STUDY OF SEDIMENTATION PROBLEM AT KIASHAHR FISHERY PORT

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This study investigates the significant sedimentation issues observed at Kiashahr Fishery Port in the southern Caspian Sea. Utilizing satellite imagery, hydrographic maps, and numerical modeling, this research examines the impact of port design and environmental factors on sediment accumulation. Despite the initial positioning of the jetties within the surf zone, the study reveals that changes in the dynamic Sefidroud Delta have intensified longshore sediment transport towards the port. Furthermore, the extension of the main breakwater, intended to enhance updrift sediment trapping, inadvertently induced a circulation current behind the secondary breakwater, leading to increased downdrift sediment transport toward the port. This, combined with the bypassing of littoral drift in front of the main breakwater, resulted in substantial sediment accumulation at the port entrance from both updrift and downdrift directions. The findings highlight the critical importance of considering both local hydrodynamics and proper layout design in the planning and construction of coastal structures, particularly for small fishery ports.

Keywords: Kiashahr Fishery Port; sedimentation; morphological simulation; diffraction current; circulation

INTRODUCTION

The construction of coastal structures such as jetties, breakwaters, and groins can significantly impact the natural dynamics of sediment transport along shorelines. When a coastal structure is built, it can block or disrupt the natural flow of Longshore Sediment Transport (LST), leading to notable changes in the adjacent shoreline. A common consequence of these disruptions is shoreline advancement on the updrift side, coupled with erosion on the downdrift side of the structure. In many cases, sediment accumulation at the updrift side, referred to as a fillet, ultimately leads to sediment bypassing in front of the structures. This phenomenon often results in the obstruction of navigational channels at port entrances. As sediment accumulates in front of port entrances, dredging becomes essential to preserve navigability, a process that can be both costly and challenging (Donkor, 2005).

This study aims to investigate the rapid shoreline changes occurring at the adjacent beaches and the resulting sedimentation at the entrance of Kiashahr Fishery Port. It seeks to identify the causes of sediment accumulation to address the challenges posed by these sediment dynamics. Understanding these processes is essential for enhancing the design, maintenance, and operation of coastal structures, particularly in regions characterized by dynamic sediment transport patterns.

STUDY AREA

Sefidroud Delta, which is located along the southern coast of the Caspian Sea in the Gilan province of Iran, is a prominent geological feature with a complex evolutionary history (Figure 1). The development of the Sefidroud Delta has played a significant role in shaping the coastline over time. The shift of the Sefidroud Estuary from its old location to the Kiashahr area was primarily driven by flooding caused by the Sefidroud River, in combination with human alterations in the surrounding catchment area. Additionally, long and short-term water level fluctuations in the Caspian Sea have further influenced the delta dynamics.

The morphology of the Sefidroud Delta was shaped by the combined effects of sea wave dynamics and the large volume of sediment transported by the river. Figure 2 displays the history of the Caspian Sea water level from 1941 to 2024. The sea level had gradually fallen before 1977 to its lowest level in the past 400 years, i.e., about 28.2 meters below the global sea level (Baltic datum). However, an unexpected rise in the water level started in 1977 and continued up to -25.7 m in 1995 (about 2.5 meters). With the sea level rising, the wave break zone also shifted, increasing the intensity of waves. Approximately 550 million tons of sediment deposition entered the sea during the water level rise from 1976 to 1994, which was coupled with the revival of the Sefidroud Dam. The influx of sediment markedly affected the region, which led to sediment accumulation along the delta's coastline. As a result, new islands began to form in the region between the estuary and the Kiashahr Bridge (Karimi and Mohammad Vali Samani, 2019).

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Figure 1. Study area.

