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تحليل ديناميكيات الرواسب في الموانئ ؛ دراسة حالة من أم قصر – البصرة للإدارة المستدامة للرواسب

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المستخلص:

تعتبر عمليات الترسيب من العمليات المعقدة فهي تتفاعل مع العديد من النظم البشرية والطبيعية المقترنة في الموانئ، اذ تؤدي الأنشطة التجارية المكثفة إلى عمليات نقل وتراكم معقدة للرواسب. لذلك ، من الضروري فحص وتحليل عوامل الترسيب التي قد تؤثر على أنشطة الشحن داخل الموانئ التجارية. وقد أجريت دراسة حالة للتحري عن هذه العوامل في ميناء أم قصر الشمالي بمحافظة البصرة في العراق. تم الحصول على البيانات المناخية من محطتي الفاو والبرجسية، كما تم الحصول على بيانات المد والجزر لميناء أم قصر لعام ٢٠٢٠ مع بعض الصور ومجموعة من الخرائط المسحية. تم تنفيذ العمل الميداني من خلال الملاحظة لتعزيز الدراسة ، مع متابعة الظواهر المختلفة داخل المنطقة. تشير النتائج إلى عدة عوامل تزيد من عمليات التعرية والترسيب داخل موقع الدراسة، بما في ذلك العوامل الطبيعية (المناخ، عمليات الأنهار والمد والجزر)، والعوامل البشرية (حركة السفن). هذه العوامل لها تأثيرات مختلفة الشدة، من حيث كمية وتكوين الرواسب داخل قناة الملاحة، والتغير الزمني في نشاط هذه العوامل. يؤدي هطول الأمطار في المنطقة المحيطة إلى تآكل الرواسب الناعمة وجرفها باتجاه الموانئ من خلال الجداول الرافدة والأنهار المؤقتة. وتفاقم توزيع الرواسب في الميناء بسبب الأنشطة البشرية وعمليات المد والجزر في القناة الملاحية. وبالتالي ، كان على الشركة العامة للموانئ في العراق تنفيذ إجراءات مراقبة الرواسب السنوية للحفاظ على المعايير التشغيلية للقناة الملاحية. على الرغم من أن هذه الإجراءات فعالة، إلا أنها تفتقر إلى الكفاءة إلى حد

كبير بسبب ارتفاع التكاليف وصعوبات التنفيذ. لذلك ، فإن هذه الدراسات ضرورية ومُشجعة لزيادة فهم ديناميكيات الرواسب في ميناء أم قصر وإيجاد الأساس لإنشاء إدارة مستدامة للرواسب.

الكلمات المفتاحية: عوامل الترسيب،الموانئ التجارية،العوامل المناخية،تقلبات المد والجزر ،مصبات الأنهار ،حركة الملاحة.

Analysis of Sediment Dynamics in Ports: A Case Study from Umm Qasr-Basra for Sustainable Sediment Management

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Abstract:
Sedimentation processes are complex and interact with many Coupled Human and Natural Systems (CHANS). In ports, intensive commercial activities result in complicated sediment transport and accumulation processes. Therefore, it is crucial to investigate and analyze the sedimentation factors that may impact shipping activities within commercial ports. A case study has been conducted to investigate these factors in the northern port of Umm Qasr, Basra Governorate in Iraq. The results indicate that several factors increase erosion and sedimentation processes within the study site, including natural factors (climate, river, and tidal processes), and anthropogenic factors (ship movements). These factors have different influences in terms of the intensity of their impact, the amount and composition of sediment within the navigation channel, and the temporal variation in the activity of these factors. Precipitation in the surrounding region causes erosion of soft-fine-sediment that is carried in suspension toward the ports through tributary creeks and temporary rivers. Sediment distribution in the port has been worsened by human activities and tidal processes in the navigation channel. Consequently, the General Company of Ports in Iraq had to implement annual sediment control procedures to maintain the operational standards of the navigation channel. Although these measures are effective, they are greatly lacking efficiency due to high costs and execution difficulties. Therefore, studies are necessary and encouraged to further understand sediment dynamics in the port of Umm

Qasr and to create the basis for establishing sustainable sediment management.

Keywords: sediment factors,commercial port,climatic fators,tidal fiuctuations,estuaries,shipping traffic.

1- Introduction :

Countries with marine access seek to develop their ports since they represent their interface and points of contact with the outside world (Hoyle, 2000. p395). The ports represent a vital artery that supplies and inputs hard currency to the national economy, as these means provide the goods and merchandise needed by people (Yan & Mitcham, 2022. p5)**.** Maritime transport is the window through which goods and commodities are imported and exported at much lower prices compared with costly transport through adjacent countries. The costs imposed on these trades are added to the final price of the product (Rotaris, et al., 2022. p100792)**.** This affects the country's inputs in relation to its outputs, i.e. its balance of trade (Tang, et al., 2022. p.2232)**.**

Coastal zones also allow investments into tourism and the construction of tourist facilities with respect to mean sea level (MSL) influences (Nikiforov, et al.,2018. p.1048)**.** The factors mentioned above push the country to preserve and develop its vital maritime connections, and to remove obstacles to their proper functioning, especially with regard to problems of sediment accumulations and increased pollutant concentrations, which are the main challenges within ports worldwide (Guarnieri, et al., 2021. p.411)**.** However, such a task on a governmental and organizational level faces complexities caused by interactions within Coupled Human and Natural Systems (CHANS), including sediment movement and anthropogenic activities within and around the navigation channels (Kadhim, et al., 2021.p2709)**.**

Sedimentation in ports and waterways is a complex problem with overlapping causative and consequential factors (Neyts, et al., 2015.p75)**.** Many countries and specialized studies have sought to find out the most

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important causes of sedimentation and the best ways to manage it or at least reduce it (Rapaglia, et al., 2015.p.7). Thus, the main question is to determine and understand the factors that activate sedimentation processes within a port. The resulting understanding imposes another question: Can measures be implemented to reduce or limit the effect of sedimentation in ports? Previous literature indicates that a combination of natural and human factors activates such deposition processes (Syvitski, et al., 2022.p.9). Some studies suggest measures to prevent or reduce sedimentation (General Company for Iraqi Ports, 2015. p.8).

This study investigates the effects of a set of potential natural and man-made causes on increased sedimentation in the port of Umm Qasr, Iraq, and its associated marine channel, to draw conclusions on improved sediment management measures. In doing so, this case study demonstrates that a profound understanding of the influencing factors on sedimentation is required to suggest appropriate countermeasures. It furthermore suggests that such an understanding is not generally transferable, but must be acquired individually for sites of different climatic and anthropogenic properties.

