



The Hydrogeomorphological Features of Qaro Island, State of Kuwait

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Abstract

Qaro Island has considerable natural marine habitats and sandy beaches. Qaro Island is uninhabited except for some coastguard staff. The coastguard accommodation building and associated facilities are often at risk due to seasonal northwestern storms. Special concern had been expressed about the stability of Qaro Island against the seasonal northwestern storms. The study investigates the prevailing hydrodynamic parameters around Qaro Island (i.e., water level variations, tidal currents, and wave fields), and the geomorphological characteristics around the island (i. e., beach profiling) under different environmental conditions. The tidal water levels, tidal currents and beach profiles were measured and the water wave fields were numerically simulated. The study focuses on the serious stability problem associated with the prevailing hydrodynamic parameters around Qaro Island. The present study provides decision makers and planners with an actual accounting of the island's stability for necessary action. Effective solutions and a proper protection system are recommended.

Introduction

Qaro Island is situated within Kuwait's southern territorial waters at latitude 28°49'04" north, and longitude 48°46'35" east (Fig. 1). The island is nearly 40km offshore of the mainland. Qaro Island has an area of about 0.1 km². Qaro Island is uninhabited except for some coastguard staff. The island has a radio and observation tower (i.e., on the northwestern side), helicopter landing stage (i.e., in the middle to one side), and an open-pile jetty (i.e., on the southwestern coast) as shown in Fig. 2(a). Qaro Island is associated with coral reef colonies and is, therefore, considered a natural marine habitat (Downing, 1985, 1989). The reefs of Qaro Island

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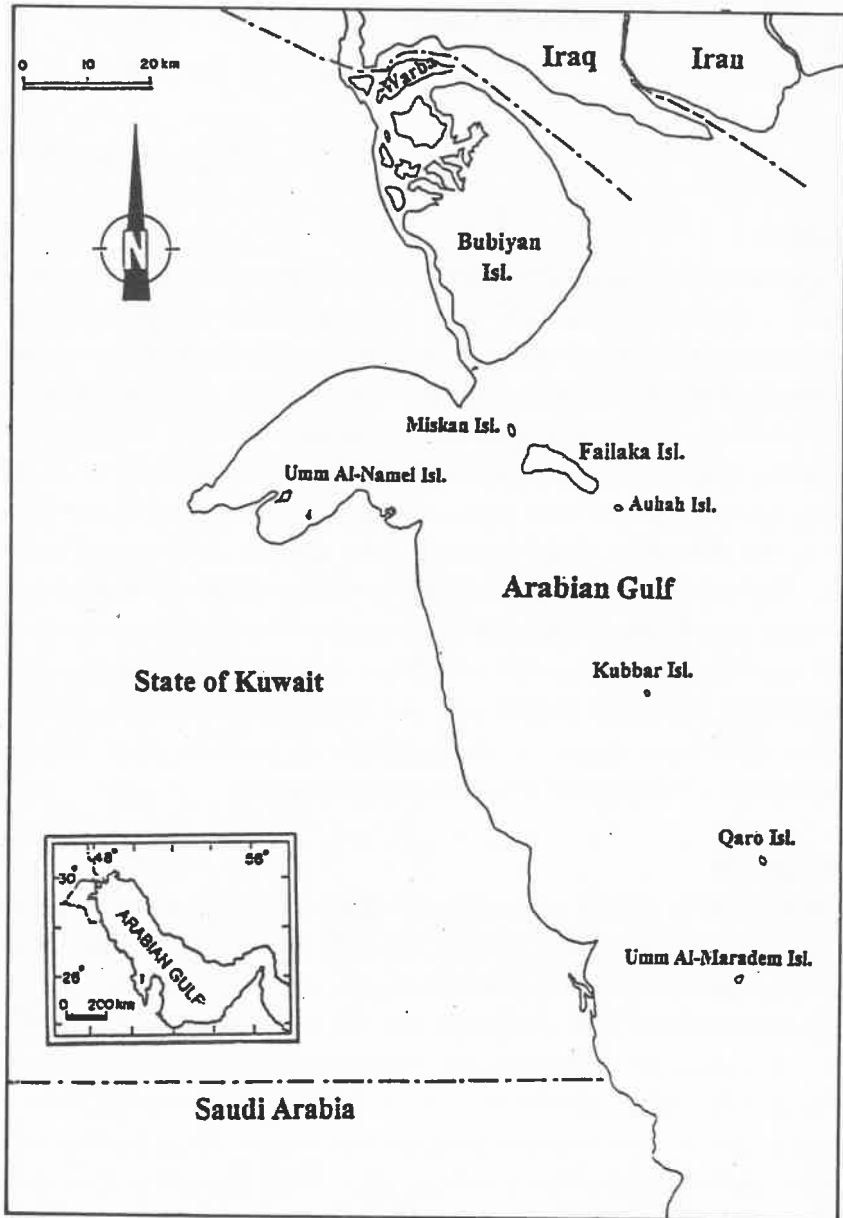


Fig. 1. Location of Qaro Island.

