Chapter

Modeling of Coastal Processes in the Mediterranean Sea: A Pilot Study on the Entrance of Suez Canal in Egypt

Mona Fouad Kaiser, Walaa Awaad Ali and Maysara Khairy El Tahan

Abstract

The main objective of this research is applying numerical modeling to simulate the impact of the Suez Canal jetties on the beach morphology and hydrodynamic regime along the Suez Canal coastal zone. In addition, coastal processes including waves and wave-induced currents will be evaluated using 2D modeling. This research will contribute to quantify the shoreline stability during the last three decades. Hydrodynamic and sediment transport (ST) models are utilized to predict sediment transport pathways and how sediment might move within the entrance of Suez Canal port. Remote sensing analyses of the Landsat Thematic Mapper images during 2000–2018 show siltation processes at the entrance of the Suez Canal. Vector analyses of the images' data indicated updrift accretion at a rate of +15 m/year and downdrift erosion at a rate of −13 m/year. Coastal processes including waves and currents contribute to shoaling problem along the navigation channel of the Suez Canal port. Applications of 2-3D models were used to simulate wave and current dissipation. In addition, beach slope profiles and hydrodynamic models are used to help in understanding the impact of coastal processes on beach morphology and hydrodynamic regime controlling siltation problem along the entrance of Port Said harbor.

Keywords: 2D modeling, Mediterranean Sea, coastal processes, Suez Canal port, hydrodynamic regime, beach morphology

1. Introduction

The Suez Canal is located in Egypt west of the Sinai Peninsula. Its construction was preceded by cutting a small freshwater canal from the Nile Delta and connecting it with a southern branch to Suez and a northern branch to Port Said. The Suez Canal is considered to be the first artificial canal to be used in Travel and Trade. It is completed to create the first saltwater passage between Port Said on the Mediterranean and Port of Suez on the Red Sea, providing an essentially direct route for transport of goods and petroleum tankers between Europe and Asia. The construction of Suez Canal, nearly from 40 centuries, by the pharaohs, aims at to do linking between the Red Sea and Mediterranean Sea. In addition, Suez Canal Authority is responsible to do periodical dredging for the navigation channel and its surroundings to keep this channel deep and safe. The canal supports approximately 8% of the world's shipping traffic with almost 50 vessels traveling through the canal daily. It has 195 km length; its width ranges from 60 to 300 m. It is able to accommodate ships as large as 150,000 tons fully loaded (Suez Canal Authority personal communication). This study aims to understand the main factors controlling siltation problem in the entrance of the Suez Canal port. Numerical modeling will be used to simulate coastal processes, beach profiles, and hydrodynamic regime. The results help in shoaling mitigation and facilitating passing of high loading ships along the canal.

As the important geographical location of Port Said Governorate, it has many activities in national and regional development. In addition, it is considered as the Gulf of Suez extension. Consequently, it has valuable resources such as the Mediterranean Sea, the Red Sea beaches, lakes, protected areas, and historical and archeological areas. These resources are suitable for tourism development. Therefore, Port Said has quickly become the third largest urban governorate in Egypt with respect to population.

2. Study site description

The Suez Canal coastal zone lies between longitudes 32°13′ and 32°25′ E and between latitudes 31°10′ and 31°20′ N (**Figure 1**). The concerned site represents a part of the Egyptian Mediterranean coast lying to the north of the Nile Delta east of Port Said. The beach profile slope has 1 m/km, and the depth of seabed reaches 25 m at the northern boundary of the study site. The beach sediment, along the coastal zone, is mainly composed of sand; its limit reaches 5 m in depth [1]. Although going to the sea bed offshore, the sediment texture that is covering the seabed was changed from muddy sand in the area limit between 5 and 10 m to muddy in deeper zone. Abu Asi [2] concluded that the coastal zone of Sinai from Port Said to El Arish is under extensive development. Consequently, several integrated development projects are being implemented along the coastal zone of North Sinai including the El-Tina plain [3]. The area is identified as it is completely covered by quaternary sediments of littoral, alluvial, and eolian origin, which show variations in their texture and composition ranging from unconsolidated sands to salinized silt and clay of chemical and biochemical origins. They also described the area as it has a concave shoreline configuration that is about 39 km long and 818 km^2 in area. The plain is subsiding at a rate of about

