Coastal Erosion Assessment of the Nile Delta Coast using Remote Sensing, GIS, and Modified Coastal Vulnerability Index

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ABSTRACT

The coastal zones are very much dynamic and are changing very fast, so it is completely important to study them in a temporal domain, for which remote sensing and GIS are the best tools. The coastal zone along the Governorates of Kafr El Sheikh, Dakahlia, and Damietta in north Egypt are reported to be facing serious environmental challenges. This study evaluates the coastline erosion and accretion and coastal vulnerability index (CVI) along these three Governorates, with a total length of 153Km over the past 34 years are analyzed using satellite images of TM 1984, ETM+ 2001, and ASTER 2018. The results showed that the study area was exposed to remarkable and non-expected changes over the study periods. Erosion and accretion were found variable over time and place, ranging from 0.14 ha/year in Dakahlia governorate during 1984-2001 to 66.12 ha/year in Kafr El Sheikh Governorate during 2001-2018 for erosion, and from 3.15 ha/year in Dakahlia Governorate at 2001-2018 to 42.45 ha/year in Kafr El Sheikh Governorate at 1984-2001 for accretion. Total land loss due to erosion as high as about 2034.68 ha of shoreline, and land gain as high as about 1459.71 ha of coastline was estimated in the study area with a net of lost lands of about 574.97 ha. In general, Kafr El Sheikh Governorate was more affected by erosion. According to Modified CVI, about 9.66%, 11.03%, 33.10%, and 46.21% of the length of the coastline is classified as very high, high, moderate, and low vulnerability, respectively.

Key words: Coastal Erosion, Coastal Accretion, CVI, Satellite Images, Northern Coast, Egypt.

INTRODUCTION

The earth is a water planet with a total coastline of about 1,634,701 km (Burke et al., 2014). The coastline is the meeting place of land and water, so it is one of the most vital features on the Earth's surface (Winarso and Budhiman, 2001). The coastlines have an abundance of natural resources and urban, for this about one-third of the humans are living close to it (Shetty et al., 2015).

In latest years, the coastal zone has been exposed to pressure and process of changes (Rahisha et al., 2016), and coastal erosion and accretion have long been important processes occurring in many coastal places around the world (Chowdhury and Tripathi, 2013). So, shoreline mapping and monitoring is a very important tool for sustainable coastal development (Hashmi and Ahmad, 2018). Coastal erosion is always accompanied by the shoreward recession of the shoreline and the loss of land area (Saravanan et al., 2014) therefore it has many bad effects on the coastal environment, causing suffering local economies (Bio et al., 2015).

Jones and Boer, (2003) define vulnerability as potential damage caused by a natural hazard. It has often been a quantitative number, which is essential for vulnerability assessment which helps in disaster prevention, management, and mitigation (Romieu et al., 2010). The researchers used several methods for the assessment of coastal vulnerability such as geographic information systems (GIS), remote sensing (RS), dynamic model assessment tools, indicator tools for vulnerability evaluation, and vulnerability indices (Chaib et al., 2020).

The Egyptian Northern coastline extends along the Mediterranean Sea, about 1000 km (Abdelaty, 2015), and the Nile delta is a dominant feature on it with its economic activities such as agriculture and industry (Eldeberky, 2011). Like other delta's worldwide, the Nile Delta has been experiencing significant shoreline erosion due to natural and human factors (Dewidar and Frihy, 2007), resulting in many serious socioeconomic impacts. Therefore, studying and analyzing this problem can not only mitigate these negative impacts of coastal erosion but also leads to the development of capabilities to deal with future changes.

Using satellite images is an effective means to dynamically monitor coastline change (Abu Zed et al., 2018) and this occurs through integration between remote sensing data and GIS, which is very helpful for measuring and monitoring coastal erosion and accretion, especially in determining the coastline using multi-temporal images and overlay temporal maps to measure coastline change detection over time (Rahisha et al., 2016; Chowdhury and Tripathi, 2013). Thus, many researchers have used RS and GIS to study coastal erosion and accretion at a global scale; For example, Saravanan et al., (2014) used RS and GIS for the management of coastal erosion in Southeast of India,

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DOI: 10.21608/asejaiqjsae.2021.188083

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Received July 06, 2021, Accepted, August 08, 2021.

(Sener et al., 2010; Karsli et al., 2011) used it for shoreline change detection in Turkey. Wang et al., (2013) detected the coastline change in the Pearl River Estuary of China from 1986 to 2011 using six remote sensing images.

Also, for the local scale, numerous studies were carried out to evaluate the coastline change using RS and GIS; for instance, (Frihy et al., 1994; White and El Asmar, 1999) used many satellite images such as MSS, TM, and ETM+ for the determination of coastal erosion. El Fishawi, (1989) found that about 14.7 km^2 from Rosetta Promontory was lost from 1909 to 1988, and Blodget et al., (1991) used MSS images to investigate the change detection in the same area between 1972 and 1987. The three TM satellite data were used to measure the changes in the Nile Delta coastline from 1984 to 1991 (White and El Asmar, 1999). The results of Elsayed and Mahmoud, (2007) showed that Rosetta Promontory lost 113.8 m annually between 1984 and 1991.