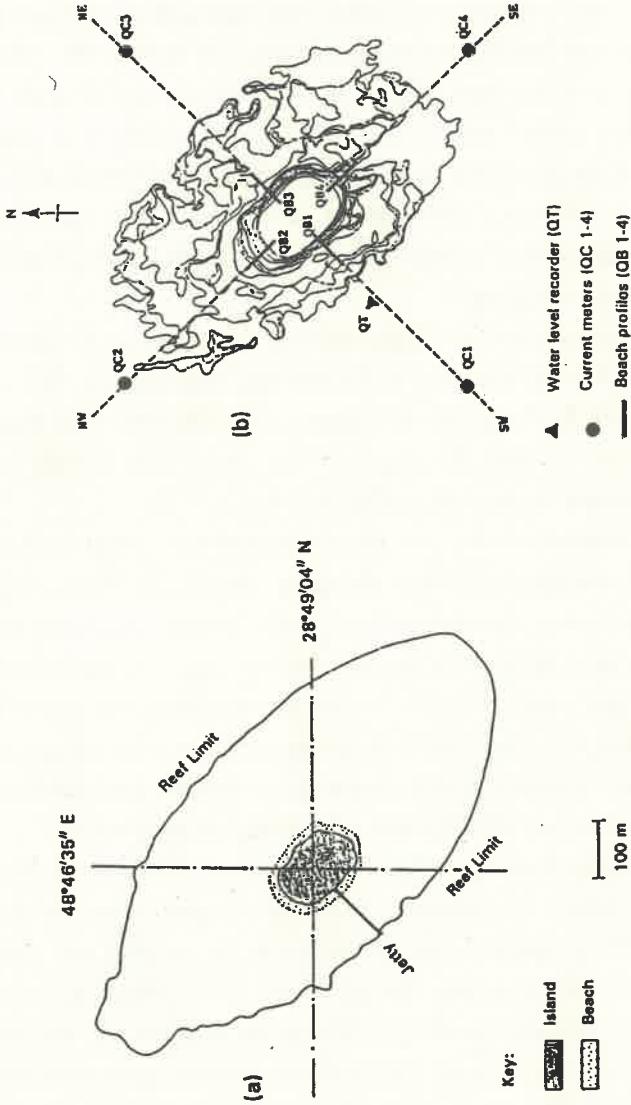


Fig. 2. (a) Qaro Island; (b) Types and locations of measurements.

support a number of commercially important fish, some of which use the reefs as breeding areas. Qaro Island is also considered to be a turtle nesting site.

In the summer of 1996, the coastguard accommodation building and associated facilities (i.e., on the northwestern side) were damaged by seasonal northwestern storms. A new building and facilities were constructed in the summer of 1997. Special concern had been expressed about the stability of Qaro Island against the seasonal northwestern storms. Generally, the stability of an island depends heavily on the prevailing hydrodynamic parameters around that island (i.e., water level variations, tidal currents, and wave fields) and the geomorphological characteristics around the island (i.e., beach profiling) under different environmental conditions.

The sediment characteristics of Qaro Island were analyzed by Al-Ghadban et al. (1990) using offshore, nearshore and inland sediment samples. The coastal area is characterized by a very coarse to coarse sand with 90% coral fragments (i.e., $D_{50} = 0.54$ to 1.10 mm). The mineralogical composition of Qaro Island's sediment was discussed in detail by Al-Ghadban et al. (1990).

Within the Arabian Gulf, the tidal phenomena are very complicated. Along the Arabian Gulf, the tides range from diurnal to semidiurnal. Within Kuwait's southern territorial waters, the tides are mixed with substantial semidiurnal tides. Over a complete tidal cycle, there are two unequal high (i.e., higher high and lower high) and two unequal low (i.e., higher low and lower low) water levels. Since no comprehensive water level field measurements exist for the area around Qaro Island, there is a need to measure and analyze the water level variation over a complete tidal cycle (i.e., 24:50 h) during the spring and neap tides.

Tidal current is an important physical characteristic for sediment transport. The tidal current within the Arabian Gulf is very complex. Along the Kuwaiti coastline, the tidal currents generally run parallel to the coastline and rarely exceed speeds of 0.5m/s (Blain and Webber, 1989). The offshore tidal currents were measured by Al-Ghadban et al. (1990) at the southern and southeastern coasts of Qaro Island at 30-m water depths. Hourly measurements were collected over periods of up to 13 h (i.e., half of a tidal cycle) to investigate the ebb and flood currents. The field measurements were taken on June 5, and August 15,

1989, i.e., during spring tides. The maximum recorded tidal current speeds were 0.9 m/s and 0.5 m/s at the southern and southeastern sites, respectively. Therefore, there is a need to measure and interpret the tidal currents around Qaro Island, during the same periods of spring and neap tides as the water level measurements were taken.