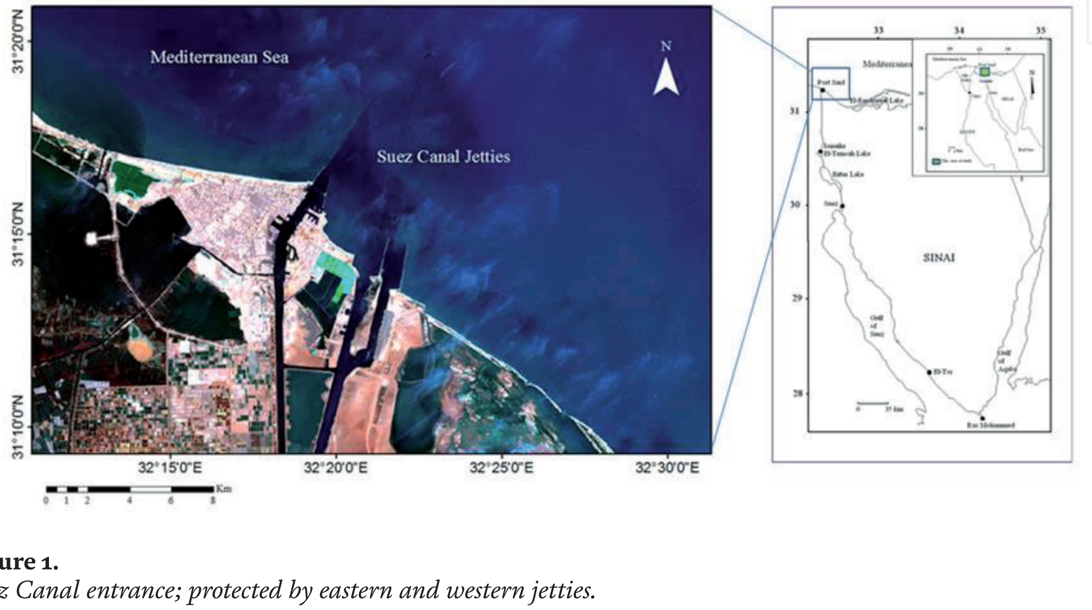

Figure 1.
Suez Canal entrance; protected by eastern and western jetties.

0.5 cm/year. The only engineering structures built at the study area are the 7.7 and 2.0 km jetties constructed to protect the inlet at Port Said and the East Port Said harbors, respectively. Additionally, the thickness of Holocene strata beneath the modern delta plain is a direct function of subsidence, which ranges from 50 m at Port Said and tends to decrease or be nearly absent westward below the Alexandria coastal plain.

The principal transporting agents in the concerned site are waves and wave-induced longshore current [4]. The wave rose was constructed based on records measured between 1997 and 1999 off the Damietta Harbor using a pressure wave gauge (InterOcean System S4DW) installed at ~12 m water depth [5]. The average significant wave height ranges from 1.04 to 4.45 m with long duration, its direction is mainly coming from NW in winter. These waves are responsible for generating the longshore currents and transporting sediment toward the east. However, the N-E waves having short duration are responsible for generating a reverse longshore current toward the west [6].

The eroded sediment of Damietta promontory was blocked west of Port Said causing accretion of +15 m/year along the western jetty of the El-Gamil inlet. Growth of tombolos occurred behind detached breakwaters at a rate of +6 m/year. The resulting break in longshore drift caused erosion of −6 m/year downdrift of the breakwaters. The eastern side of the Suez Canal, Bur Fouad, is suffering from erosion at a rate of −18 m/year. The coastline of El-Bardawil Lake is experiencing accretion of +6 m/year in some sections and erosion of −9 m/year in others [7]. The basins inside the Port Said harbor have a depth ranging from 8 to 24 m water; it is subjected to a severe sand drift. Suez Canal Authority usually keeps it clear by dredging. Maintenance dredging is simply the removal of sediments from a body of water that have accumulated due to erosion in order to maintain a desired depth, as in a navigation channel. Suez Canal navigation channel is authorized to be maintained to certain depths depending on its use, by periodic dredging of the silt, sand, and clay that are deposited in it [8].

In order to evaluate the impact of engineering protection on the coastal processes including waves and currents and beach profile configuration, numerical modeling techniques are utilized to predict the patterns of shoreline changes due to the changes in wave conditions.

