Impacts of Coastal Structures on Sediment Transport: A Case Study of Damietta, Egypt

Utjecaj obalnih struktura na transport nanosa: studija slučaja luke Damietta, Egipat

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Abstract

Within the framework of safeguarding Egypt's coastal lowlands, which face escalating susceptibility to both climate change and human interventions, this study aims to provide a comprehensive analysis of sediment transport dynamics and their implications, with Damietta serving as a case study. To achieve this, a thorough review of the existing literature on sediment transport dynamics was conducted. MIKE21 Shoreline Morphology (MIKE21 SM) model was employed to simulate longshore sediment transport (LST) dynamics both before and after the construction of Damietta Port (DP). Analysis of the model output revealed that the model underestimated the influence of waves, primarily originating from the Northwest, on shaping the LST pattern. The results indicate that the construction of DP led to a reduction in average gross longshore sediment transport (GLST) and average net longshore sediment transport (NLST) by 18%, decreasing from 1.1 to 0.9 106 x m^3/year, and 42%, decreasing from 0.73 to 0.42 x 106 m3/year, respectively. Additionally, the average monthly GLST and NLST reductions were 17% and 37%, respectively, compared to pre-construction conditions. Consequently, this research underscores the importance of continuous monitoring of sediment transport to ensure shoreline stability and protect surrounding ecological systems. This recommendation is vital for managing and mitigating the impacts of ongoing and future coastal interventions.

KEY WORDS
Coastal Zones
Marine
Sediment Transport
Damietta Port
MIKE21 SM

Sažetak

Unutar plana nadziranja obalnih područja Egipta, koja se suočavaju s eskaliranom osjeljivošću na klimatske promjene i intervenciju čovjeka, ova studija ima za cilj osigurati temeljitu analizu dinamike transporta nanosa i njezinu primjenu, gdje Damietta služi kao studija slučaja. Da bi se ovo postiglo, obavljen je temeljiti pregled postojeće literature o nanošenju sedimenta. MIKE21 Shoreline Morphology (MIKE21 SM) model upotrijebljen je da bi se simulirala dinamika obalnoga nanošenja sedimenta (LST) prije i nakon izgradnje luke Damietta (DP). Analiza ishoda modela otkrila je da je model podcijenio utjecaj valova, odnosno onih koji dolaze sa sjeverozapada, a koji oblikuju LST uzorak. Rezultati navode da je konstrukcija DP dovela do smanjenja u prosječnom bruto obalnom nanosu (GLST) i prosječnom neto obalnom nanosu sedimenata (NLST) za 18%, a koji se smanjuje s 1.1 na 0.9 106 x m^3/godišnje i 42%, koji se smanjuje s 0.73 na 0.42 x 106 m3/godišnje, redoslijedom navođenja. K tome, prosječne redukcije u GLST i NLST bile su 17% i 37%, kako je navedeno, u usporedbi s uvjetima koji su bili prije izgradnje. Posljedično tome, ovo istraživanje naglašava važnost neprestanoga nadzora transporta sedimenata, da bi se osigurala stabilnost obale i zaštitio okolni ekološki sustav. Ova je preporuka važna za upravljanje i ublažavanje utjecaja sadašnjih i budućih obalnih intervencija.

KLJUČNE RIJEČI
obalna područja
nanos morskoga sedimenta
luka Damietta
MIKE21SM

1. INTRODUCTION / *Uvod*

Coastal regions are susceptible to climate change with their hazards [1]. Such areas appeal to development and citizens in spite of the fact that sea level rise will persist throughout the coming centuries [2,3]. Accordingly, the susceptibility of these areas arises from their exposure to environmental hazards so as human activities [4]. Thus, it is of great importance to visualize the climate change impact on such zones, especially the Mediterranean region, which is vulnerable to faster temperature rises.

Sediment transport is a wave-induced-mechanisms that leads to the vitality of coastal management and consequently an escalating need for hydrodynamics studies, which could

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be achieved by the implementation of numerical models to evaluate hazards [5-9]. Accordingly, such models acquire persistent validation to boost their reliability, where different modeling approaches were established, as sustainable coastal management importance is escalating worldwide. Accordingly, managing such zones is of significance due to their complex environmental hazards as human activities [10-12].

Over centuries, human activities and climate change have induced dynamic changes in coastal regions, where such changes result in spatial changes in coastal systems. Accordingly, understanding the sediment transport pattern changing is crucial for zone management, which can be achieved by investigating long-term wave data via the implementation of numerical models, [13-16]. Coastal erosion, exacerbated by climate change and increasing human activities, poses a significant threat to coastal communities [17,18].

