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Numerical Modeling of the Sedimentation in the Chabahar Bay Area under the Influence of Shahid Beheshti Port Development

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ABSTRACT

Shahid Beheshti Port stands as a critical maritime infrastructure in Iran, serving as a pivotal transit hub for goods destined for Central Asia. This research aims to elucidate the sedimentation dynamics within Chabahar Bay, both before and following the expansion of the Shahid Beheshti Port. The study employed various modules of the MIKE21 hydrodynamic modeling suite to achieve this objective. The modeling results, comparing pre- and post-development scenarios of Shahid Beheshti Port, reveal that sediments circumnavigate the breakwater before entering the area between the Beheshti breakwater and Kalantari Port. The region north of Kalantari Port, characterized by the rocky Lipar coast and seabed, predominantly experiences erosion, with occasional sedimentation events. The coastal stretch extending from Tis Port to the beach area exhibits a complex interplay of depositional and erosional processes. Erosion rates in this sector are substantial, ranging from approximately 14,000 to 19,600 cubic meters annually. A desalination plant situated along the western coastline acts as a significant sediment trap, with pronounced accumulation on its eastern flank. Conversely, the western side of this structure is subject to erosion due to local current patterns.

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1. Introduction

The Port of Chabahar, strategically situated in the northern reaches of the Oman Sea, occupies a pivotal position in the region's maritime infrastructure. Its geographic location renders it an ideal hub for the transshipment and transit of goods, not only from ports in the Gulf region and the Oman Sea but also serving as a crucial gateway for landlocked Afghanistan and Central Asian nations. Recognizing the port's strategic significance and its potential role in driving development along the country's eastern axis, the Ports and Maritime Organization has implemented a comprehensive development plan as part of its medium-term strategic initiatives. Coastal zones function as dynamic, living systems, where alterations in one area invariably impact others. Failure to recognize and account for this interconnectedness often results in the underperformance or failure of coastal structures and can precipitate adverse effects on adjacent areas. The complex interplay of marine currents, waves, wind, and tidal forces can lead to sedimentation issues, which in turn can impede the navigation of large vessels, cause sediment accumulation in harbor basins and access channels, and ultimately compromise port efficiency [1].

A comprehensive review of recent literature reveals significant advancements in the field of coastal sediment dynamics and their implications for infrastructure development. Panigrahi et al. investigated sediment dynamics in the context of wind turbine site construction along the Arklow coast of Ireland. Their methodology incorporated MIKE21 software. This study was notable for its consideration of wave impact parameters on tidal sediment transport processes [2]. Dong-feng et al. advanced the field through their numerical and two-dimensional modeling of tidal currents, morphological alterations, and sediment transport in the coastal regions of Hangzhou Bay, China. This research provided valuable insights into the complex interplay of hydrodynamic forces in a unique coastal environment [3]. Further contributions to the field were made by Sravanthi et al., who conducted an in-depth examination of sediment transport mechanisms along the central Kerala coast of India. Their work expanded our understanding of sediment dynamics in tropical coastal systems [4]. Hendriyono et al. focused their research on quantifying sediment transport along the Batang coast in Central Java, Indonesia. Their conclusions underscored the significant impact of infrastructure development on coastal morphology and shoreline retreat in the region [5]. In another study, Babu et al. modeled and examined tidal currents using the MIKE21 hydrodynamic model in the Gulf of Kutch, India. These researchers validated the modeling results against field data of currents obtained at two time points. The comparison of model results with measured currents showed very good agreement [6].

Zhang et al. studied a process-based model for sediment transport undercurrents and waves [7]. In addition to its ability to model morphological processes in real coastal areas, its model can predict sediment transport patterns undercurrents and waves. Ganesh et al. used wave and sediment transport modeling to predict erosion in Guayaguayare Bay in the Atlantic Ocean [8]. They modeled sediment transport with wave propagation using the MIKE21 SW module [9]. In this modeling, high-risk areas in terms of erosion and sediment transport patterns were identified on a seasonal basis. Morianou et al. simulated water depth, current velocity, and sediment transport in the downstream section of the Koiliaris River (Crete - Greece)[10]. For this purpose, the two-dimensional hydraulic model MIKE 21C was used. The model was calibrated using water level data and sediment concentration data during high and low flow rates. The model simulation was consistent with field observations and yielded good results.

The phenomenon of sedimentation in the calm basin of docks ports and access channels creates problems in their operation. Due to the reduction in water depth, the wavelength decreases, and because of wave compression, they deviate from a sinusoidal state, and wave height increases. This leads to the creation of coastal currents and sediment transport in coasts and ports. To counter these hazards, wave characteristics, propagation direction, coastal and port hydrography, wind, sea currents, simulation models, and charts should be used to examine the process of sediment transport phenomenon based on them [11]. Tides, waves, and sea currents are important factors in determining coastal structure, sedimentation, and erosion around structures [12].

Sedimentation in harbors is often related to the exchange caused by tidal currents and density-driven currents. As a result, it leads to an increase in the volume of water entering the port basin in each tidal period. To reduce the exchange volume, various anti-sedimentation methods can be used [13].

Sediments are one of the factors reducing the performance and functionality of ports. To accurately determine the amount of sedimentation, having precise information about the amount of incoming sediment and identifying the factors of sedimentation plays a decisive role in the optimal positioning of ports in terms of sedimentation problems. In addition to the seabed, sediments also find their way to the sea from rivers [14].

Insufficient studies in the construction and positioning of breakwaters can lead to the ingress of strong currents and sedimentation at the channel entrance and within the port. These factors result in substantial dredging costs and can inflict irreparable damage to structures. Appropriate geometric design in the construction of breakwaters, access channels, ports, and wharves can mitigate the effects of sedimentation on these structures. Other strategies for controlling and reducing sedimentation include selecting an optimal angle for the main breakwater concerning dominant wave movements, implementing deflectors for waves and sediments, creating wave reflectors at Port entrances, constructing spurs at the end of the main breakwater, and building secondary breakwaters to prevent tidal eddies[15]. The sedimentation regime in wharves and ports presents a persistent challenge for coastal engineers. Inadequate investigation and insufficient studies concerning waves, tidal currents, wind, and other factors in ports and wharves can lead to future complications. Failure to prevent and control sedimentation in structures will impose significant costs during dredging operations. Due to the high sensitivity of this issue, this research employs information and results from various studies, including morphology, wave and current dynamics, sediment data, aerial and satellite imagery, cross-sections, and other relevant data to analyze and model the general sedimentation regime of the region [16,17]. Physical and numerical models, as well as simulations, can be utilized to examine sedimentation within wharves, ports, and access channels [18-20]. Considering the aforementioned points, the objective of this study is to conduct numerical modeling of the sedimentation regime in the Chabahar Bay area, taking into account the impact of the Shahid Beheshti Port development project.