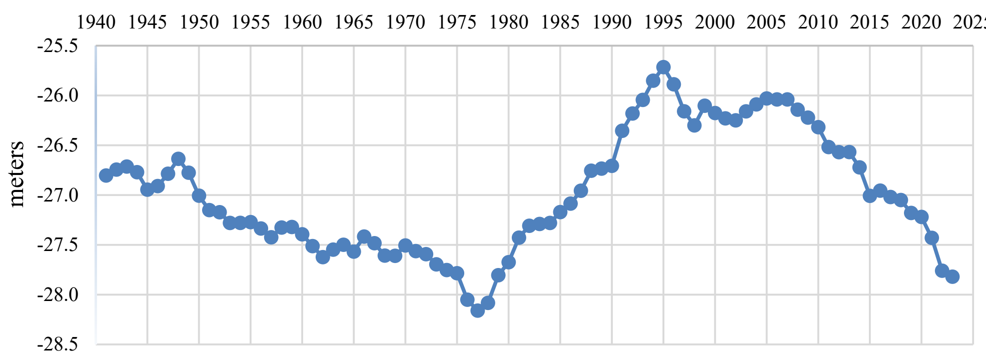

Figure 2. History of Caspian Sea water level (Anzali Station).

Kiashahr Fishery Port was designed at southwest corner of Sefidroud Delta with two parallel jetties at the lagoon to ensure the navigation (Figure 1). Soon after the start of port construction in 1997, rapid shoreline advancement at the west side of the main jetty (updrift) was observed. Despite extending the length of this jetty during the construction phase, it experienced bypassing and sedimentation at the entrance of the access channel in a very short time, which interfered with navigation just after the opening of the port.

SATELLITE IMAGES AND HYDROGRAPHIC SURVEYS

Aerial photos and satellite images are helpful to examine the topography changes over time. Landsat images are used to investigate shoreline changes in the study area. Figure 3 shows the high impact of the constructed jetties on the morphology of neighboring coasts. It is seen that the estuary of the Sefidroud River shifted eastward between 1990 and 1994. This change in direction has particularly affected the sediment distribution around the port. The formation of a sand spit towards the port is also observed in the initial stages of the construction in the 1994 and 1998 images. As port development progressed, the sand spit extended toward the main jetty, advancing the shoreline on the updrift side of the port.

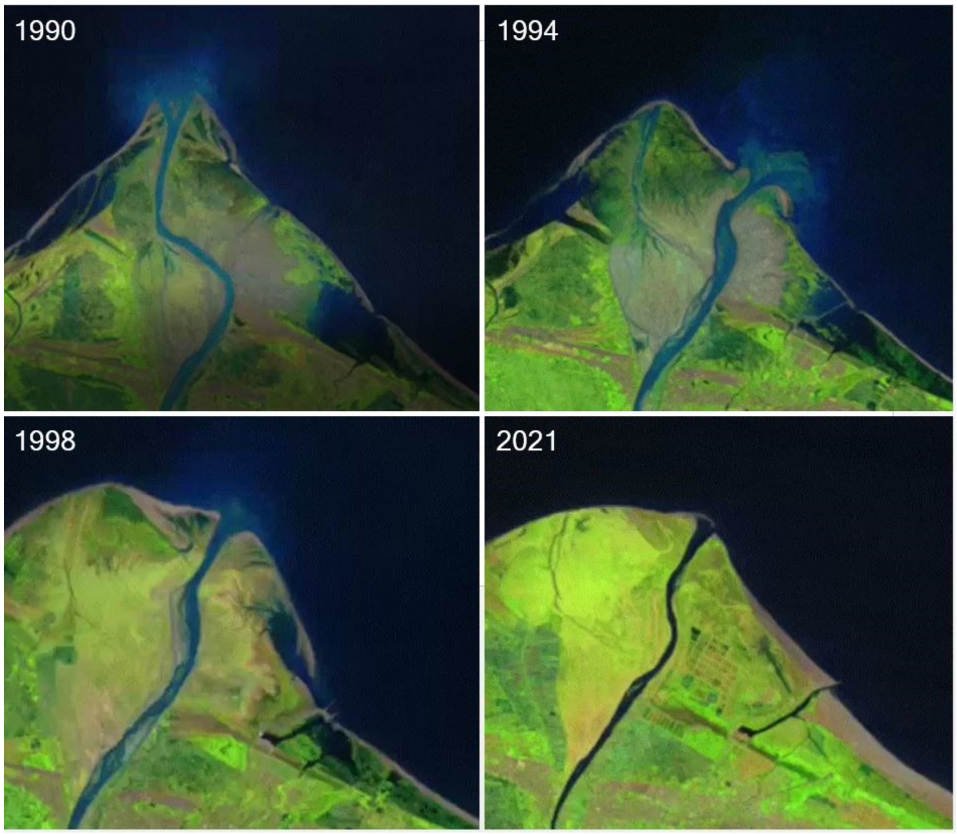

Figure 3. Landsat images of Kiashahr Fishery Port and Sefidroud Delta.