Based on field measurements, Al-Ghadban et al. (1990) concluded that the northwestern and western areas of Qaro Island represent erosion zones (i.e., high wave energy), whereas the northeastern area is a deposition zone (i.e., low wave energy). This conclusion was based on the behavior of the measured beach profiles and the nearshore wave characteristics. The data were collected at four locations around the island on August 16 and November 26, 1989. The field information was collected during a short period (i.e., three months) in calm weather. To monitor changes in beach characteristics, beach profiles are usually measured at transit lines along the coastlines of an island under varied environmental conditions. Therefore, there is still a need to measure and interpret the seasonal changes of the beach profiles around the island.

Breaking wave characteristics (i.e., wave breaking height and period) were measured during the summer and winter at four locations around Qaro Island by Al-Ghadban et al. (1990). Due to the dominant weathering conditions at the time (i.e., relatively calm weather), the measured values do not reflect actual storm conditions. Generally, wave characteristics, particularly wave height, period, and direction, are the principal criteria for an island's stability. No wave data have been recorded around Qaro Island. The wave conditions around Qaro Island can be investigated in several ways, e.g., field study, laboratory study and/or numerical modeling. Both field and laboratory studies are costly because of the expensive equipment and the extensive time required. Therefore, there is a need to use numerical modeling to predict the wave fields around the island.

The main objective of the present investigation is to determine the stability of Qaro Island under different environmental conditions. The water surface level variation and currents over a complete spring and neap tidal cycle, and the seasonal changes of the beach profiles were measured. The critical wave fields were numerically predicted.

Methodology for Present Investigation

Field Measurements

The water surface level recorder was deployed and fixed on the existing open-pile jetty of Qaro Island (i.e., at point QT in Fig. 2(b)). The variation in the water surface level was collected using an Aanderaa WLR7 water level recorder. The sampling rate was one measurement every 5 min to accurately define the tidal level fluctuations. The water surface level variation was recorded for a complete tidal cycle during the spring and neap tides.

Four current meters were distributed equidistant around Qaro Island (Fig. 2 (b)) at points QC1 (i.e., the southwestern location at latitude $28^{\circ}48'56''$ north and longitude $28^{\circ}46'29''$ east), QC2 (i.e., the northwestern location at latitude $28^{\circ}49'12''$ north and longitude $48^{\circ}46'19''$ east), QC3 (i.e., the northeastern location at latitude $28^{\circ}49'14''$ north and longitude $48^{\circ}46'42''$ east), and QC4 (i.e., the southeastern location at latitude $28^{\circ}48'49''$ north and longitude $48^{\circ}46'49''$ east). The tidal current data (i.e., speed and direction) were collected outside the surf zone (i.e., within 10-m average water depths) and 5m above the bed level using Aanderaa RCM7 current meters. The sampling rate was one measurement every 5 min. The current meters were deployed during the same periods of spring and neap tides as the water level measurements were taken.

To determine the behavior of the beach profiles around Qaro Island, four transit lines normal to the coastal line and equally distributed around Qaro Island were selected for beach profiling (Fig. 2(b)). The four selected transit lines, QB1, QB2, QB3, and QB4, were identified and referred to four fixed benchmarks (latitude $28^{\circ}49'00''$ north and longitude $48^{\circ}46'32''$ east, latitude $28^{\circ}49'06''$ north and longitude $48^{\circ}46'34''$ east, latitude $28^{\circ}49'06''$ north and longitude $48^{\circ}46'38''$ east, and latitude $28^{\circ}49'03''$ north and longitude $48^{\circ}46'37''$ east) around Qaro Island (Fig. 2(b)).

The elevation of each benchmark was arbitrarily taken to be at least 2m above the higher high water level. The beach profiles started from the benchmark on the shore and extended 50m seaward. All measurements were taken at low water levels. The ground level of the location was measured using a Nikon DTM-300 surveying level every 5m along each transit line. To monitor seasonal

changes, the beach profiles were surveyed during summer (i.e., June 1997) and winter (i.e., December 1997). Due to storms during August and September 1997, additional beach profiles were collected in October 1997.

To determine the behavior of the beach profiles around Qaro Island, the summer beach profiles (i.e., those surveyed in June 1997) were considered as the reference (i.e., datum) beach profiles. The sediment deposition/erosion due to storms was estimated as the difference between the summer and after-storm beach profiles (i.e., those surveyed in October 1997). The overall sediment deposition/erosion was estimated as the difference between the summer and winter beach profiles (i.e., those surveyed in December 1997).

Numerical Simulations

The deep water wave conditions (i.e., wave heights and periods) along specified directions (i.e., wind directions) are the basic types of information needed for numerical modeling. The deep water wave conditions are forecast based on wind speeds and effective fetch lengths (U.S. Army Corps of Engineers, 1984). The wind speeds and directions were determined by using the wind data recorded by the Arabian Oil Company at Ras Al-Khafji (i.e., latitude 28°25'36" north and longitude 48°40'00" east) during the period from 1976 to 1980 (Lo et al., 1987). Eight wind directions were selected (i.e., N, NE, E, SE, S, SW, W, and NW) for use in forecasting the maximum wave conditions in the deep offshore waters of Qaro Island. The wind speed values were corrected due to elevation (i.e., a 28-m anemometer height) and converted into wind-stress factors (U.S. Army Corps of Engineers, 1984).