2. Research Methodology

Among the numerical models used for analyzing phenomena governing seas and oceans, the MIKE21 mathematical model stands out as one of the most widely applied software in this domain. Developed by the Danish Hydraulic Institute (DHI), this program incorporates finite element models and finds extensive application in marine structures, hydraulics, ports, and coastal engineering. This study utilizes various MIKE21 modules, detailed as follows:

1. MIKE21 Flow Model: Hydrodynamic Module (HD) - Simulates tidal hydraulics and currents generated by wind and waves.
2. Mud Transport Module (MT) - Models the transport of mixed sediments, mud, or sand and gravel under the influence of currents.
3. MIKE21 Flow Model FM: Hydrodynamic Module (HD) - Performs hydrodynamic modeling, particle tracking, and sand transport.
4. Sand Transport Module (ST) - Simulates erosion, sediment transport, sand movement, and sediment transport for non-cohesive sediments.

The entire modeling period utilizes data from existing buoys and information from monitoring and modeling studies conducted from 2006 to 2007. Additionally, data about wind, currents, sediment, and hydrography from 2006 to 2007 have been incorporated.

To establish the model, after collecting the required data bases, constructing the model geometry adding an appropriate mesh network are one of the main parts required in the numerical modeling considered in this research. In the next step, the wave field resulting from wind field data file was generated and calibrated in the SW module environment. The FM module was also used to generate coastal currents file and hydrodynamic in the study area. Finally, using the SAND module of Mike, sediment transport rates were measured based on information extracted from wave, current, or wave and current combination data and analyzed.

2.1. Study Area

Chabahar is situated on the eastern shore of Chabahar Bay (60°31' E longitude and 25°12' N latitude) in Sistan and Baluchestan Province, adjacent to the warm waters of the Oman Sea and the Indian Ocean. It is strategically located near major shipping routes to Africa, Asia, and Europe. The Shahid Beheshti and Shahid Kalantari wharves were constructed between 1981 and 1983, coinciding with the Iran-Iraq War, to establish a port base outside the Persian Gulf and the Strait of Hormoz.

At the end of the sixth month, the VEC1 device was relocated to the western marsh area, while the VEC2 device was installed in the eastern marsh location (Figure 1).

Figure 1. Positioning of measurement devices at the end of the sixth month (Ports and Maritime Organization Monitoring and Modeling Project)

As part of the Ports and Maritime Organization's monitoring and modeling project, wave and current measurements were conducted at multiple locations within Chabahar Bay. This comprehensive data collection effort utilized six ADCP (Acoustic Doppler Current Profiler) devices and two ADV (Acoustic Doppler Velocimeter) instruments over one year from September 2006 to August 2007. Table 1 provides a

summary of the current and wave measurement locations, along with their respective time frames.
In this table, the abbreviations VE, AQ, and AW refer to Nortek Vector, Nortek Aquadopp, and Nortek AWAC equipment, respectively. Measurements were taken at a total of 16 distinct locations [16].

Table 1. Wave and current measurement locations (Ports and Maritime Organization Monitoring and Modeling Project)

Equipment	Station	Measurement Period		Depth (m)	UTM Coordinates (m)	
		Start	End		X	Y
AQ1	1	2006/08/21 19:00	2007/09/03 22:40	-3	248789	2815415
AQ2	2	2006/08/22 13:00	2007/03/01 18:00	-3	241983	2808755
	3	2007/03/05 15:00	2007/05/22 6:00	-5/12	248771	2799473
	4	2007/05/22 0:00	2007/07/10 7:00	-11	250017	2803607
	5	2007/07/11 11:00	2007/08/29 13:00	-5	242310	2807743
AQ3	6	2006/10/31 14:00	2007/05/31 18:00	-10	258643	2801333
	7	2007/06/01 11:00	2007/06/30 13:20	-5/9	250038	2808572
	8	2007/07/01 11:00	2007/09/03 16:00	-10	258643	2801333
AW1	9	2006/08/25 11:00	2007/09/02 11:00	-10	257785	2799179
AW2	10	2006/08/27 11:08	2007/06/14 10:20	-30	263397	2795937
AW3	11	2006/08/30 11:08	2007/09/02 11:40	-11	245745	2799632
VE1	12	2006/08/22 8:00	2006/10/26 14:00	-3	260139	2800783
	13	2006/10/31 11:00	2007/02/01 15:00	-3	242563	2805140
	14	2007/02/05 14:00	2007/02/20 7:00	-2	243427	2813452
	15	2007/02/05 12:00	2007/06/30 14:00	-2	256911	2813503
	16	2007/07/13 13:00	2007/08/31 5:00	-3	243087	2811679

To understand the type of sediments in Chabahar Bay, sediment sampling and grain size analysis are considered important activities. For this purpose, a layout (grid) of sediment sampling locations in the study area has been designed, consisting of profiles intersecting the coast. The distance between these profiles is one kilometer (based on the coastline division), such that the sediment sample collection locations are the intersection points of these profiles with, respectively, the upstream water line, at the water line, at depths of 2.5 meters and 5 meters relative to CD (Chart Datum).
The mesh network of Chabahar Bay before the Shahid Beheshti Port development plan includes 9,832 elements and 5,663 computational nodes, while the mesh network of Chabahar Bay after the Shahid Beheshti Port development plan includes 10,211 elements and 5,882 computational nodes. In the figure below, open and closed boundaries are shown (Figure 2). It should be mentioned, For calibration, with slight changes in parameters such as eddy viscosity coefficient, bed roughness coefficient, layer thickness coefficients, and bed surface variation coefficient, better agreement was achieved between the data measured at the stations and the modeling results.
The average error rate between the data recorded at the stations and the modeling results using the RMSE method for the wave height parameter was measured between 2% and 5% at different stations. This error is 3% to 5% for the wave period and is higher in the average wave direction and is associated with an error of 7% to 12%.

