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Calibration method of numerical models in coastal sediment studies of Kuhmobarak area

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Abstract

Application of numerical models is useful in coastal sediment studies; however, it is essential to calibrate the models in an appropriate method. Empirical equations, historical satellite imagery and other coastal data and evidence are proposed for the models calibration in the vicinity of coastal indicators around the site of projects.

In this study, coastal sediment process of Kuhmobarak area is investigated to evaluate construction of a new port at the southeast of Hormozgan province. For this purpose, a comprehensive study on effective parameters is performed to describe sediment process of the area. Furthermore, numerical models of sediment transport calculation and morphological evaluation are calibrated using the suggested organized methodology.

Keywords: Sediment Transport - Coastline Changes - Numerical Model – Calibration.

1. Introduction

In coastal zone, the effect of wave and current, as well as the interaction of rivers with coastal phenomena, the effect of wind on sandy plains and so on are the factors which cause morphological changes (Chang et al., 2018; Parsa et al., 2013; Baquerizo et al. 2008). Changes in most of environments occur very slowly because there is an equilibrium and stability condition between the coastal phenomena and subsequent interactions arisen in the longtime. However, if any artificial change is implemented in the coastal zone, stability between the natural processes will be lost and nature shows some reactions to attain a new stability considering the new condition. These reactions are in the form of accretion, erosion and coastline changes which continue to attain a new stability (Parsa et al., 2013; Shanehsazzadeh et al., 2012). In this regard, man-made structures are considered as a type of interference in the natural process of coastal zone which cause instability and make changes in the adjacent coastal zones of project site. These changes will continue many years to reach a new stability in the nature. As the new condition may interfere with the appropriate function of constructed structures and facilities, it is essential to investigate and predict the future condition of the coastal projects to identify

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their undesirable effects on the nature and also to find the undesirable effects of nature reaction on the projects. The investigation is useful to confront with the future undesirable happening.

In this study, construction of a new port is evaluated in terms of sediment process in Kuhmobarak area at the southeast of Hormozgan province, Iran. The nearest ports to the site of project are Kuhmobarak port in the south and Bonji port in the north of the location. In order to provide a better general view of the location, the project site is shown in Error! Reference source not found.. In the following, the project site characteristics, hydrodynamic conditions and sediment sources are investigated. Therefore, comprehensive study on effective parameters is done to describe sediment process of the area. Furthermore, calibration of numerical models of sediment transport calculation and morphological evaluation are performed using the suggested organized methodology.

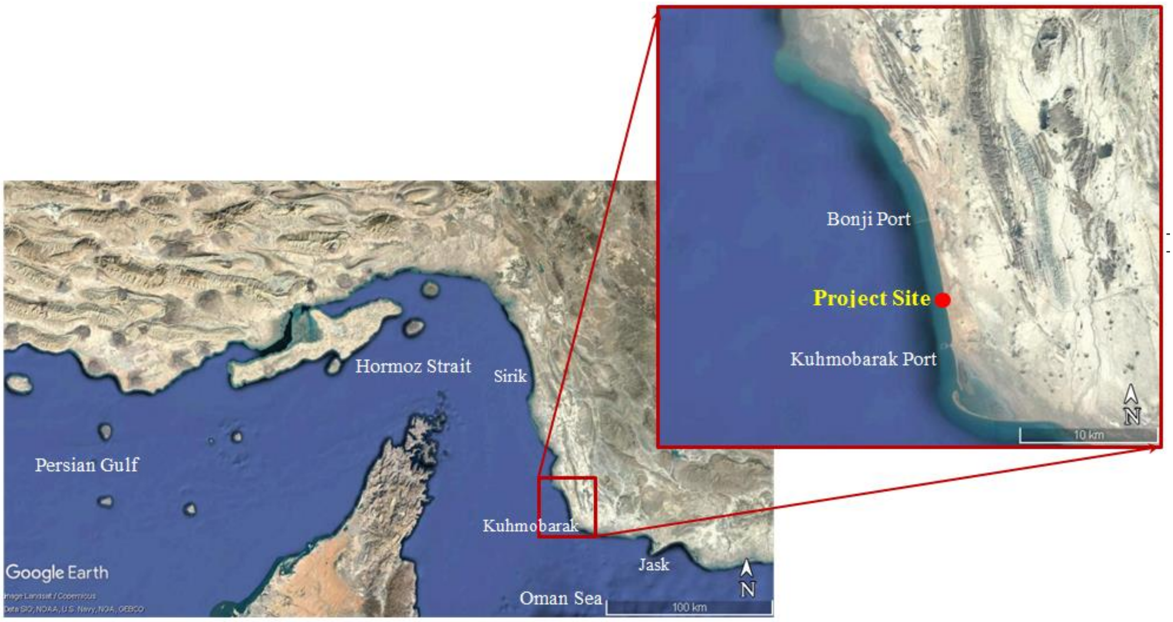

Fig. 1: Location of the project site

2. Materials and Methods

2.1. Characteristics of the Coast

Coastline direction is an effective characteristic of the coast in coastal studies. Coastline direction usually is introduced by the clockwise angle from geographical north to the normal of the coastline. This angle is important as it introduces the way waves affect sedimentary process and also it determines the vectors of longshore and crossshore current. General angle from geographical north to the normal of the coastline, in the vicinity of the site is about 260° (measured clockwise).