Thus, the aim and the novel work of the present study is to integrate RS and GIS (Digital Shoreline Analysis System (DSAS) as an available extension that works within ArcGIS software) to the assessment of Coastal Vulnerability Index (CVI). Additionally, estimate and mapping coastal erosion and accretion and its rates along the coastline of Kafr El Sheikh, Dakahlia, and Damietta Governorates between 1984 and 2018 using remote sensing and GIS as tools to demarcate the eroding zones along the coastline that can be used efficiently by decision-makers to devise an effective coastal zone management plan in the study area.

STUDY AREA

In this present study, the coastline of the study area is situated between the Rosetta River Nile branch in the west (249952.76 E and 3484780.86 N) and Dumyat River Nile branch in the east (390247.88 E 3488689.21 N) and with a total coastline length of about 153 km which protect the Nile delta from flooding.

This zone presents a major part of the Nile delta coast of Egypt and forms one of the main socioeconomic areas of Egypt with more population inhabiting the coastal areas, as well as incorporating many industries, mining sites, and other developmental projects.

The study area includes the coastline of three Egyptian Governorates that extend from west to east as follows; Kafr El Sheikh coastline, which presents about 96 km, Dakahlia coastline which extends about 26 km, and Damietta coastline which presents about 31 km (Figure 1).

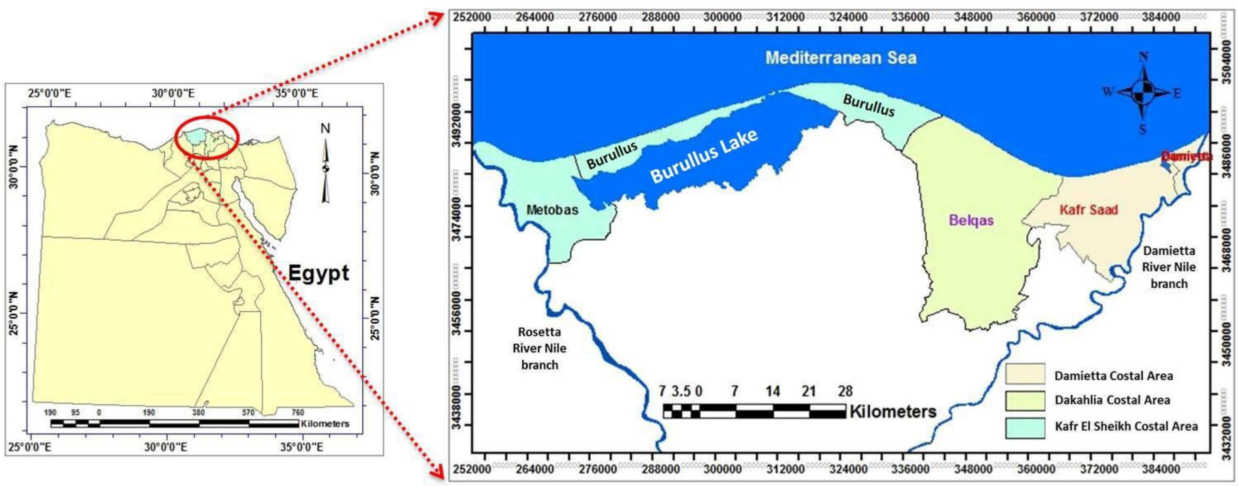

Fig. 1. Study area map

MATERIAL AND METHODS

The current study was divided into five interrelated phases as shown in Figure (2) as a research methodology flowchart. That methodology including:

Data Sources: The LandSat archive data for different years (TM 1984, ETM+ 2001) and ASTER data (2018) were downloaded from the website (EarthExplorer, 2015) and used for this study region with Universal Transverse of Mercator (UTM), zone 36 N. Two Landsat 5 (TM) images, two Landsat 7 (ETM+) images, and four ASTER images were used to extract and digitize vector shoreline data. The following Table (1) shows the characteristics of those images.

Coastline digitizing: The coastline feature was drawn using screen digitizing in Arc-GIS 10.2 environment (ArcMap 10.2, 2008).

Coastline change detection: The Digital Shoreline Analysis System (DSAS) is a free and available extension that works within ArcGIS software (ArcMap 10.2, 2008). DSAS is used to calculate the rate of coastline change using digitized shoreline for the years 1984, 2001, and 2018 in the vector format.

Software: Environment for Visualizing Images (ENVI 4.7, 2009) was used for satellite images processing and thresholding of the land-sea boundary for extraction of shorelines. Therefor (ArcMap 10.2, 2008) was used for digitization of topographic maps and generalization of extracting shorelines.

Coastal Vulnerability Index (CVI): Physical vulnerability index (PVI) parameters (Coastal slope, Geomorphology, Elevation, Shoreline change, Sea level change, Significant wave height, and Tidal range) and Social vulnerability index (SVI) parameters (Population, Land use/land cover, Road network, and Tourist areas) are used to calculate the Coastal Vulnerability Index (CVI) (Murali et al., 2013).

