J. Appl. Environ. Biol. Sci., 6(2S)240-247, 2016

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ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Modeling of Coastline Changes In Larak Island

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Received: January2, 2016
Accepted: February 29, 2016

ABSTRACT

In this article, coastline changes has been studied as a case study for Larak Island, located in south of Iran. The advanced 2D model of Mike21 has been used for this purpose. Two different time steps has been considered in order to carry out the calibration and verification. First, the hydrodynamic (HD) module of Mike21 has been used to obtain the required output for sediment transport model (ST module). The ST module modeled the area for tidal currents only. Coastline changes are resulted by series of modeling for both HD and ST module in 3 months time step. The final bathymetry in each time step is fed back as the primary bathymetry for next time step. This has been continued until coastline for year 2020 is obtained.

KEYWORDS: Hydrodynamic, Sediment Transport, Larak Island, Coastline Advance and Retreat

1. INTRODUCTION

The history of coastline engineering should be sought for in ancient times in the sidelines of the Mediterranean, the Red Sea, and the Persian Gulf. Port-related coastline engineering is dated back to around 3,500 years BC concurrent with development of marine transportations [1]. Coastline engineering can be defined as application of physical and engineering sciences in designation and construction of structures or operations in shores that can make improvements in air, sea, and land interplays in shore regions. Additionally, shore maintenance means operation and implementation of plans to make stability in shores and maintain shore facilities and structures against invasion of waves, currents, tornados, etc. Shore instabilities, significant coastline translocation, shore erosion as a result of waves, currents, tornados, etc., ensuing damages to shore facilities and structures, human interventions in changes in coastline areas, and other similar issues are among problems which are confronted by many regions and countries bordering seas. Our country, also, has a wide sea border in its southern and northern parts—the fact which, together with increasing commercial exchanges via sea and its economic importance, necessitates expansion of ports and coastline structures located at the Iranian southern and northern shores [2].

Transport of littoral sediments is divided into two transmissions: onshore and offshore, and also alongshore transports [3]. While Iran has wide sea borders in its southern and northern shores, there are no sufficient relations and appropriate models for sediment transport and context changes in the Iranian littoral regions. Decisions were made to simulate the sediment transport phenomenon and study context changes in one of the Persian Gulf and Oman Sea ports. Numerous are the studies dealing with sediment transport theory and the relationships therewith.

Studies on concentration of sediments suspended in surf zone that were conducted by Watts in 1953 [4] and Fairchild in 1972 [5] indicated that sediments suspending in this zone can compose an outstanding part of the sediment materials in alongshore transports. Studies by Davis and Fox[6] showed that sediment depositions can break elevated waves, causing a reduction in littoral erosions by dissipating their energy. Dally and Dean [7] investigated transport of the sediments traveling along the profile (perpendicular to the coast) and predicted shore’s longitudinal profiles.

Before proceeding to the next part dealing with morphology, two definitions should be made. Morphology of shores studies compatibility of shores under the impact of sediment transport induced by waves, currents, and wind [8].

Beach morphodynamics is, in fact, investigation of dynamic changes of context as a result of free or coercive mechanisms in relatively large time and location scales [9].

Along with theoretical sediment transport studies, the issue of morphological changes has been a main parameter in long-term predictions by different researchers. Vriend et al. [10] descried methods to reduce input volume, simplify modeling process, and summarize outputs. Latteux [11] expressed that long-term simulation of morphology using real time models leads to highly time-consuming computations. In their study, Roelvink et al. [12] presented a simplified method to obtain a primary estimation of context changes based on the two-dimensional sediment transport model. Vriend [13] managed to study concurrent performance of different methods using research projects and studies dealing with morphological changes of sand estuaries in Netherlands. In lapping cases, methods confirm each other; and, in complimentary cases, uncertainty is reduced. In 2006, Roelvink [14] presented come methods to calculate morphological changes, including a combination of tide-averaging and continuity correction methods. RAM (Rapidly Assessment of Morphology) method is presented following the continuity correction method. Then, the morphological factor method is addressed, and its results are compared with previous methods. Finally, a new method named parallel online is introduced,

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which has been able to obviate some of the defects of precious methods [14]. An ensemble of researchers [15] made attempts to investigate interplays of differences in such scales along with morphological changes of estuaries based on different time and location scales cited in morphological models as a result of complexities in basic information.