3. Remote sensing techniques and results

3.1 Change detection

Shoreline positions were obtained from the TM band-7 images using a region-based segmentation process in which the sea area was extracted as a region [9]. Region growing techniques are generally better in noisy images, where borders are extremely difficult to delineate. Homogeneity is an important character of regions and is used as the main segmentation criterion in region growing. Thematic Mapper band 7 (short-wave infrared) was used for the image segmentation procedure to produce a vector map of the shoreline, so that the land-sea boundary could be delineated. Shorter wavelengths can pass through shallow water, making accurate delineation of the coastline difficult [10]. Using short-wave infrared data ameliorates the high-reflectance problems caused by surf in the breaker zone [11]. A line representing shoreline position (the boundary between sea and land) was created along the Suez Canal coastal zone. The output data were saved as a vector file enabling analysis of coastline change using geographic information system (GIS) software [12]. Shoreline displacements during the 2000–2018 period were extracted from the images using the measurement tools in ERDAS IMAGINE VirtualGIS. Edge detection and segmentation seem to be the most suitable approach to produce vector map data for the study site. The results indicate updrift accretion at a rate of +15 m/year and downdrift erosion at a rate of −13 m/year along the entrance of the Suez Canal port (**Figure 2**).

3.2 Image classification

Unsupervised classification was carried out on the three data sets of the images separately using a histogram peak cluster technique to identify dense areas or frequently occurring pixels [13–15]. Generally, multispectral classification consists of a compression of all information in a multispectral data set into a single image that depicts the major types of surfaces in different colors [16]. Maximum likelihood of supervised classification was applied to detect land cover classes. Once