Cross section of coastal bathymetry is also important characteristic which has a major effect on sediment drift. General slope of the cross sections around Bonji port (north of the site), the project site and around Kuhmobarak port (south of the site) are about 0.55%, 0.52%, and 0.65%, respectively.

Bed material gradation is another characteristic of the coast, which determines properties of the bed sediment sources. In order to identify bed material gradation in the area, several samplings have been performed. According to the results, the bed is generally covered by fine sand and silts.

Sandy beach is dominant unit in the area; however, several creeks are in the middle of domain. These creeks are actually the creek-estuaries of drainage seasonal streams. At the southern part of Kuhmobarak port a sandy spit feature separates Kuhmobarak creek from sea.

2.2. Sediment Sources

Recognition of sediment sources affecting on sediment process is a fundamental step of sediment studies. Effective sediment sources on longshore sediment transport process can be generally classified in three categories as follows:

2.2.1. Wind-blown sediment from land

Most of areas around the project site are plains covered by fine sand. Sparse vegetation of bushes and shrubs can be seen in most of the areas (Fig 1). The wide sandy plains and wind blowing toward northwest directions (Fig 2) determine potential of wind-blown sediment transport from southern land towards coastal zone. Sandy storms occurrence is confirmed by local inquiries. Consequently, sediment source transported by wind blowing towards coastal zone plays role in sediment process of the project site.

Fig 1: Plains covered by fine sand with sparse vegetation

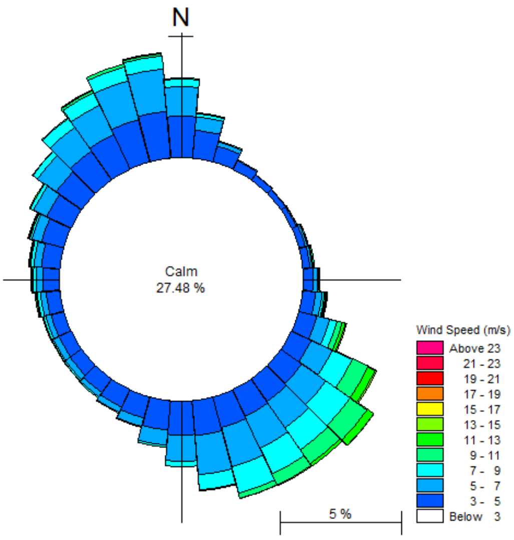

Fig 2: Windrose in the project area

2.2.2. Fluvial sediment output of rivers and streams

Fig 3 shows several estuary-creeks in the project area. These estuary-creeks are outlets of seasonal streams into sea environment. Kuhmobarak estuary-creek is at the 6 km south of the Project site; Dailu estuary-creek is near the site location, and another estuary-creek named Bonji is about 4 km north of the site. Because of vicinity of the estuary-creeks to the projects site, they effect on the sediment process of the area. Kuhmobarak and Bonji estuary-creeks just supply sediment source. Considering Dailu is near the site location, it influences the sediment process directly. Coastline variation of the outlet feature during years demonstrates its activity in the sediment process.

2.2.3. Sediment source on the sea bed and sediment of coastal erosion

Part of the deposited sediments on the sea bed can be considered as sediment sources. Sediments on the sea bed are suspended by wave induced turbulence and transported by longeshore current.

2.3. Hydrodynamics of the area

In order to investigate wave field of the area, waverose plots of time series data at 15m depth for different locations are represented in Fig 4.

