Google Earth Engine Approach in Monitoring of Mangrove Forest in Govatr Bay, on Oman Sea

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Abstract

This study investigates geomorphological changes influencing mangrove habitats along Iran's coastline using satellite photos to identify crucial sites for coastal management. Biogeomorphology helps to solve real-world problems, such as mangrove restoration and coastal management. This study explored the relationship between coastal mangrove habitats and local geomorphology in Govatr Bay by integrating field data with remote sensing. Google Earth Engine (GEE) was used to map periodic changes in geomorphology, land use, and mangrove boundaries, providing insights into their interactions. GEE's cloud-based platform enabled efficient analysis of large satellite datasets for monitoring mangrove dynamics. Mangrove area and density changes were monitored using aerial photographs (1957, 1966) and satellite imagery from Landsat (1998, 2001) and IRS-Liss III (2006). From 1957 to 2006, mangrove forests expanded from 24,601 to 53,671 hectares, despite fluctuations due to natural and human influences. Most growth occurred between 1966 and 1998, with the Bahu estuary showing higher expansion and dynamic changes compared to the Goiter. Overall, the study observed significant mangrove area changes, with a positive trend over the 20-year period.

Keywords: Mangrove Forest, Google Earth Engine, Govatr Bay

Introduction

The natural environment is a very complicated system, and every variation in one component causes subsequent effects in other parts of the environment. In the current century, climate change and sea level change have caused several regional threats on coastal habitats by changing sedimentation regimes, coastal processes and landforms (like wetlands, tidal marsh, coral reefs, barrier and estuary). Mangroves occupy a harsh environment, subjected daily to tidal and seasonal variations in temperature, salinity, and anoxic soils, and are fairly robust and highly adaptable or tolerant to such changes (Alongi 2008). These sorts of changes cause several issues in coastal ecosystems, mainly in mangrove forests, that considered one of the most important ecosystems on the earth (Alongi 2002). The uncertainty associated with the future of complex ecological systems of mangrove forests is a basic challenge to incorporating the value of ecosystem services into informed environmental decision-making (Shing Yip et al.2014). Mangrove forests lie along tropical and subtropical coastlines and serve as breeding, spawning, hatching, and nursery grounds for several marine species (Barbier 2000; Cannicci et al. 2008). Mangroves are home to resident and migratory birds, snakes, and mammals and simultaneously support incredible diversity and biomass of crabs, sponges, tunicates, and other benthic marine invertebrates. But this rich ecosystem has been under destruction and degradation as a result of climate change and human activities (Donato et al. 2012; Lovelock et al. 2015; Emadodin and Zahabnazouri, 2018).

On the other side, coastal geomorphology determines the essential environmental characteristics, such as substrate type and stability, terrestrial water regime and underwater hydrodynamics, which form the basic abiotic settings for the biota (Herkül et al. 2018). Coastal morphology and geomorphological processes define the gradients between high and low, between wet and dry and between sedimentation and erosion (Widdows 2008), so that some plants and animals can adapt to specific conditions in gradual or harsh change, but some might be harmed and demolished. Mangroves play an important role in protecting and dampening coastal land from erosion caused by storms through their unique geomorphological features (Mazda et al. 2007; Thornton and Johnstone 2015, Shirzadi et al, 2023) and from catastrophic events, such as tsunamis and cyclones (Alongi 2008).

Some geomorphological landforms like deltaic-estuarine, protected shores, bays, estuaries, deltas and river banks influence the development of mangrove forests (Dahdouh-Guebas and Koedam 2008). There is growing research on the importance of interferences between organisms and physical forces in landscape formation, which is generally referred to as biogeomorphology (Corenblit et al. 2008; Murray et al. 2008; Reinhardt et al. 2010; Zahabnazouri et al. 2021; Zahabnazouri, 2022; Shokr Behjati 2024). (Herkül et al. 2018) studied the variability of seabed fauna and flora along different shore geomorphic types; they revealed that coastal geomorphology reflects the general patterns of underwater biodiversity. Coastal morphological characteristics are related to geological setting, sediment type, sediment supply, wave climate and tidal regime (Mangor et al. 2017). Shore geomorphology also depends on the sediment supply. Because rivers are major sediment suppliers, the sediment budget is indirectly influenced by climate conditions. Physical forcing exerts a direct control on survival and species distribution of plants in coastal areas. New research and concepts have been put forward in recent years to generalize bi-directional feedbacks between ecology and geomorphology across ecosystems, whereas plant traits and temporal variability of physical forcing emerge as key determinants of local biodiversity and landscape formation.