The Mediterranean Sea (MS), connected to the Atlantic Ocean via the Strait of Gibraltar, is a region significantly impacted by both human activities and climate change. These factors exacerbate the vulnerability of its coastal zones to natural hazards, making it essential to understand and predict shoreline changes for effective coastal management strategies aimed at mitigating the impacts of climate change [19,20].

Sediment transport dynamics, particularly near the breaker zone, are highly complex due to the influence of wave-induced currents and spatially variable flow patterns [21,22]. Waves breaking near the coastline play a crucial role in mobilizing sediments, with their characteristics largely dictating sediment transport behavior. For instance, during storm events, steep waves tend to push sediments offshore, intensifying coastal erosion. On the other hand, longer-period waves contribute to sediment transport toward the shore, which promotes beach accretion [23,24]. Consequently, longshore sediment transport (LST) becomes a critical process for understanding shoreline changes over varying temporal scales and plays a significant role in maintaining coastal equilibrium and morphodynamics [25-29].

Moreover, human interventions, such as the construction of ports, harbors, and seawalls, have significantly disrupted natural coastal processes. This is especially true in regions with complex coastal geometries. These structures alter nearshore dynamics, impacting both sediment transport and ecological systems [30-32]. The extent of these disruptions varies based on the type and scale of the intervention, as well as the resilience of the affected ecosystem [33]. Such alterations often result in either sediment accumulation or increased erosion, which reduces the coastline's natural resilience to the impacts of climate change and storm events while also diminishing its capacity to absorb wave energy [34].

A prime example of this instability is the Egyptian coastal zone, particularly the Nile Delta, where both natural processes and human activities have driven considerable changes [35,36]. Seabed sediments predominantly migrate eastward along the Nile Delta, resulting in significant longshore sediment transport rates [37]. However, human interventions, such as the construction of the Aswan High Dam (AHD), have further disrupted these natural processes. Prior to the dam's full operation, approximately 30 million tons of sediment reached the Damietta promontory each year. Today, the AHD has blocked most of that sediment, leading to a sharp increase in coastal erosion [38,39].

Although numerous studies have explored wave and sediment transport dynamics along coastal regions, a critical gap remains in understanding the long-term effects of human interventions on sediment movement. This study addresses that gap by utilizing Damietta Port as a case study, given its significance for both local and international trade. Specifically, this research aims to evaluate the impact of human interventions on neighboring beaches. By focusing on Damietta Port, the findings provide valuable insights into the consequences of human activities on sediment transport and coastal stability.

2. METHODOLOGY / *Metodologija*

Coastal regions are pivotal due to their dense populations and significant economic and social roles. Therefore, they require thorough environmental insights to ensure sustainable development. In this context, this study underscores the urgent need for high-resolution data to investigate wave climatology and climate variability. Moreover, integrating observed measurements with hindcast data facilitates a more detailed analysis of coastal processes. This integration, in turn, supports informed decision-making and enhances sustainable coastal management.

This section outlines the structured methodology employed in this study, which combines primary observed measurements with secondary hindcast data. This approach provides a comprehensive understanding of coastal dynamics and ensures robustness in the analysis. To further elucidate the methodology, Figure 1 presents a flow chart that illustrates the sequential steps involved.

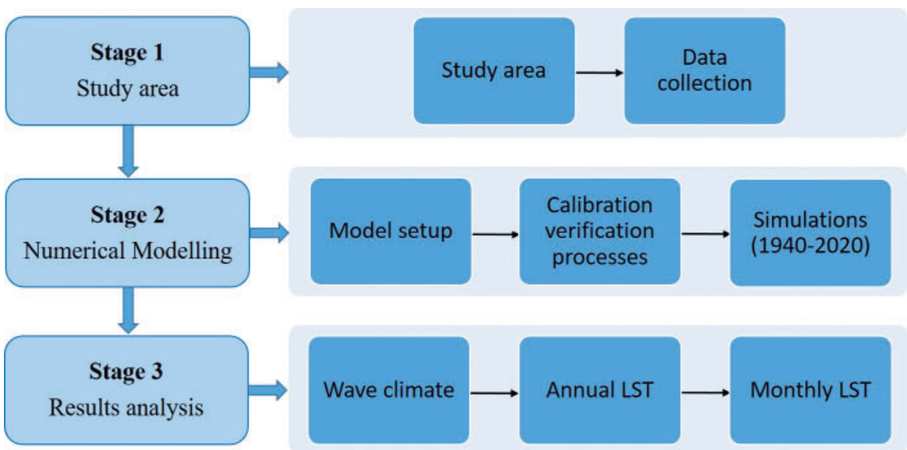

Figure 1 Flow chart of the methodology steps
Slika 1. Prikaz tijeka metodoloških koraka

2.1. Study area description / *Opis područja proučavanja*

The study area encompasses a 10 km coastal segment, within which DP is situated. Constructed in 1981, DP is an inland port with a depth of 15 m (see Figure 2) designed to accommodate the increasing demands of international trade in the Eastern Mediterranean region [40]. To mitigate sediment entrapment, the port was equipped with two jetties. It is located 9.7 km west of the Damietta Branch [41].

