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Detection of the Hazards That Threaten Some Coastal Areas, and Ecosystem-Based Solution to Strengthen the Natural Defenses

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Abstract

The coastal strip of the Nile delta has been vulnerable to environmental hazards. Field surveys, interpretation of Landsat enhanced thematic mapper imageries (ETM), and hydrochemistry analysis of the water samples was used as methods and materials to detect the hazards associated with climate change which threaten some natural protection coastal areas of the central part of the Nile Delta and assess its magnitude. The invasion of seawaters is the main hazard due to the impacts of global warming phenomena. Elimination of the coastal dunes which act as natural defenses has been accelerating the negative impacts that have been appearing clearly on low-lying lands. Planting that protected areas of the coastal strip are considered the most suitable ecosystem-based and most beneficial solution should be authorized and adopted by the local administration to preserve those areas and adapt to these disasters.

Keywords

The Ecosystem-Based Solution, Climate Change, Sea-Level Rise, Coastal Strip, Natural Protection, Nile Delta, The Adaption, Protection

1. Introduction

The coastal strip of the Nile Delta has been exposed to natural environmental hazards in the last decade. Inundation of seawater and erosion of the shoreline are the main disasters associated with global warming phenomena and climate change manifestation. Anthropogenic interferences have accelerated their impacts. Sustainability of the natural resources and current development projects are the most issues that are affected because most of these projects on the backshore plains have been established without any previous preparation or suitable studying and have been managed incorrectly.

Many recent and old publications detected these disasters but were not introduced any proposed solutions. El-Askary & Frihy (1986) and Sestini (1988) mentioned that accelerated erosion got distinct at the promontories of Rosetta and Damietta, as well as the town of Baltim resulting in an overall straightening of the shoreline. El-Raey et al. (1995) and El-Raey et al. (1999) detected the changes in beach erosion/accretion of Rosetta and Damietta-Port Said shorelines respectively. Nicholls & Branson (1998) used the term "coastal squeeze" to describe the progressive loss and inundation of coastal habitats and natural features located between coastal defenses and rising sea levels.

Mahmoud (2002) used the remote sensing technique to detect shoreline changes along the Rosetta promontory of the Nile delta over the last two decades. Kaiser (2006) calculates the lost sediments by using digital models around the Damietta branch due to the construction of the protection structures in the sites of erosion processes. El-Asmar & Hereher (2011) proved that coastal erosion was severe near Damietta promontory and decreased eastward, however, accretion was observed near Port-Said. About 50% of the coastal strip was under erosion and 13% was under accretion. Masria et al. (2016) found that the developed area increased by 8.8% although the land in the study area has contracted by 1.6% due to coastal erosion. The shoreline retreat rate has decreased by more than 70% from 1984 to 2014. Nevertheless, it still suffers from significant erosion with a maximum rate of 37 meters per year. Hzami et al. (2021) use a GIS-based multi-criteria approach combined with an analytic hierarchy process to map the Coastal Vulnerability Index and the Socioeconomic Vulnerability Index along these coasts to investigate the amplitude and extent of shoreline deterioration resulting from sudden fluctuations in sediment transport to the coastline particular. They observe that the densely populated deltaic coasts in both Tunisia and Egypt are 70% more vulnerable than any others coast in the eastern Mediterranean Basin. Both Tunisia and Egypt observed dramatic increases in the net population outflow migration by respectively 62% and 248% between 2000, and 2016, mostly from coastal areas. Their source suggests that the result is from the anthropogenic drivers of damming and rapid urban growth over the last few decades rather than the effects of global warming.

The northern part of the Nile Delta is characterized by different geomorphic units; barrier sand beaches, ridges, dunes, lagoons, salt marshes, and sabkhas. Beach barriers are essentially long strips of sand that are formed by waves and currents, and are derived from the materials eroded from the inner shelf coasts and brought to the shore by sea currents and/or wind (Sheppard et al., 1963). The coastal dominant N and NW winds transport huge amounts of sand to the beach and farther inland. The backshore plains are the main feeders of coastal dunes. Bagnold distinguished two kinds of dunes; barchan and seif types (Bagnold, 2012).

According to previous data, the Egyptian Environmental Affairs Agency has prepared a vulnerability map which was published in the technical report on the climate change adaptation strategy. The study area is included as the areas whitened by natural coastal dunes. Therefore, the aim is also to maintain this protection for a long time.

The study area is located in the central part of the northern coastal strip, extending from Gamasa town to the western boundary of the Dakhliya Governorate for a distance of about 45 km. This area is located between Latitudes 31˚28'N and 31˚31'N and longitudes 30˚21'E and 31˚50'E and occupied a surface area of about 387.8 km^2, as shown in **Figure 1**.

The objectives of this research paper are to detect the main hazards threatening some coastal areas with the natural protection of the Nile Delta and assess its magnitudes in addition to discovering the most suitable and beneficial ecosystem-based solution to strengthening the current natural defense tools, in the light of current and projected climate change manifestations.