2. MATERIALS AND METHODS

Larak Island is one of the tourist attractions located at Hormozgan Province in southern Iran that has an area of 48.7 square kilometers. It is located in a sea distance of 30 kilometers from the center of the Hormozgan Province and a sea distance of 9 kilometers from the Qeshm City. Larak Island is located at the south eastern side of this city in the Strait of Hormoz. This island is at southern Iran and in the Strait of Hormoz, at coordinated of 56 degrees and 21 minutes of eastern longitude and 26 degrees and 51 minutes of northern latitude. Layout of this island is illustrated in the Fig. 1.

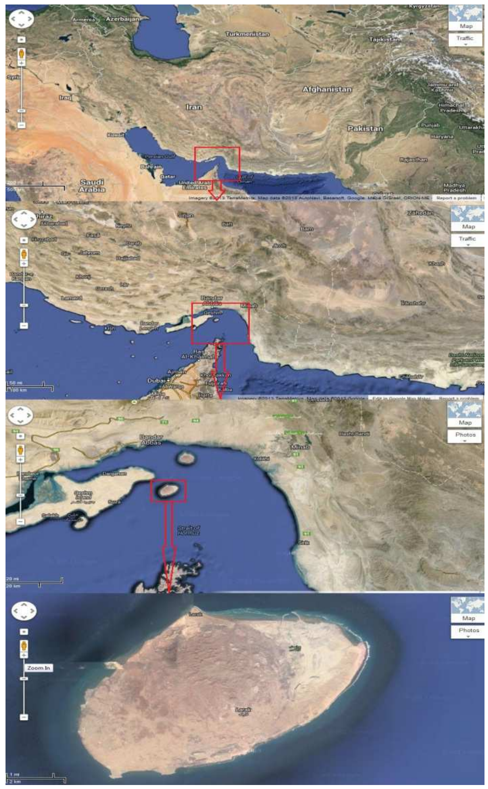

Fig. 1. Layout of Larak Island in Hormozgan shores and Strait of Hormoz [16]

In order to construct the morphology model, two models are to be constructed:

Hydrodynamic model; and,

Sediment transport model.

According to geographical location of this region and taking into account that stability criterion of the model is courant number and it is an important factor in calculation of the acceptable courant number suitable for the distance between mesh networks (Δx=500m), Bathymetry file was constructed. Courant number is equal to multiplication of wave celerity by time pace of mesh network, which can be mathematically expressed as $C_N = C\frac{\Delta t}{\Delta x}$, and wave celerity is equal to $C = \sqrt{gh}$. Courant number is calculated by calculation software, and it should be lower than one to secure model's stability.

One of the boundary conditions used in the model for sea level changes is time series. This information is gathered by the Cartography Organization in Larak Region extractable from the relevant website. The Table 1 shows the information related to sea level in terms of time for duration of two years (from 1 Jan. 2010 to 31 Dec. 2011) in Hormoz Island Station as the northern border and Suza Port Station as the southern border of the model. Another border condition used herein is wind speculations including wind celerity and direction for duration of two years (from 1 Jan. 2010 to 31 Dec. 2011) as a time series file, shown in the Table 2.

Table 1. A summary of water level changes in eastern and western borders

Station	Min Level (m)	Max Level (m)	Ave Level (m)
Chabahar	-1.99	1.23	-0.073
IranBandar	-1.82	1.52	0.092

Table 2. A summary of wind information in the region under study

Factor	Minimum	Maximum	Average
Velocity (m/s)	0.00	11.5	3.73
Direction (degree)	0.16	258.9	231.24

To calibrate model, we deal with three parameters. M=1/n is Manning's roughness coefficient, E is eddy viscosity, and F_w is friction coefficient. Manning's coefficient is related to context and resistance force formed as against the current by the context. Eddy viscosity is related to current specifications. Wind friction is associated with impact of wind on current. According to impact manner of these three parameters, this is clear that they are independent and one's performance will not influence on the others. To study impact of these parameters and impact level of each on current model's outputs, several scenarios were introduced, in which two parameters were kept fixed and one was changed. For each scenario, current model was once operated. After each operation, model's outputs as for sea level changes in Band-e-zarak Station were extracted and stored. They, finally, were compared with equivalent points in measured data. For each parameter, the amount which had the least digression from measured amounts was registered as the model's appropriate amount. Finally, model's calibration for 2010 and 2011 are obtained.

Values of obtained parameters are used, and 2010 and 2011 models are validated for the Bahman 22nd Waterfront. Layouts of these stations, together with Band-e-zarak and Bahman 22nd Waterfront, are shown in the Fig. 2 as calibration and validation stations.