Notably, the site selected for DP has low susceptibility to waves and currents, making it an accreting zone [42,43]. However, the sediment patterns in the area were significantly altered following the construction of the Aswan High Dam [44]. Despite these changes, DP's location remains characterized by accretion [45].

Several coastal protection measures have been implemented along the coastal line. These include two jetties along the Damietta Branch, a seawall, a revetment, three additional jetties, and eight detached breakwaters parallel to the shoreline. Furthermore, between 2016 and 2019, four detached breakwaters, each 200 m long with 240 m gaps, were constructed over a 1.5 km stretch to protect DP. These defense structures, along with the port, have altered the wave refraction patterns, leading to new erosion and deposition patterns in the region [46].

2.2. Data collection / *Prikupljanje podataka*

Various datasets describing the study area were collected from multiple sources to ensure a comprehensive analysis. Specifically, the observed data were sourced from the Egyptian Coastal Research Institute (CoRI), previous research conducted in the study area. While the bathymetric information was derived from two distinct surveys. The first survey, conducted in 2010, provided a detailed bathymetric map of the area (Figure 3). While, the second survey, completed in 2011, produced profiles used for calibration and verification purposes. Additionally, nearshore wave data were gathered through a buoy positioned near DP at coordinates 31°30.43′ N and 31°45.6′ E, located at a depth of 12 m. However, in regions with limited buoy measurements, methods are employed to extend the time series [47]. To complement this, long-term deep-water wave data covering 81 years (1940–2020) were obtained from the ECMWF-ERA5 reanalysis dataset. This buoy recorded data over the period 2003–2004, capturing wave measurements every four hours.

Frihy et al. [48] conducted a grain size analysis using a standard Ro-Tap sieving system, which employed whole phi sieve intervals. Their findings indicated a gradual decrease in mean grain size offshore. Specifically, the mean grain size of beach sediments fluctuates between 0.14 mm and 0.58 mm, with an average of 0.25 mm. However, offshore sediment (i.e. up to 6 m depth) varies between 0.08 and 0.22 mm, where the mean grain size varies between 0.08 and 0.22 mm with an average of 0.11 mm, where the closure depth was designated to be 8 m (approximately 1.3 km offshore).

Tidal data was accumulated to feature that the tidal range is 14 cm with a daily mean sea level variation of 60 cm at Port Said [49]**.** Additionally, currents data were augmented, where they mainly flow eastwards (i.e. NE-E sector) and westward (i.e. WSW-WNW sector). However, in winter (i.e. November to February), the highest current velocity occurred in January (i.e. 100 cm/s), where the average occurred in winter within the range between 15 and 20 cm/s [48,50].

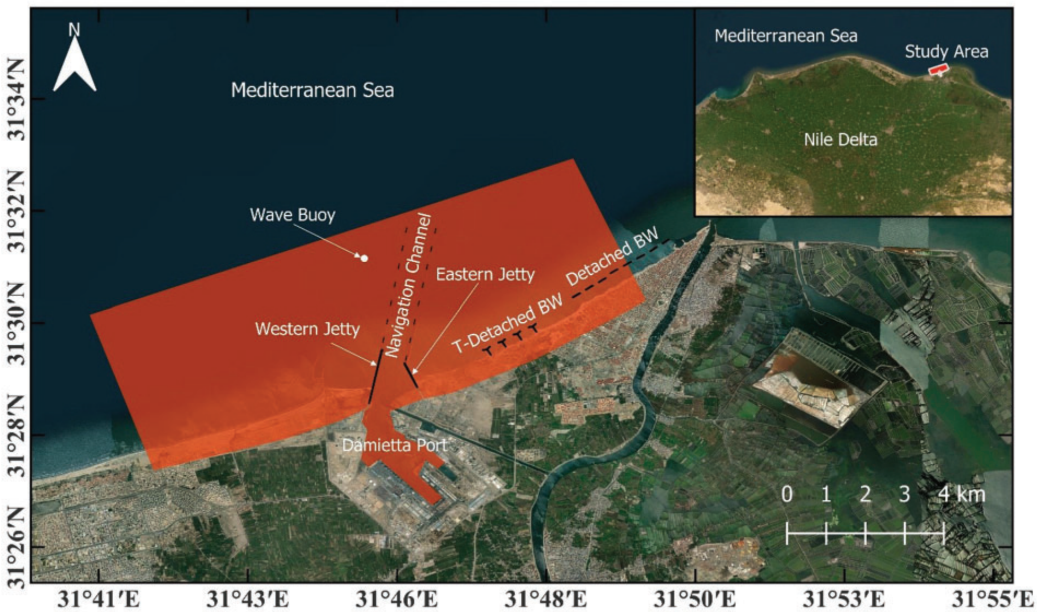

Figure 2 Study area, monitoring buoy, and location of the coastal structures
Slika 2. Područje proučavanja, nadzorna plutača i lokacija obalnih struktura