The main aim of this study is to illustrate geomorphological change impacts on mangrove habitats in Iran's coastline using a time series of satellite imagery to determine critical areas for future coastal management. Biogeomorphology research is often applied to help solve real-world problems, including salt marsh and mangrove restoration, coastal structure designs, river restoration and management and heritage conservation. Mangrove forests occur between longitude 25°19′ and 27°84′, in the north part of the Persian Gulf and Oman Sea along the Iranian shoreline (Zahed et al. 2010).

Geographical changes and anthropogenic activities cause serious problems in coastal areas, and the main issue is the changing coastal ecosystem. Biodiversity in coastal areas is not only influenced by changes in the physical environment such as climate factors, sedimentation regime, coastal landforms and geomorphology but also is affected by human interferences that trigger, enhance or reduce natural processes. As mangrove is the dominant plant in coastline, periodic monitoring of natural and human activities has a crucial role in the determination of endangered areas, conservation and coastal management

The objectives of the current work are therefore to indicate how coastal geomorphology and mangrove information derived from optical, passive remote sensing archival images data can be combined in a Coastal-GIS to contribute to the sustainable development by determination of geomorphological change impacts on mangrove forest distribution in coastline of Iran and develop a model to predict future changes in coastal geomorphology and mangrove forest. The results of these analyses can be used by coastal managers to corroborate ecosystem-based decisions (Stanbury and Starr 1999), identifying multi-use marine protection areas; monitoring coastal change; assessing environmental impacts of natural hazards or legislative decisions; or assessing new fishing grounds (Knight et al. 1997; Mumby and Edwards 2000). According to Phinn et al. (2000), four categories of information can be extracted from remote sensing data, applied to coastal studies. These categories include information about the configuration and the composition of the coast structures, the biophysical parameters, and changes over time of these elements (Zahabnazouri et al. 2019). Areas classified as mangroves were resolved from other habitat types by subsequent field verification and modification of stand boundaries. Mangroves also serve to protect and improve the quality of coastal and nearshore waters and represent an important coastal resource (Moore et al. 2015). Since 1994, there has been an increase in mangrove cover, likely because of plantation activity, the closure of nearby shipyards, and an increase in public awareness regarding mangrove preservation (Howari et al. 2009). Mangroves in the UAE appear in patchy and scattered patterns, occupying about 40 km ^{2} of the coastal zone, half of which are located in Abu Dhabi in sheltered lagoons (Al Habsh et al. 2007). These marine plant species are concentrated in specific tidal zones along sheltered intertidal coastlines in association with estuaries and lagoons; mangroves fringe the coastline encroaching into the lower intertidal region (Tomlinson 1986; Fares et al. 2009).

Study are

Mangrove forests are scattered as isolated units along the southern Iranian coast line in the Persian Gulf and the Gulf of Oman (Figure1). These forests are found within the intertidal and are among emergent plant communities occurring along land-sea margins in the Islamic Republic of Iran, Saudi Arabia, Bahrain, Qatar, United Arab Emirates, Oman and a small part of Pakistan in Govatr Bay Khor Bahu an International Wetland and Govatr Bay is formed in the southeastern of the Iran in Sistan and Baluchestan province, located on at the confluence of the Bahuklat River and the Oman Sea. Govatr Bay with 290 hectares of mangrove forest, native and migratory waterfowl, and breeding ground for aquatic species, plankton, economic fish, algae and marine mammals, the easternmost of these sensitive habitats are on the border between Iran and Pakistan in the Oman Sea.The bay is part of the Gando Protected Area, which has unique ecological values. The collection of this ecosystem includes Bahuklat River, Khor and Goater Bay, which was included in the list of Ramsar International Wetlands in 1999 with the code 1006, and is also in the category of protected area in the classification of the Environmental Protection Organization. Baho estuary and Govatr Bay, which is composed of mangrove forests, is one of the richest wetland habitats and has irreplaceable multifaceted importance and functions. Mangrove forests are also called coastal forests and tropical forests. Mangroves play an important role in providing shelter for marine animals and produce large amounts of organic matter that is consumed as food, and the most diverse aquatic organisms live in the estuaries at the entrance to the bay in this area.