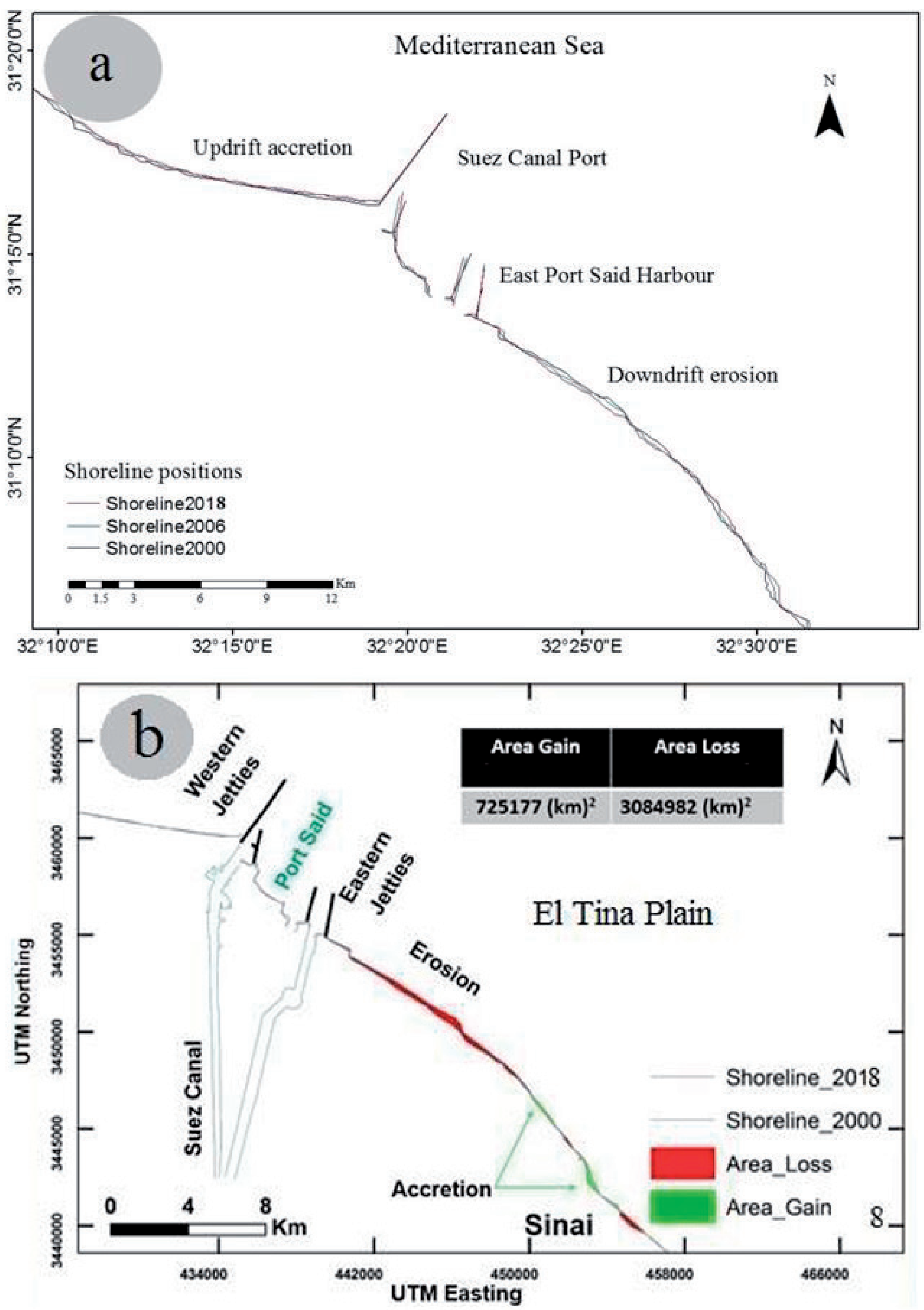

Figure 2.
(a) Patterns of shoreline changes during 2000–2018 and (b) areas of loss and gain along El-Tina plain.

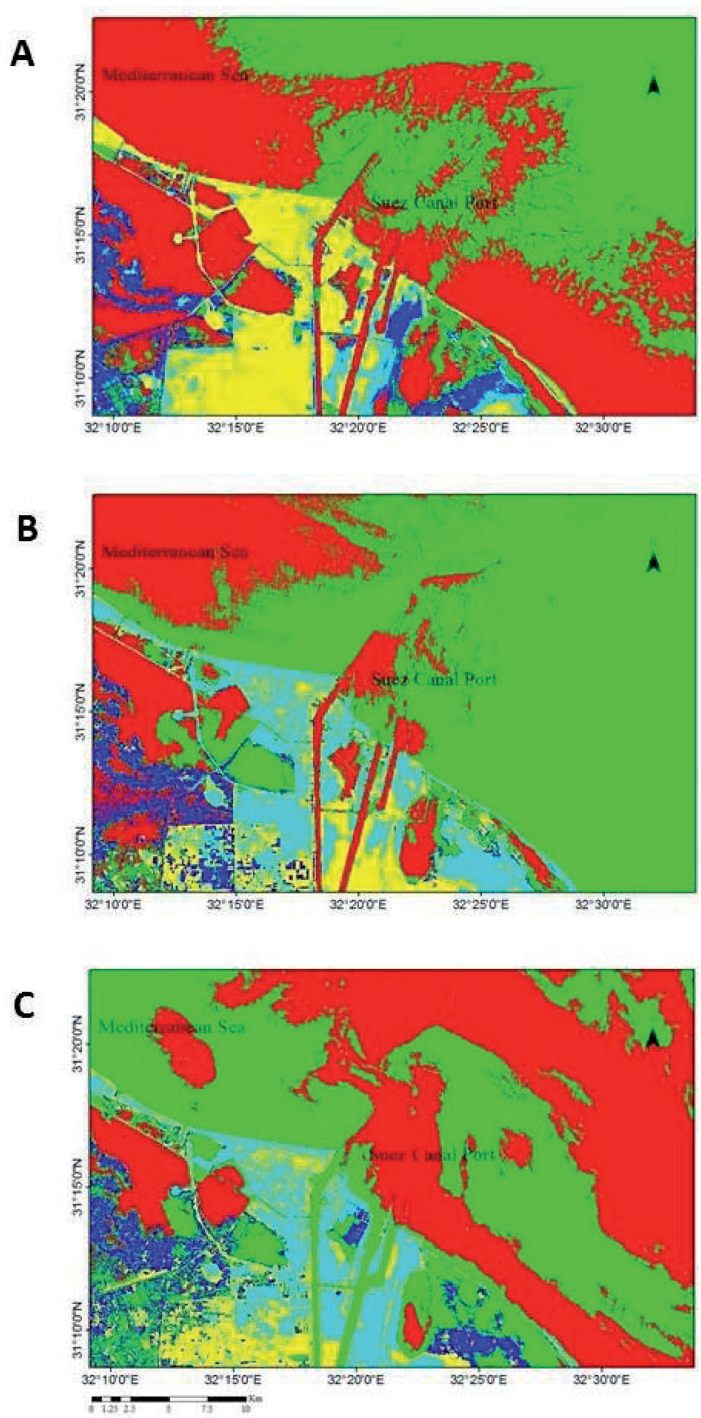

Figure 3.
Image classification during 2000–2018; green color showing siltation along the study site coastal zone.

a sufficient number of such spectral subclasses were acquired for all information classes, a maximum likelihood classification was performed with the full set of refined spectral classes [17]. Image classification of the Enhanced Landsat Thematic Mapper displays an increase in siltation problem along the entrance of the Suez Canal port during 2000–2018 (**Figure 3**).