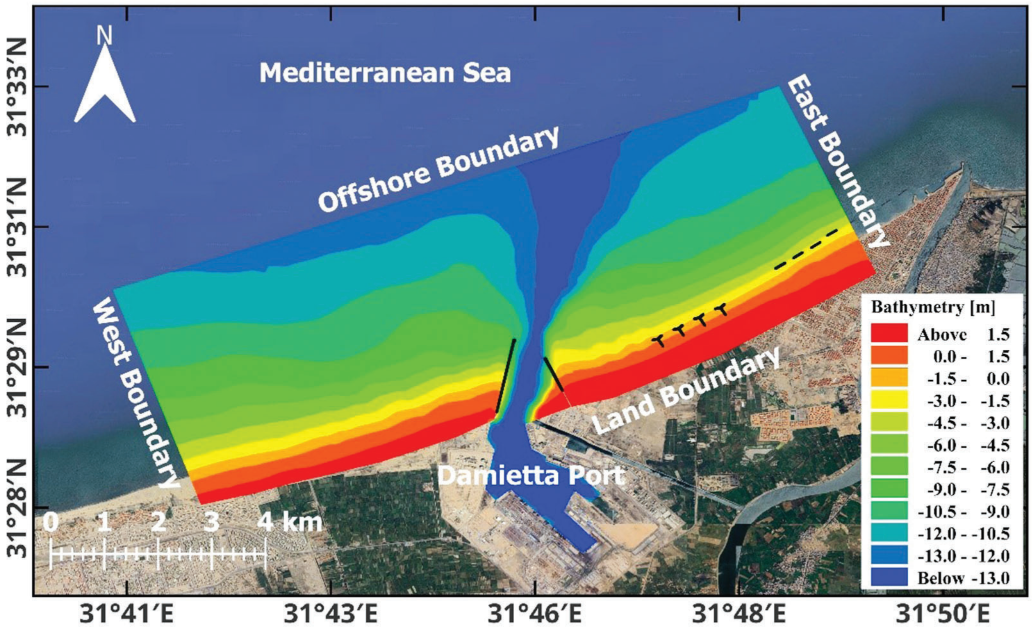

Figure 3 Bathymetric survey of the study area by CoRI, 2010
Slika 3. Batimetrijski pregled područja proučavanja s pomoću CoRI, 2010

2.3. Numerical modeling / *Numeričko modeliranje*

In this study, the MIKE 21 SM was employed to simulate the LST dynamics along the Damietta coast, both before and after the construction of Damietta Port. MIKE 21, a well-established numerical modeling tool, is recognized for its accuracy in simulating sediment transport, hydrodynamic processes, and shoreline evolution. To evaluate the impact of Damietta Port on LST, MIKE 21 SM has proven to be particularly effective due to its ability to model complex coastal dynamics with high precision. In particular, the software has been successfully applied in several coastal studies, demonstrating its reliability in predicting changes in sediment transport patterns [51-58].

2.3.1. Theoretical background / *Teoretska pozadina*

MIKE21 SM, developed by the Danish Hydraulic Institute (DHI), is a shoreline morphology tool designed to model coastal dynamics. As part of the MIKE21 program framework, it integrates hydrodynamic and sediment transport functionalities. MIKE21 was chosen for this study due to its global acceptance and proven effectiveness in various applications. Its flexible grid-based structure excels in simulating two-dimensional dynamics, such as waves and sediment transport in coastal areas and estuaries.

MIKE21 is a comprehensive software package that simulates coastal processes through several modules. It includes four main modules: Spectral Wave (MIKE21 SW), Hydrodynamic (MIKE21 HD), Sand Transport (MIKE21 ST), and Shoreline Morphology. MIKE21 HD addresses the conservation of mass and momentum, while MIKE21 SW employs a cell-centered finite-volume technique to solve the differential equations governing wave dynamics. The governing equations in MIKE21 SW are available in both Cartesian and Polar coordinates [59,60], as follows:

$$\frac{S}{\sigma} = \frac{\partial N}{\partial t} + \nabla(\vec{v}N) \tag{1}$$

Where:

Where: $N(\sigma, \theta, x, t)$ represents the action density, with t as the time. (x, y) denotes the Cartesian coordinates x, while $v = (c_\sigma, c_\theta, c_x, c_y)$ are the group propagation velocity in four dimensions. ∇ is a four-dimensional differential operator in space (v, σ, and θ).