The fetch lengths along the specified directions (i.e., wind directions) were measured from the Admiralty Chart. The effective fetch lengths were estimated based on the depth-weighted average along each fetch length as follows: whenever the fetch line crossed a contour line, the contour value and the corresponding distance between the two crossing points were recorded. The procedure was repeated along the fetch, and then the weighted average was computed from contour data given in Admiralty Chart No. 2858. The depth-weighted average along each specified wind direction was considered to be the

average water depth along the fetch length. The maximum deep water wind and wave conditions are listed in Table 1.

Table 1. Maximum Deep Water Wind and Wave Conditions for Qaro Island

Direction	Wind Conditions		Wave Conditions		
	Speed (m/s)	Fetch (m)	Depth (m)	Height (m)	Period (m)
N	27.5	132,000	12.6	3.2	7.4
NE	17.5	192,750	19.8	3.0	7.0
E	17.5	222,000	31.1	3.6	7.6
SE	17.5	727,500	21.4	3.6	8.3
S	22.5	90,750	11.1	2.5	6.3
SW	22.5	45,000	13.5	2.3	5.6
W	17.5	45,750	10.3	1.7	4.9
NW	27.5	114,000	11.4	3.0	7.1

Considering the maximum deep water waves as boundary conditions, the shallow water wave conditions for Qaro Island were predicted using a wave refraction-shoaling numerical model (Lo et al., 1987). A 1-km-x-1-km grid system was constructed for Kuwait's southern territorial waters. The water waves propagated from the deep water to the shallow water of Qaro Island were presented as wave refraction-shoaling maps.

Considering the shallow water waves as boundary conditions, the wave fields around Qaro Island were predicted using a wave refraction-diffraction numerical model (Lo, 1991). A 100-m-x-100-m grid system was constructed for the shallow water of Qaro Island. The maximum wave conditions were utilized to predict the critical wave fields around the island.

Results and Discussion

Field Measurements

The maximum measured spring and neap tidal ranges were 1.8m and 1.3m, respectively. A maximum spring tidal current of 0.7m/s (i.e., at point QC1) and a maximum neap tidal current of 0.5m/s (i.e., at points QC2, and QC3) were recorded around Qaro Island. The tidal current speeds measured by Al-Ghadban et al. (1990) were reasonably confirmed through the tidal currents recorded around Qaro Island in the present investigation.

For demonstration purposes, the correlation between the water level and current during a complete spring tidal cycle at point QC1 is presented in Fig. 3. The water surface level variation refers to the mean water surface level from the recorded data (i.e., over a complete tidal cycle). Generally, the maximum current speeds during the spring and neap tidal cycles usually occurred within the ebb and flood periods of the maximum tidal ranges.

The general behavior of the tidal current speeds (i.e., variations with respect to tidal water levels) was almost the same all around Qaro Island. The tidal currents within the ebb and flood periods of the maximum spring tidal ranges at points C₁, C₂, and QC3 were in almost exactly the same prevailing direction. At point QC4, the tidal currents had variable directions. The tidal currents within the ebb and flood periods of the maximum neap tidal range at QC1 and QC3 were in almost exactly the same prevailing direction. At QC2 and QC4, the tidal currents had variable directions.

Generally, the dominant tidal current direction around Qaro Island can be specified as being northwest-southeast. To the northwest and southeast of Qaro Island, tidal currents with relatively variable directions were usually recorded. Toward the island's shoreline, the tidal currents (i.e., with a maximum offshore speed of 0.7m/s) are expected to decrease (i.e., due to bed shear stress) over the flat coral reefs. Therefore, the tidal currents have only a minor effect on the stability of the coarse sandy beaches of Qaro Island.

The beach at transit line QB1 (i.e., in a southwestern direction) is a sandy beach. The after-storm beach profile showed a gain in sediments which was