The six most important variables based on the coastal conditions of the study area were selected to calculate the modified Coastal Vulnerability Index (CVI): a: shoreline change rate (m/y), b: Land use/Land cover, c: coastal geomorphology, d: regional elevation (m), e: coastal slope (degree), and f: road network (distance from the shoreline). The CVI was calculated as the square root of the results of the ranked variables divided by the total number of variables (Ahammed et al., 2016) as shown in the following equation. Risk ratings for selected parameters have been assigned in Table (2) according to Murali et al., 2013.

$$CVI=\sqrt{(a*b*c*d*e*f)/n}$$

Table1. Satellite images and their sensor specification used in the study

Specification	Satellite		
	Landsat 5	**Landsat 7**	**ASTER**
Sensor	Thematic Mapper (TM)	Enhanced Thematic Mapper Plus (ETM+)	Advanced Space-borne Thermal Emission and Reflection Radiometer
Spectral Resolution (bands)	7	8	14
Spatial Resolution (m)	bands 1 to 5 and 7 (30m) – band 6 (120m)	bands 1 to 5 and 7 (30m) – band 6 (60m) – band 8 (15m)	bands 1 to 3 (15m) – bands 4 to 9 (30m) – bands 10 to 14 (90m)
Radiometric Resolution (bit)	8 bit	8 bit	bands 1 to 9 (8 bit) – bands 10 to 14 (12 bit)
Temporal Resolution (days)	16 days		
Acquired Date	1984	2001	2018
Coordinate System/Datum	UTM/WGS 84		
Zone	36		
Source	(EarthExplorer, 2015)		

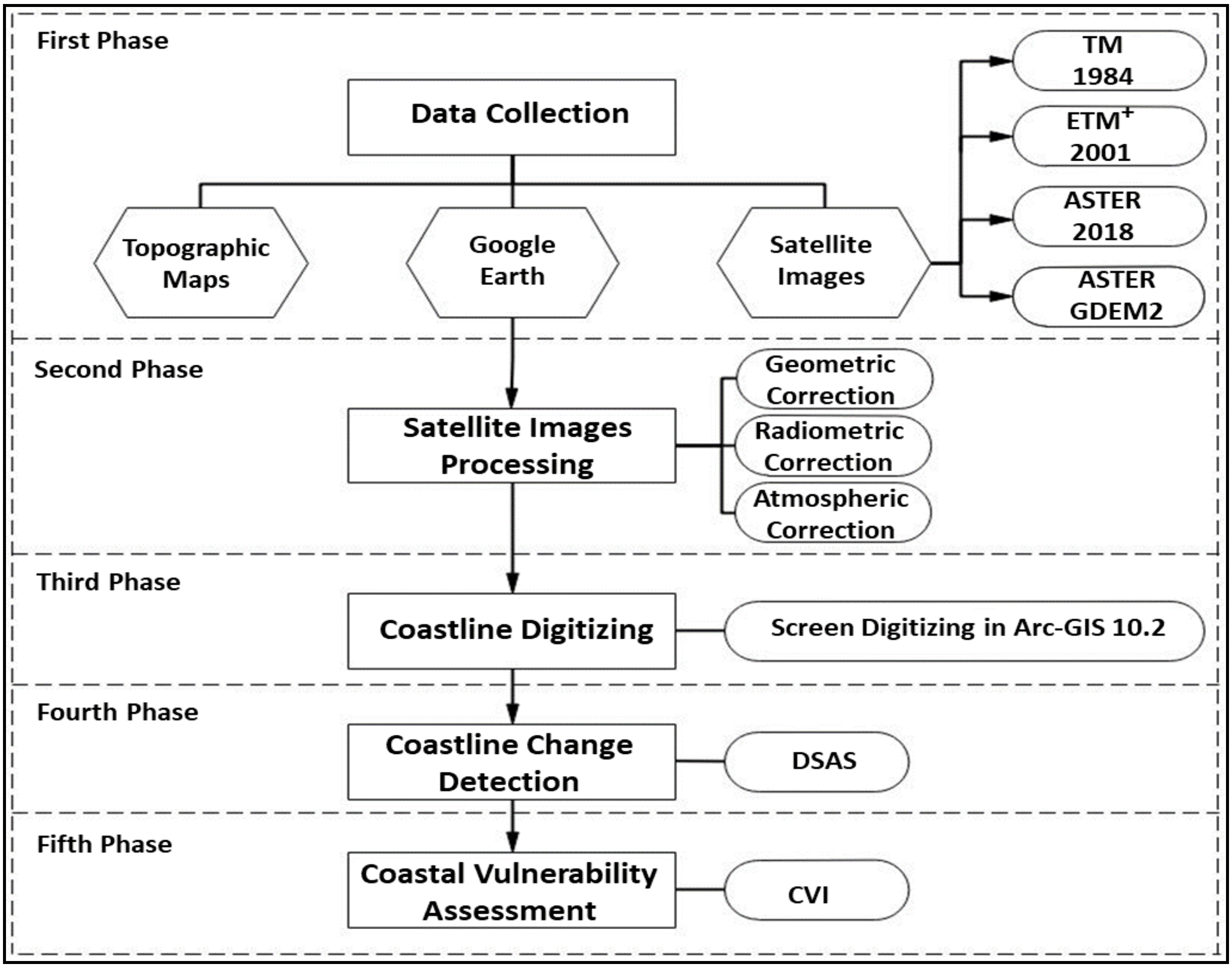

Fig. 2. Research methodology flowchart

Table 2. Risk rating assigned for different parameters (Murali et al., 2013)

Variable	Risk Rating			
	Low (1)	**Moderate (2)**	**High (3)**	**Very high (4)**
a- Shoreline change rate (m/y)	> 10 (high accretion)	0–10 (accretion)	≥ - 10 and <0 (erosion)	< - 10 (severe erosion)
b- Land use/Land cover	Wetlands, Salt marshes, Open lands, River and Inlets mouths (low capital)	Mangroves, Dune vegetations, Vegetations (moderate capital)	Scattered villages, Agricultural lands, Saltpans (high capital)	Hotels, Jetties, Fisheries (very high capital)
c- Geomorphology	Rocky coast	Embayed/indented coast	Dunes/estuaries and lagoons	Mudflats, mangroves, beaches, barrier-spits
d- Elevation (m)	> 6	> 3 and < 6	> 0 and < 3	< 0
e- Coastal slope (Degree)	0-10	11-20	21-45	> 45
f- Road network (distance from)	2 km buffer	1 km buffer	500 m buffer	250 m buffer

An overall Coastal Vulnerability Index (CVI) is further computed of each 1 km segment (total of 145 segments) of the shoreline, and it was mapped within the littoral zone extending 1 km landward from the shoreline. The calculate of CVI involves data obtained from various sources, as in Table (3).