Despite the extension of the main jetty during the construction phase, the entrance experienced bypassing and sedimentation in a very short time. The extension of the main breakwater does not reduce the sedimentation bypassing towards the downdrift side, and thus the shoreline advancement is observed on both sides. The accumulation of sediments adjacent to the secondary breakwater ultimately resulted to the closure of the port entrance and access channel shortly after it opened.

In addition to satellite images, this study analyzed sedimentation and erosion processes through a comparative examination of hydrographic surveys from various years between 1999 and 2014 (Figure 4). The purpose of this analysis is to find the main causes and patterns of sedimentation at the port entrance, as well as to gain a comprehensive understanding of coastal changes.

A sand spit is observed on the upper side of the jetty in 1999 hydrography survey, which is a remarkable source of sediment towards the port. Significant changes in the shoreline can be noted between 1999 and 2003 records, highlighting considerable developments in the area soon after the completion of the port's construction. The advancement of the updrift shoreline is attributed to the longshore sediment transport and changes in the Sefidroud River and its delta. Hydrographic surveys also confirm the advancement of downdrift coast behind the secondary breakwater.

A clear advancement on the updrift coast is observed in 2003 hydrography survey. As a countermeasure, the main breakwater was lengthened between 2003 and 2008 to create a larger fillet to trap LST (SPI, 1998). The comparison between the 2003 and 2008 hydrographic surveys reveals that the shoreline has continued to advance due to longshore sediment transport. However, the rate of this advancement has decreased compared to previous years. The shoreline advancement on the west coast, extending to the tip of the secondary breakwater, is also observed, resulting in sedimentation at the entrance of access channel. The 2014 hydrographic survey shows ongoing sedimentation and shoreline advancement on both sides. The survey also reveals significant sediment infiltration within the access channel.