4. Required data for modeling

The data input for Mike 21-2D modeling, which is the key parameter to run spectral wave (SW) model, the flow model of hydrodynamics (HD), and flow model of sediment transport (ST), includes bathymetry, tide, wind, waves, sediment grain size, and shoreline position. Simulation of shoreline changes, waves, sediment transport, and hydrodynamic regime, using the Mike 21 HD (Flow Model and Hydrodynamic Module), needs some data sets, which are not changed during all simulation analyses. The required data are (4.1) extracted shoreline positions, (4.2) offshore wave parameters, (4.3) bathymetric survey, and (4.4) sediment grain size.

4.1 Extracted shoreline positions

The shoreline positions provided for modeling were extracted from remote sensing results using Thematic Mapper image technique. Wave characteristics required for modeling are wave height, period, and direction. Wave data were measured at Ras El-Bar station. Waves were recorded using a Cassette Acquisition System (CAS); the wave gauge was installed about 1200 m away from the western side of the navigation channel of the Damietta harbor, at water depth of 12 m. The recorder measured the wave characteristics for 20 min each 4 h during a day [18]. Data provided from the Coastal Research Institute in Alexandria have been analyzed in order to determine wave height, period, and direction. These data represent the wave parameters in year 1986 for eastern Nile Delta coast. Bathymetric data were supplied from the Suez Canal Authority. It shows parallel offshore contours to the shoreline trend from 0 to 20 m depth within the nearshore zone.

Satellite images are the main source of data for shoreline positions in this study. Data acquired include SPOT-4 images for year 2006, ETM+ Landsat 7 images during 2000–2012, EgyptSat images for year 2010, and Landsat 8 images for years 2013, 2014, and 2018.

4.2 Offshore wave parameters

Tidal data along the Egyptian Mediterranean coast do not exceed 44–50 cm range. Consequently, tide has insignificant role as input data for MIKE 21 modeling. One-year measurements (1990–2000) of wind and wave series data used in this study were measured in Port Said. The strongest wind series are coming from SSW to WSW direction and blowing from land; therefore, it did not create any waves approaching the shoreline. However, it transported beach sand toward offshore. The velocity of this series is 13.8 m/s. This speed is not strong enough to generate storm (wind speed 18 between 24.5 and 32.6 m/s). The main input wave parameters for the hydraulic computations in LITDRIFT and LITLINE are wave height, wave angle, and wave period. Longshore currents crossing beach profiles are generated using these programs due to shoaling and refraction of the incident waves. Wave data were supplied from many sources such as Suez Canal Authority and Delft Hydraulics. For year 2003, it was measured in Damietta promontory, while wave data for years 1986, 1987, and 1990 were measured in Rosetta promontory. Finally, during 2009–2013, it was measured in Alexandria.

4.3 Bathymetric survey

The bathymetric data used in this study were supplied from the Egyptian Military Survey as hard copy maps. Bathymetric data for year 2004 was used in Port Said and Suez Canal areas. This data was scanned by AutoCAD 2014 software to be digitized and processed using civil 3D software to get (x, y, z) format and work with Mike 21 Flow Model. Mesh file map was generated from the x, y, z digital file using MIKE 21 to understand hydrodynamics regime and sediment transport.

4.4 Sediment grain size

The sediment properties should be defined for each grid point in the cross-shore profile. The average grain size diameter at one of the concerned site, Port Said, is 0.14–1.21 mm (fine sand), and the closure depth is at a range of 2–4 m, and berm height varies from 0.5 to 1 m [18]. The changes in this range produce slight response in shoreline changes (which calculated by Genesis 1D modeling) [19]. When the median grain size decreased from 0.40 to 0.14 mm, there was no change in the shoreline position. The LITPACK module calculates the sediment transport capacity (i.e., it assumes that there is an unlimited source of sediment supply) [20].