Table 3. Parameters used in this study and its data sources

Variables	Sources
a- Shoreline change rate (m/y)	Landsat TM, Landsat ETM$^+$, ASTER (EarthExplorer, 2015)
b- Land use/Land cover	Topographic maps, ASTER, Google Earth
c-Geomorphology	Geological maps, ASTER, Google Earth
d- Elevation (m)	ASTER GDEM 2 (EarthExplorer, 2015)
e- Coastal slope (Degree)	Extracted from the digital elevation model
f- Road network (distance from)	Topographic maps, ASTER, Google Earth

RESULTS AND DISCUSSION

Shoreline change and coastal erosion hazard

The coastal zones are a source of economy, used as tourists attraction, while erosion is a great threat to the economy and human life. So, a remote sensing-based vulnerability assessment approach of erosion is crucial to generate detailed vulnerability information to support coastal development strategies. To estimate the rate of change of coastline on the study area, 1984 to 2018 coastline are investigated. The coastline of three Governorates (Kafr El Sheikh, Dakahlia, and Damietta) has been delineated during different periods using Satellite data of 1984, 2001, and 2018.

The extents of the shoreline accreting or eroding for the periods 1984- 2001 and 2001-2018 are shown in Table (4) of the entire length of 153 km. The extreme erosion is specifically observed at Kafr El Sheikh governorate coastline in the period from 2001 to 2018 as shown in Table (4) and Figure (3).

Table 4. The coastal erosion and accretion made in the Governorates of the study area

Process	Area and Annual Rate	Governorate					
		Kafr El Sheikh		Dakahlia		Damietta	
		1984 - 2001	2001 - 2018	1984 - 2001	2001 - 2018	1984 - 2001	2001 - 2018
Erosion	Area (ha)	622.67	1124.07	2.30	99.34	84.07	102.22
	Annual Rate (ha/year)	36.63	66.12	0.14	5.84	4.95	6.01
Accretion	Area (ha)	721.59	125.16	224.60	53.69	210.40	124.25
	Annual Rate (ha/year)	42.45	7.36	13.21	3.15	12.38	7.30

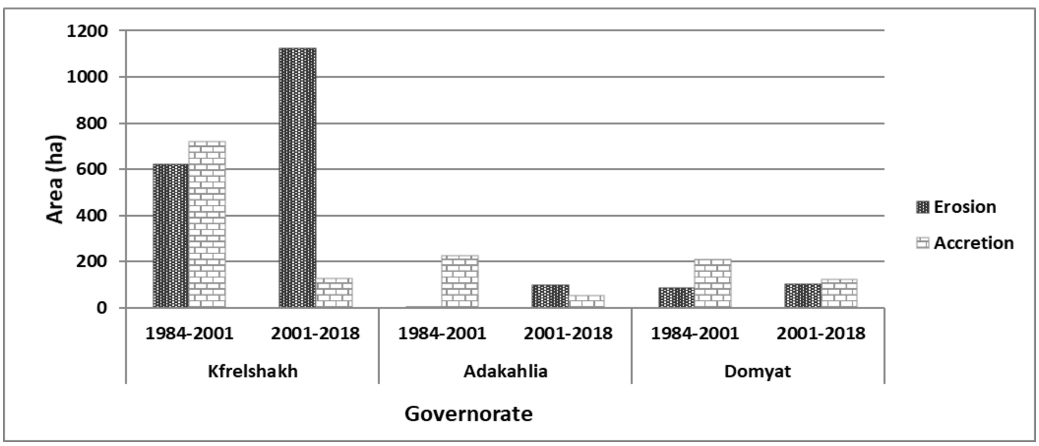

Fig.3. Eroded and accreted areas at different Governorates for different periods

Table 5. Total area (ha) and annual rate (ha/year) of erosion and accretion

Period	Erosion			Accretion		
	Total Area (ha)	Annual Rate (ha/Year)	%	Total Area (ha)	Annual Rate (ha/Year)	%
1984-2001	709.05	41.71	58.23	1156.60	68.04	41.77
2001-2018	1325.63	77.97		303.11	17.83	
1984-2018	2034.68	59.84		1459.71	42.93	

The total eroded and accreted areas during the whole period (1984 to 2018) were 2034.68 and 1459.71 ha, respectively, and about 58% of the shoreline is observed to be eroding over 34 years (Table 5). The shoreline changes from 2001 to 2018 show an extreme annual rate of erosion (77.97 ha/year). And from 1984- 2001 annual rate of accretion was 68 ha/year.

Overall, from 1984-2018, the shoreline analysis of this coastline (153 km), shows that the annual eroding trend was 59.84 ha/year, and the annual rate of accretion was 42.93 ha/year. About 2034.68 ha of land were eroded in the study area and on the other hand, there had been an accretion of about 1459.71 ha.