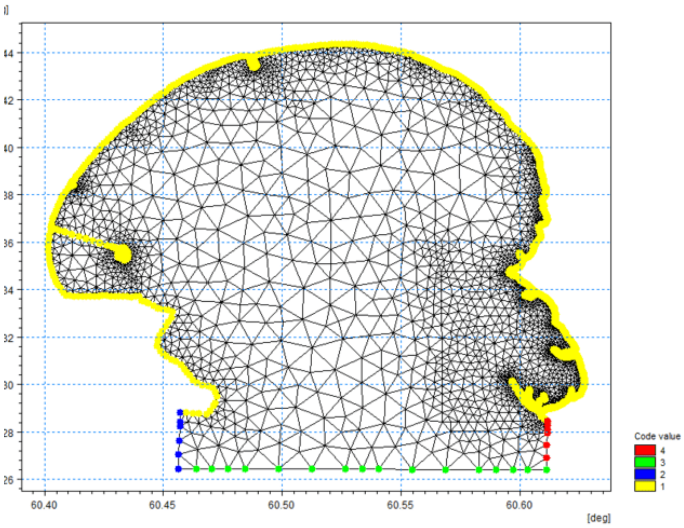

Figure 2. Computational network and boundary codes

3. Findings

3.1 Wave Modeling

The AW2 station was the main criterion for determining the wave transmission boundaries to Chabahar Bay. Approximately 30 spectral wave model simulations were run, both before and after the development of the Shahid Beheshti Port. Various input data scenarios and changes in wave-breaking coefficients and bed roughness coefficients were examined within the study area. The modeling results were compared with measured data. Ultimately, the modeling results show very good agreement with the measured data.
According to Figure (3), the incoming wave direction is from the south. After passing the Shahid Beheshti breakwater, the waves slightly change direction and extend towards the Sepah and Tis wharves. Due to wave diffraction, they move towards the space between Beheshti and Kalantari wharves and then move behind the Kalantari and Haft-e Tir breakwaters. The wave height inside the Haft-e Tir and Kalantari Port area

ranges from 0.1 to 0.3 meters. In the area between Kalantari and Haft-e Tir wharves, the very low bed slope and calm current cause sedimentation and sediment accumulation in this region.

At Shahid Kalantari Port, waves enter this area through diffraction, and the wave height ranges from 0.1 to 0.4 meters [16]. The current near the shore and Port Number 1 is very calm, which is one of the important factors for sedimentation in this area. In the Lipar area, which is located above the Shahid Kalantari Port, the wave height reaches 0.1 to 0.7 meters, and because the coastal area is mostly rocky, erosion occurs in this area due to wave impact (Figures 4 and 5)

Near Tis Port, due to the presence of Tis headland, the wave direction changes and enters the Tis Port area and eastern lagoon through diffraction and refraction. The wave height in this area is about 0.1 to 0.4 meters due to the low slope. One of the factors of sedimentation at Tis Port is the low wave height and very weak current velocity in this area, which causes sediment accumulation. The wave height in the area between the beach and the eastern lagoon is very low, which is due to the very low slope in this area (Figure 3).

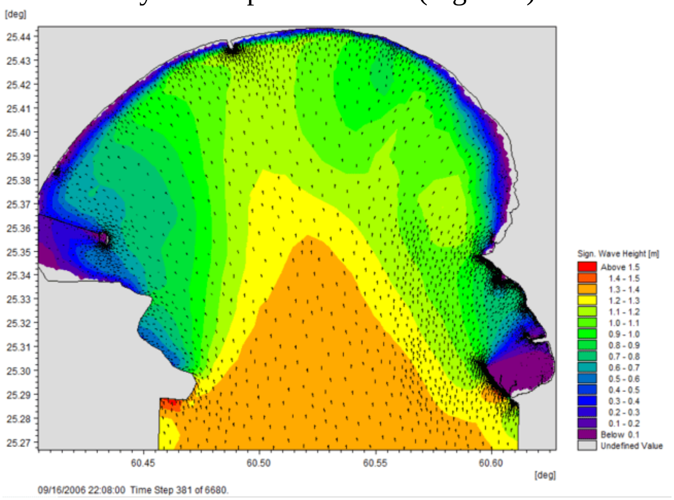

Figure 3.Wave height variations in Chabahar Bay for a one-time step after calibration

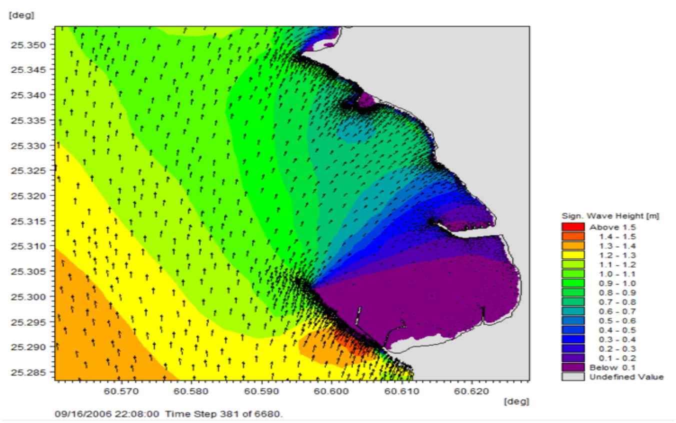

Figure 4. Wave height variations for a one-time step after calibration in the Kalantari and Beheshti port area

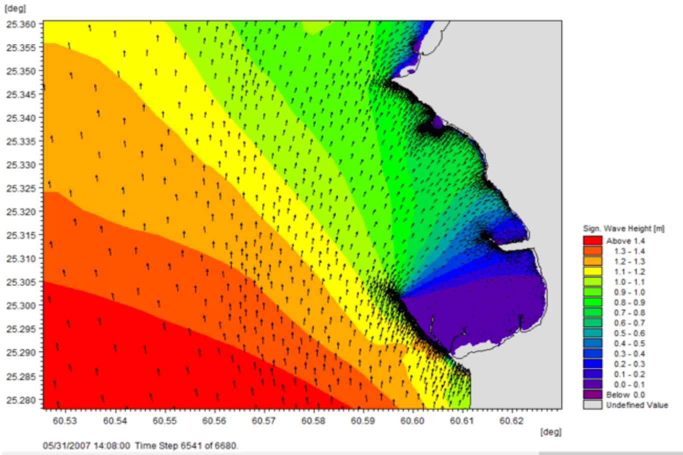

Figure 5. Wave height variations for a one-time step after calibration in the Kalantari and Beheshti port area