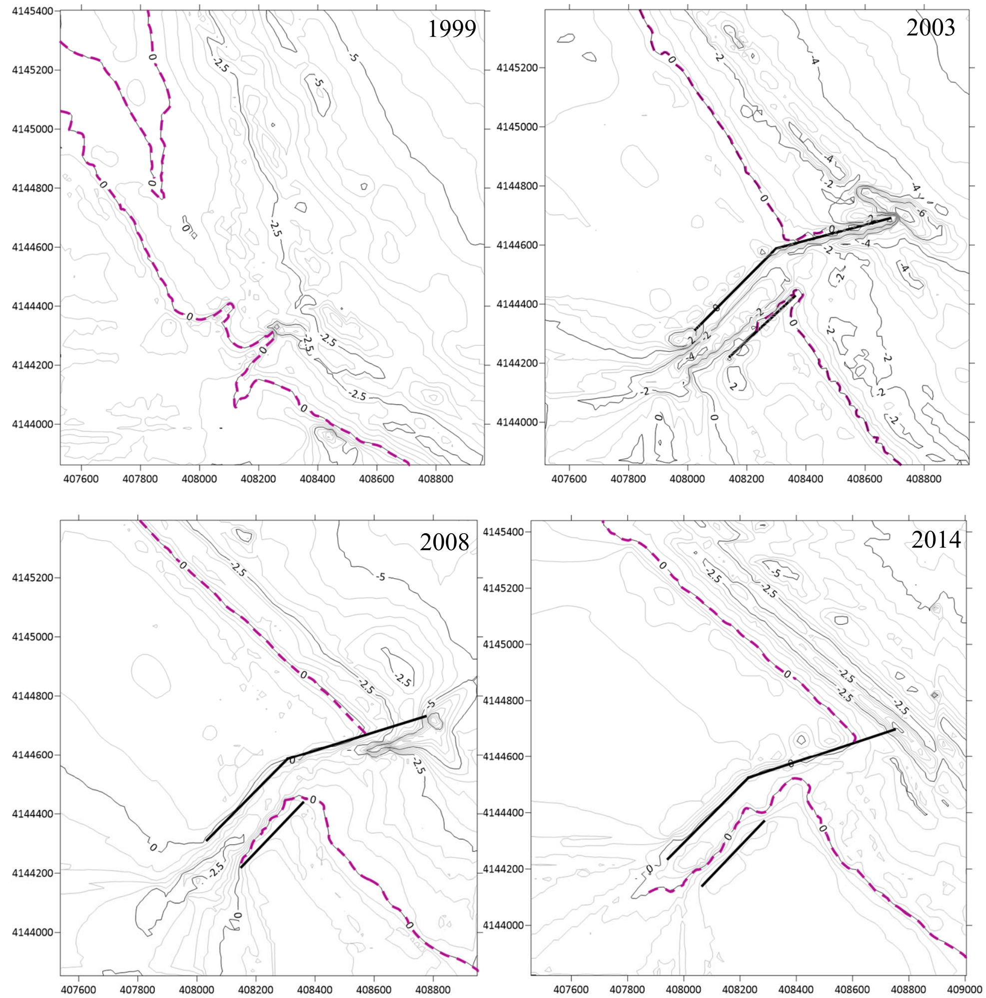

Figure 4. Hydrographic surveys in 1999, 2003, 2008 and 2014.

Surfer software is used in order to calculate coastal changes and quantify the rates of sedimentation and erosion. Given the recent fall in the Caspian Sea water level, it is important to exclude changes in the shoreline caused by the water level falling (Enayatighadikolaei et al., 2024). Water depths in the hydrographic surveys have been adjusted based on the 1999 water level to account for fluctuations in the Caspian Sea's water level (Figure 2).

Bruun Rule (1962) is used to calculate the rate of shoreline change in relation to variations in water levels. He suggested that the equilibrium profile will stay the same as the shoreline shifts in reaction to sea level changes (Eq. 1).

$$R = S\frac{W_*}{h_* + B} \quad (1)$$

where R is the shoreline retreat, S is sea level rise, B is berm height, and h_* and W_* are closure depth and active profile length after sea level change, respectively.

Figure 5 shows the bathymetry changes between 1999 to 2003, and between 2003 to 2008. Areas of sedimentation/erosion are evident in different locations. If LST is fully trapped by a coastal structure, continuous erosion is usually expected downdrift. However, the significant observed sedimentation that is on the downdrift coast, particularly from 1999 to 2003 (Figure 5, left panel), indicates that sand is bypassing the port. Comparing the surveys between 2003 and 2008 (Figure 5, right panel), it is clear that beach accretion continues due to continued input of sediment by LST. However, the sedimentation rate has decreased compared to previous years, indicating that the shoreline is approaching equilibrium.

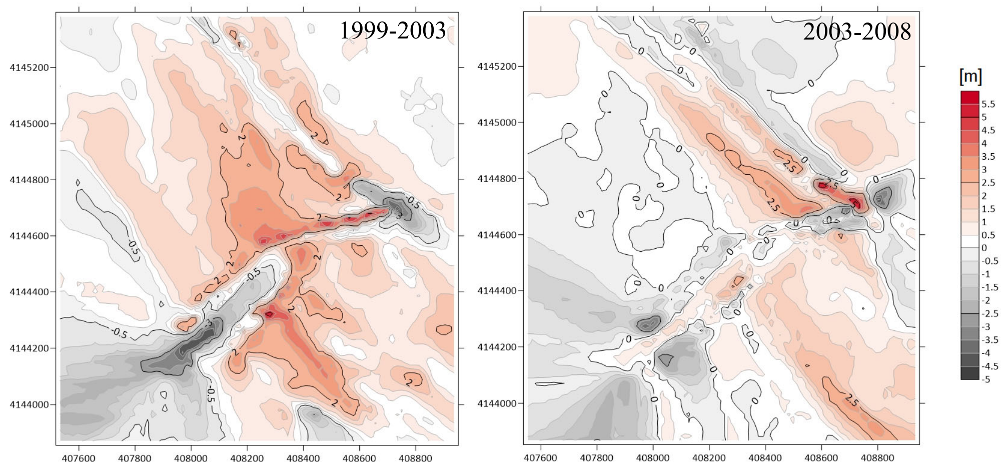

Figure 5. Comparisons of hydrographic surveys.