On the other hand, MIKE21 ST calculates sediment transport due to wave-current interaction and other factors (i.e. turbulence and sediment concentration). MIKE21 ST calculates bed- and suspended-load-transport, using flow velocity Shields parameter, where the vertical variation in the sediment concentration is estimated by a diffusion equation. MIKE21 ST provides the littoral drift gradient, shape shoreline morphology by the continuity equation of MIKE21 SM via the implementation of the one-line theory, which divides the shore into perpendicular strips to calculate the changes in shoreline position due to the volumetric relationship of each strip, as follows:

$$\frac{\Delta N}{\Delta t} = \frac{vol}{dA_z} \tag{2}$$

Where: Δt: time increment, ΔN is the distance the shoreline moves perpendicular to its orientation and dAz is the vertical area of the active coastal profile in each shoreface strip over which MIKE21 SM uniformly distributes.

For a detailed description of MIKE21 SM and its applications, refer to [53,61–64]. These sources offer comprehensive insights into the model's framework and its implementation for sediment transport analysis.

2.4. Calibration-verification processes / *Procedure kalibracije-verifikacije*

The calibration and verification results were analyzed by implementing statistical metrics, including average ($\bar{x}$), correlation coefficient (CC), Root Mean Square Error (RMSE), bias, Scatter Index (SI), where bias quantifies is the disparity between the measured and computed values, as follows:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x \tag{3}$$

$$CC = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2 \sum_{i=1}^{n}(y_i-\bar{y})^2}} \tag{4}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y-x)^2} \quad (5)$$

$$BIAS = \frac{1}{n}\sum_{i=1}^{n}(y-\bar{x}) \quad (6)$$

$$SI = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y-x-BIAS)^2}}{\frac{1}{n}\sum_{i=1}^{n}|x_i|} \quad (7)$$

Where: n represents the number of data, x is the measured value, y is the simulated value, and $\bar{x}$ represent the average values.

2.4.1. Calibration / *Kalibracija*

Model calibration is an important phase of numerical modeling, through which the model parameters are tuned to force the model to produce output data similar to observed data. Accordingly, MIKE 21 was calibrated in terms of wave height, wave period and bed level (i.e. H, T and d). During the calibration process, ERA5 deep wave data for the year 2003 were implemented and the output (i.e. near-shore wave data) was contrasted against the measured near shore wave data of 2003. During the calibration process, 2 profiles of the 2011 bathymetrical survey were implemented and the output was analogized against the bathymetrical survey data of 2011.

2.4.2. Verification / *Verifikacija*

Model verification is a crucial stage in numerical modeling, during which the tuned model parameters are implemented (i.e. together with input data for an interval different from that implemented during the calibration process) to produce output data similar to observed data during the same interval. Accordingly, MIKE 21 was verified in terms of wave height, wave period and bed level (i.e. H, T and d). During the verification process, ERA5 deep wave data for the year 2004 were implemented and the output (i.e. near shore wave data) was contrasted against the measured near shore wave data of 2004. During the verification process, another 2 profiles of the 2011 bathymetrical survey were utilized and the output was compared to the bathymetrical data of 2011.

2.5. Simulations / *Simulacije*

Confident with the calibration and verification results, MIKE 21 was implemented to simulate a time interval of 81 years. Primarily, data was introduced to the model, where they encompassed the wave data of ERA5 during 1940-2020 and the bathymetrical data of 2010. Simultaneously, all the structures were introduced to the model upon their construction year (i.e. DP and all the protective structures).

MIKE 21 was operated, where its internal computation utilized the input data. During the internal computation, the deep waves were transformed to near shore waves. Also, during the internal computation, MIKE 21 calculated GLST and NLST for the pre- and post- construction of DP with its protective measures. It is of significance to mention that DP was constructed in 1982. Accordingly, the pre-construction condition prevailed before 1982, while the post-construction condition reflects the duration after 1982.

3. RESULTS ANALYSIS AND DISCUSSION / *Analiza rezultata i rasprava*

3.1. Calibration-verification results analysis and discussion / *Analiza rezultata kalibracije-verifikacije i rasprava*

During the calibration process, using equations 3 through 7, the model demonstrated high correlation values with the measured data for all parameters. Specifically, the Correlation Coefficient for wave height and water depth were 0.93 and 0.99, respectively. Additionally, the Root Mean Square Error values were relatively low, indicating a strong agreement between the computed and measured data. However, a slight bias was observed in some cases, such as a negative bias in wave height (i.e., -0.03). In the subsequent verification process, as described by equations 3 through 7, the model continued to show a high correlation with the measured data. Nevertheless, some parameters exhibited slightly higher RMSE values, as detailed in Table 1. Despite this, the data presented in Table 1 clearly demonstrate the model's capability to effectively predict crucial parameters for the study area. This verification highlights the model's potential for providing valuable results in future applications.