1.1. Study area

The study area is located in the far southeast of Iraq (northern head of the Arabian Gulf) between the Zubair and Faw waterways, in Umm Qasr in the district of Zubair/Basra (Figure 1). The Umm Qasr port (also Umm Qasr Al Shamali port) is connected to the southeast with the Arabian Gulf by a 25.1 km long channel, measuring 12-13.2 m in depth and 125-250 m in width. Sediments in the channel consist of clay, silt, and sand. Umm Qasr's water body exhibits a turbulent flow type due to the channel narrowness and the high tidal range (Romdani, et al., 2022. P50).

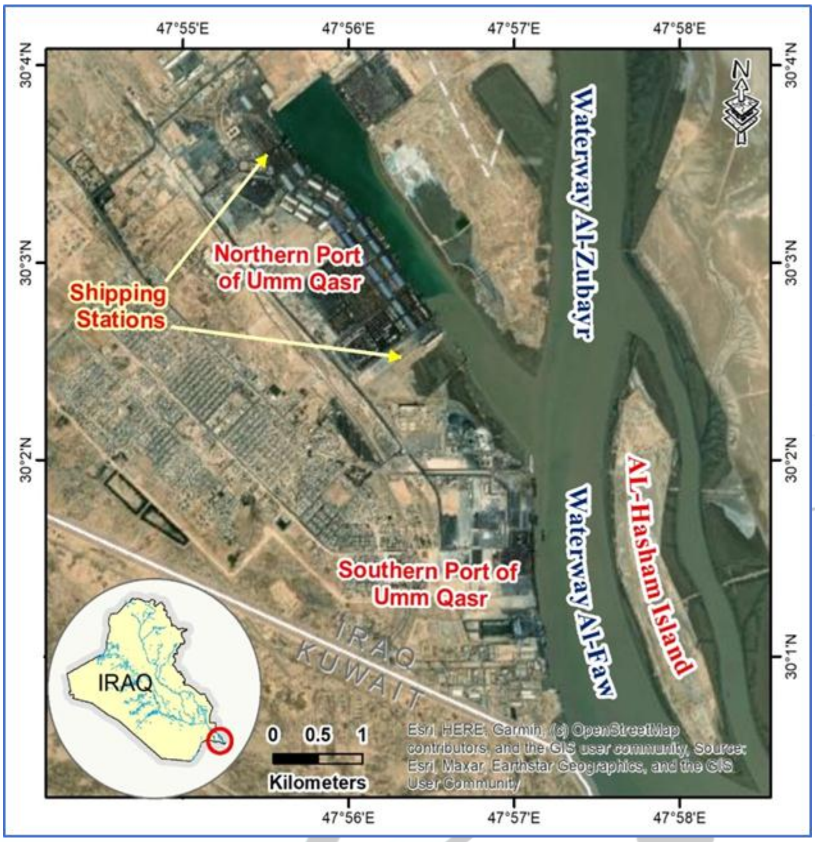

Figure 1. The location of the Umm Qasr Port study area and its associated waterways.
Source: Arc GIS 10.5 was used to analyze: (1) an Iraq administrative map (Ministry of Water Resources, 2012); (2) an aerial image of the study area (US Geological Survey, 2022), geo-corrected, from the BING sensor, with an accuracy of 1 m; and (3) an administrative map of Umm Qasr Port and its surroundings (General Company for Iraqi Ports, 2019).

Salt concentration in the Umm Qasr port is about 32,700 mg/l, which is only slightly lower than within the Arabian Gulf itself (~40,000 mg/l) and categorized as not suitable for human or agricultural usage (Al-Suqine & Al-Asadi, 2005.p199).

Economically, the waterways within the study site are the most important commercial channels in Iraq compared to all other navigation channels combined (Hamdan, 2017. p109). Most of the exported oil and most of the country's exported and imported goods, in general, are transported on these waterways.

Iraq has very limited marine access to the Arabian Gulf, with 58 km of coastline compared to its size of nearly half a million square kilometres and a population of over 40 million. Its coastline is mostly shallow, silty, and unsuitable for marine navigation. Sediment along the Iraqi marine shoreline is mostly supplied from the Tigris-Euphrates River system and from aeolian transportation, compounded by the distances of the Umm Qasr and Zubair ports from the open Arabian Gulf (Al-Aesawi, et al., 2020. p.498). The estimated sediment accumulation rate in the entire channel is about one million tonnes per year (Hamdan, 2017. p109). Accumulation of these sediments reduces the depth of the estuarine channel and leads to changes in the location of the thalweg line and navigation channel. For all these reasons, it is difficult to establish facilities that help to maintain marine navigation and to keep the Iraqi ports open (Al-Aesawi, et al., 2020. p.500). The waterway Faw (Figure 1) provides the only access to the Umm Qasr and Zubair ports. It is a narrow and shallow channel with many shallow-silty bodies and swamps. Therefore, it can only provide access to the Umm Qasr port when continuous excavation of accumulated sediment is conducted.

2. Methodology and Material

This research relied on a comparative analytical investigative method (variation-finding and universalization) to identify and monitor the main factors causing increased sedimentation, which in turn affects ports by limiting navigation. Data collection was mainly based on fieldwork, with sampling and sediment measurements carried out in December 2021 in the study area. Data collection included obtaining the latest statistics related to climatic and hydrological data from local and regional stations.

The field study was carried out on a camel ship specialized in marine surveying and equipped with the latest surveying and monitoring devices, such as a mono-wave acoustic probe to measure depths, as well as devices for monitoring climatic parameters (such as an anemometer, wind vane, and barometer). Geomorphological and natural phenomena, especially sedimentation and tidal processes, were monitored bimonthly throughout the study period from January 2020 to March 2022. This study particularly used the following marine surveying and monitoring equipment: an echo sounder for bathymetric measurements, a gyro compass, and a differential GPS. Additionally, this study used sediment data from hydrological, navigational, and, drill-based methods for sedimentological analysis.

In order to investigate the strength of the impact of natural factors such as wind and rain, this project relied on data from the Al-Barjisiya (installed on

22/9/2019) and Faw (installed on 3/12/2013) weather stations which represent the closest weather stations to the study area (Figure 2).