NUMERICAL MODELING

Dynamic nearshore processes, including wind, currents, waves, and the interaction between estuaries and nearshore zones, primarily govern sediment transport in coastal areas. These factors collectively influence the movement and redistribution of sediment along the coastline (Wang et al. 2014; Joshi et al. 2017). Consequently, a comprehensive study of the local hydrodynamics is crucial in the initial phases of designing and constructing coastal structures, as well as in analyzing sediment transport within coastal zones (Baldock et al. 2014).

MIKE 21, developed by the Danish Hydraulic Institute, was utilized in this study to simulate the hydrodynamics, sediment transport and morphology within study area (DHI, 2014). The modules used for analysis in this study include:

- Spectral Wave (SW): to simulation wave propagation and transformation.
- Hydrodynamic (FM): to simulate currents including wave-induced currents.
- Sand Transport (ST): to simulate sediment transport rates for the prediction of shoreline changes and morphological evolution.

The input data for numerical modeling includes bathymetry data within the modeling domain, significant wave heights, and mean wave directions. The computational grid is divided into various sections with varying mesh sizes to reduce simulation time (Figure 6, left panel). The gridded bathymetry data was created using the 1999 hydrographic survey. The domain extends approximately 17 kilometers along the beach. Given that the Sefidroud River serves as the primary source of sediment input to the study area, the west boundary extends beyond the river estuary.

Considering the very low tide in the enclosed Caspian Sea, tidal currents are negligible. While wind-induced currents also influence coastal areas of the southern Caspian Sea (Bohluly et al., 2018), the wave-induced currents are the primary drivers of longshore sediment transport.

Hindcast data from the Iranian Sea Wave Modeling (ISWM) project, spanning the period 1992–2003, was utilized to provide wave characteristics as input for the model. Figure 6 (right panel) shows the deep-water wave rose in the study area.

Sediment grain size is a critical parameter significantly influencing sedimentation rates. Based on sediment sampling and laboratory tests conducted during the Caspian Sea Monitoring Project, it was observed that the sediments in the study area were predominantly composed of sand-grained materials with an average diameter of approximately 0.2 mm. Figure 7 illustrates the grain size distribution of a disturbed sediment sample.

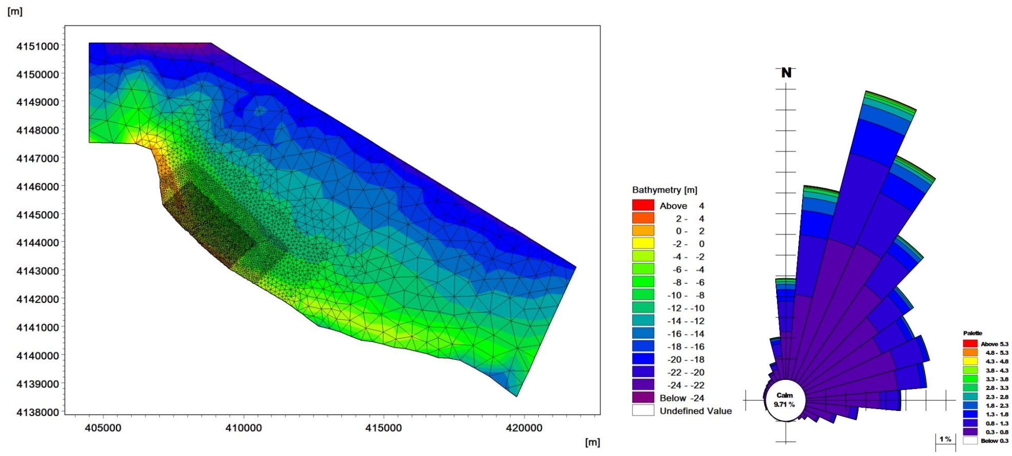

Figure 6. Computational grid (left) and wave rose (right) in front of Kiashahr Fishery Port.