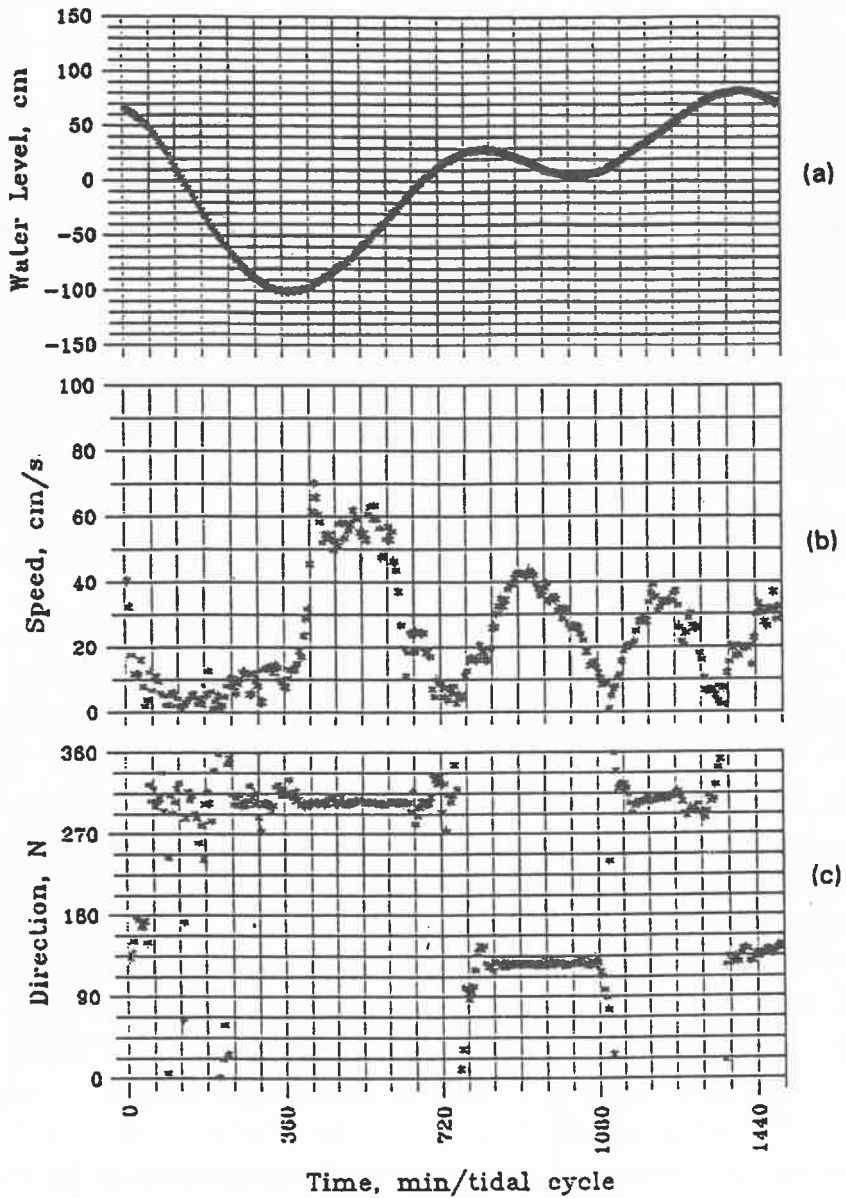
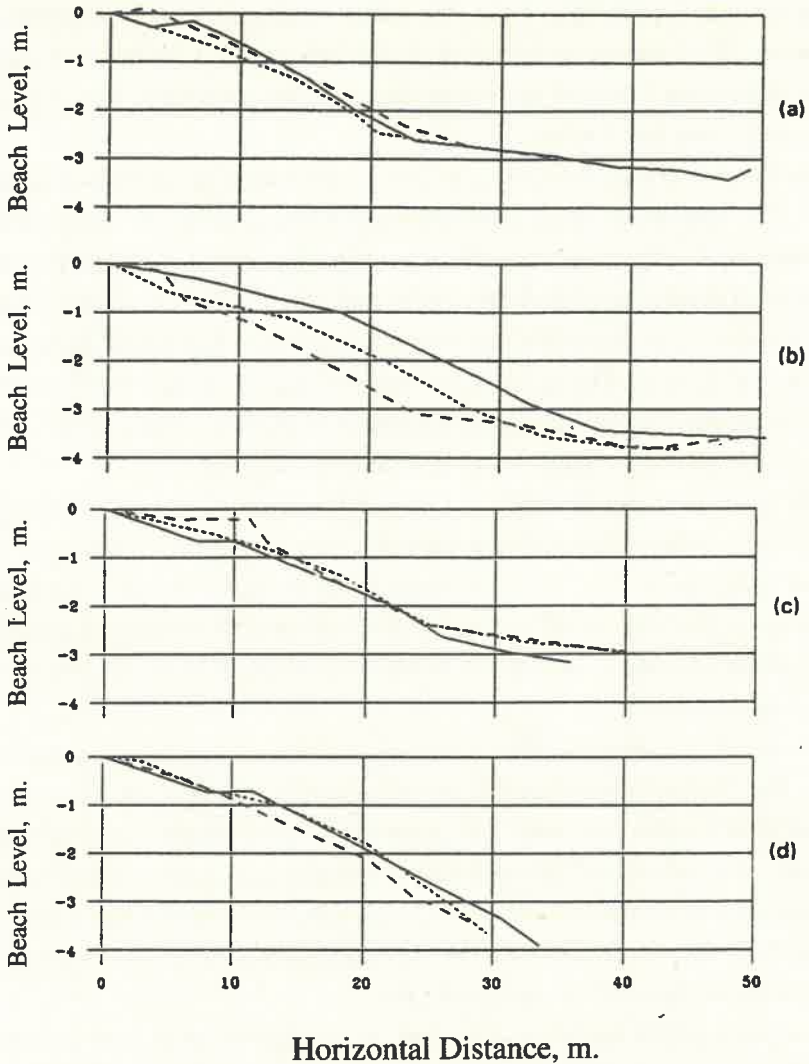


Fig. 3. Spring tidal cycle at site QC1: (a) Water level variation; (b) Current Speed; (c) Current direction.