In general, the western region of the Indian Ocean in Oman Sea is affected by two major climatic currents each year, which are called summer monsoon and winter monsoon. The cause of these storms is the temperature differences that causes movement of air masses and as a result, storms and heavy rains in the region. The intensity of these air currents is so great that in summer it affects and limits fishing activities in the region. Monsoon currents cause up welling in the north-western Indian Ocean region and thus increase the amount of nutrients into the surface. In the months after the monsoon storms, due to the calm of the sea and the presence of nutrients, the conditions for the life of various organisms are suitable, and as a result, in the months of October, November, December and January, the production rate increases in different parts of these region. In Govatr wetland in the mentioned months, especially in December and January, due to the provision of a suitable environment, we see an increase in the abundance of biomass. As the abundance of plant and animal, plankton and benthic, organisms increase and as a result, the population of nektons also increases. Due to the increase in the abundance of different organisms in November, December and January, these fish can be described as the peak time of biological production in Bahoo estuary and Govatr Bay.

Mangrove forests around the estuaries of Govatr Bay is also a factor in increasing production. The loss of leaves and branches of these plants in coastal areas, especially estuaries, increases nutrient production in these areas. At the same time, their roots and aerial stems also cause the accumulation of fine soil particles and, as a result, increase the amount of organic matter in the sediments. In any case, these communities have made the region fertile and created a balance in its environmental conditions. Scattered rainfall in some months of the year (December, January, July and August) causes nutrients to flow through the drainage system into the estuaries and Govatr Bay. On the other hand, the presence of Bahuklat and Dasht-e Khor rivers in the region during the rainy season intensifies the entry of materials into Govatr Bay. Two species of Avicennia marina from Avicenniaceae and Rhizophora macrunata from Rhizophoraceae mangrove are found in Iranian coast. *Avicennia* species grow in oxygen-poor sediments that cannot supply the underground roots with sufficient oxygen. Consequently, their root system also includes vertically growing aerial roots (pneumatophores). These aerial roots also anchor the plants during the frequent inundation with seawater in the soft substrate of tidal systems, and they play a significant role in sustaining mangroves

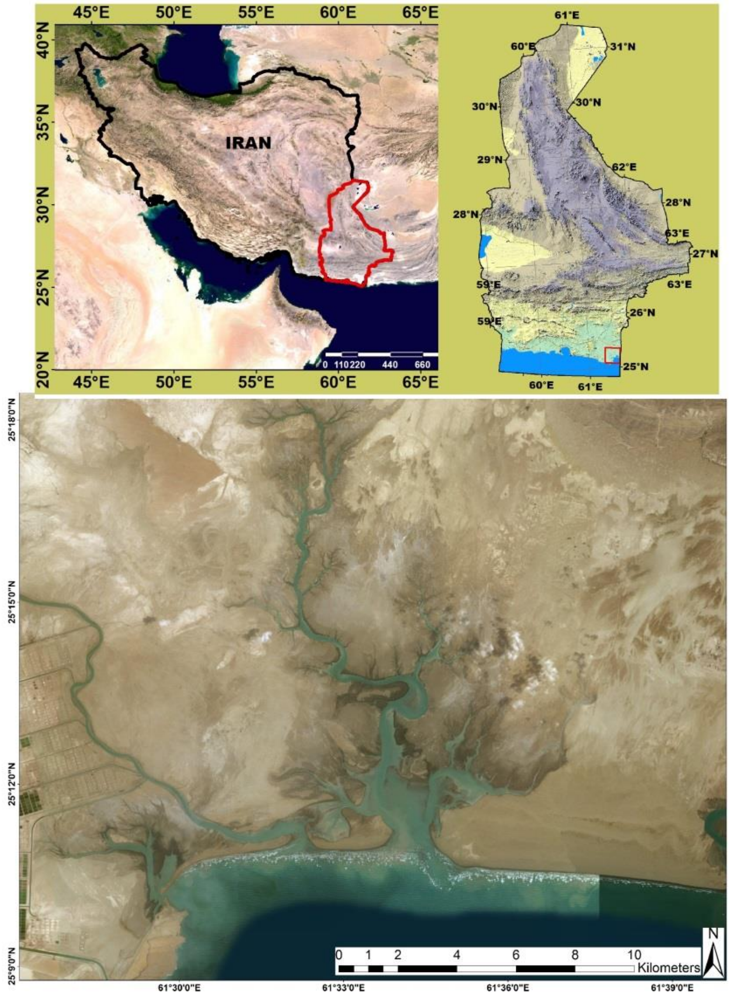

Figure 1. Study area.