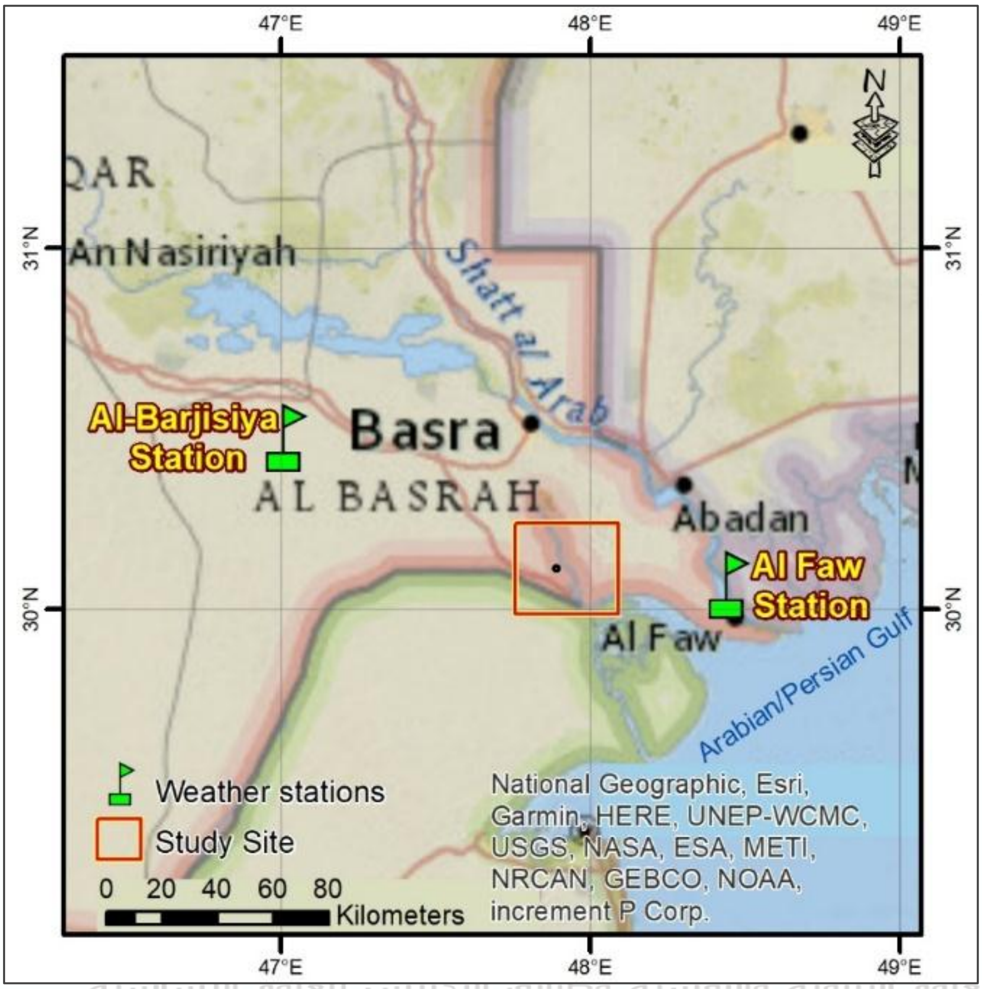

Figure 2. Locations of weather stations in the study area from the Ministry of Agriculture / Iraqi Agricultural Meteorological Network, Meteorology Department.

The Beaufort scale was used to determine the amount of atmospheric pressure applied to the land to move disaggregated materials, using the formula:

$v = 0.837B^{3/2} m/s$ ---- (1) (Wheeler & Wilkinson, 2004.p187) and (Engineering ToolBox, 2003)

Where v is the equivalent wind speed at 10 metres above the land surface, and B is the Beaufort scale number (see Figure 3).

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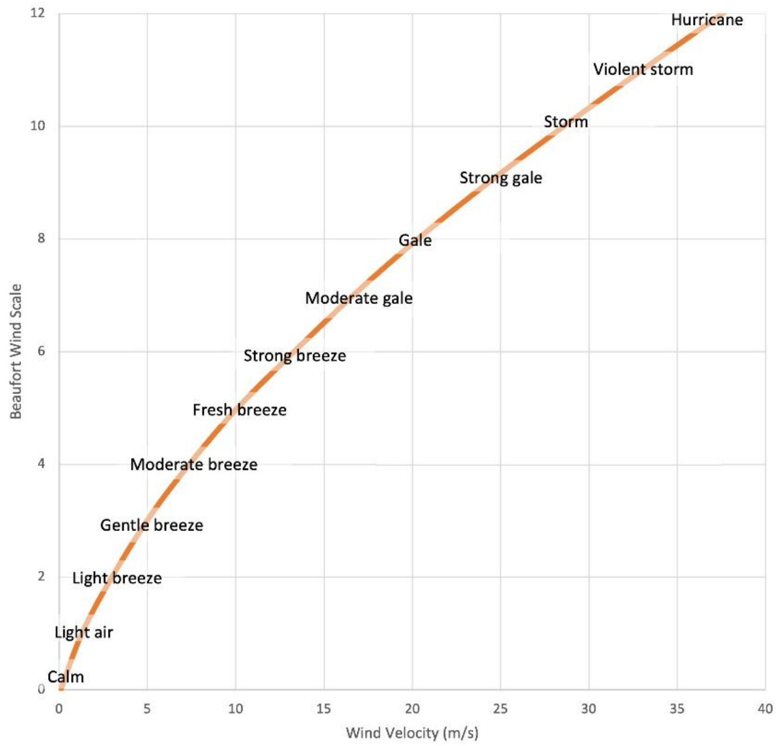

Figure 3. The Beaufort wind scale (Wheeler & Wilkinson, 2004.p187) (Engineering ToolBox, 2003)

3. Results

3.1 Wind speed, type and associated pressure force

The annual, seasonal, and monthly wind speed within the research area (Table 1 and Figure 4), shows that the Al-Barjisiya station recorded an annual average wind speed of 2.8 m/s, with an average summer velocity of 4.01 m/s and the highest monthly average speed in June (4.73 m/s). At the Faw station, the annual average wind speed was 3.17 m/s, the average summer speed was 4.29 m/s, and the highest monthly average wind speed was in June (4.65 m/s).

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Table 1. Wind speed, type, and pressure(m/s) within the Umm Qasr (study area) based on the Ministry of Agriculture, Iraqi Agricultural Meteorological Network, Meteorology Department, unpublished data, for the year 2020.