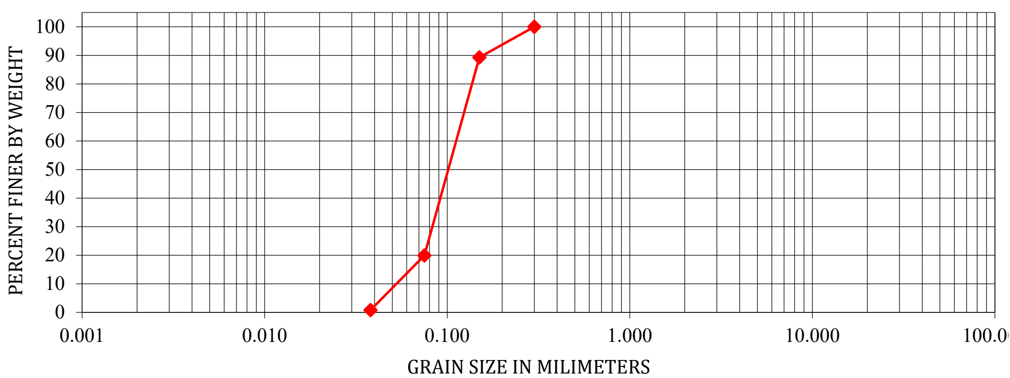

Figure 7. A sample of sediment grain size distribution, D_{50} = 0.22 mm.

RESULTS AND DISCUSSION

Figures 8 and 9 illustrate snapshots of longshore currents during a typical non-storm event and a severe storm event, respectively. An increase in wave height results in a corresponding increase in current speed and an expansion of the breaking zone. This leads to the breaking zone shifting further offshore and extending beyond the tip of the main breakwater. As the current approaches the site from the updrift side, its speed generally decreases. The maximum current speed is observed at the tip of the main jetty, gradually diminishing as it moves further into deeper waters. This analysis reveals that the port jetties were constructed within the surf zone from the outset, which explains the significant sedimentation and rapid sand bypassing in front of the port entrance. A circulation current is also evident behind the secondary jetty. Velocity vectors indicate that this circulating current terminates in the outer region, east of the secondary jetty. Beyond this point, the longshore current pattern re-establishes itself.

Given the significant sedimentation at the entrance, it is crucial to investigate the formation of the circulation current behind the secondary breakwater. While it is well-established that a gradient in the breaking wave height within the sheltered area of secondary breakwaters generates a diffraction current toward the port, the results of the present hydrodynamic modeling suggest that an eddy current also contributes to this circulation. This eddy likely arises from the horizontal entrainment of the longshore current towards the lee side of the jetty, potentially influenced by the substantial length deference between the two constructed jetties. Therefore, a combination of diffraction currents and eddy currents likely drives the observed circulation patterns downdrift of the port. However, quantifying the relative contribution of each of these two factors to the overall observed circulation behind the secondary breakwater through numerical modeling remains challenging.

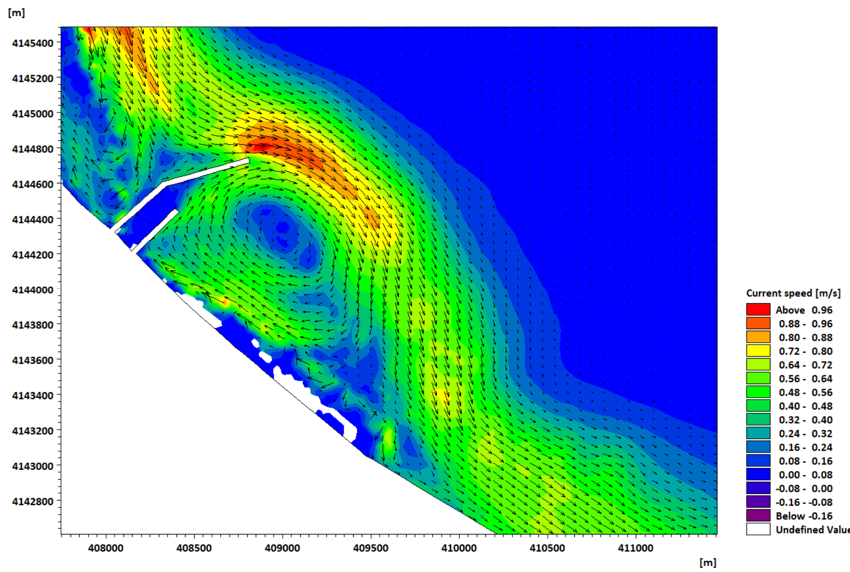

Figure 8. Hydrodynamic modeling results of current speed and direction under storm conditions (1999-4-6, 00:00:00).