Methods

In this study, we examined the relationship between coastal mangrove habitats and local coastal geomorphology along Govatr Bay by integrating field-collected vegetation data and remotely sensed imagery. Google Earth Engine was used to map periodic change in geomorphological (Zahabnazouri et al. 2024), land use and mangrove ecosystem boundaries and find their relationships. Google Earth Engine (GEE) is commonly used in mangrove research to map, monitor, and analyze changes over time. Its cloud-based platform supports the analysis of large satellite imagery datasets, making it perfect for studying mangrove dynamics.

An image processing technique entitled normalized differential vegetation index (NDVI) was used to detect mangrove forests in Govatr Bay Even though the results show negative effects of human activity in some regions, overall, mangrove forests increased during 2000-2020. This increase in mangrove forests in Govatr Bay represent sustainable development and management for mangrove ecosystems in this region.

Results and Discussion

Forest monitoring can be conducted using data from various sensors and geographic information systems, as precise mapping is one of the primary ways for long-term conservation of mangrove forests. Meanwhile, satellite-based assessment of quantitative and qualitative changes in forests provides a comprehensive and specific insight of the type and speed of destruction, as well as expansion.

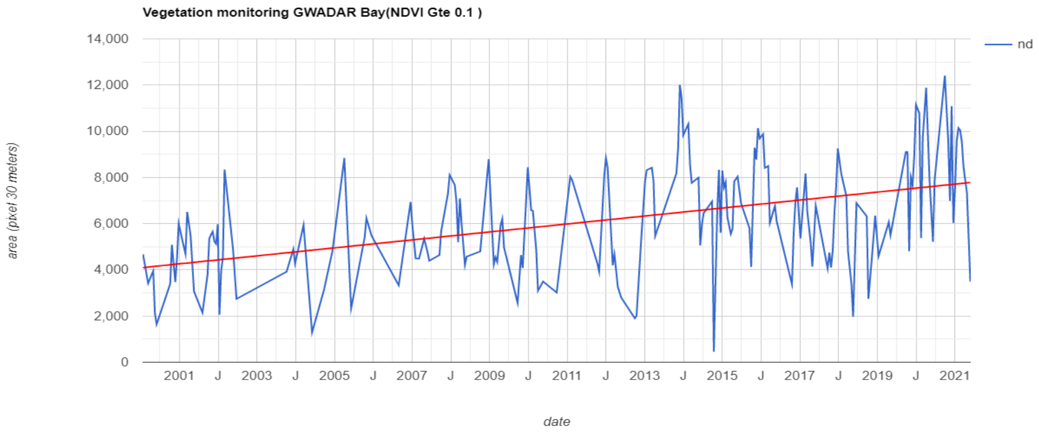

Figure 2. Changes in the sum of NDVI index pixels with values higher than 0.3.

Calculation of mangrove vegetation cover using the NDVI and NDWI indices. The major spectral reflectance of mangrove leaves ranges from 350 to 2500 nm, with the spectral reflectance curves of various mangrove leaves corresponding to the red light zone (620 to 760 nm) (Dou et al. 2018). Figure 2 shows a graph of variations in NDVI index pixels with values greater than 0.3 during a 20-year period. The data request was issued to the Surveying Organization to obtain tide information. Due to the absence of a data station in this location, the NDWI index was calculated during the research period. The total pixel values were found to be less than -0.2 (Figure 3). According to the index's properties, images with zero values correspond to low tide times. We choose photographs from this time period that have the least impact on the blue zone. This study was carried out between the dates 05/09/2020, when the graph had a value of zero, and 04/07/2020, when the graph had a value of 60,000 pixels. The first image was tied to low tide, and the second image was related to high tide, with the blue zone excised.

According to Figure 3, when the NDWI index declines, which is caused by a change in water level and a decrease in water in the region, the NDVI index reaches its peak and the impacts of water are eliminated. To inspect and compute the picture with greatest precision while removing the water area and the time of low tide, four photographs are chosen when the water area has a minimum value of 200 pixels according to the NDWI index (Figure 4).