Table (6) shows that the maximum negative net growth observed in Kfrelshakh Governorate (-899.99 ha) with a rate of -26.47 ha/year, whereas the total erosion rate is more than the total accretion rate. On the other hand, the accretion is more in Dakahlia and Damietta Governorates with a positive net growth of about 176.65 and 148.37 ha, and the coastline is accreting at a rate of 5.19 and 4.36 ha/year, respectively.

In general, total land loss due to erosion is about 2034.68 ha of shoreline, and land gain is about 1459.71 ha of coastline in whole the study area with a net of lost lands of about 574.97 ha.

Assessment and mapping of Kafr El Sheikh Governorate shoreline erosion and accretion

The period from 1984 to 2001

The analysis of the shoreline changes between 1984 and 2001 is shown in Figure (3). About 622.67 ha of land were eroded from the shoreline in the Kafr El Sheikh Governorate. However, there had been an accretion of about 721.59 ha at the same time in the area.

The period from 2001 to 2018

Figure (3) also shows shoreline remarkable changes between 2001 and 2018. About 1124.07 ha of land were eroded from the shoreline in this part of the study area. Also, it shows an area of gain (accretion), about 125.16 ha.

In a span of 17 years (2001-2018) Kafr El Sheikh Governorate has experienced maximum erosion among all the Governorates of the entire study area, and it faces severe erosion threat especially in its western part (Figure 4). This is maybe because of river mouse as well as human activities. The temporal comparison between various satellite images of Kafr El Sheikh western part displays the significant reclamation of the coastal zone and using this part as fish farms under Egyptian strategy for the development of the north coast.

Table 6. Erosion and accretion during 1984-2018 in the study area

Erosion and accretion during 1984-2018	**Governorate**			**Total Area**
	Kafr El Sheikh	**Dakahlia**	**Damietta**	
Total Area (ha)	2593.50	379.93	520.95	3494.38
Total Erosion (ha)	1746.75	101.64	186.29	2034.68
Total Accretion (ha)	846.75	278.29	334.66	1459.7
Erosion %	67.35	26.75	35.76	129.86
Acceration %	32.65	73.25	64.24	170.14
Net Growth (ha)	-899.99	176.65	148.37	-574.97
Growth rate (ha/year)	-26.47	5.19	4.36	-16.92

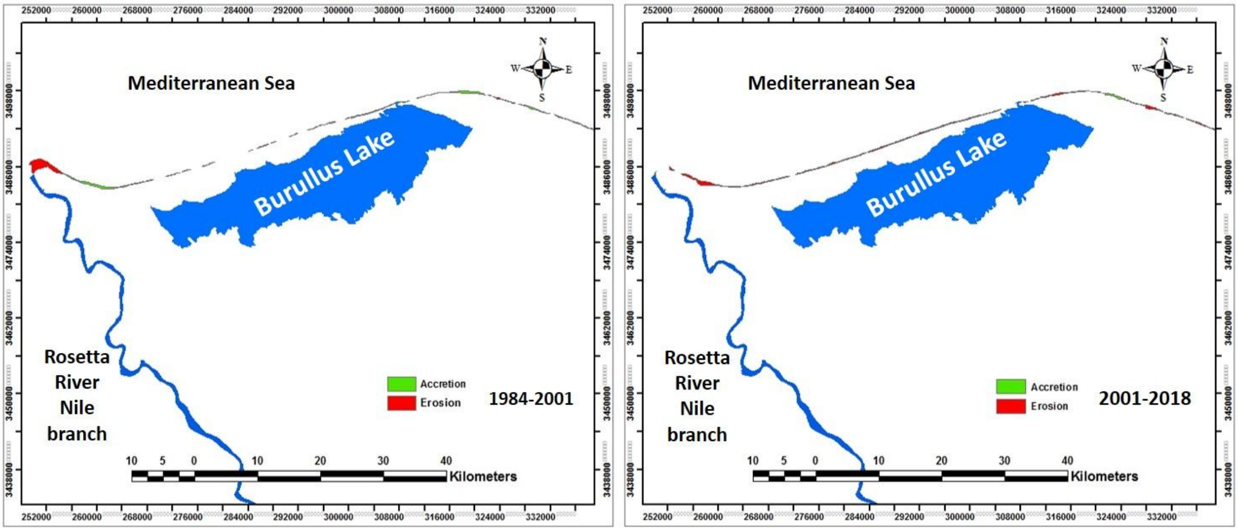

Fig.4. Total area of erosion and accretion in Kafr El Sheikh Governorate

Assessment and mapping of Dakahlia Governorate shoreline erosion and accretion

The period from 1984 to 2001

There were considerable shoreline changes in this Governorate from 1984 to 2001. There was less shoreline erosion (only 2.30 ha) in the study area. However, there was more accretion during this period, which formed a continuous piece of land with an area of 224.60. In a span of 17 years (1984-2001) this Governorate has shown minimum erosion (Figure 3).

The period from 2001 to 2018

Between 2001 and 2018 about 99.34 ha of land, were eroded from the shoreline in the Dakahlia Governorate, the green color in the photomap, whereas the red color represents the accreted area which was about 53.69 ha over the same period (Figure 5).