Fig 3: Estuary-creeks of the project area

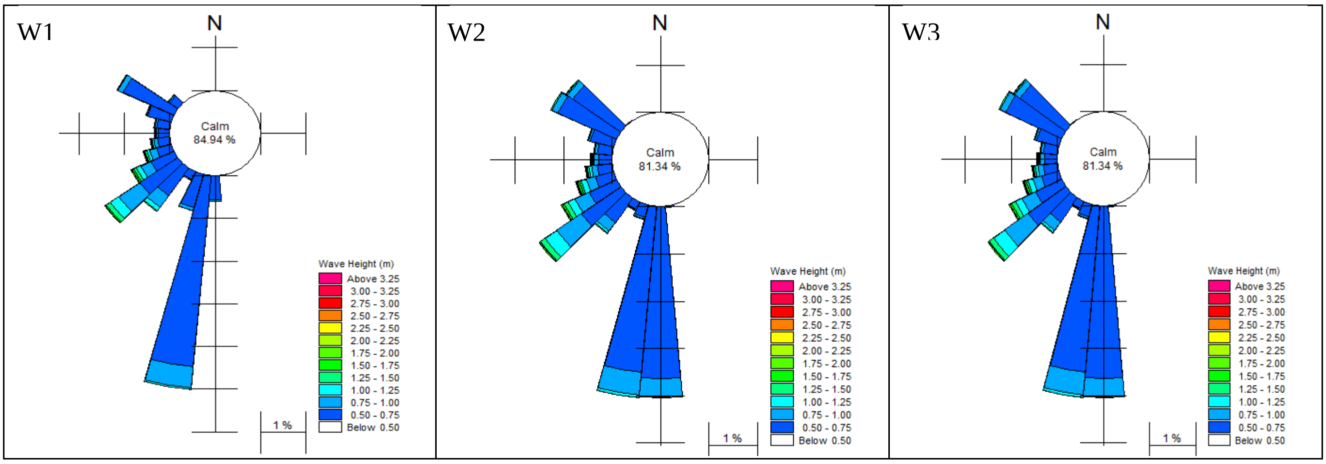

Fig 4: Waverose plot of data at 15m depth - W1: in front of Bonji port (north of the project site) - W2: in front of the project site - W3: in front of Kuhmobarak port (south of the project site)

According to the waveroses, wave calmness condition (wave height smaller than 0.5m) is more than 80% of time at the north (W1) and in front of project site (W2); however, in the south of Kuhmobarak port (W3), wave calmness becomes 77%. Prevailing wave direction is from south and southwest direction; therefore, northward sediment drift is expected.

Current rose plots of tidal current time series data at 8m depth for different locations are shown in Fig 5. According to the plots, current calmness condition (current speed less than 0.1 m/s) is more than 50% of time at the northern part of the project location (C1); 41% of time in front of the project site (C2) and 32% in the south of the Kuhmobarak port (C3). Longshore current velocity is not considerable; therefore, independent activity of current is not expected in the sediment process. Tidal current actually joins wave induced current and transports sediments which arise with the wave turbulence effect. Two-sided current in the area, results in similar effect of current on different side sediment drift; however, a bit southward dominance of the current direction affects quantity of the sediment drift.