5. Results of modeling techniques

Coastal zones are one of the most important areas for human activities and infrastructure growth. However, the systems in these areas are dynamic and need to be studied extensively before planning infrastructure to avoid damages. Numerical modeling is considered as important tool to evaluate coastal zone systems and predict its environmental characteristics. Quantitative prediction of coastal processes and coastal evolution via numerical modeling is now possible due to the major advances that have been made in understanding physical processes and mathematical modeling techniques. The problem of Nile Delta localities is the intensive erosion following construction of some engineering protection and transporting of these materials from beach face by waves and longshore currents. Consequently, the application of modeling is very important to understand hydrodynamic regime and coastal processes controlling coastal erosion and accretion at the concerned sites. In addition, the impact of construction of some engineering protections on the coastal morphodynamic during 2000–2015 will be evaluated. MIKE 21 by Danish Hydraulic Institute (DHI) software is such an integrated complete coastal modeling suite, commercially marketed by Danish Hydraulic Institute, which delivers superior technology, expert support, and outstanding value based on 40 years of experience. The DHI group helped us in this study by giving a permission to use the original package of MIKE 21 with a limited license. Certain modules were selected from MIKE 21 to achieve the objectives of this study; they are (1) MIKE 21 SW, (2) MIKE 21 HD, and (3) MIKE 21 sand transport (ST).

5.1 MIKE 21 spectral wave

Wave characteristics required for modeling are wave height, period, and direction. Wave data were measured at Ras El-Bar station for the eastern part of the Mediterranean coastal zone. The station was put nearly 1200 m away from the western side of the navigation channel of the Damietta harbor, at water depth of 12 m [7, 19]. The recorder measured the wave characteristics for 20 min each 4 h during a day. Data provided from the Coastal Research Institute in Alexandria have been analyzed in order to determine wave height, period, and direction. These data represent the wave parameters in year 1992 for eastern Nile Delta coast.

In order to simulate the growth, transformation of wind-generated waves, and swell in offshore in coastal zones, MIKE 21 spectral analysis module (SW) has been used to get two-dimensional wave heights for the study area according to wave bottom interactions and wave structure interactions (shoaling, refraction, diffraction, reflection, bottom friction, and wave breaking) [20] (**Figure 4**).