2. Materials, Methods, and Techniques

In an attempt to recognize, detect, and assess the magnitude of the main hazards affecting the study area, different materials, methods, and techniques were used. Two subsets of ETM+ (Enhanced Thematic Mapper) and SPOT (System Pour la Observation de la Terre) images acquired in 1984, 2002, and 2018, respectively were corrected and rectified related to specific ground control points (GCPs),

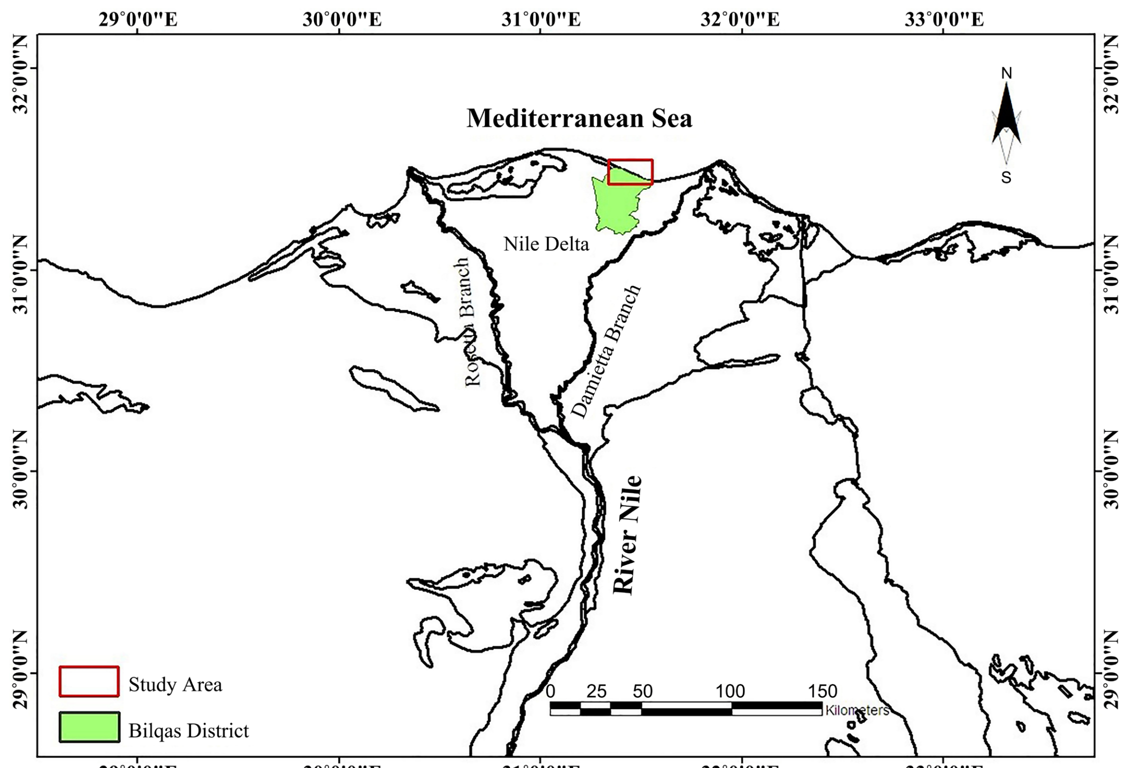

Figure 1. Location map of the study area.

and topographic maps and then were analyzed and interpreted to monitor the erosion processes along the shoreline and detect the changes that happened in dunes accumulations.

To identify the origin of water accumulated on the surface or dug coastal pools and to confirm the depth of seawater that inundated the backshore, five collected water samples were analyzed in the laboratory of the Water Researches Institute which belongs Ministry of Irrigation and Water Resources. The concentrations of major anions (Cl, SO_4, CO_3, and HCO_3), and major cations (Ca, Na, Mg, and K) were determined according to the methods described by the American Public Health Association (1971). The dominant salt types in water samples were determined from the calculated ratios of different anions (Cl/SO_4, HCO_3/SO_4, HCO_3/Cl) and cations (Na/Mg, Na/Ca, Mg/Ca).

3. The Results

3.1. Seawater Invasion

To examine seawater invasion of the coastal backshore plain, five swamps and dug pools were chosen in specific sites in the low-lying lands to collect five water samples. The depths to the water level in dug pools were less than 10 cm. Hydrochemistry analysis of collected water samples was done to prove the origin of inundation waters.

The results of the hydro-chemistry analysis are represented in **Table 1**. The total dissolved salt concentrations (TDS) ranged from 66456 ppm in the sample (5) to 179,859 ppm in the sample (3), with an of average 63795 ppm.

Chlorides are the major anions in the water samples, their concentrations ranged from 10,703 ppm in the sample (5) to 127,379 ppm in the sample (3). The sulphates are the second dominant anions, their concentrations ranged from 995 ppm in the sample (5) to 9947 ppm in the sample (2). The Bicarbonates are the least anion, its concentration ranged from 168 ppm in the sample (3) to 387 ppm in the sample (5), see **Figure 2**.