easons	Faw station				Barjisiya station				Months
	pressure force	wind description	Wind speed		pressure force	wind description	Wind speed		
			maximum speed	average			maximum speed	average	
winter	14.7	medium wind	13.97	2.54	9.6	strong breeze	11.52	1.75	**December**
	21.6	active wind	16.25	2.79	21.6	active wind	15.75	2.55	**January**
	21.6	active wind	16.43	3.01	21.6	active wind	15.94	2.62	**February**
	21.6	**active wind**	**15.55**	**2.78**	**14.70**	**medium wind**	**14.40**	**2.31**	**average**
spring	14.7	medium wind	14.84	3.03	14.7	medium wind	13.96	2.55	**March**
	21.6	active wind	18.57	3.29	21.6	active wind	15.32	2.75	**April**
	21.6	active wind	18.61	2.7	21.6	active wind	17.62	2.46	**May**
	21.6	**active wind**	**17.34**	**3.01**	**21.60**	**active wind**	**15.63**	**2.59**	**average**
summer	30.7	Strong wind	18.82	4.65	30.7	Strong wind	19.98	4.73	**June**
	30.7	Strong wind	18.54	4.42	30.7	Strong wind	18.68	4.18	**July**
	21.6	active wind	15.18	3.79	21.6	active wind	15.01	3.11	**August**
	21.60	**active wind**	**17.51**	**4.29**	**21.60**	**active wind**	**17.89**	**4.01**	**average**
autumn	14.7	medium wind	12.42	2.65	14.7	medium wind	13.75	2.72	**September**
	30.7	Strong wind	20.46	2.37	30.7	Strong wind	18.35	2.02	**October**
	14.7	medium wind	14.9	2.83	9.6	strong breeze	12.33	2.12	**November**
	21.60	**active wind**	**15.93**	**2.62**	**14.70**	medium wind	**14.81**	**2.29**	**average**
-	**21.6**	**active wind**	**16.58**	**3.17**	**21.6**	**active wind**	**15.68**	**2.80**	**General Average**

The annual average of the monthly maximum wind speeds at the Faw and Al-Barjisiya stations was 16.58 and 15.68 m/s, respectively. This is in the range of the Beaufort categories High wind, Moderate gale, and near gale (see equation 1 and figure 3), which are classified as erosion-active winds that exert a ground pressure force of >21.6 kg/m^2, according to the Beaufort wind scale**.** The seasonal wind speed averages at the Faw station did not

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vary significantly and can be classified as active winds throughout. However, at the Al-Barjisiya station, somewhat more significant variations from active winds in summer and spring compared to medium winds in winter and autumn were recorded.

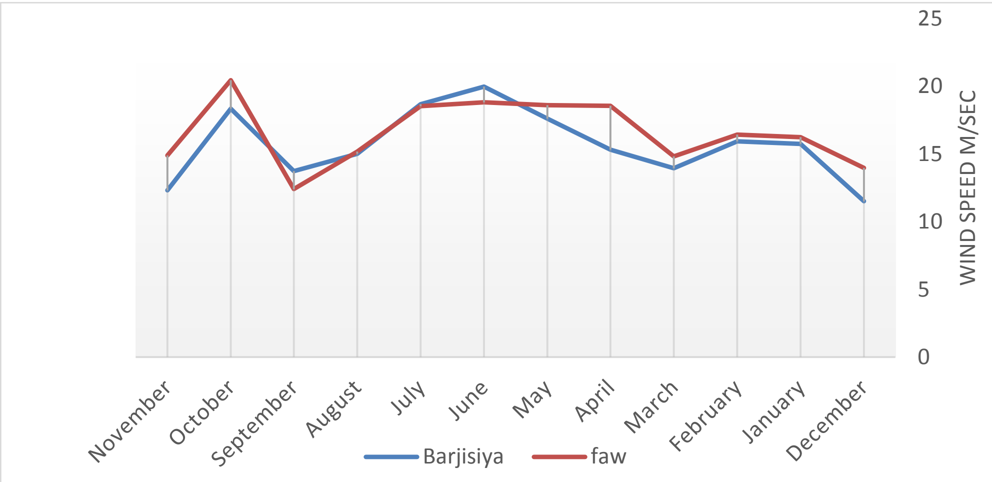

Figure 4. Monthly maximum wind speeds in the year 2020, recorded at the Al-Barjisiya and Faw weather stations, within the study (see also Table 1).

The highest monthly average wind speed at the Faw station occurred in October (20.46 m/s) and is classified as a strong wind. For the Al-Barjisiya station, the highest monthly average wind speed occurred in June (19.98 m/s), which is also classified as strong wind. Wind gusts of more than 85 m/s were recorded, which is classified as gale force and exerts a pressure force estimated at 42.3 kg/m2.

3.2 Rainfall

The annual amount of rain in 2020 at Al-Barjisiya and Faw stations was 163 and 152.7 mm, respectively, and winter rainfall amounted to 87.1 and 95.3 mm, respectively. The other seasons all experienced less rain with no rain during summer. The highest monthly rainfall was observed in January at both stations, with 36.2 mm at Al-Barjisiya station and 39.7 mm at Faw station, while June, July, August, and September did not record any precipitation.

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Table 2. Annual, seasonal, and monthly rainfall at the Faw and Al-Barjisiya stations from the Ministry of Agriculture, the Iraqi Agricultural Meteorological Network, Meteorology Department (unpublished data) for the year 2020.

Months	Barjisiya station	Faw station	Seasons
December(2019)	32.2	37	Winter
January	36.2	39.7	
February	18.9	18.6	
Total	87.3	95.3	
average	29.1	31. 7	
March	22.9	14.9	Spring
April	17.2	9	
May	4.5	7.2	
Total	44.6	31.1	
average	14.9	10.3	
June	0	0	Summer
July	0	0	
August	0	0	
Total	0	0	
average	0	0	
September	0	0	Autumn
October	17.8	5.3	
November	13.3	21	
Total	31.1	26.3	
Average	10.4	8.8	
General total	163	152.7	
Monthly Average	13.58	12.73	

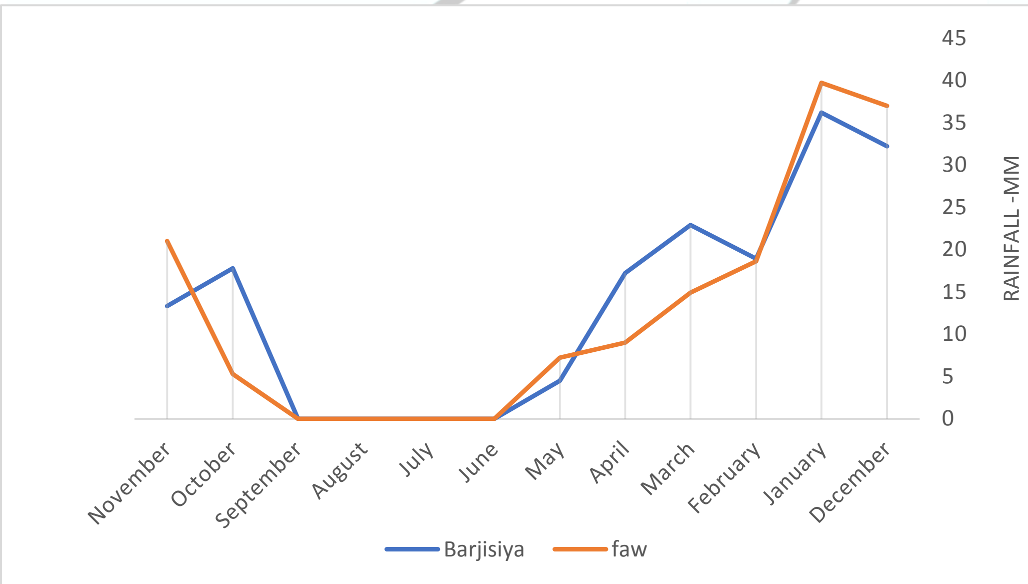

Figure 5. Monthly rainfall in 2020 recorded at the Faw and Al-Barjisiya stations.