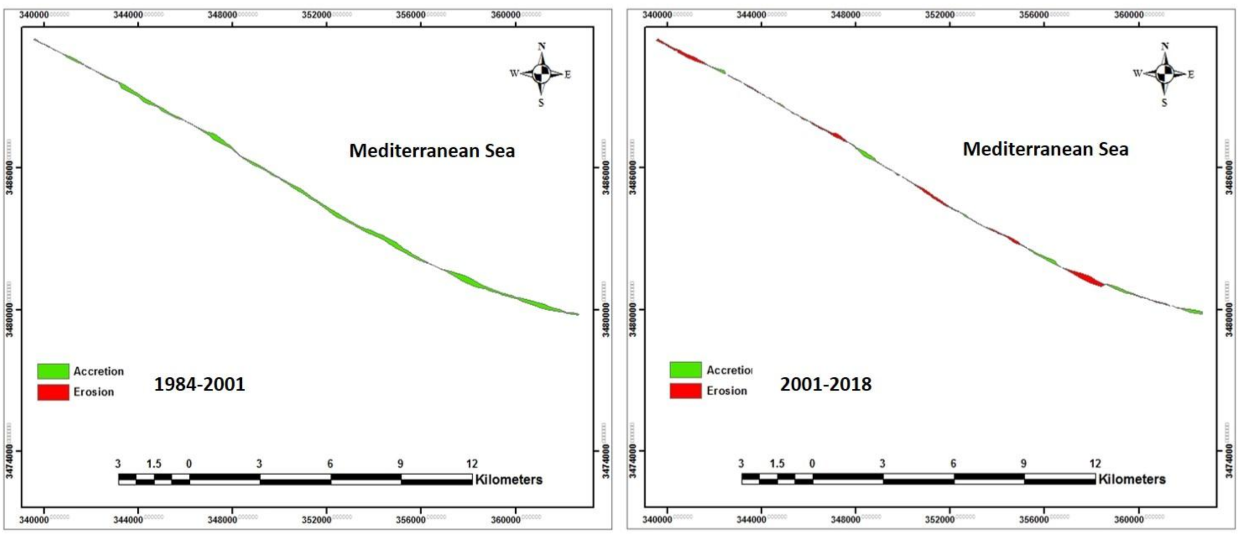

Fig.5. Total area of erosion and accretion in Dakahlia Governorate

Assessment and mapping of Damietta Governorate shoreline erosion and accretion

The period from 1984 to 2001

During 1984–2001 about 84.07 ha of land was eroded from the Damietta Governorate, red color in the photomap in Figure (6). There was a more accretion of about 210.40 ha in the area colored with green.

The period from 2001 to 2018

Figure (6) also shows the shoreline change between 2001 and 2018. About 102.22 ha of land were eroded from the shore in Damietta Governorate. Also, it shows the accretion area, which measures 124.25 ha.

Assessment and mapping of Coastal Vulnerability Index (CVI)

The main purpose of coastal vulnerability assessments is to be an indicator for scientists, and policymakers to improve their understanding of coastlines changes. This understanding gives better management of the coastline, as management efforts can be oriented for especially vulnerable areas (Hinkel and Klein, 2009). The coastal vulnerability assessment in wide form involves calculating an index to simplify several complex and interacting parameters to a form that is more easily understood (McLaughlin et al., 2010).

The minimum value of the coastal vulnerability index in this study is 1.15 and the maximum value is 11.31. Therefore, the CVI values were separated into 4 class intervals as low, moderate, high, and very high (Table 7).

Figure (7) shows the percentage of CVI and its parameters in the study area. The coastal slope is recorded high vulnerability compared to other parameters, then following by land use/land cover, shoreline change rate, and road network; it means that these parameters are controlling factors for coastal vulnerability.

The very highly Vulnerable Index is recorded in Kafr El Sheikh Governorate, with an 11.31 index value and the lowest vulnerable index was recorded in Damietta Governorate with a 1.15 index value. The results indicate that about 9.66% are categorized under very high vulnerability and it comes 14.77 km length of the study area. About 11.03% of the total coastline is classified as high vulnerability (16.88 Km). Moderate and low vulnerable areas contributing 33.10% and 46.21%, which cover 50.65 Km and 70.70 Km of the total coastline, respectively (Figure 7).