The concentrations of the cations for all collected water samples were very high compared to their values in fresh water. The concentration of calcium is ranged from 133 ppm in the sample (5) to 220 ppm in the sample (1). Magnesium concentrations ranged from 45 ppm in the sample (2) to 68 in the sample (4).

Table 1. Results of hydro-chemical analysis of major anions and major cations of collected water samples.

Code	EC (Mohs/cm)	Anions (ppm)					Cations (ppm)				TDS (ppm)
		CO_3^-	HCO_3^-	Cl^-	NO_3^-	SO_4^-	Na^+	Ca^+	Mg^+	K^+	
SW1	93.1	0	232	69,912	8300	9352	25,000	220	65	840	**113,921**
SW2	101.8	0	264	117,306	6200	9947	28,000	150	45	600	**156,312**
SW3	158.4	0	168	127,379	6500	9667	41,000	130	75	1440	**179,859**
SW4	123	0	220	81,046	4200	6515	34,000	156	68	1050	**123,055**
SW5	22.1	0	387	10,703	3250	995	54,000	133	73	165	**66,456**

Sodium concentrations were the dominant cation in the water samples and ranged from 250 ppm in the sample (1) to 54,000 ppm in the sample (5). Potassium ranged from 165 ppm in the sample (5) to 1440 ppm in the sample (4), see Figure 3.

The results of the hydro-chemistry analysis proved that the concentration of major anions, major cations, and total dissolved salts was high compared to the concentration of the same in freshwater. Chlorides were the dominant anion, and the carbonates were the least dominant, while sodium was the dominant cation. The origin of all water samples either collected from the coastal surface swamps or dug pools is marine water. The concentration of TDS in the sample (1) is relatively lower than the concentration of the other samples where this sample was collected from a surface swamp located to the south of the study area and surrounded by fish farms and an agricultural drain, so ground saltwater has diluted with the seeps of the surrounding sources.

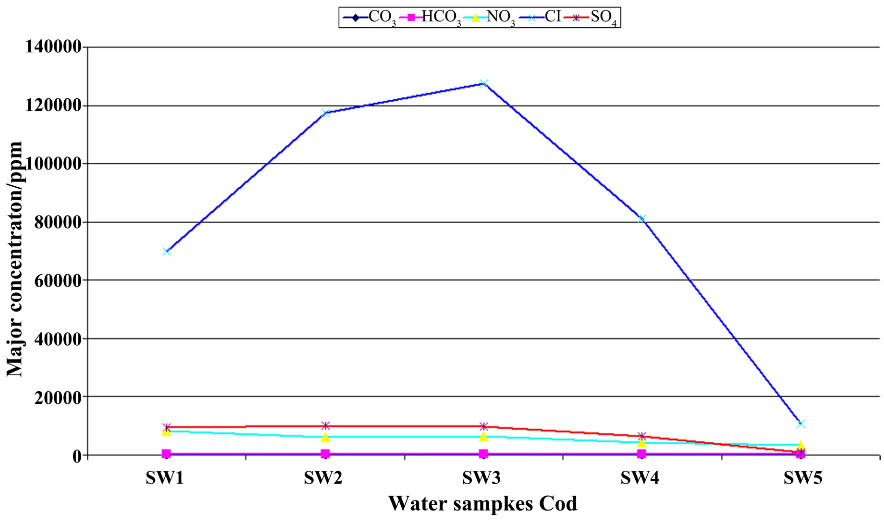

Figure 2. Anion concentrations in different water samples.

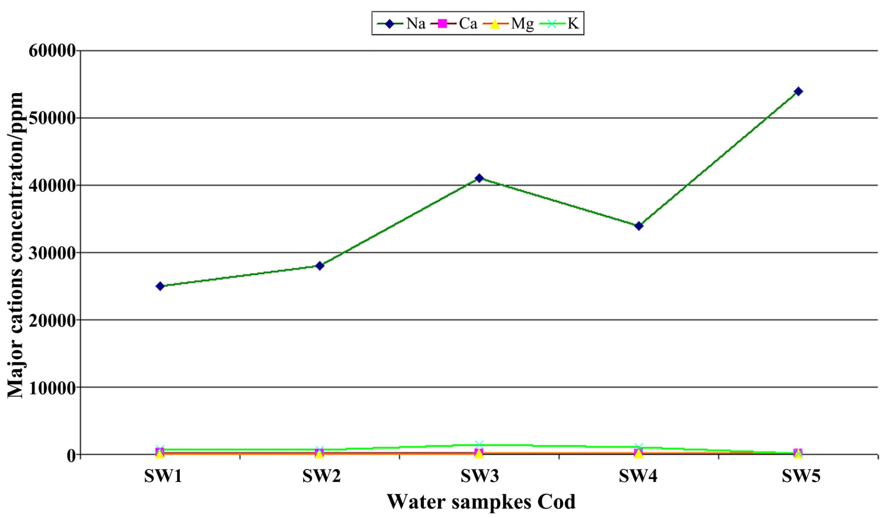

Figure 3. Cation concentrations in different water samples.