The verification results from this study align with previous research in the Mediterranean Sea using ERA5 data. Amarouche et al. [19] reported Bias, RMSE, and SI values for Hs of 0.04m, 0.31m, and 0.3%, respectively. Similarly, Abu Zed et al. [65] using the SWAN model, found Bias, RMSE, and SI values for Hs of 0.06m, 0.22m, and 0.33%, and for Tp of 0.43s, 1.34s, and 0.18%. Elkut et al. [66] also found comparable values for Hs, with Bias, RMSE, and SI of -0.28m, 0.29m, and 0.31%.

Table 1 Statistical metrics of the model calibration and verification processes

Tablica 1. Metrička statistika modela procesa kalibracije i verifikacije

Parameters	Calibration				Verification			
	CC	Bias	RMSE	SI (%)	CC	Bias	RMSE	SI (%)
Wave height (m)	0.93	0.03	0.18	0.29	0.9	-0.03	0.23	0.31
Wave period (s)	0.78	-0.29	1.04	0.15	0.72	-0.19	1.26	0.19
Bed level (m)	0.99	0.05	0.21	0.04	0.99	0.09	0.21	0.04

3.2. Wave climate results analysis and discussion / *Analiza rezultata klimatskih valova i rasprava*

The computed wave data obtained from MIKE 21 are presented in Figure 4, where the figure represents the long term wave distribution, in terms of direction and height simulated over 81-year.

From the figure, it is evident that the dominant wave along Damietta is propagating from the North-North West sector (i.e. N-NW) sector. The obtained rose indicates that H_s is less than 1 m during 90% of the year, with an annual average of around 0.9 m. However, H_s ranges between 1.5 and 4.9 m during 10% of the year.

Moreover, Figure 4 indicates that the predominant wave direction originates from the north-northwest (NNW), where 40% of waves approach from the sector of 320 to 340 degrees. However, the maximum wave height reach 4.98 m from the North direction, while throughout the year, the waves predominantly approach from the NW 87% of the year.

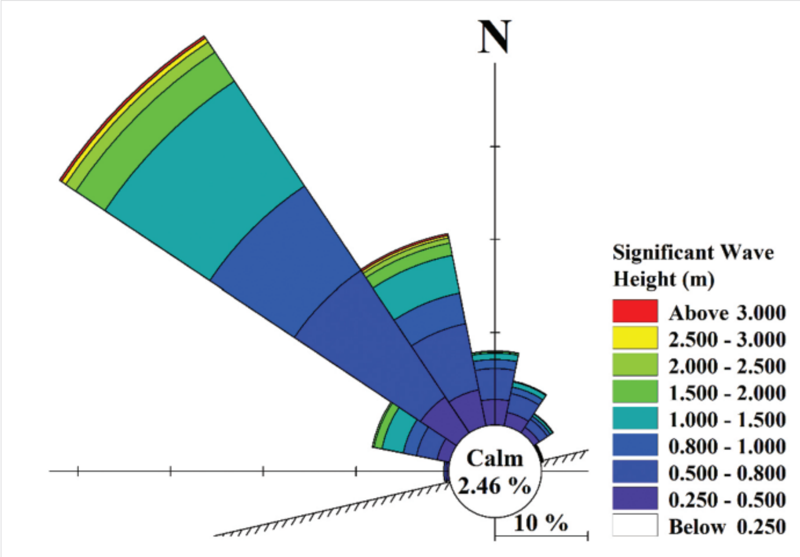

Figure 4 Wave rose of significant wave height at a depth of 14 m (1940-2020)
Slika 4. Ruža valova značajnih visina valova na dubini od 14 m (1940. – 2020.)

3.3. Longshore sediment transport results analysis and discussion / *Analiza rezultata nanosa sedimenta na obali i rasprava*

The model results indicated that the major annual LST moves from West to East, as the waves originate from the NW. This section elaborates the results of the annual LST, monthly GLST and monthly NLST, as follows:

3.3.1. Annual longshore sediment transport / *Godišnji nanos sedimenata na obali*

The annual LST (i.e. NLST and GLST) was analyzed and presented on figures 5 and 6. The figures provide the computed values pre- and post-DP construction (i.e. 1940-1981 and 1982-2020), respectively.