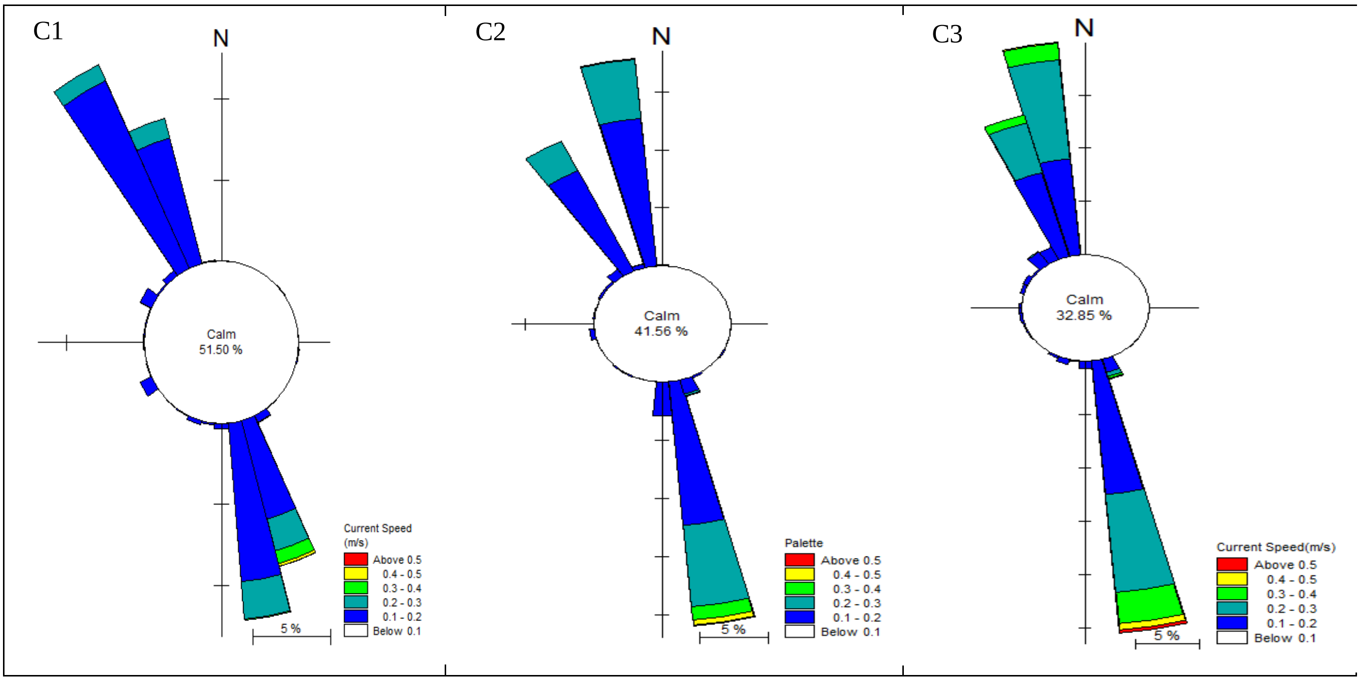

Fig 5: Current rose plot of data at 8m depth - C1: in front of Bonji port (north of the project site) – C2: in front of the project site – C3: in Kuhmobarak area (south of the project site)

2.4. Satellite Imagery Analysis

Aerial photos and satellite images play an important role in determination of coastal morphology and sediment transport pattern. Comparison of different images reveals coastline changes and subsequently identifies erosion and accretion region of the coast (Vanhellemont and Ruddick, 2018).

Satellite imagery analysis near Kuhmobarak port is applied as a criterion for the studies of morphology and sediment process of the project site, because it is the nearest coastal structure to the project site and also for its long duration (since 2005). Five different satellite imagery of the area are available including, Landsat, 1994, Google

Earth, 2012, Landsat, 2015, Sentinel 2, 2015, Sentinel 2, 2018.

To provide the best comparison, coastlines of 1994 when no port was built in the domain and 2018 when the latest satellite image was accessible, are selected. In Fig 6, comparison of 1994 and 2018 coastlines changes in the vicinity of Kuhmobarak port are presented. Since, construction of Kuhmobarak structure in 2005, no coastline changes had been expected before that time. According to satellite imagery analysis, coastlines progress at the north and south of the port's breakwater are about 218 and 280 meter, respectively. Considering Kuhmobarak construction time, average annual coastlines progress at the northern and southern coast of the port are about 17 and 21 meters, respectively. Moreover, the alongshore length of southern sedimentation area is about twice the length of northern part (Shanehsazzadeh et al. 2014). Therefore, net sediment drift is northward; although southward drift has led to accretion at the north side of the port.

Sedimentation area at the north of the port has been developed about 42,000 (m2) since 2005 to 2018 which is equivalent to volume of 252,000 (m3). Therefore, the southward annual sedimentation is about 19,000 (m3/yr). On the other hands, accretion area at the southern coast of the breakwater has been progressed about 74,000 (m2) which is equivalent to volume of 445,000 (m3). So, the northward annual accretion is about 34,000 (m3/yr) (Fig 6).

Fig 6: Accretion around Kuhmobarak port based on 1994 – 2018 coastlines (background: Google Earth 2012)

2.5. Longshore Sediment Transport

2.5.1. Empirical Equation

As empirical equation, CERC formula is a common equation for estimating annual sediment transport; however, it does not include the surf zone width and sediment grain diameter. Kamphuis developed CERC formula considering above mentioned parameters and provided a new formula with higher compatibility in the investigated case studies (Kamphuis, 2000).

In this study, potential of annual longshore sediment transport is calculated utilizing Kamphuis formula. Net annual longshore sediment transport obtained from Kamphuis formula is estimated 28,800 (m^3/yr) in northward direction. Annual sediment drift in different direction are summarized in Error! Reference source not found..

Table 1: Annual sediment transport potential calculated by Kamphuis formula

Project Site	Sediment Drift Rate (m^3/yr)
Gross Annual Sediment Drift	64,800
Northward Annual Sediment Drift	(+) 46,800
Southward Annual Sediment Drift	(-) 18,000
Net Annual Sediment Drift	(+) 28,800

(+) Northward (-) Southward

2.5.2. Numerical Modeling

Longshore sediment transport in the project site is also estimated applying numerical model developed considering hydrodynamic field and characteristics of profile (Engelund and Fredsoe, 1976; Fredsoe et al., 1985). To calculate the annual longshore sediment transport, model is set up based on the input data related to the study area. The most important calibration parameters are bed roughness and geometrical spreading factor.

In the first step, model is set up under wave effect to compare the model results with the estimations of Kamphuis formula. The comparison confirms a good correlation between these two calculations. Therefore, the order of sediment drifts calculated by the model is reliable. Based on the numerical model, net annual longshore sediment transport is estimated about 32,000 (m3/yr) in northward direction. In Error! Reference source not found., annual sediment transport under wave effect obtained by the model is summarized.