In this context, one thousand and hundred (1100) topographic contour points were collected to design a digital elevation model. The lateral intervals between consecutive points ranged from 0.3 to 0.85 m. The interpolation was done by using the software of ArcGIS 9.1, as shown in the Figure 4.

Based on the statistical analysis, the study area was classified into four main topography categories as the following:

- The first sector represents the low-lying lands located in-between the coastal dune accumulations, their elevation ≤ 1 m. These lands occupy about 37% of the whole study area, as shown in the Figure 5.
- The second sector represents the coastal flat backshore plain and its topography level ranging from 1 m to 2 m. This sand plain occupies about 20% of the whole study area. Most of these areas are reclaimed or planned to be cultivated lands, see Figure 6.

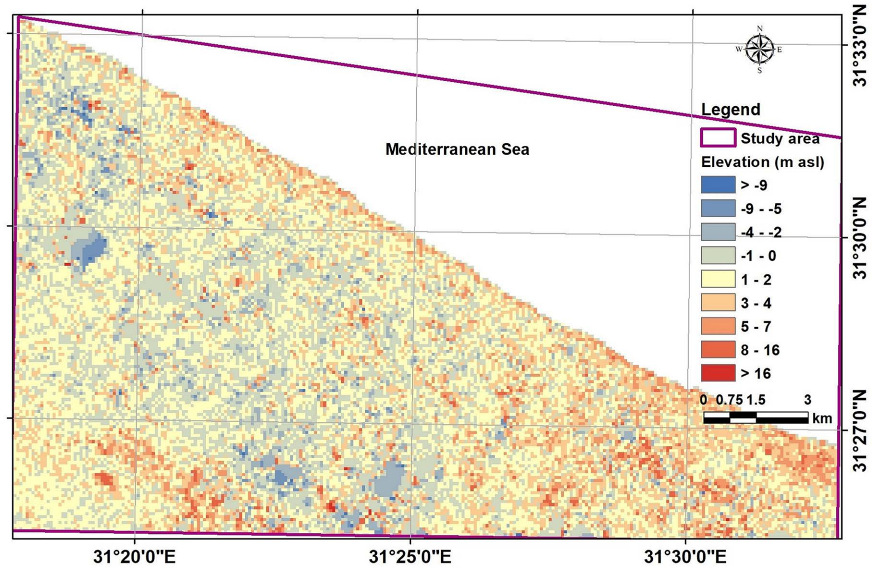

Figure 4. Digital elevation model of the study area.

Figure 5. Inundation waters in low-lying lands in the coastal strip.

Figure 6. Unexploited, reclaimed, and cultivated areas of coastal sand plain.

- The third sector represents the high lands of the coastal backshore plain and the relatively low sand dunes. The heights of these coastal dunes ranged from 2 m to 3 m. This sector occupies about 15% of the whole study area and its accumulations are scattered in the northern and western parts. The occurrence of coastal dune accumulations acts as natural barriers to prevent or at least mitigate the damage of seawater inundation. The vast square areas of these dunes have been eliminated recently as a result of anthropogenic activities.
- The fourth sector represents the high coastal dune accumulations, their heights ranging from 3 m to reach about 22 m, see Figure 7. The remnant of these dunes occupies about 28% of the whole study area. These accumulations concentrate in the eastern and southern parts of the study area.

3.2. Change Detection

3.2.1. Changes in the Shoreline

The changes in the shoreline during the past thirty-four years were detected by using ETM imageries in the years 1984, 2002, and 2018. The results showed that the shoreline along the study area was subjected to erosion and accretion processes. The maximum eroded rate was recorded in the sites to the west of the study area, while the lowest rate is recorded in the site to the west of new Mansoura city, as shown in Figure 8.

During the period from 1984 to 2002, changes in the shoreline were detected and evaluated. The statistics of change were calculated in the following Table 2 and Table 3.

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During the period from 1984 to 2018, the changes in the shorelines were detected and evaluated. The statistics of change were calculated in the following Table 6 and Table 7.

Figure 7. Remnants of coastal dunes in the southern part of the study area.

Table 2. Mini., Max., and Ave. values for different accretion parameter changes between the years 1984 & 2002.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	10.860	1315.916	3206.434
Accretion Area (m^2)	0.892	553317.689	105509.237
Accretion Rate (m/y)	0.111	13.591	3.835

Table 3. Mini., Max., and Ave. values for different erosion parameter changes between the years 1984 & 2002.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	6.206	3948.041	992.604
Erosion Area (m^2)	0.494	110112.646	17615.934
Erosion Rate (m/y)	−4.936	−0.068	−1.919

Table 4. Mini., Max., and Ave. values for different accretion parameter changes between the years 2002 & 2018.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	13.084	7588.995	2077.552
Accretion Area (m^2)	1.712	312297.851	65740.499
Accretion Rate (m/y)	0.002	14.837	4.059