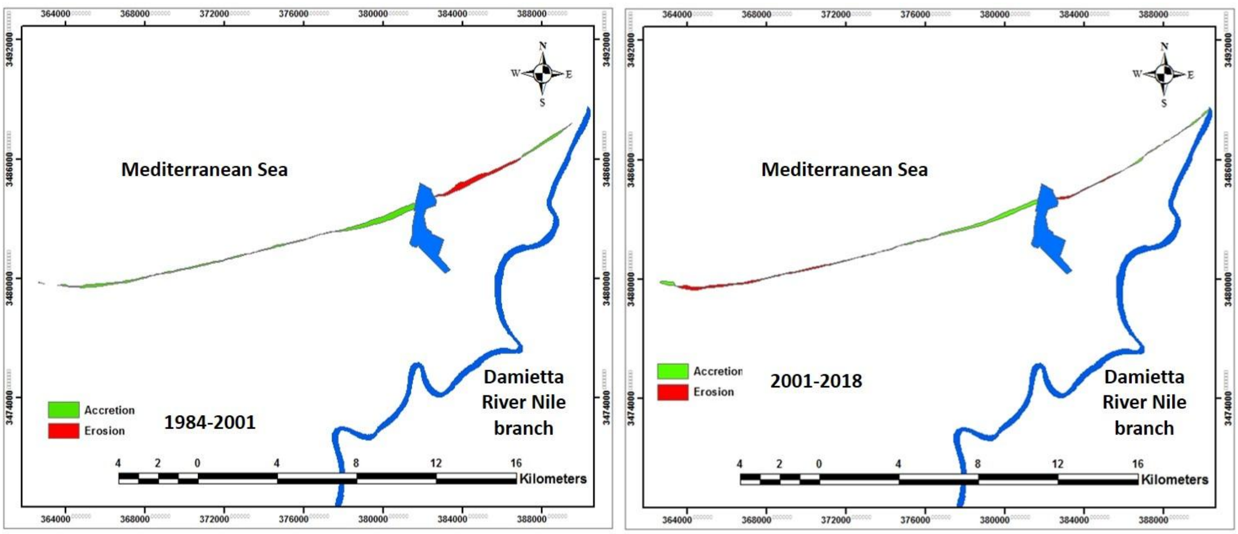

Fig.6. Total area of erosion and accretion in Damietta Governorate

Table 7. Classes of Coastal Vulnerability Index

	CVI			
Risk	Low Vulnerable	Moderate Vulnerable	Highly Vulnerable	Very highly Vulnerable
Value	1.15 - 3.69	> 3.69 - 6.23	> 6.23 - 8.77	> 8.77 – 11.31

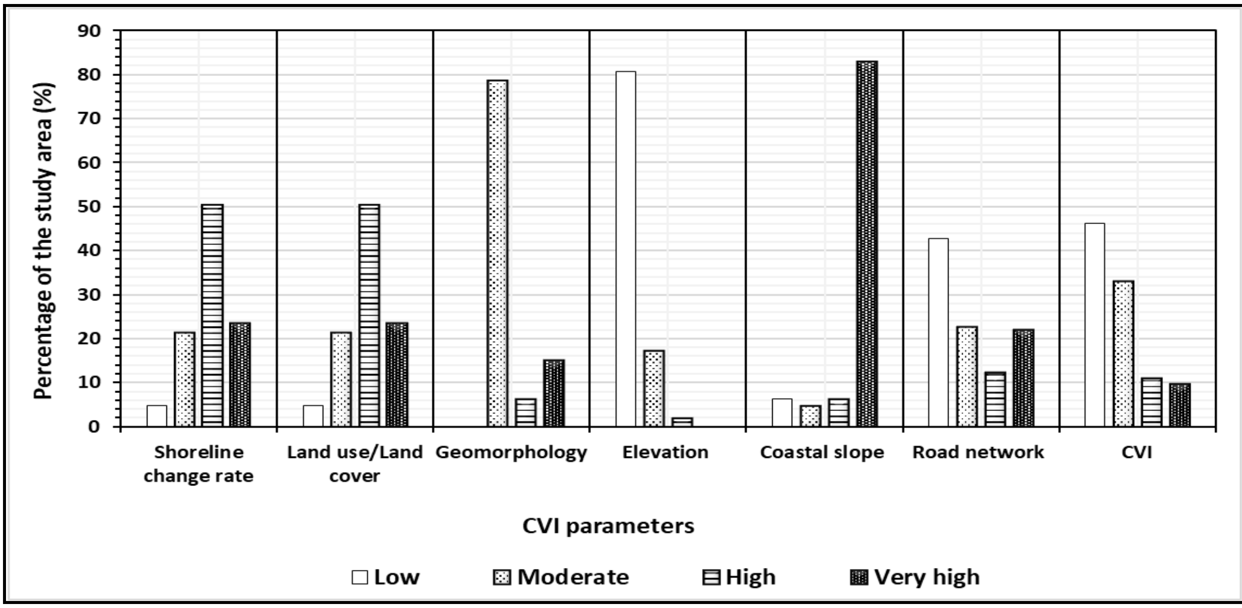

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Fig. 7. The percentage of CVI and its parameters in the study area

The very highly vulnerable area was recorded in two places through the coastline; the first one was located at the point of connecting Burullus lake with the Mediterranean Sea, and the second place was sited in the Eastern part of the study area when the Damietta River Nile branch connects with the Mediterranean Sea.

The highly vulnerable area was in three places; the first one was placed in the western part of the study area when the Rosetta River Nile branch connects with the Mediterranean Sea, the second one was placed in the area between Dakahlia Governorate and Damietta Governorate, and the third place was in the front of the new Damietta city. Moderate and Low Vulnerable were spread across the coastline (Figure 8).

