversely affected by the loss of coastal habitats, primarily due to the long run of extensive coastal reclamation practices in the region. If appropriate conservation measures are not implemented to rehabilitate these ecosystems, the situation is likely to exacerbate further, resulting in increased degradation on the ecosystem. The study also provides evidence of the effectiveness of combining high-resolution satellite images with the MNDWI approach in detecting land-sea changes. The comprehensive analysis of the impact of human activities on coastal habitat changes underscores the significant challenges faced by coastal ecosystems at large. It emphasized the importance of continuous monitoring on coastal environment and its wider implications for human societies. The significant knowledge acquired from this research are instrumental in guiding coastal management strategies, conservation efforts, and enhancing our understanding of the ramification of human activities on coastal ecosystems.

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