Table 5. Mini., Max., and Ave. values for different erosion parameter changes between the years 2002 & 2018.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	2.146	3625.760	848.857
Erosion Area (m^2)	0.041	83881.795	13740.320
Erosion Rate (m/y)	−10.216	−0.029	−1.932

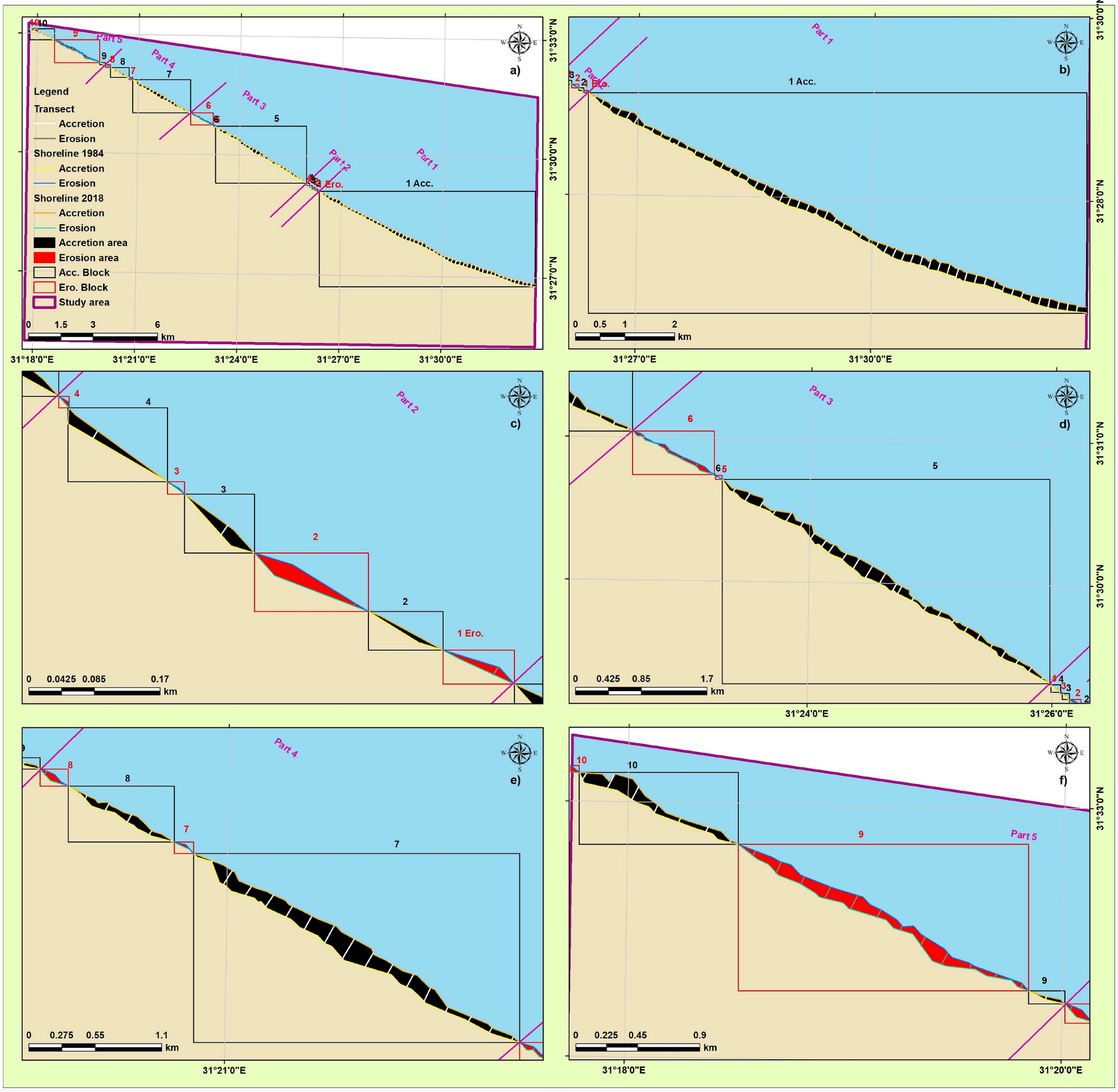

Figure 8. Erosion and accretion sites along the shoreline of the coastal study area.

Table 6. Mini., Max., and Ave. values for different accretion parameter changes between the years 1984 & 2018.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	44.401	22700.521	4563.635
Accretion Area (m^2)	9.289	1485100.990	233951.154
Accretion Rate (m/y)	0.155	6.196	3.122

The net result of change detection displayed that the coastal strip during the period of 1984-2018 has affected by morphological changes due to the shoreline changes (such as accretion and erosion). The coastal strip has been affected by

Table 7. Mini., Max., and Ave. values for different erosion parameter changes between the years 1984 & 2018.