Table 2: Annual sediment transport potential unde wave effect obtained by numerical model

Project Site (under wave effect)	Sediment Drift Rate (m^3/yr)
Gross Annual Sediment Drift	66,000
Northward Annual Sediment Drift	(+) 49,000
Southward Annual Sediment Drift	(-) 17,000
Net Annual Sediment Drift	(+) 32000

(+) Northward (-) Southward

Secondly, to calculate actual sediment drift in the area, model is developed under the effects of the both wave and current forces using a complete hydrodynamic input file with a combined wave and current table. In this step, as Kuhmobarak port is the nearest coastal structure to the project site and also because of its long life, it is considered as a reference calibration point for the numerical models in this studies. Therefore, coastline changes in the vicinity of Kuhmobarak port is simulated using morphological model coupled to the model of sediment transport calculation; to attain a calibrated model based on determined coastline progress concluded from satellite images analysis (Shanehsazzadeh et al., 2013). The calibrated model is applied to estimate sediment transport rate in the project site (using the model of sediment transport calculation) and also predict future coastline changes in the vicinity of the new port (the morphological model).

3. Results and Discussion

Based on the results of the calibrated numerical model, annual cumulative sediment transport potential is estimated about 72,000 (m3/yr) (Fig 7-a). Annual cumulative sediment transport potential is about 51,500 (m3/yr) toward north and about 20,000 (m3/yr) in southward direction. Also, net annual sediment transport potential obtained is about 31,500 (m3/yr) in northward direction (Fig 7-b). In Table 3, annual sediment transport potential under wave and current effects are summarized.

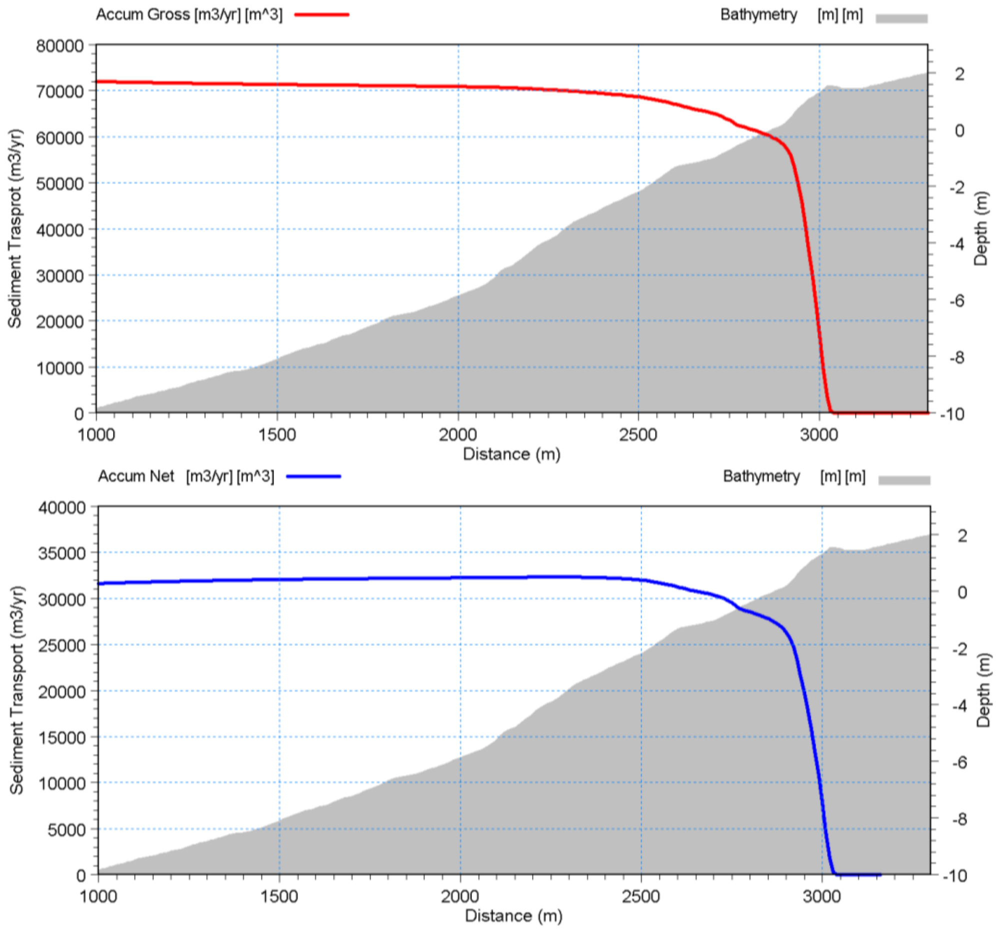

Fig 7: a: Cumulative sediment transport potential and cross section of bathymetry
b: Cumulative net sediment transport potential and cross section of bathymetry

Table 3: Annual sediment transport potential under wave and current effects obtained by the model

Project Site (wave and current effect)	**Sediment Drift Rate** (m^3/yr)
Gross Annual Sediment Drift	72,000
Northward Annual Sediment Drift	(+) 51,500
Southward Annual Sediment Drift	(-) 20,000
Net Annual Sediment Drift	(+) 31,500