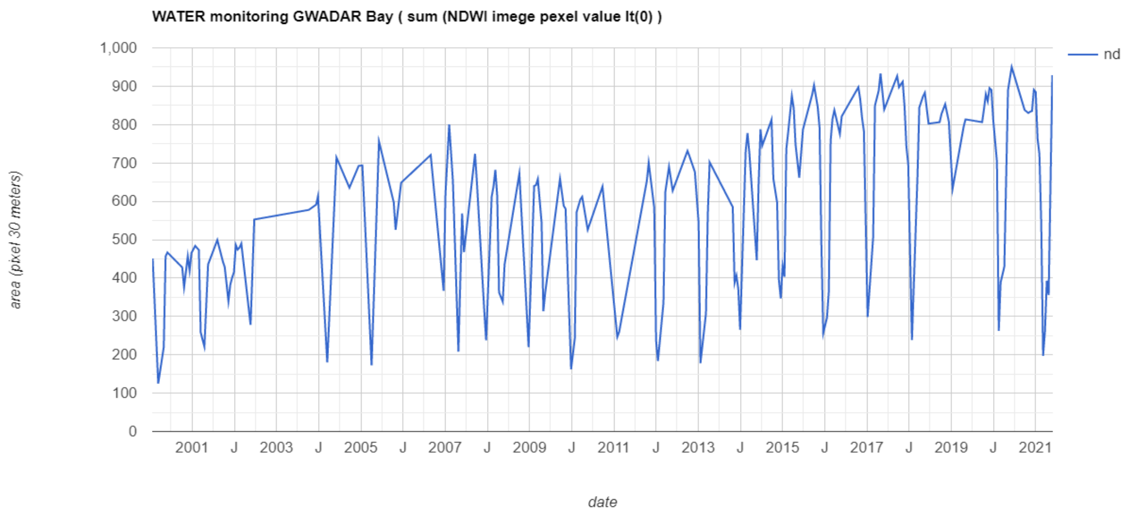

Figure 3. Graph of changes in the sum of NDWI index pixels with a value less than -0.2.

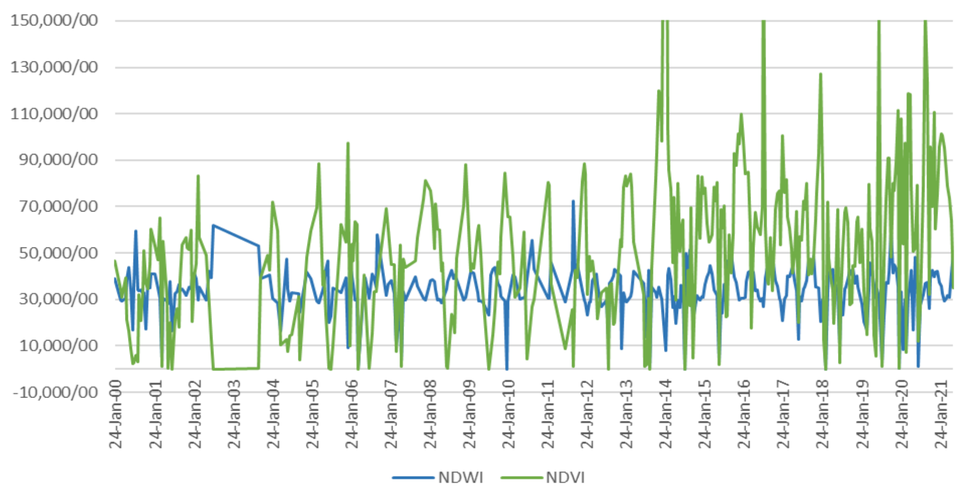

Figure 4. NDVI and NDWI index Time series.

The seasons of June, July, and August were chosen for the process of detecting changes in the period under the same conditions, taking into account the phenological cycle of the mangrove plant (beginning of the flowering cycle and the end of the period, as well as low biological stresses) and the lowest level of tourist activity in the region. By applying the time filter and selecting the aforementioned months, the NDWI index was applied again, and four photos were selected in the time range with a minimum size of 100 pixels:

The first image associated to the Landsat 5 satellite was taken on May 11, 2000. The second image is related to the Landsat 7 satellite on May 13, 2008. The third photograph of the Landsat 8 satellite on May 17, 2018. The fourth image is related to the Landsat 8 satellite on May 25, 2021. They were picked under identical criteria. The first and fourth photographs are analyzed.