3.3. Tidal Range at Umm Qasr

At Umm Qasr, the high tide rose to a maximum of 5.2 m in spring through to autumn and 5.13 m on average above mean sea level (MSL) in 2020, while the low tide minimum was recorded at -0,4 m in winter, with an average of -0.04 m below MSL, resulting in a maximum and average range of 5,4 and 5.17 m, respectively (Table 3). The maximum high levels usually occur after twelve o'clock. Therefore, before this time, low tidal levels are in place, and it results in the appearance of some shallow-water seabed above MSL forming temporary islands. The most frequent appearance of these islands is in the seasons that record minimum low tidal levels during autumn and winter.

Table 3. Tides in the port of Umm Qasr in 2020. Source: (Abdul-Hussein, 2019. p9)

Month	Date	Time	Highest Tide (m)	Date	Time	Lowest tide (m)	Tidal range (m)
January	23	1:17	4.9	23	8:44	-0.4	5.3
February	20	00:33	4.9	20	7:42	-0.3	5.2
March	14	16:42	5.1	21	7:19	0.0	5.1
April	12	16:12	5.2	21	20:48	0.1	5.1
May	10	15:03	5.2	20	20:31	0.0	5.2
June	15	10:44	5.2	17	19:31	0.1	5.1
July	30	9:52	5.2	17	19:55	0.3	4.9
August	31	12:58	5.1	31	20:00	0.0	5.1
September	22	4:13	5.2	1	20:42	0.0	5.2
October	20	2:56	5.2	30	8:25	0.0	5.2
November	17	2:33	5.2	28	8:10	-0.2	5.4
December	24	23:04	5.1	28	8:37	-0.1	5.2
average	-	-	5.13	-	-	-0.04	5.17

3.4 Ship Movements

A maximum draft of 12 m is set for the passage of ships within the northern port of Umm Qasr; hence very large ships cannot pass within the study area because of this depth limit. When commercial ships with drafts close to 12 m pass through the navigation channel their propellers stir up the bottom sediment and their momentum causes frictional drag and bank erosion.

To keep the channel open, two types of dredging vessels are used. Shallow draft barges use suction pumps to dredge shallow areas near the banks. The dredged silt is dumped through floating pipes into a receiving basin behind the banks. Larger basin dredgers, > 120 m long with a draft of

>8 m and a carrying capacity of > 12,000 m^3, are used to remove sediment from the centre of the channel. The dredged sediment is dumped in the same marine channel but at a distance of 10 km downstream from Umm Qasr near Al-Ghuriq Al-Hilla.

3.5 Dredged Sediment

Dredged sediment from Khor Zubair at Umm Qasr shows a sedimentary texture dominated by fine particles of clay and silt which results in a high-water content (up to 73.94%; Table 4) that is greater than the value of the liquidity limit (61.60%). The plasticity is low (29.50%), so the sediments are subject to erosion by any hydrodynamic activity.

Table 4. Physical and geotechnical characteristics of sediments in Khor Zubair channel and Umm Qasr port (General Company for Iraqi Ports,

Parameter	Characteristics	Parameter	Characteristics
Sand %	0.69	Water content (W%)	73.94
Silt %	56.61	Liquid Limit (L.L%)	61.60
Clay %	42.70	Plastic Limit (P.L%)	30
Sediment Texture	Silty Clay	Plasticity Index (P.I%)	29.50
$CaCO_3$ %	40.21	Clay activity	0.74
TOC %	0.53	Clay mineral	Kaolinite/Illite

4. Discussion

Coastal-shoreline sediment accumulation is one of the largest obstacles for marine transport in general (Jones, et al., 2003. p653), and ports in particular, causing an impediment to the navigation process and restricting the movement of ships within the navigation channel. In addition, sedimentation poses a danger to the safety of ships to run aground in shallow waters within navigating channels (Nasser, 2013.p134). It can also result in substantial changes to the shape of coasts as a result of several geomorphological processes (Figure 6).

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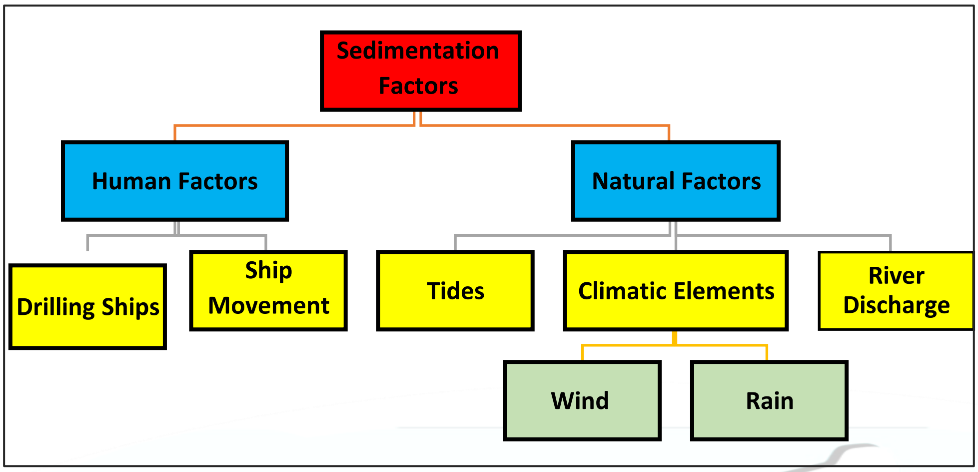

Figure 6. Diagram representing the sedimentation factors within the study area

4.1. Natural factors

There are several factors influencing and activating the sedimentation processes, including natural factors in general and climatic elements in particular. Climatic elements (wind and rainfall) often activate sedimentation within navigation channels as a result of water and wind erosion. The activated weathering processes represent a prelude to the erosion process, transferring decomposed and loose terrestrial materials.

4.1.1. Winds

The likelihood of erosion and means of sediment transport caused by wind predominantly depends on the wind speed and the grain size of the transported materials. Some materials are transported in suspension (transferring very fine particles – silt and smaller – as dust), by saltation (fine sand), and by rolling (gravel to cobbles in rare cases) (Jones, et al., 2003.p655). Also, wind causes some waves that can break up shoreline material and drag it into the navigation channel.