(+) Northward (-) Southward

3.1. Coastline Changes

As Kuhmobarak port is the nearest coastal structure to the project site and also because of its long life, it is considered as a reference calibration point for the numerical models in this studies. Therefore, coastline changes in the vicinity of Kuhmobarak port is simulated using morphological model developed based on one-line theory (Skou et al., 1991; Foster et al. 1991); to attain a calibrated model based on determined coastline progress concluded from satellite images analysis. In the first step, the morphological model is set up to investigate coastline changes in the vicinity of Kuhmobarak port which leads to a calibrated model. The numerical result of coastline changes since 2005 to 2018 (same period of satellite imagery analysis) is shown in Fig 8. According to the figure, south and north coasts of Kuhmobarak port progress about 280 and 215 meter, respectively; which show a good correlation with the results of satellite imagery analysis (280 and 218 m, respectively); therefore, the model is reliable. The calibrated model can be applied to predict future coastline changes in the vicinity of the new port.

In the second step, assuming new port construction in 2019, the morphological model is set up in existence of both Kuhmobarak port and new port using ex-calibrated model. The coastline changes are investigated 10, 20, 30, 50 and 100 years after port construction which are represented in Fig 9.

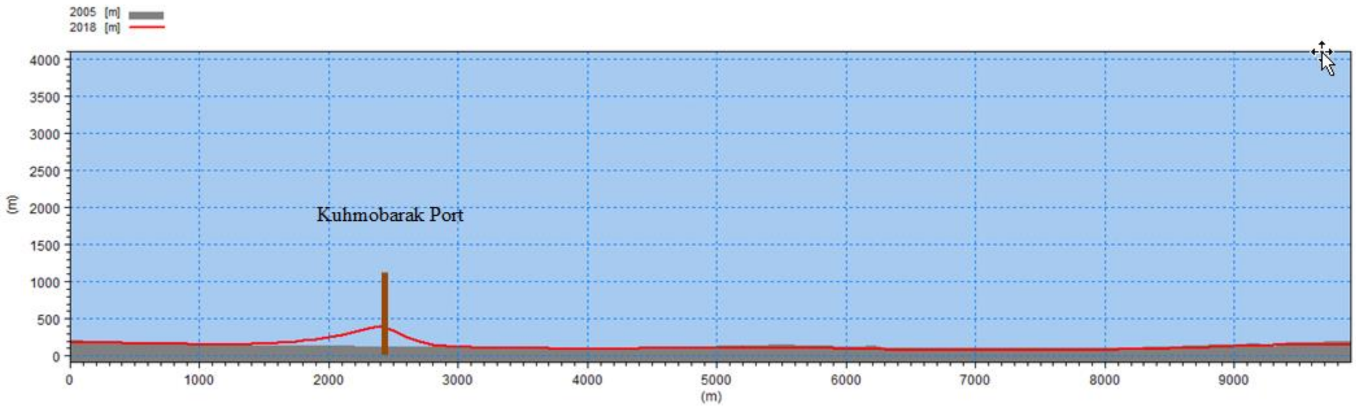

Fig 8: Coastline changes in the vicinity of Kuhmobarak port since 2005 to 2018

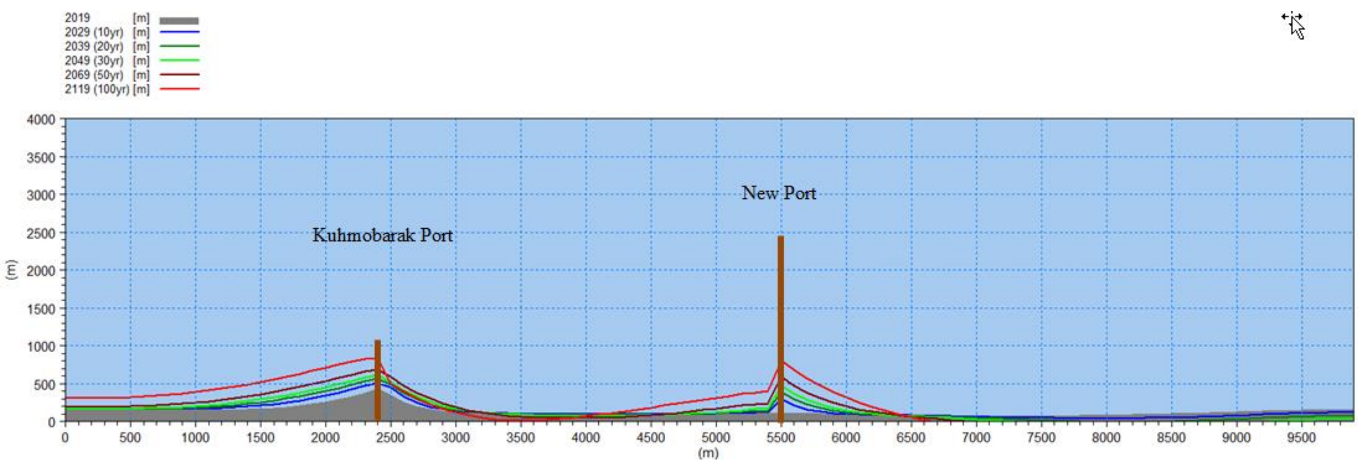

Fig 9: Coastline changes in the vicinity of Kuhmobarak port and new port in the project site since 2019 to 2119