—— June 1997
- - - - Oct. 1997
..... Dec. 1997

Fig. 4. Beach profile: (a) Transit line QB1; (b) Transit line QB2; (c) Transit line QB3; (d) Transit line QB4.

estimated to be 3 m³/m (Fig. 4(a)). The winter beach profile showed a loss in sediments. The behavior of the beach profile indicates that the beach is subject to deposition followed by erosion due to storm conditions. The overall sediment erosion was 2 m³/m.

The beach at transit line QB2 (i.e., in a northwestern direction) is a sandy beach. The after-storm beach profile showed a loss in sediments which was estimated as 29 m³/m (Fig. 4(b)). The winter beach profile showed less loss in sediments. The behavior of the beach profile indicates that the beach is subject to erosion followed by deposition due to storm conditions. The overall sediment erosion was 21 m³/m. During the field measurements in October 1997, severe sediment erosion extended up to the foundation of the observation tower, and failure of the water tanks (adjacent to the beach) had occurred.

The beach at transit line QB3 (i.e., in a northeastern direction) is a sandy beach. The after-storm beach profile showed a gain in sediments which was estimated to be 8 m³/m (Fig. 4(c)). The winter beach profile showed less of a gain in sediments. The behavior of the beach profile indicates that the beach is subject to deposition followed by erosion due to storm conditions. The overall sediment deposition was 6 m³/m.

The beach at transit line QB4 (i.e., in a southeastern direction) is a sandy beach. The after-storm beach profile showed a gain in sediments which was estimated to be 1 m³/m (Fig. 4(d)). The winter beach profile showed more gain in sediments. The behavior of the beach profile indicates that the beach is subject to deposition due to storm conditions. The overall sediment deposition was 5 m³/m. During the field measurement in October 1997, sediment accumulations were observed to the left and right of transit line QB4.

The beach profile behaviors described by Al-Ghadban et al. (1990) were found to be transitional due to only northwestern storm conditions. Based on beach profile measurements, the most important aspects of the sediment transport around Qaro Island are as follows.

- The storm waves have a severe effect on the stability of the coastal beaches of Qaro Island.
- Due to prevailing northwestern storm conditions, the northwestern coast (i.e.,

lying between the west and north) is subject to sediment erosion. Due to currents induced by storm waves, the eroded sediments are transported, deposited, and accumulate at the southeastern coast of the island.

- Due to prevailing southeastern storm conditions, the currents induced by storm waves transport the accumulated sediments from the southeastern coast to the northwestern coast of the island.
- The southeastern coast of Qaro Island is considered to be a storage area for sediment accumulations during the prevailing northwestern wave storms.
- The northwestern coast of Qaro Island is subjected to severe erosion. A protection system is urgently needed.
- The total sediment budget around Qaro Island depends on storm occurrence (i.e., frequency, duration and direction) and storm waves (i.e., heights and periods).
- A long-term program for beach profile measurement is urgently needed to estimate the sediment budget around Qaro Island.

Numerical Simulations

The critical wave fields around Qaro Island are presented as vectors in Fig. 5. The length and direction of each vector indicates the wave height and direction of the wave field at the vector location. Based on the presented wave fields, the most important aspects of the wave fields around Qaro Island are as follows.

- Due to northern storms, the northern waves approach the island with orthogonals perpendicular to the northwestern-northeastern coast, which causes sediment erosion. The longshore currents induced by waves are parallel to the northeastern-northwestern coasts. These longshore currents are responsible for the sediment transport from the eroded northern coast to the southern coast of Qaro Island.
- Due to southeastern storms, the southeastern waves approach the island with orthogonals perpendicular to the southeastern-northeastern coast, which causes sediment erosion. The longshore currents induced by waves are parallel to the northeastern-northwestern and southeastern-southern coasts. The longshore currents are responsible for the sediment transport from the southeastern-northeastern coasts to the northeastern-northwestern and southeastern-southern coasts of Qaro Island.