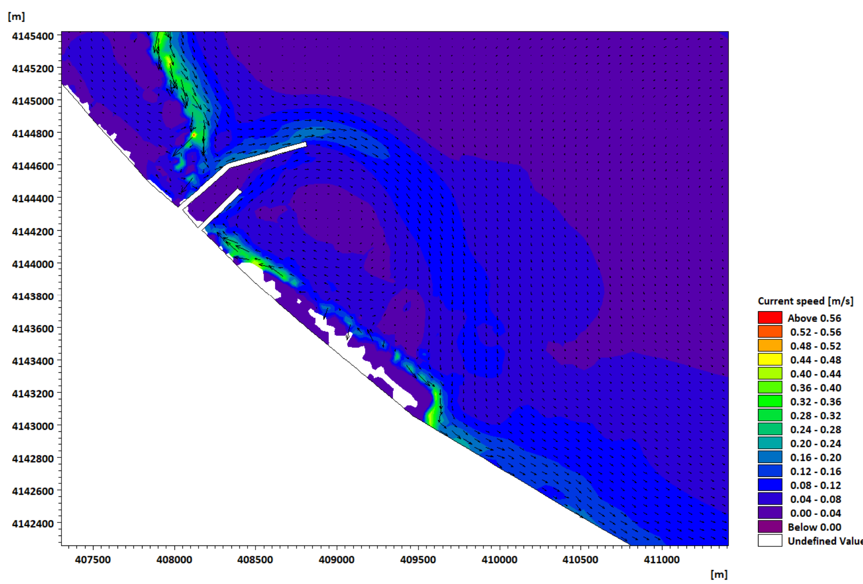

Figure 9. Hydrodynamic modeling results of current speed and directions under non-storm conditions (1999-6-15, 00:00:00).

Satellite imagery clearly demonstrates the significant impact of the Sefidroud Delta on the surroundings (Figure 3). Changes within the delta, coupled with the development of a sand spit updrift of the port, have consistently influenced the hydrodynamic conditions around the area since the start of the port construction. The updrift sandbar and the main jetty together act as a barrier, effectively deflecting the longshore current into deeper water depths.

Following the analysis of the current patterns, the sand transport model can be employed to simulate the shoreline changes and morphological evolution. The model was run from 1999 to 2003. Figure 10 illustrates the bed level at the beginning (1999) and end (2003) of the simulation period. The modeling results, which can be compared with 2003 hydrographic survey data presented in Figure 4, indicate significant shoreline advancement due to widespread sedimentation on both sides of the port. The simulated bed level in 2003 also shows the sedimentation behind the secondary breakwater.

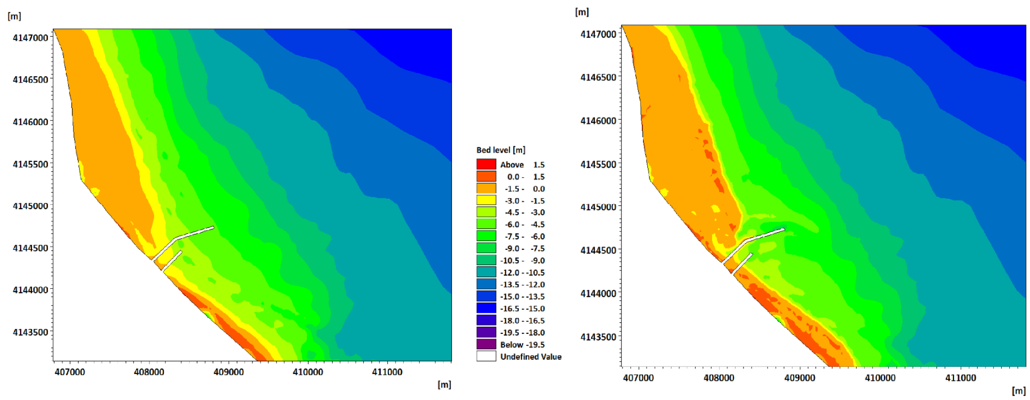

Figure 10. Bathymetry data in 1999 (left) and simulation results in 2003 (right).