Although, the prevailing calculated sediment drift in project site is northward similar to the Kuhmobarak area, this northward drift is weakened as it is blocked toward project site by Kuhmobarak port. Therefore the contribution of southward sediment drift in sediment process is more than northward drift in the project area. Consequently, more coastline progress and also more sedimentation in the north side of new port are happened. Coastlines progresses in two sides of the new port are summarized since 2019 to 2119 in Table 4. According to the table, in the first 10 years, the average coastline progress at the northern side is about 18 (m/yr) which decreases gradually over the years; however, at the southern side almost no change happens because northward sediment drifts is blocked by Kuhmobarak port. Moreover, northern coastline of the new port progresses about 275 m and southern side progresses 30 m in 20 years after port construction. North and south coasts of the new port also progress 475 and 125 meter seaward after 50 years, respectively.

Table 4: Coastline changes in the vicinity of project port since 2019 to 2119

Tim (year)		Coastline Seaward Progress	
		Southern Coast of New Port (m)	**Northern Coast of New Port** (m)
2029	(after 10 yr)	5	180
2039	(after 20 yr)	30	275
2049	(after 30 yr)	60	355
2069	(after 50 yr)	125	475
2119	(after 100 yr)	280	695

* New Port Construction in 2019

3.2. Description of the Sediment Process

In the project area, wave field calmness (wave height lower than 0.5 m) is more than 77%. Also, prevailing wave direction is from south and southwest. Moreover, current field is almost along coastline with two-sided directions. The current velocity is usually less than 0.3 (m/s). Consequently, the hydrodynamic field in terms of wave and current forces is categorized as a low energy domain with a limit capability for sediment transport.

However, presence of several estuary-creeks in the area has serious effect on the conditions as supply sediment sources. These estuary-creeks are almost outlets of seasonal streams into sea environment. Although, Dailu estuary-creek is seasonal stream, it is a risk potential for the project. It is ideal if no estuary-creek is near the project sites; but, if there is no alternative option for the port, construction of several sediment trap dams in the upstream of Dailu estuary-creek is strongly recommended to control stream sediment yields specifically in the fluvial flood conditions.

Based on satellite imagery analysis, coastlines at the north and south of the Kuhmobarak port's breakwaters progress about 218 and 280 m since 2005 to 2018, respectively. Average annual coastlines progress at the northern and southern coast of the port are about 17 and 21 meter. Moreover, the alongshore length of southern sedimentation area is about twice the length of northern part. Therefore, net sediment drift is northward; although southward drift has led to accretion at the north side of the port. Therefore, it is obvious that both northward and southward sediment drift direction play an active role in the domain. Sedimentation area at the north of Kuhmobarak port is about 42,000 (m2) since 2005 to 2018 which is equivalent to volume of 252,000 (m3). Therefore, the southward annual activated drift is about 19,000 (m3/yr). Fig 10 shows sedimentation at the northern coast of Kuhmobarak port. On the other hands, accretion area at the southern coast of the breakwater has been progressed about 74,000 (m2) which is equivalent to volume of 445,000 (m3). So, the northward annual activated drift is about 34,000 (m3/yr). Fig 11 presents accretion at the southern coast of Kuhmobarak port.

Fig 10: Northern coast of Kuhmobarak port

Fig 11: Southern coast of Kuhmobarak port

Consequently, considering the evidences, sediment drift direction is two-sided; therefore, sedimentation is expected in two side of any port in the area similar to what happened near Kohmobarak port. As Kuhmobarak port is the nearest coastal structure to the project site and also because of its long life, it is considered as a reference calibration point for the numerical models in this studies.

According to the results of the calibrated numerical model based on the evidences, annual cumulative sediment transport potential is estimated about 72,000 (m3/yr). Annual cumulative sediment transport potential is about 51,500 (m3/yr) toward north and about 20,000 (m3/yr) in southward direction. Also, net annual sediment transport potential is obtained about 31,500 (m3/yr) in northward direction. Regarding to satellite imagery analysis near Kuhmobarak port, almost 65% of northward sediment drift is activated (34,000 from 51,500); however, almost all southward drift is activated (19,000 from 20,000) over years; similar to this situation is expected for the north side of the new port; but northward drift is weakened because it is blocked by Kuhmobarak port.