Fig. 2. Layout of Hormoz Stations and Suza Port as borders of the model, and Bandzarak Station and 22nd Bahman Waterfront as calibration and validation stations (source: maps.google.com)

Afterwards, the outputs obtained from hydrodynamic model construction phase are introduced as inputs into the sediment transport model. These outputs include current, current flow rate, and sea level changes. Type of modeling should be selected in this stage. Modeling is performed by the software in two current-only and wave-impacted current modes, of which the former one is here adopted.

3. RESULTS AND DISCUSSIONS

After several investigations on roughness coefficient from 23 to 34 and eddy viscosity from 26 to 43, roughness coefficient was selected to be 26 and eddy viscosity to be 31, the selections which resulted in the best outcomes. Wind friction coefficient, being considered as 0.026, had insignificant impacts on results.

Referring to CERC empirical relation, validity of the constructed model is authenticated. Model was operated in mentioned points, and obtained values were compared with CERC relation. Comparison of results affirmed validity of the model. Results of the model for sediment transport in the defined section around the island (Fig. 3) obtained by the CERC relation in the time segment 1 Jan. 2010 to 31 Dec. 2010 are shown in the Table. 3.

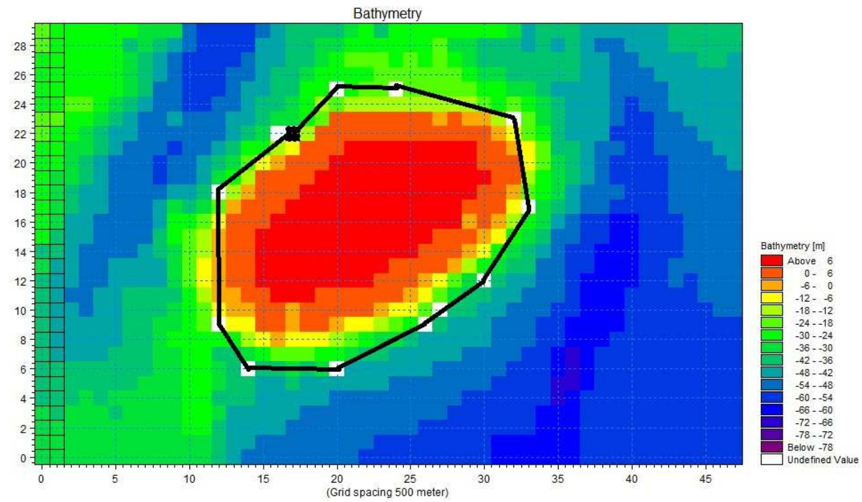

Fig. 3. The segment specified around the island to calculate sediment transport

Table 3. Calculated sediment and empirical equation

Equation	Calculated Sediment Volume From Model in Section 1 (m^3)	Calculated Sediment Volume From CERC in Section 1 (m^3)
Engelund & Hansen	-8982674	-5970839
Engelund & Fredsoe	-4334979	
Zyseman & Fredsoe	-4799647	
Meyer-peter & Muller	-853317	
Ackers & White	-5339693	

From the CERC equation, current rate, and energy movement, we have:

$$P_{ls} = \frac{\rho g H_b^2}{16} C \sin 2\alpha \quad (1)$$

After needed replacements, value of energy rate in coastline length unit (kilometers) is as follows:

$$P_{ls} = \frac{1020 \times 9.81 \times 0.501^2}{16} \times 4.43 \times \sin(2 \times 13) = 200.957 \frac{\mathrm{N}}{s}$$

$$Q = \frac{0.41(1-n)P_{ls}}{\rho g} = 0.0074934 \frac{m^3}{s}$$

This value is sediment flow rate in terms of cubic meters per seconds for each kilometer of shoreline. Considering an approximate amount of 25 kilometers for shoreline and changing it into the flow rate amount per year, we have:

$$Q = 5907839 \frac{m^3}{year}$$

This sediment amount is ensuing from currents and waves.

Comparison of calculated values by the software and values obtained from the CERC relation are indicative of slight impacts left by waves in transport of region's sediments. A comparison of values in the empirical relation and values presented by the software shows that the relation found by Ackers and White has the nearest value of the calculated volume; thus, it is selected as the basis of computations. The relation found by Meyer-peter and Muller shows very small values, which is not unexpected as for exclusiveness of this relation to context load. The relation found by Engelund and Hansen represents a high volume, which can possibly be attributed to disregarding natural slope of the region.