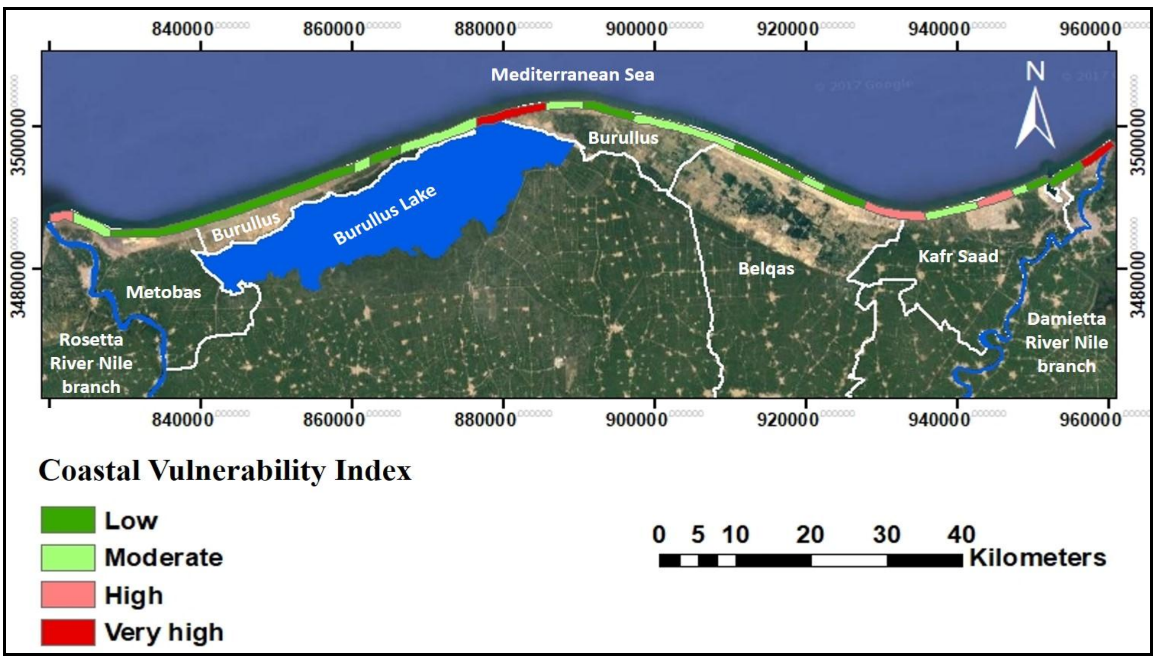

Fig. 8. Coastal Vulnerability Index in the study area

CONCLUSIONS

Lack of coastal zone management has caused severe environmental problems such as land subsidence, coastal erosion, the intrusion of saltwater, degradation of agricultural land. This paper analyzed coastline change, erosion-accretion evolution, by using remote sensing data and geographical information system technology. The study has revealed that during the study period of 33 years, coastal erosion is predominant over accretion and major erosion is evidenced in all the study area during 2001-2018.

Erosion is highest on the coast of Kafr El Sheikh governorate (67.35 %) with a net growth of about (-899.99 ha), but accretion is highest in Dakahlia governorate (73.25 %) with a net growth of about (176.65 ha). The coastal zone along the governorates of Kafr El Sheikh, Dakahlia, and Damietta in North Egypt are reported to be facing serious environmental challenges. The results of this study are very valuable for the decision-makers who are interested in the sustainable development of the Egyptian north coast and protecting the Nile Delta from coastal erosion.

Coastal Vulnerability Index highlights the more challenging parts (high and very highly vulnerable) along the coastline that demand further attention. Accordingly, the preliminary planning can be applied using the results of this study in the conservation of the coastal zone in the Nile delta.

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الملخص العربي

تقييم التعرية الساحلية لساحل دلتا النيل باستخدام الاستشعار عن بعد ونظم المعلومات الجغرافية ومؤشر الضعف الساحلي المعدل

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حيث أن المناطق الساحلية تعتبر ديناميكية للغاية وتتغير بسرعة كبيرة، لذلك من المهم تماما دراستها في نطاق زمني محدد، ويعتبر الاستشعار عن بعد ونظم المعلومات الجغرافية أفضل الأدوات لذلك. تشير التقارير إلى أن المنطقة الساحلية على طول محافظات كفر الشيخ والدقهلية ودمياط في شمال مصر تواجه تحديات بيئية خطيرة. تقوم هذه الدراسة بتقييم تآكل وتراكم الساحل ومؤشر الضعف الساحلي (CVI) على طول هذه المحافظات الثلاث، بطول إجمالي يبلغ ١٥٣ كم على مدى السنوات الـ ٣٤ الماضية، ويتم تحليلها باستخدام صور الأقمار الصناعية TM 1984 و ETM + 2001 و ASTER 2018. وأظهرت النتائج أن منطقة الدراسة تعرضت لتغيرات ملحوظة وغير متوقعة خلال فترات الدراسة. تم العثور على تآكل وتراكم متغير بمرور الوقت والمكان، حيث تراوحت بين ٠,١٤ هكتار/ سنة في محافظة الدقهلية خلال الفترة ١٩٨٤-٢٠٠١ إلى ٦٦,١٢ هكتار/ سنة في محافظة كفر الشيخ خلال الفترة ٢٠٠١-٢٠١٨ للتعرية، ومن ٣,١٥ هكتار/ سنة في محافظة الدقهلية عام ٢٠٠١-٢٠١٨ إلى ٤٢,٤٥ هكتار/ سنة بمحافظة كفر الشيخ ١٩٨٤-٢٠٠١ للتراكم. تم تقدير إجمالي خسارة الأراضي بسبب التعرية بحوالي ٢٠٣٤,٦٨ هكتار من الخط الساحلي، وتم تقدير مكاسب الأرض التي تصل إلى حوالي ١٤٥٩,٧١ هكتار من الخط الساحلي في منطقة الدراسة مع صافي الأراضي المفقودة بحوالي ٥٧٤,٩٧ هكتار. بشكل عام كانت محافظة كفر الشيخ أكثر تأثرا بالتعرية. وفقا لـ CVI، تم تصنيف حوالي ٩,٦٦٪ و ١١,٠٣٪ و ٣٣,١٠٪ و ٤٦,٢١٪ من طول الخط الساحلي على أنها عالية جدا وعالية ومتوسطة ومنخفضة الضعف على التوالي.