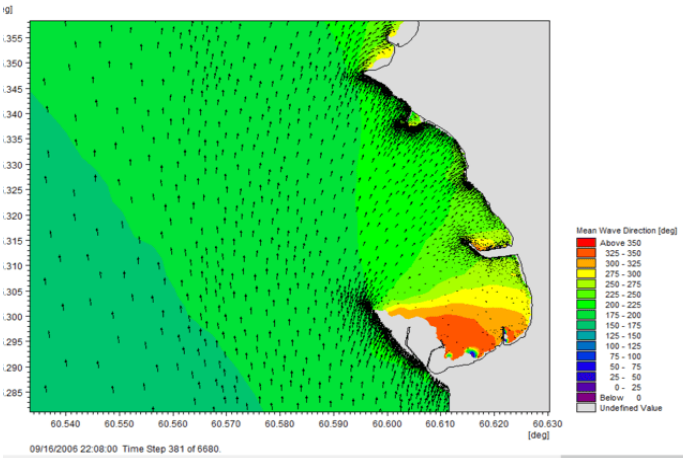

Figure 6. Average wave direction variations for the one-time step after calibration in the Kalantari and Beheshti port area

The figures show the wave period and direction at different time steps after calibration. The Shahid Beheshti development plan model has not significantly changed the waves in Chabahar Bay.

Incoming waves from the south towards the bay, after hitting the secondary arm of the Beheshti breakwater, move towards the Tis headland at their maximum. In some cases, incoming waves from the southeast enter the bay, and after passing the secondary arm of Beheshti Port, they move towards Pozm headland and Konarak (Figures 7 and 8).

According to the model, the wave height inside the Shahid Beheshti basin is very low, and in the area between Shahid Beheshti Port to behind Kalantari Port, the wave height reaches up to 0.15 meters. One of the factors contributing to sedimentation in this area is the low wave height, very calm current velocity, and the enclosed nature of this region. Next to the Shahid Kalantari Port and its shore, the wave height decreases, and the effect of diffraction in this area is very high, which is one of the factors causing sedimentation in this area. (Figures 9 and 10).

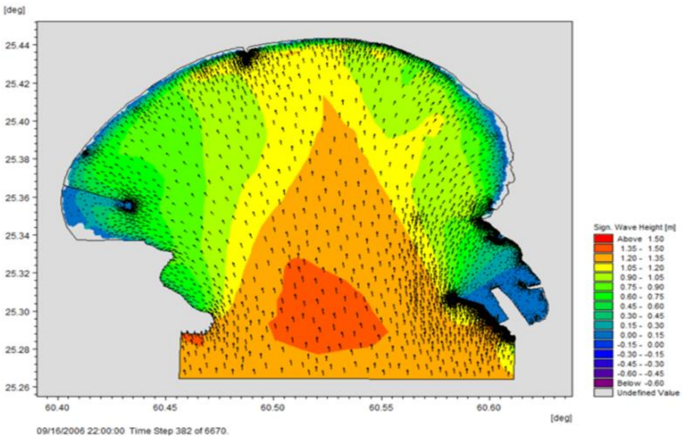

Figure 7. Wave height variations in Chabahar Bay for a one-time step after calibration

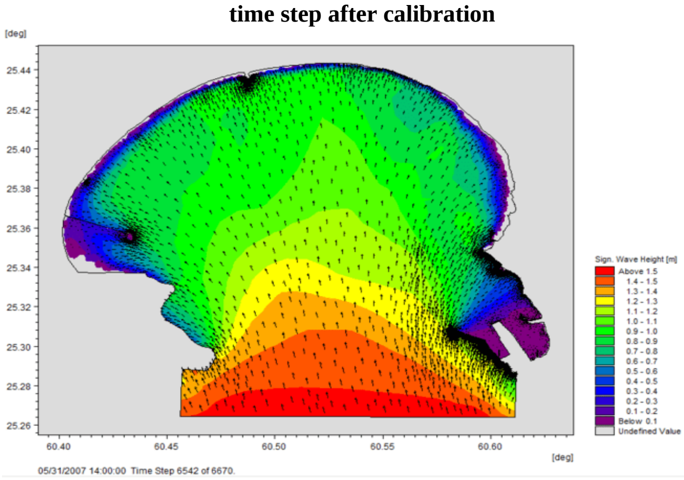

Figure 8. Wave height variations in Chabahar Bay for a one-time step after calibration

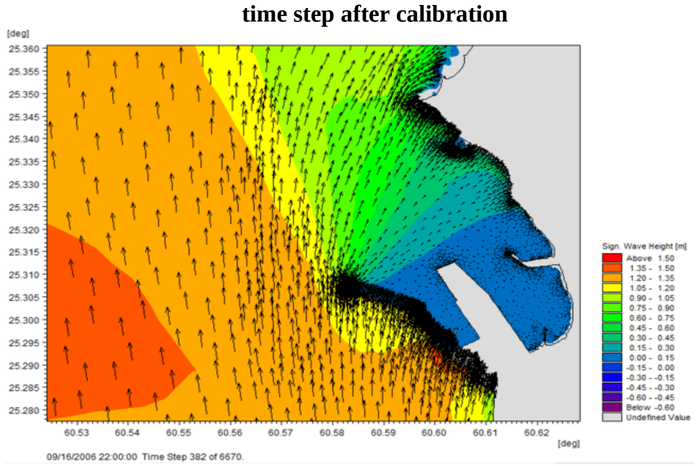

Figure 9. Wave height variations for the one-time step after calibration in the Kalantari and Beheshti port area