Wind speed increases significantly during summer, due to the heat in addition to the nature of the prevailing pressure systems. There is a scarcity of vegetation cover or any barrier that hinders the erosion work of the wind. However, average wind velocities are inaccurate when it comes to quantifying the effect of wind erosion.

Wind gusts of more than 85 m/s were recorded, which is classified as gale force and exerts a pressure force estimated at 42.3 kg/m^2. When such wind speeds and pressures are applied to the water, they produce waves that hit the coasts with considerable hydraulic thrust (Nasser, 2013. p134), which loosens rocks and coastal materials and drags them into the navigation channel with the formation of an undersea plain (sandy or pebble beaches) on the eastern side of the channel (Figure 7). They also occur on the western side of the channel at the entrance to the no rthern port of Umm Qasr (fieldwork observations).

Figure 7. The sandy beaches in the east of the channel during island pro-gradation within the study area. The red arrows refer to the active-dynamic/accumulating shorelines. Location: 30°02'27.9"N, 47°57'02.2"E. Photo date: 9/18/2020.

4.1.2. Rainfall

The study area is under the influence of a Mediterranean climate. Rain causes erosion by raindrop impact, sheet wash, and stream channel erosion of mud, sand, and pebbles (Arzouki, A.M. p45). This type of erosion is evident on the eastern side of the navigation channel (Figure 8).

Figure 8. Springs and streams east of the marine navigation channel. The red arrows refer to the active-dynamic/accumulating shorelines. Location: 30°03'38.3"N, 47°56'03.3"E. Photo date: 03/1/2020.

Rainfall erosion factors are likely to operate differently according to the seasons and months of the year. During summer (the dry season), erosion processes are dominated by wind, whereas rain erosion is taking over in winter. However, the strength of the effect varies between the types of erosion. Direct wind erosion can move shoreline material directly into the channel, while indirect wind causes waves that are capable of eroding shorelines by loosening material and dragging it into the navigation channel of Umm Qasr. During the wet season, rain erosion takes over and transports most of the region's soft sediment into the main waterway (Knowles, 2022).

4.1.3. Tides

Tidal activity is another direct erosion factor, combining the impacts of waves and currents and affecting the sedimentation process (Al-Maliki, 1999.p55). Tides represent the periodic vertical movement of seawater resulting from the combined gravitational and centrifugal forces between the Earth and both the moon and the sun (Faraci, et al, 2021). The water depth within the navigational lanes depends on the tide, and for the safety of ships, their tonnage and draft determine the dates and times of their entry to and

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exit from the port, as well as the height of any bridges located along the navigation lanes (Abdul-Hussein, 2018.p68).

During a flood tide, the hydraulic force can erode the seabed and transport sediment in suspension (silt and clay) or by saltation (fine sand). The quantity of sediment moved depends on the grain size of the transported materials and the strength of the tide. At Umm Qasr port, suspended materials cannot pass the silo quay at the highest tide because of the standing water in the turning basin (Figure 9). Also, salty material can penetrate into the channel and be deposited, but these materials start scattering at berth No. 15 (mid-port) and cannot reach all the port' berths (Abdella, 1991.p199). From over 10 years of observation and experience, sediment deposited by the tide cannot be removed past the islands 10 km southeast of Umm Qasr port, because of the stronger flood tide from the Gulf compared to the ebb tide due to the comparatively slow withdrawal of water from the channels, lagoons, and small bays. Tide cycles control sediment mechanisms and seaward escape of suspended sediment. Large-scale erosion and resuspension occur during spring tides, increasing the residence time of fine sediments within the port of Umm Qasr. The net sediment transport in tidal basins is a subtle imbalance between large fluxes produced by the ebb alternation. Sediment accretion in the port front increases the dissipation of tides and decreases the shipping navigability. Current tidal reduction lowers the sediment flushing capacity of the system, which increases deposition and tidal dissipation (McCave, 2002.p4).

At Zubair port, tides are within the middle range (5 m) (Hamdan, 2017.p109), and the port itself can be classified as an estuarine lagoon with strong tidal flows.

Figure 9. The penetration of suspended materials into the channel has stopped near the silo quay at the highest tide. The red line is bordering the accumulated fresh sediment. Depth was measured using the Echo Sounder device. Location: 30°02'32.0"N, 47°56'49.3"E. Photo date: 8/12/2020.

4.1.4. Rivers

Fresh water coming down from Shat Al Arab towards Zubair port leads to the accumulation of substantial amounts of sediment near the north shore of the Arabian Gulf (Al-Fartousi, 2017.p165). Moreover, the intensity of the northwest wind (which is dominant in the region) in combination with the Coriolis force causes periodic water currents that lead to surface water movement from the Iranian side of Shatt Al Arab to the Arabian side and creates water disturbances (Al-Suqine & Al-Asadi, 2005.p201). Although, the Umm Qasr study site has limited riverine water resource connections, small creeks, and temporary rivers during rainfall events flow south and discharge surface runoff with a heavy load of fine-suspended particles (Figure 10) from the Zubair region towards the Zubair and Umm Qasr ports (see Figure 11).

(a) (b)

Figure 10. Temporary rivers and creeks from the Al-Zubair region, which discharge surface water to Al-Zubair and Umm Qasr ports: (a) aerial photography of main "Khor Zubair" northern channel during a wet season; (b) A zoomed view of (a) that is showing fine-soft material surrounding the region and channels. *Source: fieldwork visit to the north of the Zubair and Umm Qasr ports - using a drone on 2022-07-12 at 3.52.38 PM and 2022-07-12 at 4.51.47 PM.*