To proceed context changes, hydrodynamic and sediment transport models were operated for a two-month period, and new context of the sediment transport model was introduced into the model as the initial input of the hydrodynamic model as the context of modeling the next three-month period. This process is continued to predict context at the beginning of 2020. Initial 2010 context is exhibited in the Fig. 4.

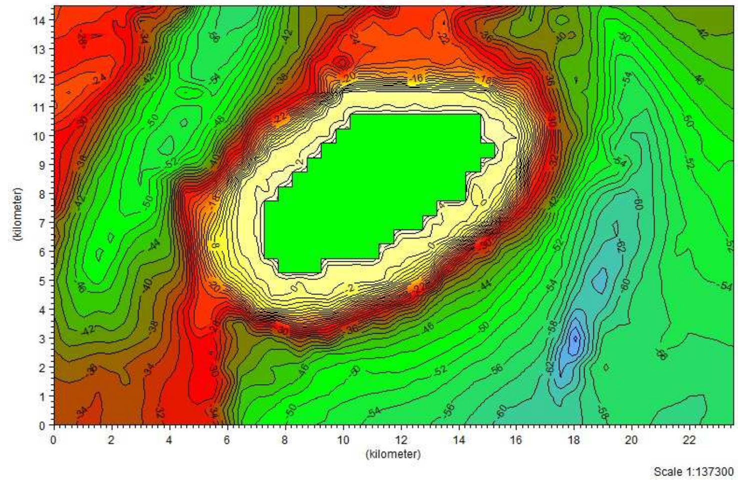

Fig. 4. primary bathymetry of modeling

To study shoreline changes, island shore is divided into four sections to enable investigation of them in a numerical manner. Island coast is divided into four northern, eastern, southern, and western sections as shown in the Fig. 5.

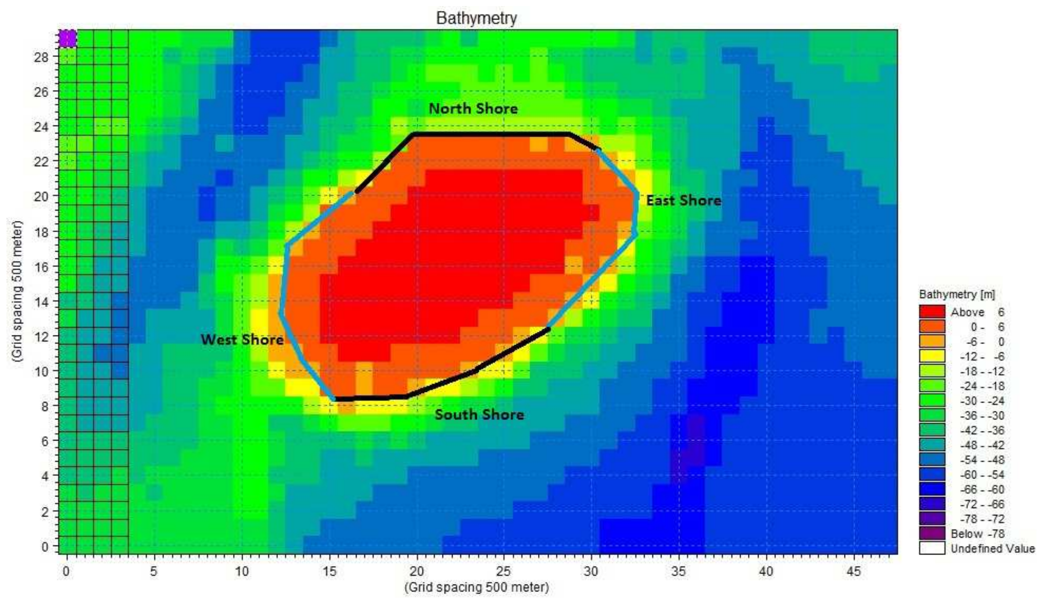

Fig. 5. Coast classification defined for investigation of coastline changes

Profile changes of the sections' coastlines in two-year time span are exhibited in the diagrams 6 to 9 where depth changes along coastlines for two consecutive years are shown.

In the diagrams, positive values are indicative of sedimentation and reduction of depth, and negative values imply erosion and increase of depth in coastlines. Reduction of depth in coastlines is taken to mean progression of coastline, where increase of depth regression of coastline.

Mesh points, which have the highest changes, are then named and finally illustrated over the region area (Fig. 10).