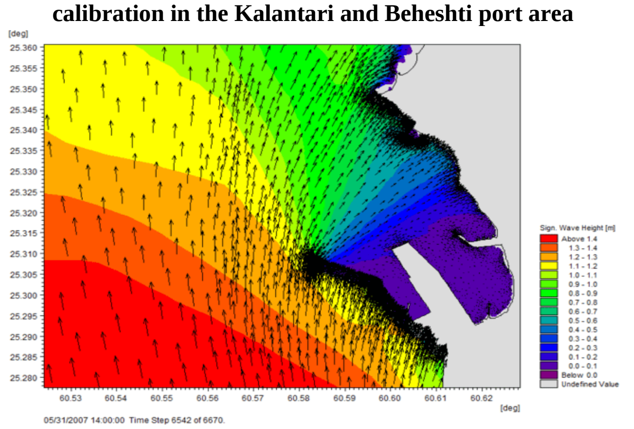

Figure 10. Wave height variations for the one-time step after calibration in the Kalantari and Beheshti port area

3.2. Current Modeling

In this modeling, three open boundaries were used for simulation. Currents enter Chabahar Bay from the southeast and southwest directions. Currents entering from the southeast pass by the Beheshti breakwater. The current velocity in this area ranges from 0.1 to 0.4. The current pattern in the area from Tis to the eastern lagoon is irregular, with low wave height and current velocity. Near the beach shore, due to the very low depth slope, the current is clockwise and moves towards Tis Port, which could be one of the reasons for sedimentation in the area. The current movement after the eastern lagoon is towards the desalination plant, and the current velocity parallel to the coastline is low. Sediments carried by the calm current move towards the east of the desalination plant and accumulate in this area (Figures 11 and 12).

Nearshore currents at Konarak enter the Konarak area from the south and southwest of the bay. The current velocity at Iran-Bandar headland and Pozm headland is higher than in other areas near the Konarak shore. The current velocity between Konarak Port and the southern rocks is calm, and sediments entering this area settle due to the calm current. A vortex current has formed next to the Port entrance and below it, causing sediment movement. However, due to the long length of the Port and the direction of incoming currents and waves to this area, sediments cannot be transported to the Port entrance (Figures 11 and 12).

There is a circular current at the Beheshti breakwater, which has a higher velocity compared to the area between Haft-e Tir and Kalantari. The current entering the area between Kalantari and Haft-e Tir wharves is clockwise, causing sedimentation behind Haft-e Tir port and south of Kalantari Port (Figures 13 and 14).

In the area near the shore and Kalantari Port, where wave directions are diffracted and the current is clockwise, the possibility of sedimentation is very high. After passing the Shahid Kalantari Port, the current pattern moves towards Sepah and Tis wharves, with the current velocity weakening parallel to the coastline (Figures 13 and 14).

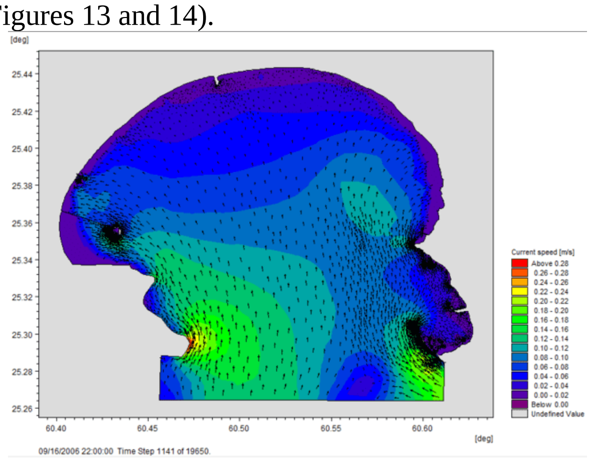

Figure 11. Changes in the current velocity of Chabahar Bay at a one-time step after calibration

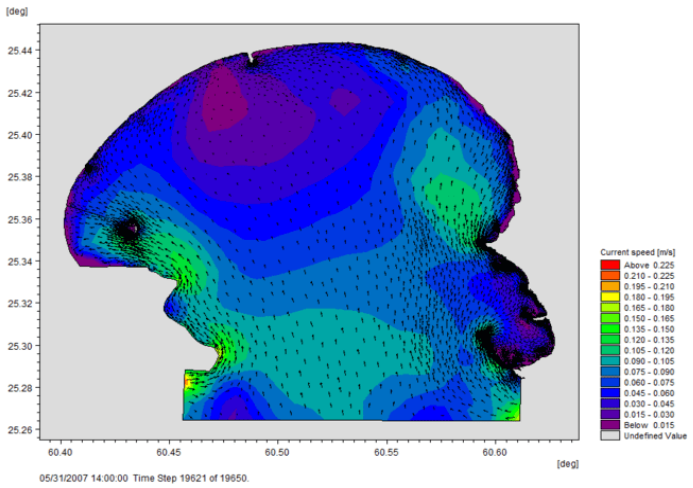

Figure 12. Changes in the current velocity of Chabahar Bay at a one-time step after calibration

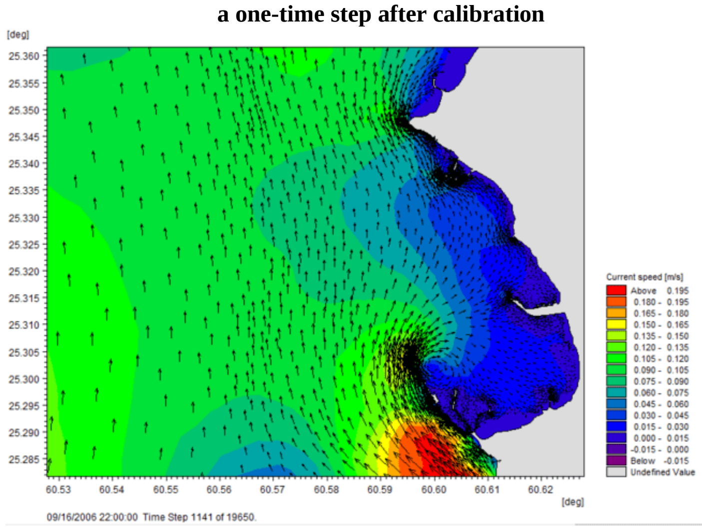

Figure 13. Changes in current velocity at a one-time step after calibration in the area of Shahid Beheshti and Kalantari ports