To download the products, Google Earth Engine was used, and for each of the Landsat 5, 7, and 8 satellites, the 1 Surface Reflectance Tier photos of the Earth were picked. After applying the filters, the desired dates of the study region were chosen and specified, and the images were cropped. Given the manufacturing process of this product, the preliminary analysis of the performance of Landsat 8 (EricVermotea2016) atmospheric adjustments were applied to this product, and the required bands (visible and infrared bands) were created for usage using the following approach. Landsat 5 and 7 have visible and infrared bands 1 through 5, as well as short-wave infrared band 7. To obtain pixel reflectance values, multiply the scale factor of these bands by 0.0001. The thermal band is band 6 of this product, multiplied by a scaling factor of 0.1. The generated photos are stacked, trimmed to the correct size using the clip command, and downloaded. Landsat 8 photos are layered in the same fashion as Landsat 5 and 7, with the exception that in Landsat 8, bands 1-7 are multiplied by a scale factor of 0.0001, and the pixel reflectance values are acquired. The thermal band is band 6 of this product, multiplied by a scaling factor of 0.1. The generated photos are stacked, trimmed to the correct size using the clip command, and downloaded. Landsat 8 photos are stacked in the same fashion as Landsat 5 and 7, with the exception that bands 1–7 are multiplied by a scale factor of 0.0001, and bands 10 and 11 are thermal bands that are downloaded at a scale factor of 0.1, as mentioned above. The generated images for each time are analyzed separately, and the quantity of vegetation cover in each image is first retrieved from the REMOTEPIXEL site using the DEM SRTM 30m image index and stacked with the photos from the periods. Because the best area for mangrove forest growth is in the tidal range, and heights above the tidal height are places without mangrove forests, the heights 15 meters below are acceptable, while heights above it are devoid of mangrove species. The tidal range is an important factor in the growth of plant species in mangrove forests, and it is estimated using the MNDWI (Modified Normalize Different Water Index) index, which uses the following formula; MNDWI= (Green – SWIR1) / (Green + SWIR1)

Values greater than (-0.13) in the resulting image, based on the survey and the use of the NASA Landsat Mangrove product in 2000, which is shown below, indicate areas prone to the growth of mangrove forests with a false green color, and this index, along with the DEM of the area (Figure 5), is stacked with images from the period under study.

To further identify and illustrate the soil type and visual changes (zahabnazouri, 2020) , the produced stack was subjected to PCA spectral transformation. The resulting image clearly showed the visual variations, and the necessary classes were extracted for more accurate image classification. Six classes were identified for region separation. The Support Vector Machine approach was utilized for classification. Figure 6 depicts the resultant and categorized image of the region.

Table 1 describes the error percentages and accuracy matrices. To obtain the table and calculate the accuracy of the issues using Google Earth Engine, the date was set within the year 2000 and for each group, the formula Point number = Z^2(P) (Q) / E^2 taken from the book Introductory Digital Image Processing: A Remote Sensing Perspective Image (John R. Jensen) page 596 was applied. In the above formula, P represents the desired precision, Q=100-P, Z=2, and E represents the permitted error. The minimal number of points required for 85 percent accuracy with a 5 percent margin of error is 204. Because of the high quality of Google Earth Engine photos, at least 400 pixels were collected as points for each part, and vast portions in larger classes were captured as polygons and used into the computations. Given that mangrove forests are the most important class in this classification, and NASA (SEDAC) collected and separated this species in all regions, the mangrove product in Google Earth Engine is a valid reference for evaluating the accuracy of the forest estimate. This product's collection date is dated 2000, and the aforementioned classification gathered this species in 2000. Following conversion to a shapefile in the ARCMAP environment, the classification was compared to the previously indicated mangrove class (Figure 7).

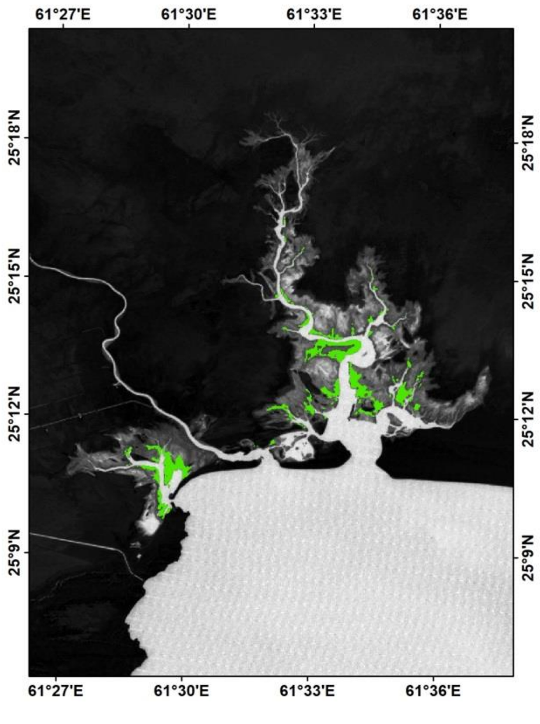

Figure 5. Mangrove-prone areas.