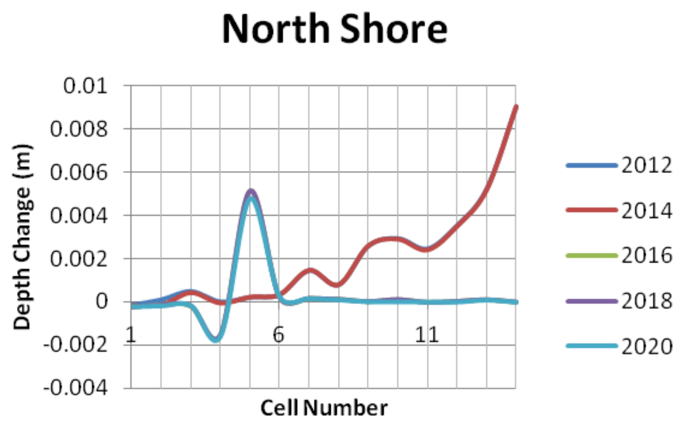

Fig. 6. Changes of coastlines along the north shore

Fig. 6 shows depth changes in coastline along the northern coast. Investigation of this diagram indicates that changes are mainly scant, whose amounts become even less after passage of time. In the northern coast, this is clearly seen that depth is increased in the initial years up to 2016, and coastline is regressed; however, it reaches a relative poise thereafter. The highest change until 2020 is 10 millimeters erosion in depth. The highest changes have happened in points 5, 13, and 14 that are named as N5, N13, and N14, respectively.

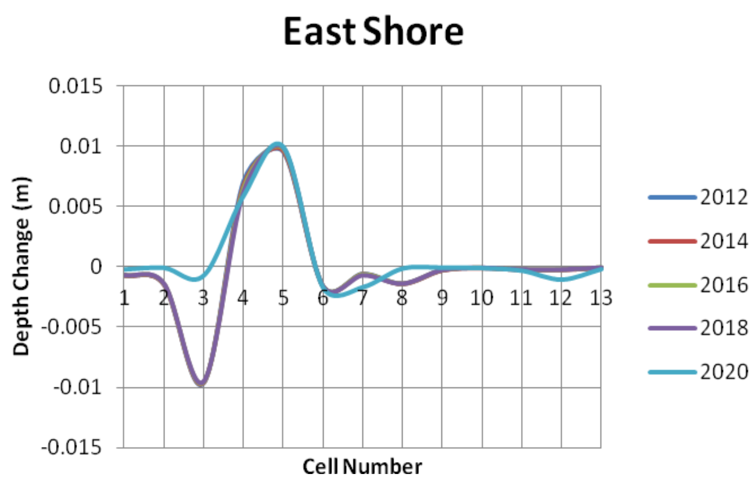

Fig. 7. Changes of coastlines along the east shore

Fig. 7 shows depth changes in coastline along the eastern coast. The comparison made between Fig. 6 and 7 indicates that changes are less in this coast, and higher levels of correlation are achieved with passage of years. Save for points 3, 4, and 5, other points experience slight erosive changes. The highest changes have happened in points 3, 4, and 5 that are named as E3, E4, and E5, respectively.

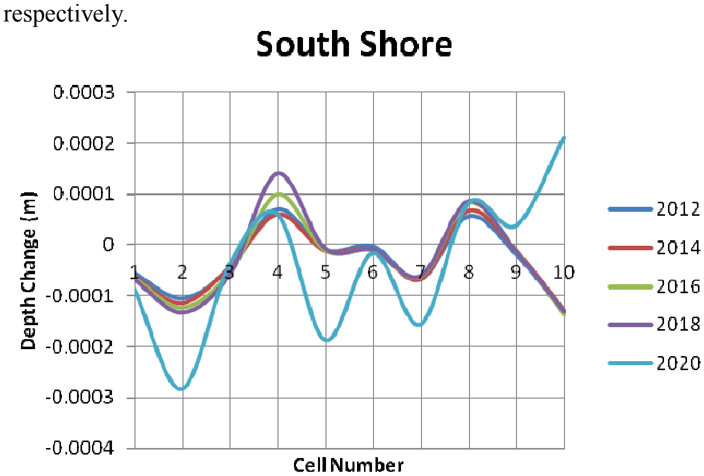

Fig. 8. Changes of coastlines along the south shore

Fig. 8, which shows changes in coastline depth along the southern coast, and its comparison with Fig. 6 and 7 express that this coast is very serene, and has experienced small changes during the time. Values of these changes and other two coasts investigated are very small.