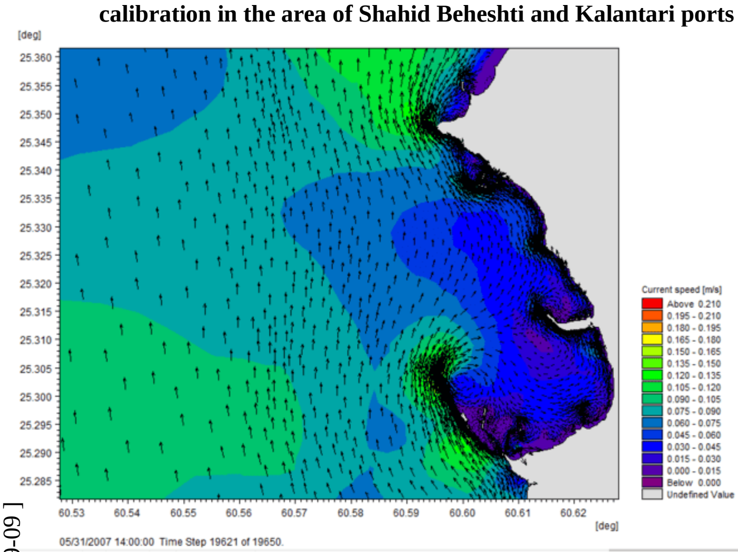

Figure 14. Changes in current velocity at a one-time step after calibration in the area of Shahid Beheshti and Kalantari ports

The current pattern has changed compared to before the construction of the Shahid Beheshti breakwater and after its completion, moving more towards Tis (Figure 15). After the completion of the Shahid Beheshti breakwater, a large clockwise circular current is observed at the headland and entrance channel of the Shahid Beheshti basin, with higher current velocity in this area. The current velocity and wave height in the area between Shahid Kalantari and Beheshti wharves are very low, which could be one of the reasons for sedimentation behind the Shahid Kalantari breakwater, beside the Haft-e Tir Port, and the Shahid Beheshti Port. A calm current moves from the entrance between Kalantari and Beheshti wharves towards the south of Beheshti Port, causing sedimentation in the area between Haft-e Tir and Beheshti ports. In the area opposite Shahid Kalantari Port's pier number 1, the current is calm and incoming waves result from diffraction, with sedimentation observed in this area. The current pattern and velocity in the Konarak area have changed slightly compared to before the development plan, with increased current velocity near Pozm headland. However, these changes do not seem to be related to the Shahid Beheshti port development plan and likely have another source. The current pattern in other parts of the bay has not changed significantly (Figure 16).

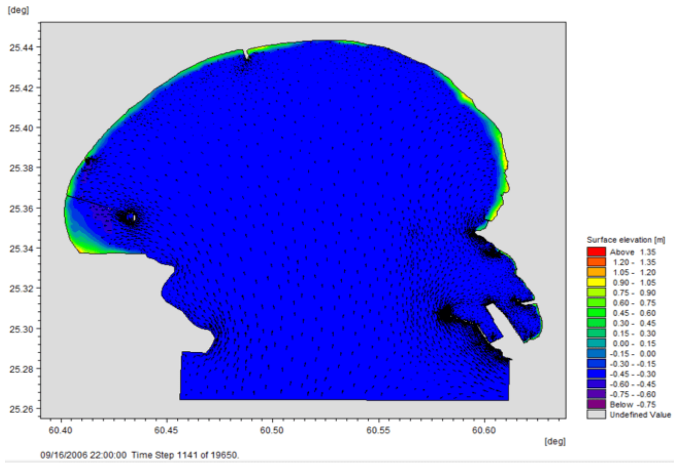

Figure 15. Changes in the water level of Chabahar Bay at a one-time step after calibration

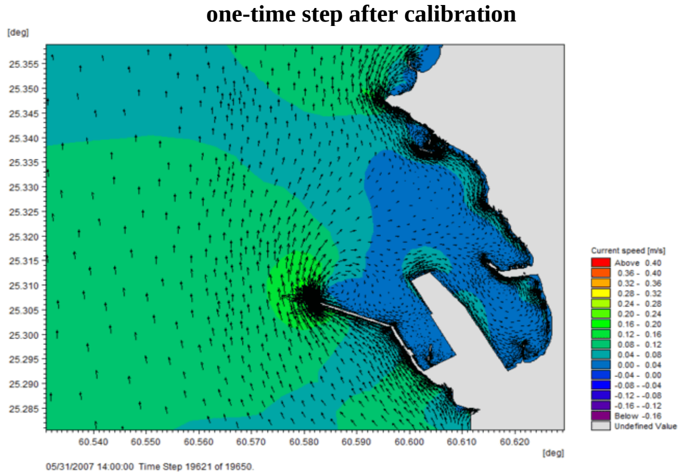

Figure 16. Changes in current velocity at a one-time step after calibration in the area of Shahid Beheshti and Kalantari ports

3.3. Sediment Modeling

According to the modeling before the Shahid Beheshti Port development plan, sediments enter the area between the Beheshti breakwater and Kalantari Port after circling the breakwater. Due to the vortex state at the tip of the Beheshti breakwater, sediments enter the Beheshti basin up to behind the Kalantari Port (Figure 17). Some sediments settle between Haft-e Tir port and the Beheshti breakwater along its shore. The sedimentation area in this region is about 2,600 square meters, and considering the profile change height of 5 to 6 meters, the sediment volume in this area is between 13,000 to 15,600 m³ per year. Factors contributing to sedimentation in this area include very calm currents and low bed slope, noting that calmer currents in an area can lead to more sedimentation, provided that sediments are present in the area.

Next to Haft-e Tir port towards the east, there is a sedimentation area. Most of the accumulated sediments in this area enter through a flood channel, and some sediments settle due to the calm current in this area. The sedimentation pattern in this area moves towards the downstream of Haft-e Tir port, with calm currents transporting sediments to this area. The sedimentation area in this region up to the flood channel is about 1,200 square meters, and considering the profile change height of 5 to 6 meters, the sediment volume in this area is between 6,000 to 7,200 cubic meters (Figure 18).