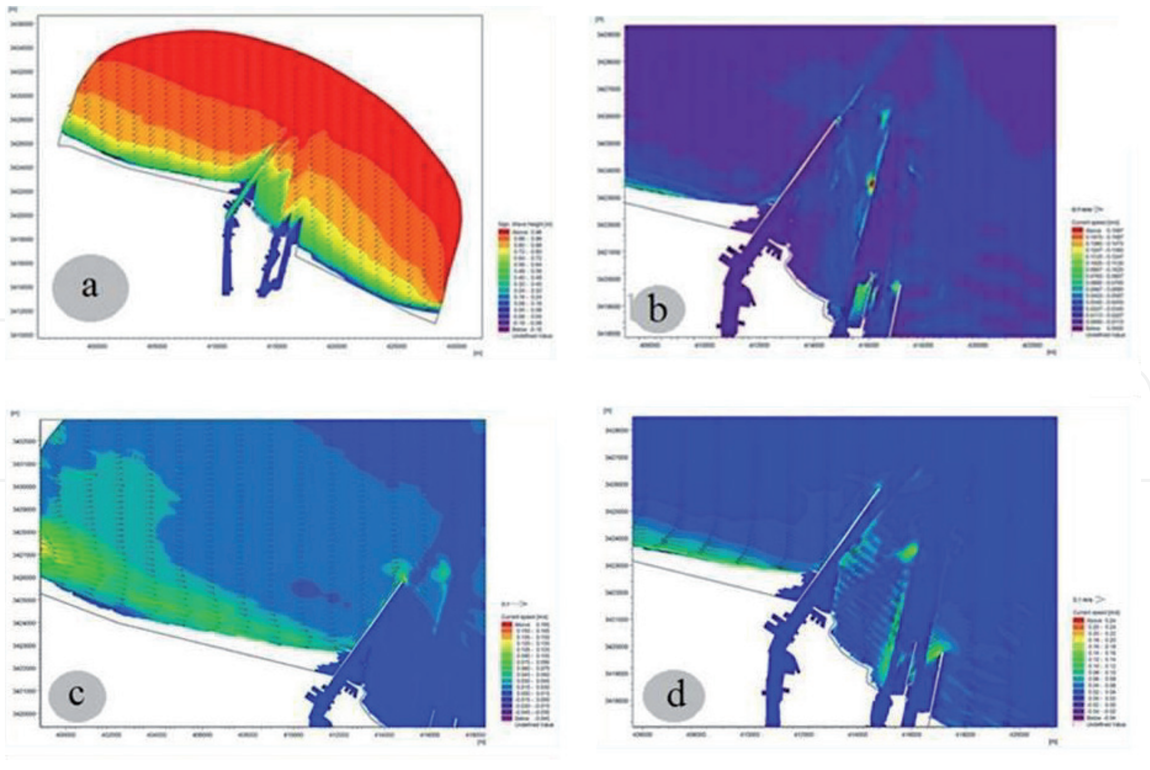

Figure 4.
Simulated spectral wave (SW) model for Suez Canal entrance including (a) spectral waves in NNW direction, (b) spectral waves in NW direction, (c) spectral waves in N direction, and (d) spectral waves in NE direction.

The model has coarsely triangle mesh at offshore zones and finely triangle mesh at surf zones and study area to get more accurate wave heights with acceptable model run period [21].

MIKE 21 SW includes two different formulations:

1. Directional decoupled parametric formulation

2. Fully spectral formulation [22].

5.2 MIKE 21 hydrodynamics

MIKE 21 hydrodynamic has modeled to solve currents due to interaction between wave radiation stresses and water level variations with bottom depths and structures at study area in addition to updrift and downdrift zones. The hydrodynamic forces due to wave breaking are the main effective parameters that lead sediments to move [23].

5.3 MIKE 21 sand transport

This model will be used to predict coastal sand transport and morphodynamics; MIKE 21 sediment transport is designed for the assessment of the sediment transport rates and related initial rates of bed level changes of non-cohesive sediment (sand) due to currents or combined wave-current flow [24]. It is only adapted for non-cohesive sediment (e.g., sand) for which it provides good results. Mathematical shoreline models are tools which are widely used to study the effect of hydrographic parameters on coastal processes and calculate the sediment transport rates and consequently the shoreline changes. The sediment transport process at onshore/offshore and/or alongshore is very complicated problem because it results from