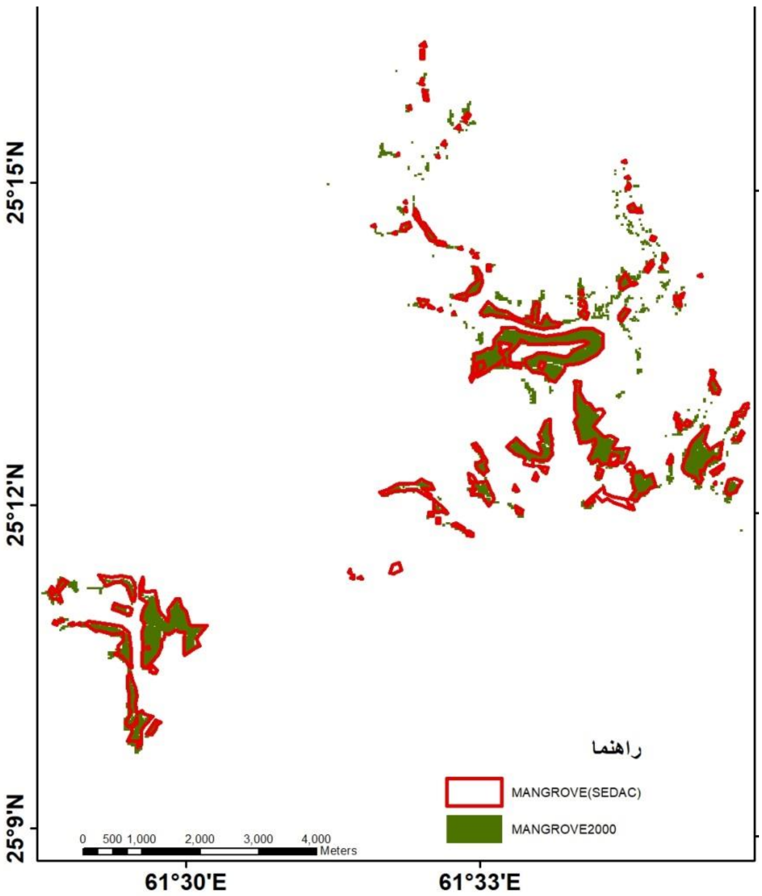

Figure 6. Mangrove product in Google Earth Engine reference 2000.