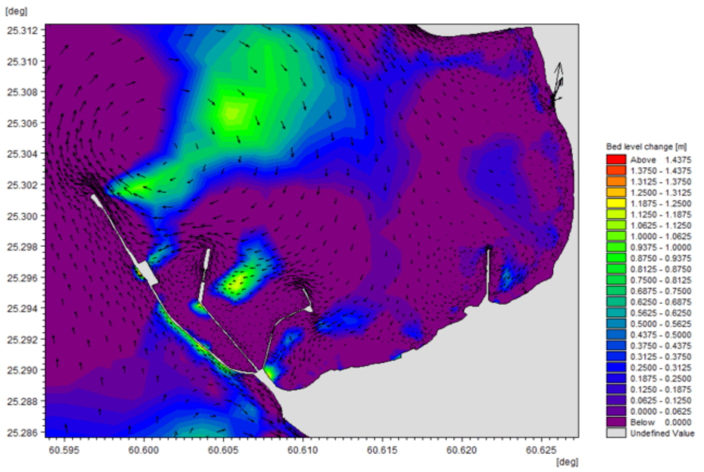

Figure 17. Changes in bed level before the Shahid Beheshti Port development plan

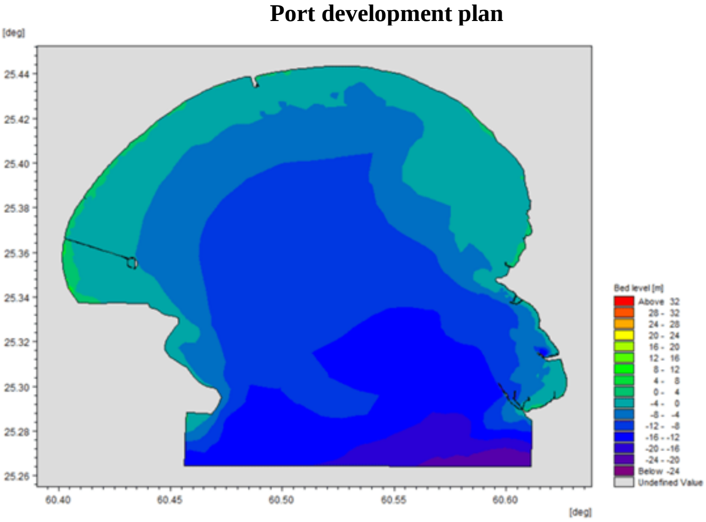

Figure 18. Bed level of Chabahar Bay before the development of Shahid Beheshti port

After the Shahid Beheshti Port development plan and completion of its breakwater, sediment movement from the south towards the bay is diverted by the breakwater and moves towards Pozm headland. In some cases, sediment movement at the breakwater tip enters the Beheshti, Kalantari, and northeastern Bay areas through diffraction and vortex action (Figure 19).

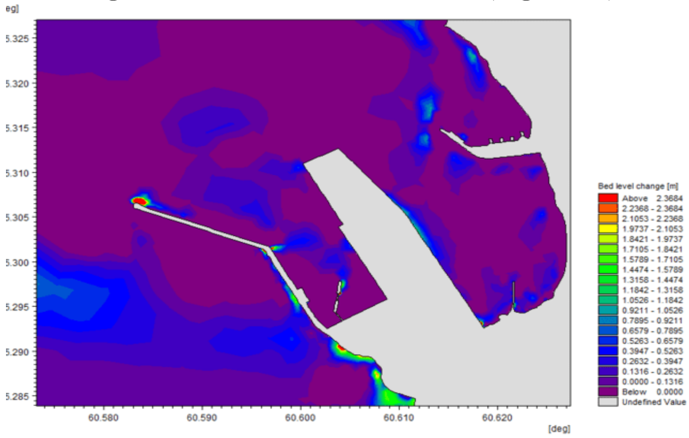

Figure 19. Changes in bed level after the Shahid Beheshti Port development plan

Sediments transported through rock erosion move towards the Sepah Port shore, pass through its breakwater and move towards Tis headland. In the northern part of Sepah Port, we face rock erosion, with some sediments settling along its shore and some passing through Tis headland (Figure 20).

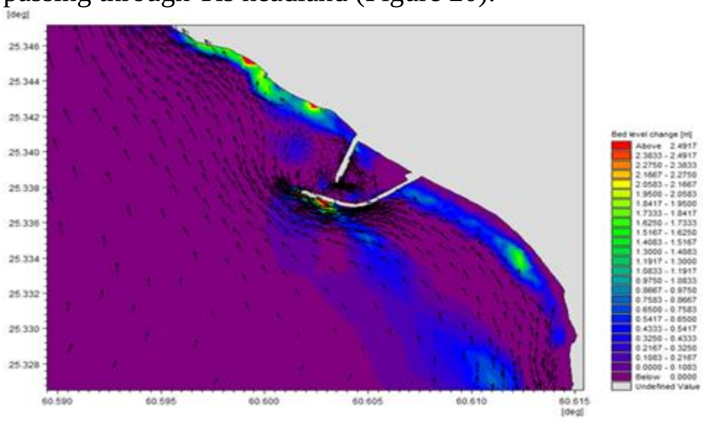

Figure 20. Changes in bed level of Sepah Port after the Shahid Beheshti Port development plan

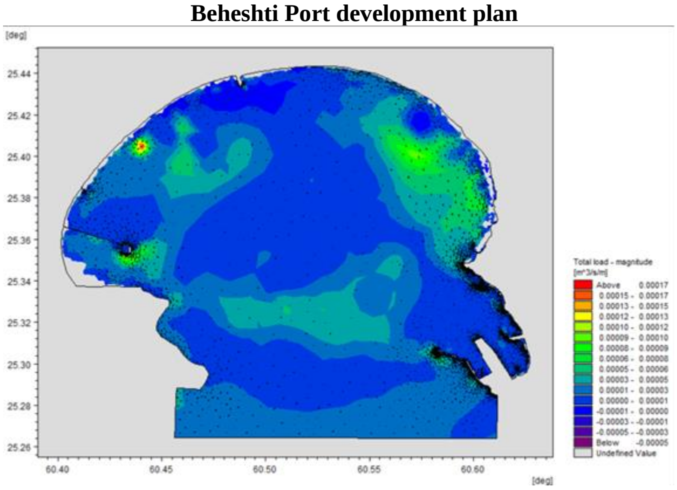

Figure 21. Changes in total sediment load, Chabahar Bay after the Shahid Beheshti Port development plan

4. Results and Discussion

The wave modeling analysis conducted before and after the Shahid Beheshti port development plan reveals significant insights into the hydrodynamic changes in the region. Before the development, incoming waves predominantly approached from the south, undergoing a slight directional shift upon encountering the Shahid Beheshti breakwater before propagating towards the Sepah and Tis wharves. Wave diffraction effects were observed in the intermediate space between the Beheshti and Kalantari wharves, with subsequent wave movement behind the Kalantari and Haft-e Tir breakwaters. Wave heights within the Haft-e Tir and Kalantari Port area exhibited a range of 0.1 to 0.3 meters. The region between these wharves was characterized by a very low bed slope and calm currents, conditions conducive to sedimentation and sediment accumulation. At the Shahid Kalantari Port, diffracted waves entered the area with heights ranging from 0.1 to 0.4 meters. The proximity of calm currents near the shore and Port Number 1 was identified as a significant factor contributing to sedimentation in this vicinity. In the Lipar area, situated above the Shahid Kalantari Port, wave heights increased to 0.1 to 0.7 meters, with the predominantly rocky coastal morphology leading to erosion due to wave impact.