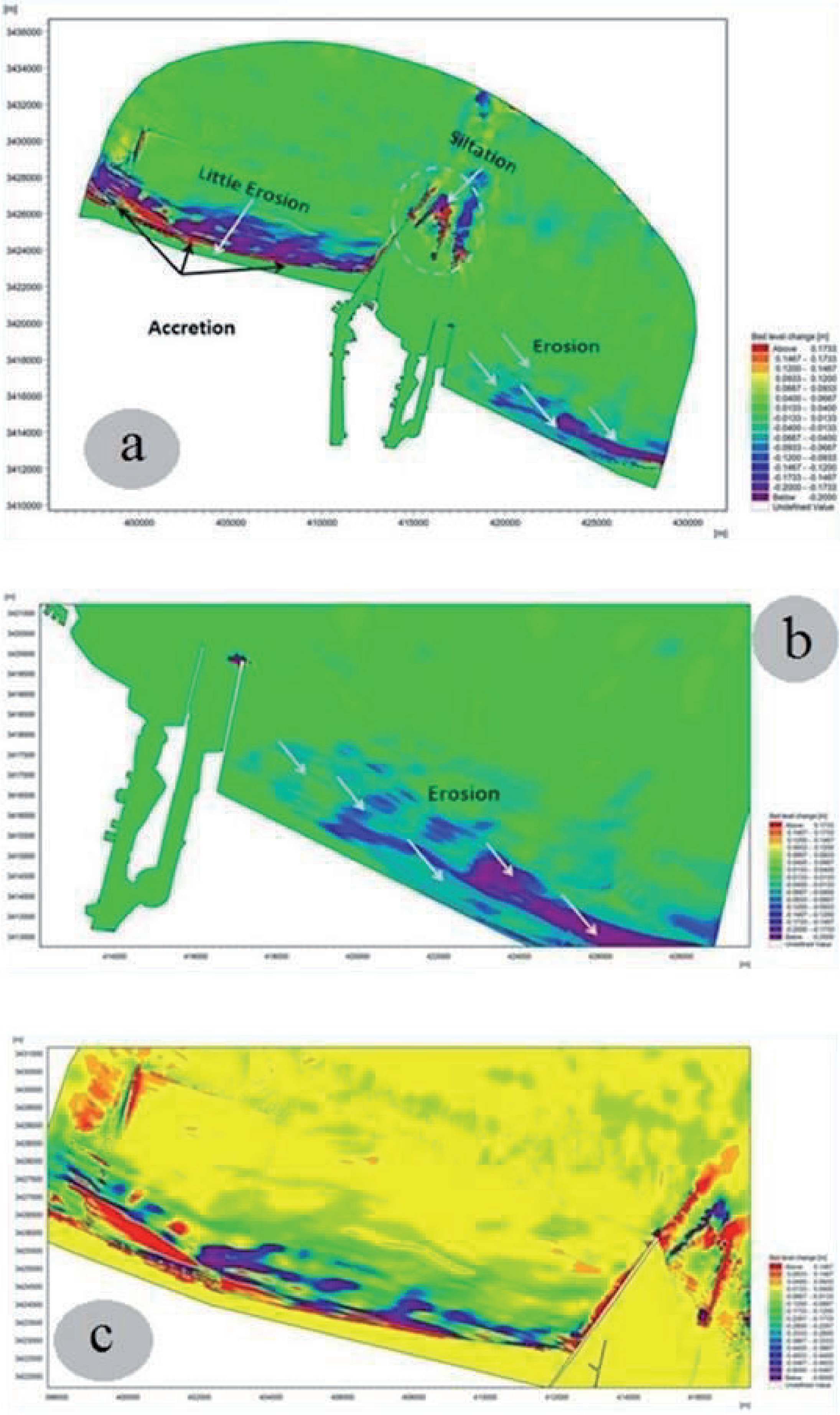

Figure 5.
Modeling simulation of 10 years sediment transport during 2008–2018 along the Suez Canal coastal zone; (a) accretion along the updrift site and the entrance otherwise, erosion along the downdrift site; (b) erosion behind the eastern Jetty; and (c) siltation behind the western jetty.

iteration from wind, waves, and currents with the bottom sediments and/or the shore face. The orbital velocity of the waves is the principal force to shake the sediments in its place and put them in suspended case, while the currents existing in this area are responsible for transport of sediment from one place to another.

Therefore, the sand movement in the longshore direction is the longshore sediment transport, while the actual volume of sand involved in the transport are termed the littoral drift Qs that counted in m^3/year or month. All morphological changes happen due to the littoral drift current, which was created as a result of waves that approach the coastline with an oblique angle. Based on that, the relationship between the incident wave and shoreline orientation is a major factor in evaluating the morphological changes for any studied area. All morphological changes happen due to the littoral drift current, which was created as a result of waves that approaches the coastline with an oblique angle. Based on that, the relationship between the incident wave and shoreline orientation is the goal of this study.

In conclusion, siltation inside Suez Canal entrance can be explained due to moving of waves and currents at west Port Said and inside the entrance of Suez Canal. Therefore, when current comes from shallow depths at west of Port Said in the direction of W-E to deep depths at the entrance of Suez Canal, while it is carrying sediment load, its speed gradually decreases near the long western Suez Canal jetty and starts making eddies up to the long jetty, and once it becomes quiet, it starts throwing its sediment load inside Suez Canal entrance (**Figure 5a–c**).

6. Discussion and conclusion

Construction of ports such as in the Suez Canal entrance has a significant potential effect on natural sediment transport processes. This causes disruption to the adjacent beaches. When current transfers from low contour level at west of Suez Canal long jetty, it decreases gradually inside the entrance of Suez Canal then started to increase and decrease back and forth, by making eddies. This eddies around the eastern and western jetties start to throw their load, while the high current speed at the eastern side of Port Said causes erosion. Consequently, some recommendations are suggested as follows:

- Increasing coastal development has led to a conflict between man desire and nature processes that modified the used land. Therefore, most countries that are located on coastal areas should study in details the coastal zone management problems and risk as a result of the protection work structure effect on coastal area hydrodynamic regime.

- Choice should be taken between allowing unlimited construction of high-valued property and implementing the regulations that prevent developments which would be exposed to major hazards. This choice requires the estimation and prediction of probable future shoreline position and risk assessment to balance between the possible losses of development against the reduction of the existing shoreline.

- Integration between remote sensing and 2D finite hydrodynamic flow models is mandatory to evaluate, interpret, and analyze the effect of costal processes and protection hard structures.

- Because of high current speed at Suez Canal east jetties, the downdrift area is exposed to sever erosion, and there is an investment plan to implement big national projects on it, so it is mandatory to study and monitor the rates of erosion and consider it in any construction plans.

- Studying of sediment transport and bed level change and highlighting the risky and hot spot areas of erosions of east and west of Suez Canal to predict the annual rates before implementing any projects.

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