During the pre-DP construction, GLST ranged between 0.87 and 1.5 x10^6 m^3/yr with an average of 1.1 x10^6 m^3/yr. During the pre-DP construction, NLST ranged between 0.49 and 1.04 x10^6 m^3/yr, with an average of 0.73 x10^6 m^3/yr. These values agree to previous findings in the study area, where researchers estimated the transport to be 0.66 x10^6 m^3/year to the East and 0.26 x10^6 m^3/year to the West with NLST of 0.4x10^6 m^3/year to the East [43]. However, other researchers estimated NLST to be 0.8x10^6 m^3/year [67], while [68] estimated it to be 0.6-1.8x10^6 m^3/year.

During the post-DP construction, GLST ranged between 0.75 and 1.07 x10^6 m^3/yr with an average of 0.9 x10^6 m^3/yr. During the pre-DP construction, NLST ranged between 0.25 and 0.65 x10^6 m^3/yr, with an average of 0.42 x10^6 m^3/yr. A similar estimate was previously documented. However, Frihy et al. [48] employed fluorescent tracers to designate the annual LST. The study revealed that GLST was 0.85x10^6 m^3/year, while NLST was 0.49x10^6 m^3/year.

Based on figures 4 and 5, apparent was the following:

Human intervention resulted in LST alterations, where GLST was 1.1 x10^6 m^3/yr, pre-human-intervention, and decreased to 0.9 x10^6 m^3/yr, post-human-intervention, with a decrease of 18%. Similarly, the average NLST was 0.73 x10^6 m^3/yr, pre-human-intervention, and decreased to 0.42 m^3/yr, post-human-intervention, with a decrease of 42%.

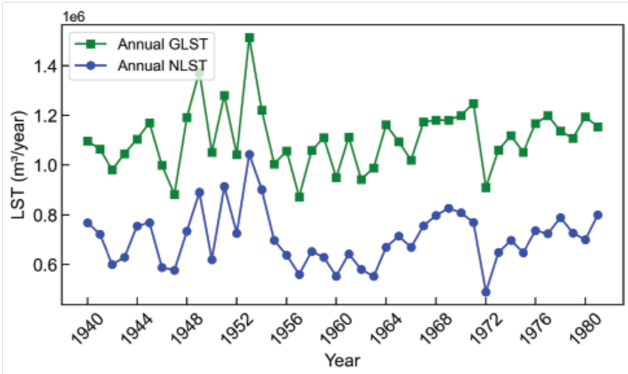

Figure 5 Annual LST pre- DP construction in x10^6 m^3/yr (1940-1981)
Slika 5. Godišnji LST prije izgradnje DP u x 10^6 m^3/godišnje (1940. – 1981.)

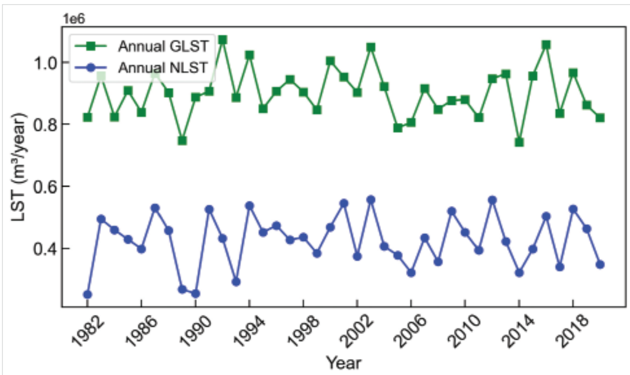

Figure 6 Annual LST post-DP construction in x10^6 m^3/yr (1982-2020)
Slika 6. Godišnji LST nakon izgradnje DP u x 10^6 m^3/godišnje (1982. – 2020.)

3.3.2. Monthly gross longshore sediment transport / *Mjesečni bruto nanos sedimenata na obalu*

The monthly GLST was analyzed and presented on figure 7, where the figure provides the monthly GLST alteration of pre- and post-human-intervention (i.e. DP construction and establishment of the protection measures) in 10^5 m^3/yr.

Pre-human-intervention, the GLST was 1.45 x 10^5 m^3 in January, while this value was reduced to be 1.15 x 10^5 m^3 with 21% reduction. February value experienced 10% reduction, in terms of January value. March and April indicated a significant increase of 28% and 25%, in terms of February and March, respectively. May recorded a marginal increment of 1%, in terms of April. June, July, August and September marked an increase of 18, 27, 35 and 22% in terms of May, June, July and August, respectively. October, November and December reflected minor decrease of 2, 3 and 11%, in terms of August, October and November, respectively. This indicated that GLST decreased by 2 to 21%, while NLST increased by 1 to 35%.