Parameter	Minimum change	Maximum change	Average change
Perimeter (m)	42.907	4858.677	928.052
Erosion Area (m^2)	25.782	143398.756	19525.537
Erosion Rate (m/y)	−3.272	−0.040	−1.226

an increase of accretion areas by nearly 2.34 km^2, and defected by lost erosion areas by nearly 0.195 km^2, whereas shoreline accretion area was observed at an average rate of around 3.12 m/y, and a nearly average value of −1.23 m/y was detected for shoreline erosion area. The shoreline in the study area is mostly an accretion shoreline. The erosion areas are which may need protection are very limited.

3.2.2. Changes in Coastal Dunes Accumulations

Embabi (2004) proved that coastal dunes are spread along the plain of the northern fringes of the Delta at disconnected localities. The density of dunes varies greatly in this north Delta field, but the largest area covered by dunes with the highest density is that one extending from El-Borg to Gamasa. Dune types in the north Delta field vary between simple barchans with horns pointing southward, especially in the Mid-Delta sector, complex and deformed barchans, and small linear dunes. The most prevailing height of coastal dunes is 2 - 3 m.

According to Frihy et al. (1998), Sestine (1976), Smith & Abdel-Kader (1988), and Manohar (1981) meanwhile, southeastward-directed winds shared in the development of coastal dunes migrating at present onto wetlands and over the cultivated Delta plain. Sesteini (1976) mentioned that the sands of the Nile Delta coastal dune field originated from the Nile deposits that were deposited along the coasts of the Delta or along the northern margins of the Delta. Elagouz et al. (2020) detect a continuous increase in agricultural, urban, fish farms, and natural vegetation areas and a continuous decrease in water bodies and sand areas in the period between 1987 to 2015 in the Nile delta.

In an attempt to detect the changes that happened in density (occupied surface areas) and position of the coastal dune accumulations in the study area, two image subsets (TM 1984 and SPOT 2006) were processed and classified with accuracy assessment varies from 92.8% for TM 1984 to 98% for SPOT 2006. The results of images classification indicated that sand dunes fields have been undergoing dramatic changes that led to a decrease in the total surface area of more elevated sand dune accumulations from 157.63 km^2 in (1984) to 39.58 km^2 in (2006), as shown in the **Figure 9**.

Due to continuously removing huge quantities of coastal sands by the local administration for using them for different purposes. Foreshore sand dunes were accumulated as series liner types in northern parts and extended from east to west parallel to the shoreline and as Barchan types in eastern south parts as appear in

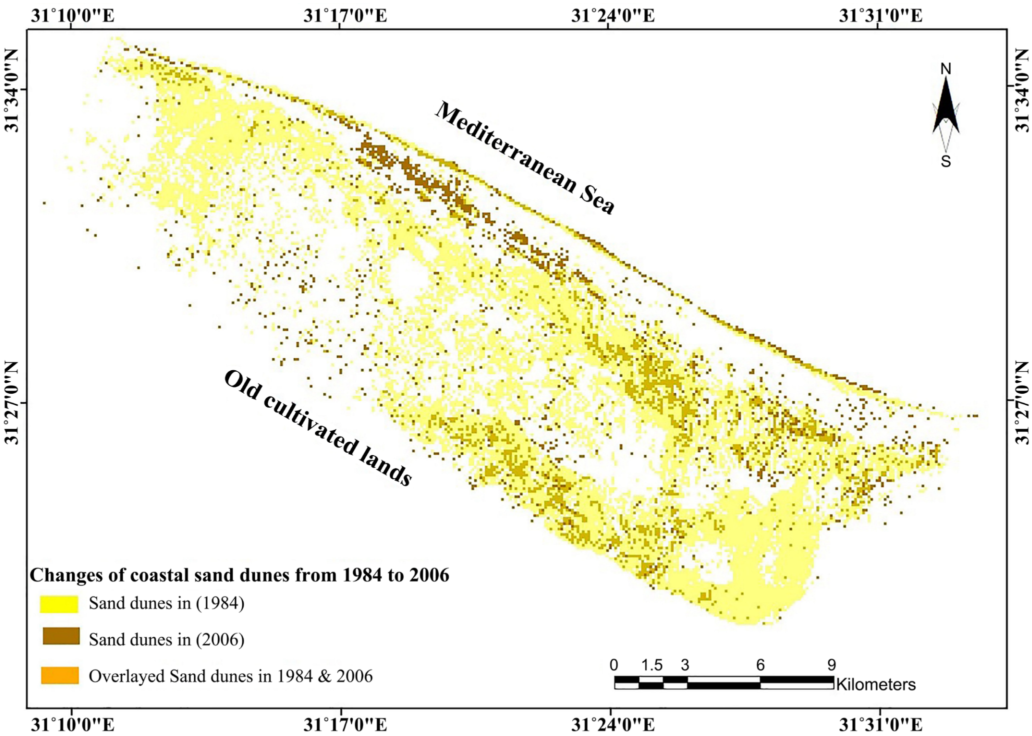

Figure 9. Changes in coastal dunes during the period from 1984 to 2006.

image 1984, while the remnants of these dunes after 22 years have been concentrated as little accumulations in eastern south and northern central parts.