Coastlines progresses in two sides of the new port are expected similar to Kuhmobarak port; but as mentioned, progress of southern coast will be slower in the first decade as northward drift is blocked by Kuhmobarak port. According to the results of the calibrated numerical model, in the first 10 years, the average coastline progress at the new port's northern side is about 18 (m/yr) which decreases gradually over the years; however, at the southern side almost no change is happened. Moreover, northern coastline of the new port progresses about 275 m and southern side progresses 30 m in 20 years after port construction. North and south coasts of the new port also experience 475 and 125 meter seaward progress after 50 years, respectively.

As, accretion is happened in the both side of the new port, the new port's should have long breakwater being extended more than 2 km to provide safe condition for the next 50 years. Based on the above descriptions, Fig 12 represents sediment process of the area.

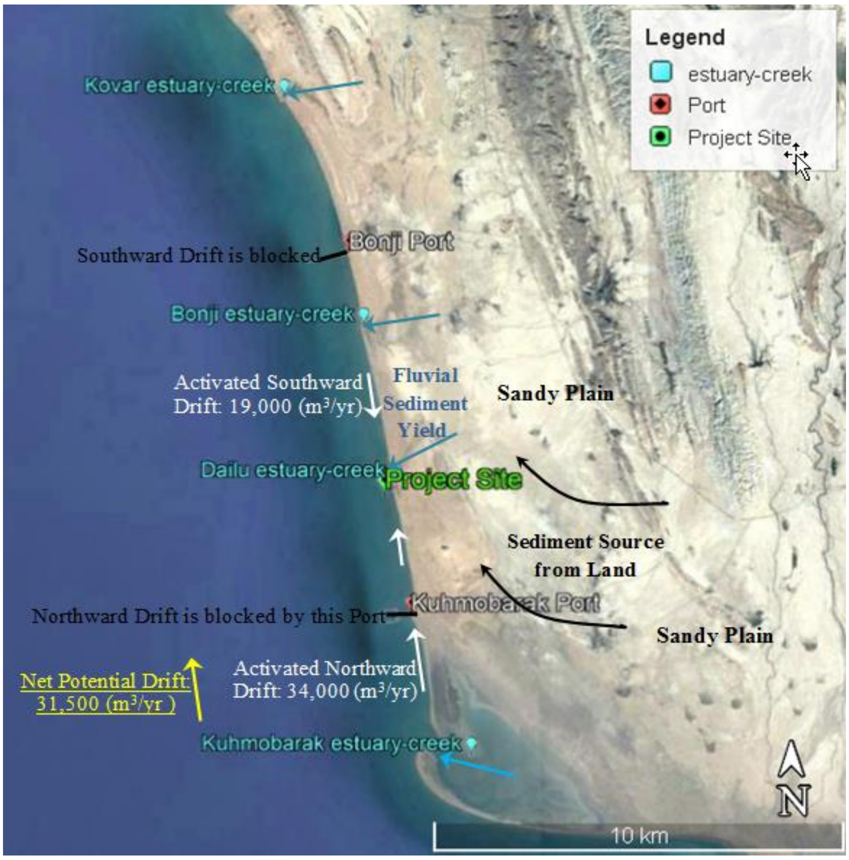

Fig 12: Sediment process in the project area

3.3. Conclusions

In this article, comprehensive study in Kuhmobarak area is performed to describe sediment process of the site of project. For this purpose, coastal characteristic, hydrodynamic condition, satellite imagery and other data and evidences such as information of site visiting is investigated and analyzed. Moreover, numerical models of sediment transport calculation and morphological evaluation are calibrated using the suggested organized methodology by empirical equation estimation of sediment drift and evaluation of coastline changes depicted on historical satellite imagery.

According to the results of the numerical model, annual cumulative sediment transport potential is estimated about 72,000 (m3/yr). Annual cumulative sediment transport potential is about 51,500 (m3/yr) toward north and about 20,000 (m3/yr) in southward direction. Also, annual net sediment transport potential is obtained about 31,500 (m3/yr) in northward direction. Regarding to satellite imagery analysis near Kuhmobarak port, almost 65% of northward sediment drift is activated (34,000 from 51,500); however, almost all southward drift is activated (19,000 from 20,000) over years; similar to this situation is expected for the north side of the new port; but sedimentation at the southern coast will be slower in the first decade as northward drift is blocked by Kuhmobarak port. According to the numerical model, in the first 10 years, the average coastline progress at the port's northern side is about 18 (m/yr) which decreases gradually over the years; however, at the southern side almost no change is happened. Moreover, northern coastline of new port progresses about 275 m and southern side progresses 30 m in 20 years after port construction. Although, accretion is happened in the both side of the new port, the new port's lengthy breakwater being extended more than 2 km leads to safe condition for the next 50 years.

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