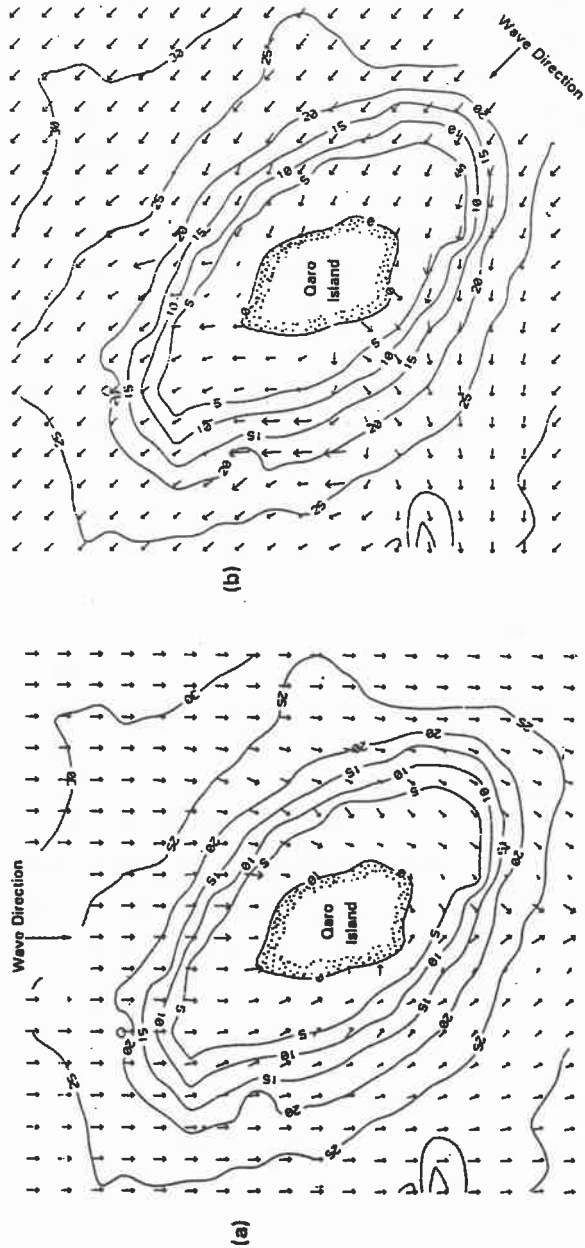


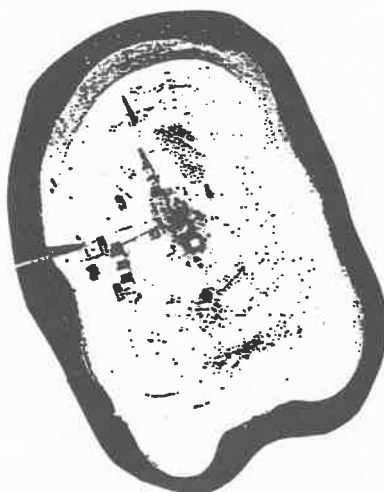
Fig. 5. Critical wave fields due to (a) Northern waves; (b) Southeastern waves.

- Under the other storm conditions, the sediment eroded from the coast is exposed to direct wave energy. Then, the eroded sediments are transported and deposited on other coastal locations, as governed by the longshore currents induced by waves.
- A comprehensive numerical model for sediment transport supported by actual storm conditions and associated beach profile measurements is greatly needed to predict the sediment budget around Qaro Island.

The available aerial photographs of Qaro Island taken in 1982, 1983, and March 1996, indicate that the general configuration of the main inland area of the island is unstable (Fig. 6). The coastal shoreline has changed due to seasonal storm conditions. The exact dates (i.e., months) of the aerial photographs taken in 1982 and 1983 are not available. It is thought that the aerial photographs from 1982 and 1996 were taken within the same season when the island was exposed to southeastern storms. The aerial photograph from 1983 reflects the effect of northwestern storms. The aerial photographs confirmed the general conclusions regarding sediment transport around Qaro Island.

The coastal zone of Qaro Island is characterized by coarse sand. The storm waves have a severe effect on the stability of the coastal beaches of Qaro Island. During the seasonal northwestern storms, the northwestern coast is considered to be a severe erosion area and the southeastern coast is considered to be a depositional area. This situation is reversed during the seasonal southeastern storms.

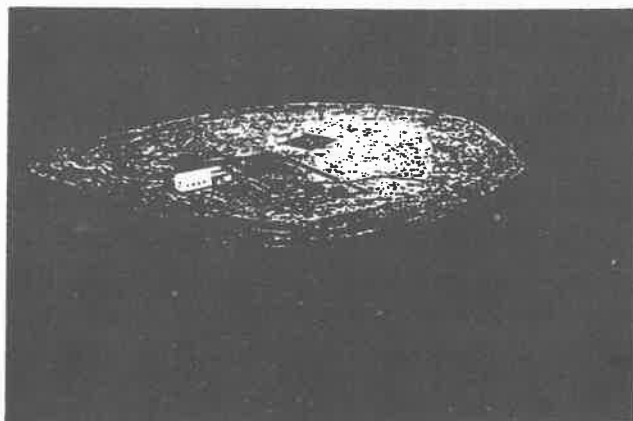
Generally, sediments are eroded from the coasts exposed to direct wave energy. Then the eroded sediments are transported and deposited, and accumulate on other coastal locations, governed by the longshore currents induced by waves. The total sediment budget around Qaro Island depends on storm occurrence, storm waves, and associated longshore currents induced by waves. The northwestern coast of Qaro Island is usually subjected to severe erosion. The coast-guard accommodation building and associated facilities are often at risk from seasonal northwestern storms. The location of the radio and observation tower used to be away from the shoreline. Now the tower's foundation is on the shoreline. This means that the island is slowly shifting to the southeast. The field measurements and numerical simulations around Qaro Island were discussed in detail by Marmoush et al. (1998).