Most areas occupied by coastal dunes are under reclamation to be used for several purposes a long time ago. By comparison of sand dunes accumulations in the two images, it is clear that the most of sand dunes have been lost to account for the construction of the coastal highway, cultivation lands, newly reclaimed lands, and fish farms as shown in the **Figure 10**.

Therefore, the risks of coastal sand dunes' movements become negligible because they are gradually disappearing. It is expected that these coastal dunes will disappear completely in the next decade or so.

4. Discussion

The results of the change detection during the period from 1984 to 2018 proved that the shoreline along the study area is mostly characterized as an accretion except for some eroded sites. Despite this, the seawater invasion remains the most important hazard that threatens the coastal strip of the Nile delta due to sea level rise, the subsidence of the delta's sediments, and other reasons.

The results of the hydro-chemical analysis of water samples proved that the origin of the water in natural swamps and dog pools is marine, where the concentrations of TDS of all samples were relatively higher than else the natural salt water in the Mediterranean Sea, because of the evaporation process. In addition to the dominant anions were chlorides and sulfates, while the dominant cations were sodium and calcium.

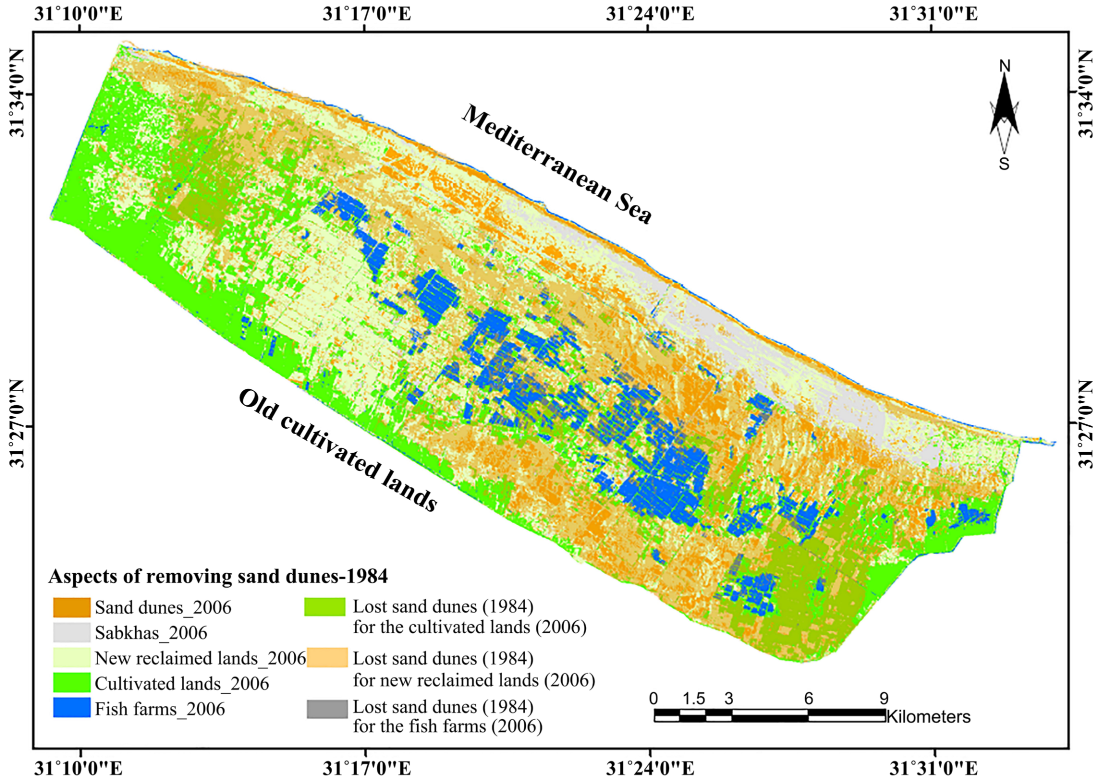

Figure 10. Aspects of removing coastal dunes in 1984 after 25 years.

The study area was classified as a natural protection area due to the presence of coastal dunes, while in recent years, this protection became threatened as a result of anthropogenic interventions which lead to removing huge amounts of dune sands. Therefore, strengthening this protection with ecosystem-based tools became urgent demand.

Although the coastal strip of the study area is narrow and is characterized by poor content of natural resources, there are many various land uses. Only about 43% of the total surface area is occupied with current land uses such as cultivated lands, industrial activities, fish farms, resorts, and urban areas, see Figure 11.