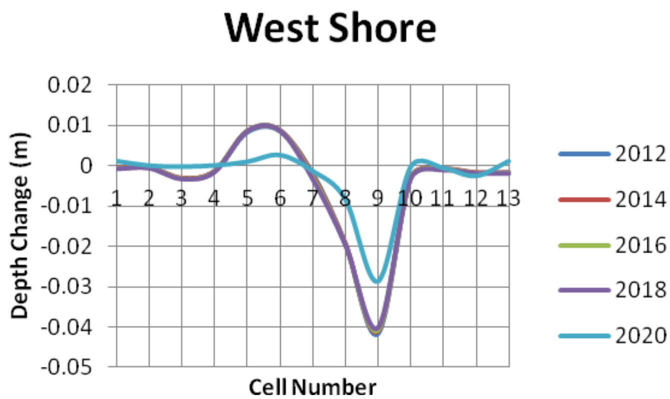

Fig. 9. Changes of coastlines along the west shore

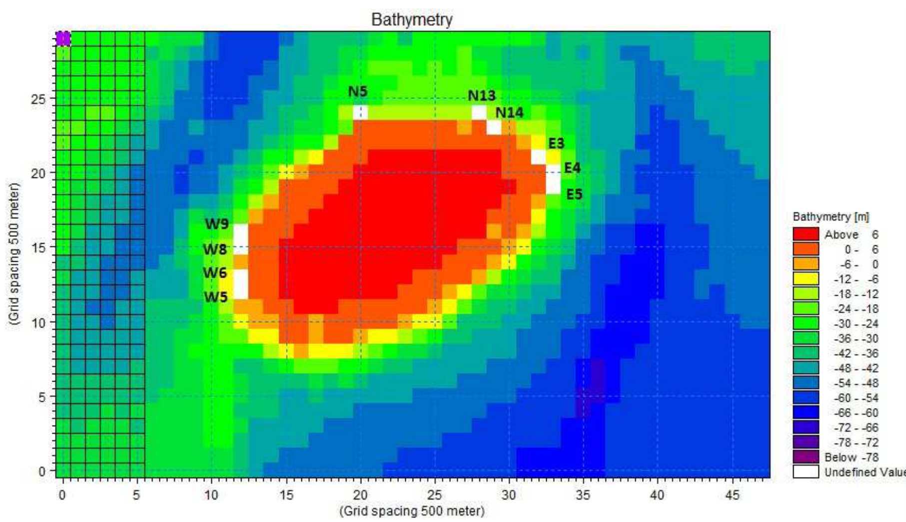

Fig. 6. Points with the highest detectable changes at each coast region

Fig. 9, which shows changes in coastline depth along the western coast, and its comparison with Fig. 6, 7, and 8 express that this coast has comparatively higher changes as to other three coasts, and its depth changes are larger than other three areas. Main changes of this coast are materialized as erosion and depth increase. Higher changes have happened in points 5, 6, 8, and 9 that are named as W5, W6, W8, and W9, respectively.

4. Conclusions

The model constructed for different sediment transport theories was operated and obtained results indicated that the hypothesis of dominant impact left by tidal currents in region is correct and waves have a small share in transport of sediments. Moreover, sediments are mainly transported as a result of tide-generated forces.

In addition, diagrams and results show that sediment transport phenomenon has largely happened in western and, followed by, northern coasts. Eastern coast has had relatively low changes, and changes in southern coasts are very small. Western coast, due possibly to its vicinity to Qeshm Island and existence of a larger sediment source, experiences the highest changes.

In ten-year time spans, there are no considerable changes in coastlines. Notwithstanding, dominant sediment regime is in an erosive manner and coastline is on the regression. This regime is calculated in sediment volume around the island.

A basic comparison of figures shows that this region is experiencing a relative balance respecting its sediment load and context changes. Diagrams indicate that perceptible changes happen only in western coast. Results achieved from different relations show that the one calculated by Ackers and White is the closest outcome. The results show that the relation by Engelund and Hansen comparatively has lower accuracy because of disregarding impact of the region's natural slope and simplification hypotheses made by the relation.

This is, additionally, observed that load value of the MPM relation is approximately 20 percent of the sediment load obtained by other relations, which may be possibly due to the fact that sediment load of the MPM relation is context load-related whereas sediment load obtained by other relations is a total (bed load + suspended load) load, a comparison of which verifies accuracy of the model.

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