1983 (Source: Downing, 1985)



1982 (Source: Downing, 1985)



1997 (Source: CRSK, 1997)

Fig. 6. Historical aerial photographs of Qaro Island.

Conclusions and Recommendations

Detailed study of the hydrodynamics and coastal processes of Qaro Island led to the following conclusions:

- The dominant wave direction can be specified as the northwest-southeast direction. The storm waves have a major effect on the stability of the coastal beaches.
- The coastal zones are characterized by coarse sand.
- The sediments are eroded from the sandy coasts exposed to direct wave energy. Then the eroded sediments are transported and deposited, and accumulate on other coastal locations, as governed by the longshore currents induced by waves.
- The coastal shorelines may change seasonally due to seasonal storm conditions.
- The storm waves have a severe effect on the stability of the coastal beaches of Qaro Island. The northwestern coast of Qaro Island is usually subjected to severe erosion.
- The total sediment budget depends on storm occurrence, storm waves and associated longshore currents induced by waves.

The research areas recommended for future implementation are as follows:

- A protection system is urgently needed for Qaro Island.
- The historical areal photographs and/or satellite images are greatly useful in confirming the long-term geomorphological changes of Qaro Island.
- A long-term program of beach profile measurement is greatly needed to monitor the annual changes and estimate the sediment budget around Qaro Island.
- A comprehensive numerical model for sediment transport supported by seasonal storm conditions and associated beach profile measurements is needed to predict the sediment budget around Qaro Island.

Acknowledgements

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References

- Al-Ghadban, A.N., M. Abdul Rahman, and A.S. Salman. 1990. Physiographic and hydrographic features of Kubbar, Qaro and Umm Al-Maradem Islands. Kuwait Institute for Scientific Research, Report No. KISR 2221, Kuwait.
- Blain, W.R., and N.B. Webber, 1989. Planning and Feasibility. Proceedings of the International Conference on Marinas, Southampton, U.K.
- CRSK. 1997. Kuwait from Above. Kuwait, the Center for Research and Studies on Kuwait.
- Downing, N. 1985. Coral Reef Communities in an Extreme Environment: The Northwestern Arabian Gulf. Proceedings, 5th International Coral Reef Congress, Tahiti, Vol. 6, pp. 343-348.
- Downing, N. 1989. A Study of the Corals and Coral Reef Fishes of Kuwait. Kuwait Institute for Scientific Research, Report No. KISR 3256, Kuwait.
- Lo, Jen-Men. 1991. A Numerical Model for Combined Refraction-Diffraction of Shore Waves on an Island. *Ocean Engineering Journal* 15(5): 419-434.
- Lo, Jen-Men, A. Tayfun, and L. Ra'ad. 1987. Wave Refraction-Shoaling Maps for Kuwait's Coastal Area. Kuwait Institute for Scientific Research, Report No. KISR 2221, Kuwait.
- Marmoush, Y.; M. Al-Sarawi; F. Al-Hulail; K. Al-Salem; and N. Al-Amer. 1998. Sustainable Development of the Southern islands of Kuwait. Kuwait Institute for Scientific Research, Report No. KISR 5/94, Kuwait.
- U. S. Army Corps of Engineers. 1984. Shore Protection Manual. Department of the Army Corps of Engineers, Washington, D.C: Government Printing Office.

ABSTRACT

هيدروجيو مورفولوجية جزيرة قاروه بدولة الكويت

د. يحيى مرموش *

تمتاز جزيرة قاروه بالمواطن الطبيعية للأحياء المائية والشواطئ الرملية ، علما بأن الجزيرة ليست أهلة بالسكان باستثناء بعض أفراد خفر السواحل ، تمثل الرياح الشمال غربية وما يصاحبها من الأمواج البحرية تهديدا مستمرا للمباني والمرافق الخاصة بخفر السواحل وبناء عليه فهناك اهتمام خاص باتزان الجزيرة تحت تأثير العواصف الموسمية التي تهب في اتجاه الشمال الغربي .

والدراسة المقدمة تبحث تأثير العوامل الهيدروديناميكية السائدة حول الجزيرة (التغير في سطح المياه - التيارات البحرية - الأمواج) والعامل الجيومورفولوجية (قطاعات الشواطئ) حيث تم قياس مناسيب سطح المياه والتيارات البحرية وقطاعات الشاطئ، وتم أيضا التمثيل العددي باستخدام النماذج الرياضية للأمواج ، وتم تركيز الدراسة على المشاكل الهامة التي تؤثر على الاتزان العام للجزيرة ومدى التأثير للعوامل الهيدروديناميكية السائدة حول الجزيرة ، والدراسة المقدمة توفر لمتخذ القرار والمخطط البيانات الخاصة للاتزان العام للجزيرة وذلك لاتخاذ التدابير اللازمة ، وتم وضع التوصيات الخاصة بالحلول الفعالة وطرق الحماية المطلوبة .