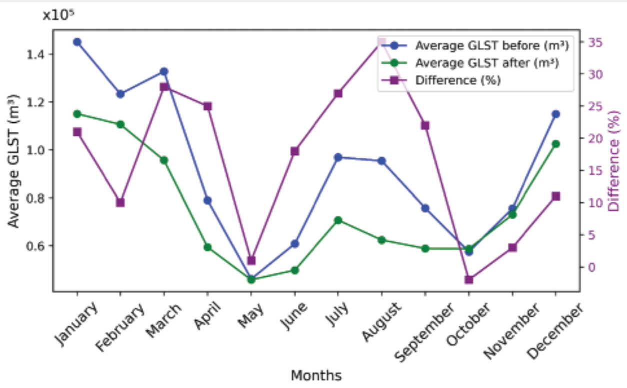

Figure 7 GLST monthly alteration pre- and post-human intervention (10^5 m^3/yr)

Slika 7. GLST mjesečne alteracije prije i nakon intervencija čovjeka (10^5 m^3/godišnje)

3.3.3. Monthly net longshore sediment transport / *Mjesečni neto nanos sedimenta na obalu*

The monthly NLST was analyzed and presented on figure 8, where the figure provides the monthly NLST alteration of pre- and post-human-intervention (i.e. DP construction and establishment of the protection measures) in 10^5 m^3/yr.

Post-human-intervention, NLST exhibited a decrease throughout the year, in terms of pre-human-intervention. The average decrease was 37%, in terms of pre-human-intervention. Pre-human intervention, NLST was 0.96 x 10^5 m^3, while post-human-intervention it decreased to be 0.49 x 10^5 m^3, with a reduction of 49%. This reflects the immediate impact of human intervention on sediment transport. February, March, April, May decreased by 34, 47, 43 and 9%, in terms of January, February, March and April, respectively. June, July, August, September, October, November and December witnessed an increase of 28, 34, 43, 27, 46 and 37% in terms of May, June, July, August, September, October and November, respectively. These results underscored the dynamic changes in NLST, which emphasized the significance of monitoring sediment transport within the framework of human intervention.

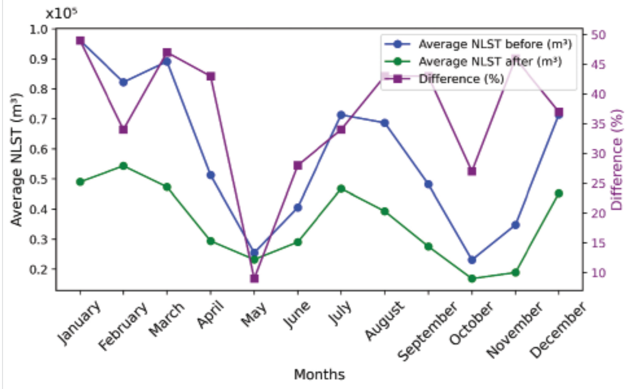

Figure 8 NLST monthly alteration pre- and post-human intervention (10^5 m^3/yr)

Slika 8. NLST mjesečna alternacija prije i poslije čovjekove intervencije (10^5 m^3/godišnje)

4. CONCLUSIONS / *Zaključci*

This study has offered important insights into the effects of DP construction on LST dynamics along the Egyptian coast. By using simulations that were calibrated and validated with field data from the DP coast, it has been demonstrated that significant changes in sediment transport patterns have occurred due to the port's construction and its associated protection measures. Specifically, the findings indicate that sediment transport predominantly flows from west to east, with the DP jetties acting as barriers, trapping most of the net longshore sediment in the western part and the navigation channel. As a result of this obstruction, sediment has accumulated on the western side of the port while significant erosion has taken place on the eastern side, disrupting the natural sediment transport processes. Moreover, the construction of DP and its protective structures has led to a reduction in GLST by 18% and NLST by 42%. When examining this on a monthly scale, the reductions in GLST and NLST were found to be 17% and 37%, respectively, when comparing pre- and post-construction periods. These substantial reductions underscore the considerable impact of human interventions on natural coastal processes.

Looking at the broader implications, the results emphasize the critical importance of understanding and incorporating sediment transport dynamics into coastal management and infrastructure planning. The reduction in sediment transport rates is likely to affect shoreline stability, ecological balance, and the long-term sustainability of DP. Ultimately, by revealing the complex relationship between human development and coastal processes, this study provides valuable information for future coastal engineering projects. It also underscores the need for careful planning to ensure the long-term resilience of coastal regions.

Based on the conclusions, the following recommendations were suggested:

- Additional study and monitoring efforts are required to provide a better comprehension to promote the mitigation strategies.
- Further research is recommended to refine the MIKE21 SM model and incorporate a more comprehensive understanding of the wave dynamics. It will enhance the accuracy of the model and its ability to predict sediment

transport dynamics, thereby contributing to more effective coastal management strategies.

Environmental policies should be established and protection measures should be established. Future research should assess alteration in sediment transport on ecosystems and biodiversity to ensure management and sustainable development to ensure a harmonic balance between infrastructure and ecologic resilience.

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