Post-development modeling revealed notable changes in wave dynamics. The Shahid Beheshti basin exhibited very low wave heights, with the area extending from the Shahid Beheshti Port to behind the Kalantari Port experiencing wave heights up to 0.15 meters. The combination of low wave heights, very calm current velocities, and the enclosed nature of this region were identified as key factors promoting sedimentation. Adjacent to the Shahid Kalantari Port and its shoreline, wave heights decreased, while diffraction effects intensified, further contributing to sedimentation processes. The model also indicated that incoming waves from the south, upon interaction with the secondary arm of the Beheshti breakwater, predominantly moved towards the Tis headland. In certain instances, waves approaching from the southeast entered the bay and, after passing the secondary arm of the Beheshti Port, proceeded towards the Pozm headland and Konarak.

Regarding current modeling before the construction of the Beheshti breakwater, findings revealed that the incoming wave direction to Chabahar Bay was predominantly from the southeast, south, and southwest. The currents, induced by these waves, entered the bay accordingly. Before the breakwater's construction, current velocities were notably high at the headlands of Beheshti Port, Pozm, and Tis. The incoming current velocity was particularly intense as it approached the Haft-e Tir Port behind the Shahid Beheshti Port, leading to erosion of the rocky shoreline near the Maritime University. In contrast, the current near the Kalantari Port and its adjacent shoreline was calm, contributing to sedimentation in this area.

Post-construction of the Shahid Beheshti breakwater, the current modeling results indicated that currents primarily entered Chabahar Bay from the southeast and southwest. Currents from the southeast passed alongside the Beheshti breakwater, with velocities ranging from 0.1 to 0.4 m/s. A circular current was observed at the Beheshti breakwater, exhibiting higher velocities compared to the area between Haft-e Tir and Kalantari wharves. The current entering the area between Kalantari and Haft-e Tir wharves was clockwise, promoting sedimentation behind Haft-e Tir port and south of Kalantari Port. Near the shore and Kalantari Port, the current was calm, and waves resulted from diffraction, factors contributing to sedimentation in this area.

Sediment modeling results before the Shahid Beheshti Port development plan demonstrated that after circling the breakwater, sediments entered the area between the Beheshti breakwater and Kalantari Port. The vortex-like conditions at the tip of the Beheshti breakwater facilitated sediment entry into the Beheshti basin, extending to the area behind Kalantari Port. A portion of the sediments settled between Haft-e Tir port and the Beheshti breakwater along its shore. The sedimentation area in this region was approximately 2,600 square meters. Considering the profile change height of 5 to 6 meters, the annual sediment volume in this area ranged between 13,000 and 15,600 m^3. Factors contributing to sedimentation in this area included very calm currents and low bed slope, with the understanding that calmer currents generally promote increased sedimentation, provided that sediments are present in the area.

Beyond the beach coastline towards the eastern lagoon, sedimentation rates increase dramatically. The eastern lagoon's high sedimentation is attributed to flood-induced sediment influx and the prevailing unstable yet calm current regime in the area.

On the opposite side of the bay, where Konarak Port is located, the sedimentation pattern follows an east-to-west trajectory. This area receives sediment inputs from both the western lagoon and the Pozm headland. Notably, the hydrodynamic conditions in the vicinity of Konarak Port, both to its north and south, are characterized by calm current patterns.

Regarding sediment modeling, results after the development of the Shahid Beheshti Port revealed significant changes in sediment transport patterns. Following the completion of the breakwater, sediment movement from the south towards the bay was redirected by the breakwater towards the Pozm headland. In some instances, sediment movement at the breakwater tip entered the Beheshti and Kalantari Port areas and the northeastern part of the bay through diffraction and vortex action. Changes in bed level within the Beheshti basin, particularly at its far end, indicated calm currents and slight sedimentation. Annual sedimentation rates of approximately 10 cm were observed in the Beheshti basin and channel. Sediment movement, influenced by diffraction effects and current patterns after the Beheshti Port, entered the Kalantari basin and the area between Beheshti and Kalantari. The volume of sediments entering the area between Kalantari and Beheshti was primarily attributed to flood channels near the Haft-e Tir Port and behind the Maritime University.

Some sediments settled after entering the Beheshti and Haft-e Tir areas. The current in this region was very calm, facilitating easy settlement of transported sediments. The sedimentation area between Beheshti and Haft-e Tir wharves was approximately 1,200 square meters, with an annual sedimentation volume ranging from 6,000 to 7,200 cubic meters, predominantly occurring alongside the Beheshti Port. Annual sedimentation rates in this area ranged from 8 to 12 cm.

Comparing bed level changes before and after modeling, coastal areas post-development showed relatively lower sedimentation volumes than pre-development. This indicates that most shoreline areas did not undergo significant changes during the modeling period. Satellite imagery and field observations confirmed that these changes stabilized after the development plan. Bed level changes were more pronounced near ports and flood channels. Changes in total sediment load were minimal in the Beheshti Port Basin area and slightly noticeable in the Kalantari Port Basin.

5. Conclution

In general, it can be stated that, due to changes in bed level, the volume of sedimentation after the port development is relatively less than before the development plan. This slight difference in sediment volume is more significant in port areas and river estuaries.

It seems that periodic field measurements, such as hydrography, especially in more important areas such as around ports and river estuaries, along with numerical modeling, can provide a more accurate understanding of the problem. Also, before constructing projects and structures based on the regional development plan in Chabahar Bay, their impact on sedimentation should be investigated.

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