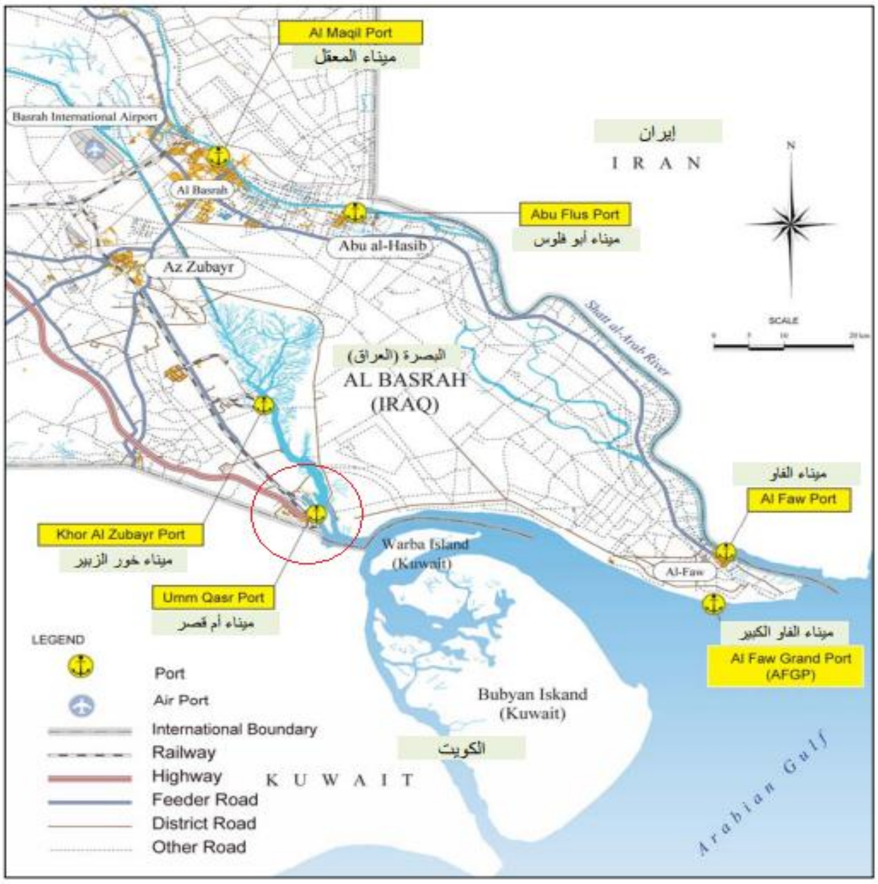

Figure 11. Regional overview of the surrounding riverine network supplying sediment to the study site. (Romdani, et al, 2022. P50)

4.2. Human activities

Direct human impact on sediment dynamics within the ports and channels is mainly due to shipping (merchant ships and dredging vessels). The currents surrounding these ships worsen the erosion processes within the navigation channel (Al-Mansoori, 2011.p28).

4.2.1. Ship movements

Ports are the starting and end points for maritime transport operations, with commercial ships used to export and import goods and commodities, especially natural resources (e.g. oil and gas). Some ports, including the study area, are connected to the open seas and oceans through maritime navigation channels.

Merchant ships come in a great range of shapes and designs depending on the nature of their work (Figure 12). Very large ships are more economical, but they tend to have a large draft below the water. However, the maximum draft of 12 m set for the passage of ships within the northern port of Umm Qasr means that very large ships cannot pass within the study area (Nasrallah & Al-Saadoun, 2008.p229). When commercial ships with a draft of close to 12 m pass through the navigation channel, their propellers stir up the bottom sediment and their momentum causes frictional drag (Mohsen, 2012. p347). These hydraulic forces generate water currents that cause direct bank erosion with the material being redistributed and settled elsewhere within the channel (Figure 13). This increases sedimentation processes within the channel and gradually reduces the channel depth, which causes a future danger to the passage of ships through the channel.

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(a)

(b)

Figure 12. Commercial ships in the northern port of Umm Qasr: (a) Location: 30°03'37.4"N 47°55'38.1"E, Photo date: 2/5/2022; (b) Location: 30°03'14.4"N 47°56'05.2"E, Photo date: 1/16/2022.

Figure 13. Sediment scattering during the operation of the ship's propellers. Location: 30°03'04.7"N 47°56'15.5"E, Photo date: 2/11/2021.

4.2.2. Dredging vessels

The maintenance of a 12 m deep channel requires dredging that also restricts the bottom of the channel from meandering and grooving. This improves the ease and safety of navigation within the channel and reduces the risk of ships scraping the bottom.

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Shallow draft barges (Figure 14) are used to deepen the margins of the channel that cannot be accessed by larger dredging ships. The dredged silt is pumped into a receiving basin behind the banks. This method is ideal for getting rid of the fine sediments within these areas and maintains the limit set by the General Company for Ports for the purpose of navigation in the channel.

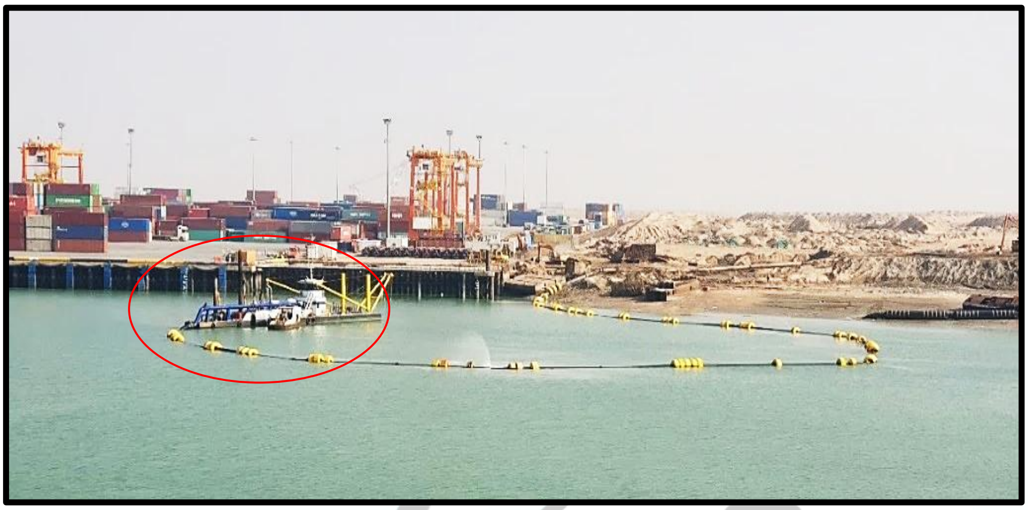

Figure 14. The shallow dredger barge is deepening the channel. Location: 30°03'28.4"N 47°56'08.0"E, Photo date: 9/1/2022.

Larger basin dredgers maintain the 12 m deep navigation channel by loading the dredge spoil into the vessel and transporting silt 10 km downstream to Al-Ghuriq Al-Hilla. The dredge cargo is dumped on the margin of the same marine channel, allowing the return of silt to the shipping channel caused by tidal processes since these disaggregated materials are easily entrained in suspension or can move by saltation, initiated by the tidal current.

The ongoing dredging program clearly indicates that sedimentation continues within the study area. Some of the sediment is locally derived but much of it is brought into the area by tidal and fluvial processes. This has prompted decision-makers to intensify actions to reduce the impact of sedimentation within the navigation channel.

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4.3. Physical and geotechnical characteristics of the sediments of the case study

The geotechnical properties of the sediment provide an impression of the mechanism and environment of sedimentation and determine the source of the sediments and the nature of the hydrodynamic conditions. The high water content in the fine-grained channel sediments means that minor disturbances can generate viscous fluid flows of this sediment that had rapidly accumulated on slopes on the channel margins and in the areas near the banks.