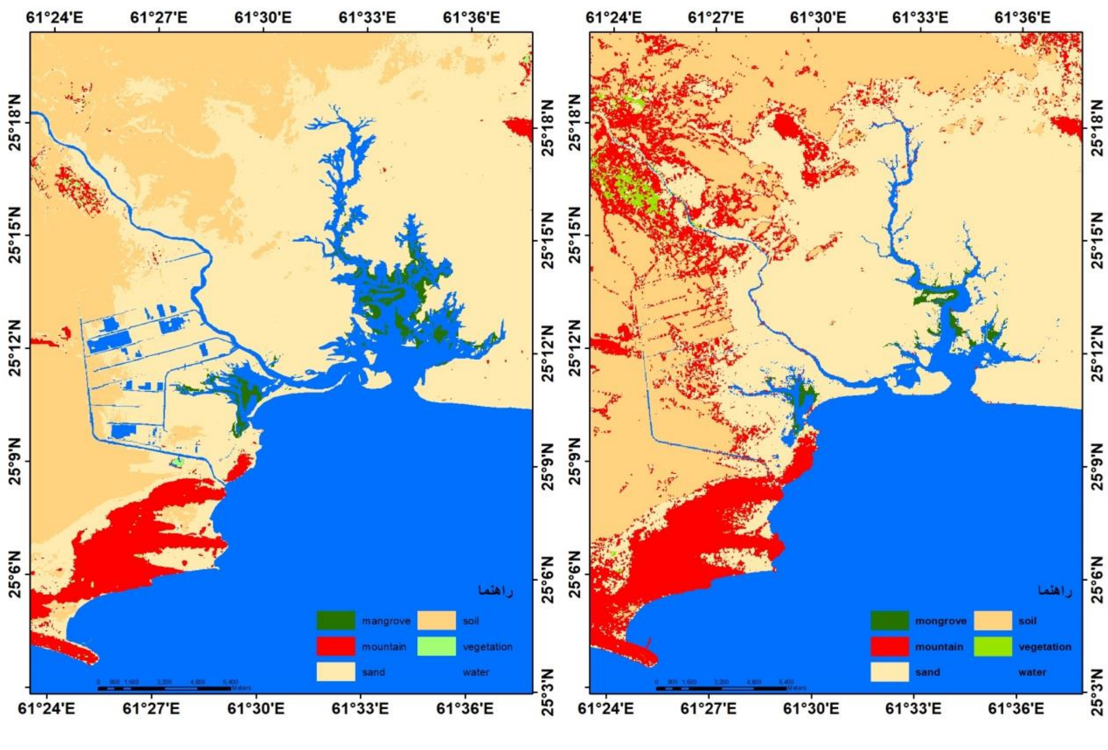

Figure 7. Land and mangrove classification 2000 left and 2020 right.

Table 1. The error percentages and accuracy matrices.

Confusion Matrix

Overall Accuracy = (91/100) 91%

Kappa Coefficient = 0.8884

Ground Truth (Percent)

Class	Mangrove	Vegetation	Water	Soil	Mountain	Sand
Unclassified	0	0	0	0	0	0
Mangrove	270	0	0	0	0	0
Vegetation	0	110	110	0	10	0
Water	0	0	0	90	10	0
Soil	0	0	0	0	5	0
Mountain	0	0	0	0	50	190
Sand	0	0	0	10	0	0
Total	270	110	110	10	120	190

Ground truth (percent)

Class	Sand	Total
Unclassified	0	0
Mangrove	0	270
Vegetation	0	120
Water	0	100
Soil	0	50
Mountain	10	250
Sand	200	210
Total	210	1000

Ground truth (percent)

Class (Percent)	Commission (Percent)	Omission (Pixels)	Commission (Pixels)	Omission
Mangrove	0	0	0.27	0.27
Vegetation	8.33	0	1.12	0.11
Water	10	10	1.1	1.1
Soil	0	58	0.5	7.12
Mountain	24	0	6.25	0.19
Sand	4.76	4.76	1.21	1.21

Ground truth (percent)

Class	Prod Acc (Percent)	User Acc (Percent)	Prod Acc (Pixels)	User Acc (Pixels)
Mangrove	100	100	270/270	270/270
Vegetation	100	91	110/110	110/120
Water	90	90	90/100	90/100
Soil	41	100	50/120	50/50
Mountain	100	76	190/190	190/250
Sand	95	95	200/210	200/210

4. Conclusion

changes in mangrove area and density were monitored using a combination of aerial photographs and satellite imagery spanning nearly five decades. Aerial photographs from 1957 and 1966 provided the earliest records of mangrove distribution, allowing for an initial assessment of their extent and density. Satellite imagery from Landsat missions, specifically using Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) sensors, was utilized for analysis in 1998 and 2001, enabling more detailed and consistent monitoring of mangrove coverage. Additionally, high-resolution imagery from IRS-Liss III in 2006 offered further insights into more recent changes in mangrove forests. Over the study period from 1957 to 2006, the total area of mangrove forest stands showed an overall increasing trend, expanding from 24,601 hectares in 1957 to 53,671 hectares in 2006. However, this growth was not linear, as the mangrove extent experienced fluctuations and occasional decreases due to natural and anthropogenic influences. Factors such as coastal erosion, land use changes, and climatic variations may have contributed to periodic declines. At the same time, conservation efforts, sediment deposition, and favorable environmental conditions likely played a role in the overall expansion of mangrove habitats. The majority of this expansion happened between 1966 and 1998, and the findings suggest that the growth potential of these woods is greater in the Bahu estuary than in the Goiter. This estuary has also been more dynamic in terms of area change across the study periods. The study found considerable changes in the area of mangroves. Fortunately, over the 20-year study period, the mangrove area has expanded.

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