Planting unexploited land which represents about 57% with suitable trees and using thousands of cubic meters of the agricultural drainage waters for irrigation which are disposed daily to the Mediterranean Sea, could be the most suitable ecosystem-based solution to adapt to the seawater invasion and strengthen the natural protection throughout the following aspects:

- Resist inundation or flooding of seawater.
- Reducing greenhouse gases
- Maintain and fixed the coastal dunes.
- Lowering the level of subsurface salt water by plant transpiration

Besides the aspects mentioned before, there are some other environmental and economic benefits that could be achieved either directly or indirectly methods such as:

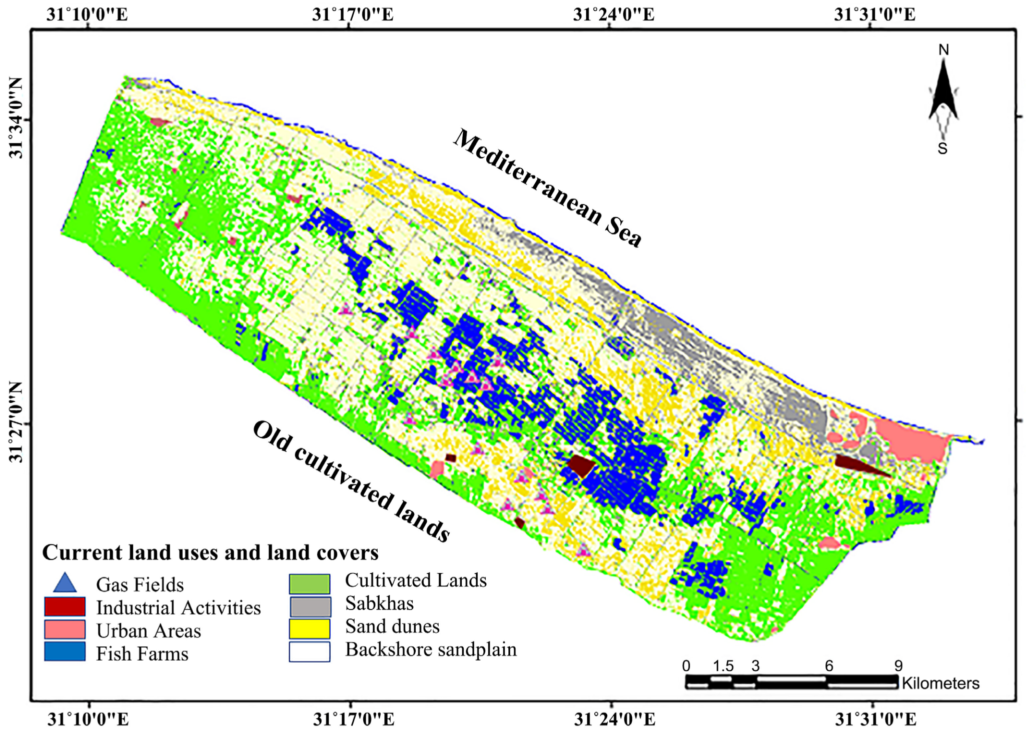

Figure 11. Current land uses of the study area.

- Improving the biodiversity in this coastal area.
- Conserving soil and protecting water resources
- Improving the ambient air quality.
- Create new professions and then new gobs and labor opportunities.
- Strengthen unconventional tourism.
- Creating new entertainment places.

5. Conclusion

The study area is classified as a natural protection area, due to the spread of the coastal dunes to cover vast areas and the shoreline is mostly an accretion shoreline. Actually, the result of the change detection proved that these dunes have reduced from 157.6 km^2 in 1984 to 39.6 km^2 in 2006, and it is on the way to disappearing completely in the coming years as a result of anthropogenic interventions and the impacts of unplanned development projects. As mentioned before the seawater inundation has been appearing in a low-lying area that represents about 37% of the whole study area, and this inundation is expected to expand to include new area, especially as the sea level rise. Most unexploited lands are located at the low topographic level, so they have vulnerable to the invasion of seawater and the high salinity proportion in them become a reality, so they are not safe till now. On the other hand, the southern actual cultivated land, industrial and urban areas are located at relatively high topographic levels, so they are safer for the time because they are far from the beach. Therefore, the establishment of new development projects must be suitable, sustainable, and commensurate with the nature of the coastal region and not change its characteristics. The strengths of this natural protection are in urgent demand now rather than at any other time. Planting the coastal strip located between the shoreline and the coastal highway is considered a suitable ecosystem-based solution to adapt to and mitigate the hazards that threaten this area. Reforestation could achieve many benefits such as reducing greenhouse gases, improving the local environment, conserving soil, protecting water resources, and improving biodiversity.

Recommendations

Based on the results which have been included in this study, it is recommended the following:

- Removing of the remnant dunes must stop where they are considered natural barriers that can be protected the coastal area from the risk of sea levels rising.
- Warned planning must be executed for certain simple projects which are suited to the characteristics of the region and its natural resources.
- It should be adopted as an ecosystem-based solution to protect the coastal strip rather than the current engineering projects.
- It should be adopted to a new project to plant unexploited lands to strengthen natural protection.
- The development projects in the coastal areas should be temporary and commensurate with the nature of the coastal strip and do not change its characteristics.
- Haphazard and unplanned development projects should be stopped because they contribute to accelerating the invasion of seawater.
- Egyptian Environmental Affairs Agency should be adopted to establish in the Nile Delta a center for monitoring and early alert for monitoring and follow-up on the natural hazards associated with climate changes.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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