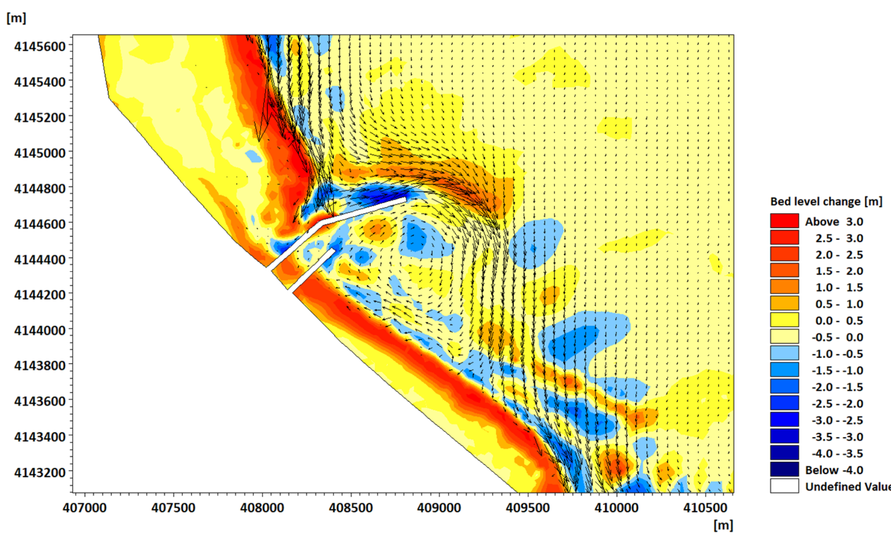

Figure 11. Bed level changes from 1999 to 2003.

Figure 11 presents the bed level changes from 1999 to 2003, which can be compared with Figure 5 (left panel). The direction of the sediment transport vectors closely follows the direction of the currents in the study area. Modeling results reveal that the designed jetties were initially positioned within the surf zone, and subsequent changes in the Sefidroud Delta have only intensified the severe sedimentation problem at the port.

To assess the accuracy of morphological modeling results at both the downdrift and updrift sides of the port, Brier Skill Scores (BSS) were used to compare the simulated bed level at the end of the simulation (2003) with the corresponding survey data. Table 1 presents the range of acceptable BSS values, where a higher value, closer to one, indicates greater accuracy in the numerical model (van Rijn, 2003). This comparison was conducted within a defined area, extending 3 km along the shoreline on either side of the port and 800 m offshore. Table 2 presents the calculated values of BSS, indicating the acceptable accuracy of the modeling results in comparision to hydrographic survey data.

CONCLUSION

The study of significant sedimentation at Kiashahr Fishery Port highlighted the improper site selection of the port, which is located very close to the Sefidroud Delta. This proximity has accelerated the severity of sedimentation process due to a shift in the river mouth between 1990 and 1994. To accommodate a larger fillet for the high LST rate, the consultant decided to elongate the main jetty by extending it into deeper waters (SPI, 1998).

Table 1. Qualification of error ranges of BSS parameter (van Rijn, 2003).	
Qualification	**Morphology; BSS**
Excellent	1.0-0.8
Good	0.8-0.6
Reasonable/fair	0.6-0.3
Poor	0.3-0
Bad	<0

Table 2. Calculated BSS		
Cross-shore distance (m)	**West coast**	**East coast**
0-400	0.56	0.57
400-800	0.44	0.32

However, a large circulation current, confirmed by numerical modeling in the present study, was generated on the downdrift side. The downdrift sediment transport, combined with the bypassing of LST in front of the main breakwater, led to significant sediment accumulation at the entrance of the port access channel from both the east and west directions. Ultimately, this accumulation of sediments resulted in the blockage of the port entrance just a few years after the construction was completed.

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