The channel sediment has been predominantly transported by both dust storms and rivers. The predominance of inactive minerals, such as kaolinite in some of the sediment indicates that it was mainly transported by dust storms from the continental environment, while large portions of other clay minerals indicate transportation in the Tigris, Euphrates, and Karun Rivers. The presence of mixed-layer minerals of clastic origin indicates the processes of sculpting, erosion, and re-deposition from nearby areas. At the bottom of the channel, sandy and coarser alluvial particles are sometimes present as lag accumulations because of the suspension washing of fine particles by currents. The medium and coarse particles are mainly rolled as a result of the disturbance by bottom currents. This sediment sorting depends on changes in the speed of water movement at the channel bottom and the sorting mechanism of local and transported bottom sediments from Shatt al-Arab (see the Location of Shatt al-Arab in figure 11).

One of the main marine sediment sources is the discharged sediment from the Shat Al Arab into the Arabian Gulf along the Iraqi marine shorelines (Al-Aesawi, et al., 2020. p499). This sediment is transported and redistributed by the tides in various directions, including towards the Zubair waterway and into the Umm Qasr port area.

4.4. Measures taken to reduce the effects of the sedimentation process

In order to preserve navigation in the channel and prevent any process that hinders navigation within the northern port of Umm Qasr, the following measures have been implemented.

1. Construction of a 300 m long side wall on the channel margin made of stones and cement along the loading zone of the port (Figure 15). The length of this wall is 300 m and the width of the port is 50 m. The wall prevents the movement of sediment into the navigation channel from the shore, and

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additionally absorbs and disperses the erosive momentum of bow waves and tidal and fluvial currents.

2. Establishment of receiving basins for the pumped silt and water slurry from the small dredge rigs in order to deposit the silt on shore and discharge the water through pipes back to the channel (Figure 16). The combined volume of these reservoirs is up to 27 Mm^2 (the length of this sediment' reservoir is 3.75 km, the width is 600 m, and the depth is 8-12 m). The dredging vessels pump the dredged silt slurry from the coast into the onshore reservoirs through floating pipes (Figure 14).

Figure 15. Construction of a 300 m long side wall to block the movement of waves and prevent sedimentation within the channel. Location: 30°03'50.5"N, 47°55'42.2"E, Photo date: 11/19/2021.

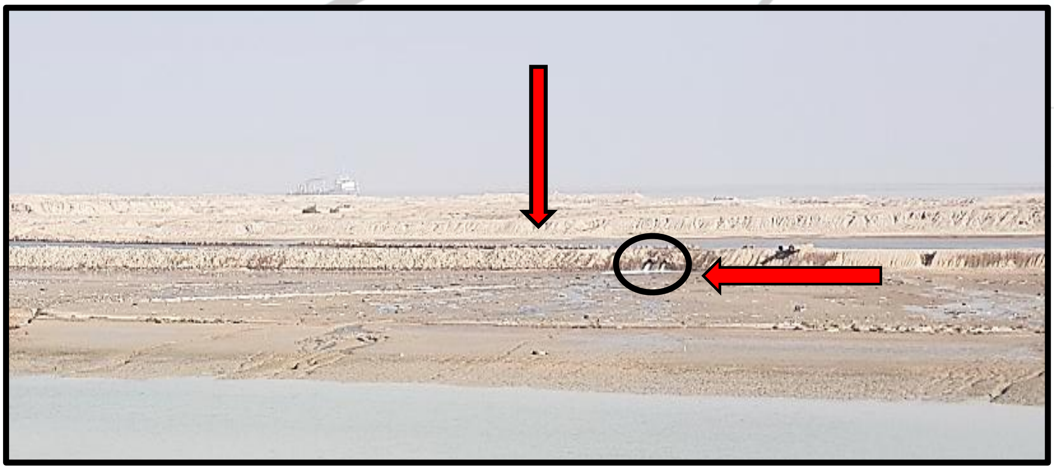

Figure 16. Locat ion of the silt storage basins and the method of piped discharge of water back into the channel. The red arrows are showing the sediment collector reservoir and the overflow-water-discharging pipes. Location: 30°03'08.6"N, 47°56'25.4"E, Photo date: 9/12/2021.

3. Continuation of dredging with large dredging ships within the navigation channel. This removes approximately 10,000 m^3 of sediment per day, except for days where work is impossible due to bad weather conditions that cause a lack of visibility, very high wind speeds, heavy rain or very high waves. The ships are considered the most efficient and effective solution for maintaining the navigation channel because of their high ability to remove large amounts of silt from within the channel (Figure 17). In the future, the dredging ships should unload their dredge spoil (silt) at a distance of at least 15 km downstream of the northern port of Umm Qasr and outside the main channel, in order to reduce the re-sedimentation by tidal currents as much as possible.

Figure 17. The process of dredging within the channel with the pelvic dredging rig. Location: 30°02'53.7"N 47°56'31.1"E, Photo date: 6/1/2022.

4. Establishment of additional berths, as the berth works as a barrier wall. However, it is more efficient than a wall because it is not affected by erosion factors, and it can be used for the transport and loading of goods. It is a proposed model to be used in the future plans of the General Company for Ports of Iraq, where the eastern side of the channel has the current shipping berths. This design was based on the construction of three berths next to the Philippine berth within the turning basin in the northern port of Umm Qasr.

5. The future establishment of a station to measure the tides, as well as to monitor the climatic elements within the northern port of Umm Qasr on a

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daily basis. This would provide accurate information about the changes that occur within this vital site, which in turn would enable better-informed sediment management decisions.

5. Conclusions

Sedimentation processes have a significant impact on coastal navigation by reducing the depth of water within ports and navigation channels, thus increasing navigational difficulties and the risk of running aground and therefore affecting especially commercial shipping. In this study, the factors causing sedimentation have been determined including climatic elements, rivers, tides, and anthropogenic factors. Tidal processes were determined to be the most influential factor for sedimentation by facilitating the intrusion of large amounts of silt into the channel. Climate (rain and wind) affects the sedimentation processes within the region with the presence of high wind speeds in the dry seasons and large amounts of rain in wet seasons that activate erosion processes and displace sediment into the channels and ports. More importantly, however, wind forces sea waves upon the coast, leading to significant coastal erosion and morphological changes. The surface runoff caused by seasonal precipitation transports abundant suspended fine sediment to the ports and navigation channels via small creeks and temporary rivers. It is interesting to monitor and understand how all these processes work and how they supply large amounts of sediment to the channel and the port. However, the factors and processes that caused the described problems, and how these problems are intended to be solved are unquantifiable and assessable. They are simply all working together to create the massive problem that this paper is describing.

Heavy shipping movement causes human attempts to reduce the amount of material deposited in the channel to fail. The navigational activities contribute an effective disturbance factor for sedimentation in the channel. Finally, the procedures carried out by the General Company for Ports of Iraq could help to treat the effects of sedimentation and to remove most of the deposited materials inside the channel, but this is done at a high cost.

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