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Predictive numerical modelling of sediment transport patterns along the Ras Al-Zour Coast, Kuwait

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Abstract

A nearshore sediment transport model was developed to predict changes in nearshore bottom topography caused by wave action. The model included two major components: a nonlinear nearshore circulation numerical model and an integrated coastal sediment transport computer program. The nonlinear nearshore circulation numerical model predicts nearshore wave and current fields based on the given deep-water wave and local bottom topographic conditions. The results of the nonlinear nearshore circulation numerical model are used by the integrated coastal sediment transport computer program to predict changes in bottom topography. This study is an attempt to develop a comprehensive nearshore sediment transport numerical model for Kuwait's coastal area. The model was applied to predict the deposition and erosion patterns of one section of the beach at Ras Al-Zour, south of Kuwait.

1 Introduction

Kuwait has approximately 500 km of coastal land including that located on its eight islands. The coastal zone has been the historical center of several economic developments; and most urban, industrial, commercial and recreational activities are concentrated in this zone. It is, therefore, important to study the coastal processes and associated problems in this area of Kuwait. The problem of coastal sediment transport is one of primary concern to local coastal communities. In the coastal zone, the complexity of sediment transport stems from the interaction of the coastline, waves, tides, winds and currents. The difference between the sediment inflow and outflow may cause erosion, deposition or equilibrium within the area of interest. All plans for shoreline protection or beach stabilization, therefore, should be based on a thorough understanding of the dynamics of sediment transport near the coastline.

Abou-Seida et al. [1] developed an integrated model for coastal sediment transport. In this model, the modified bed load function due to wave action was used together with Einstein's suspended load expression as reported by Bijker [2] to calculate the total load. In order for the model's assessment of sediment transport to be used, information on the nearshore wave climate is crucial input for the coastal sediment study. The refraction-shoaling transformation of waves from deep water to the breaker line including the effect of bathymetric variations and bottom friction for the entire Kuwaiti coast is available from Lo et al. [3]. The wave-induced circulation in the nearshore zone is also provided by Lo et al. [4]. The wave-induced circulation model is modified and presented in a form that can be used by the sediment transport model to develop a comprehensive computer model for predicting the rate of coastal sediment transport along the Kuwaiti coast.

The developed numerical model was applied to a certain segment of the coast (i.e., Ras Al-Zour) as an example to be followed to investigate the patterns of accretion and erosion along the coast of Kuwait.

2 Numerical Modelling

A wave-induced nonlinear nearshore circulation numerical model was first applied to determine the hydrodynamics of the nearshore region. The output from the nearshore circulation numerical model includes the local wave heights, wave directions, wave number, mean free surface displacements, and the mass-transport velocities U and V.

The change of water depth (or bottom elevation) can be determined only if the spatial sediment transport distribution within the area of interest is known. The rate of the water's change in depth and its relation to the sediment transport rate is provided by the following equation:

$$\frac{\partial h}{\partial t} = \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} \tag{1}$$

where t is time, x and y are the horizontal coordinates, and q_x and q_y are the components of the sediment transport rate per unit width in the x and y directions.

From the nonlinear nearshore circulation numerical model, the wave and current fields were determined at all grid points. The sediment transport rates, q_x and q_y, at each grid point, therefore, could be determined by using the output from the nonlinear nearshore circulation numerical model and the sediment concentration computer program.

Integrating the sediment transport equation over time yields the following equation:

$$h(x,y,t_2) = h(x,y,t_1) + \int_{t_1}^{t_2} \left(\frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} \right) dt \tag{2}$$

where $h(x,y,t_1)$ is the initial water depth at location (x,y), and $h(x,y,t_2)$ is the water depth at the same location at the later time, t_2.

The central difference approximation was applied to estimate the unknown $h_{i,j}$ at time $t+\Delta t$ where the values of q_x and q_y at different grid points are those values calculated at time t. It can be seen that the water depth changes over time, and this change affects the wave and current fields. However, due to computational time restrictions, it is not recommended that a fully unsteady, interactive model is used to simulate waves, current, and topographic changes simultaneously. Therefore, the present study assumed that the wave and current fields remain unchanged for a specified time duration, even though the bottom topography changed.

3 Model results

The Ras Al-Zour headland is located in the south of Kuwait. Fig. 1 shows the shoreline at Ras Al-Zour. The Getty Oil facility is located at Ras Al-Zour and extends 1.3 km west and 2.9 km south from the tip of Ras Al-Zour. The Getty recreational beach is located just south of the tip, between the oil-loading pipelines and the old pier. During 1981, the recreational beach eroded to an extent that affected the recreational value of the beach and the safety of the coastal structures. Comprehensive field measurement and analysis were carried out by Harms et al. [5]. They concluded that the sediment transport in this area was mainly due to wave action. Deep-water waves and wave refraction were also studied by Harms et al. [5]. Since the bottom topography and the sediment characteristics were recorded by Harms et al. [5], that information, was selected to be the initial conditions for the demonstration of the newly-developed nearshore sediment transport model. Unfortunately, there are no field measurements of the bottom topography after wave action (i.e., final stage). It was not possible to calculate the actual field deposition and erosion patterns for model calibration and numerical result verification.

Due to limitations in the computer's memory (IBM-compatible 486 PC), only 215 m in the alongshore direction and 172 m in the offshore direction of the beach area was selected for the demonstration. Fig. 2 depicts the bathymetry of the test area, where Δx (offshore direction) is equal to 5 m, and Δy (alongshore direction) is equal to 4 m. The time increment is 0.15 s. The deep-water wave direction is from the southwest with a period of 3.28 s and a height of 0.66 m. The bottom friction coefficient is 0.08. The median diameter of the bed sediment is 0.3 mm. Fig. 3 presents the predicted wave field, and Fig. 4 shows the predicted nearshore current field due to wave action. Fig. 5 presents the bottom topography 30 min after wave action. Fig. 6 shows the deposition and erosion patterns in the study area.

4 Conclusions

A nearshore sediment transport numerical model was developed for predicting changes in nearshore beach topography due to the presence of waves. The model included two major components: a nonlinear nearshore circulation numerical model and an integrated coastal sediment transport computer model.

The nonlinear nearshore circulation numerical model (Lo et al. [4]) was modified from the model developed by Ebersole and Dalrymple [6]. Both deep-water wave conditions and bottom topography are key input for the model. The model included the physics of wave refraction, wave-current interaction, and surf zone hydrodynamics. The results of the model predict both the wave field and the nearshore current field within the area of interest. An integrated coastal sediment transport computer program was also developed in this study to predict the total sediment transport rate.

The nearshore sediment transport model was applied to predict changes in the bottom topography of one section of the beach area at Ras Al-Zour for a given wave condition. The model predicted the wave field, the nearshore current field, the new bottom topography, and the deposition and erosion patterns for the study area. In general, throughout this exercise, it was demonstrated that the model can be utilized to test the real conditions. However, the bottom friction and eddy viscosity coefficients need to be calibrated with field measurements, and further verification of the model's results with field measurements is strongly recommended in order to ensure the reliability of the model.

Due to a stability requirement, the model required the use of a fine grid size for the study area, which meant that a large amount of computer memory was required. Depending on the selected wave condition, therefore, the model could not be applied for a coastline longer than 500 m.

Acknowledgements

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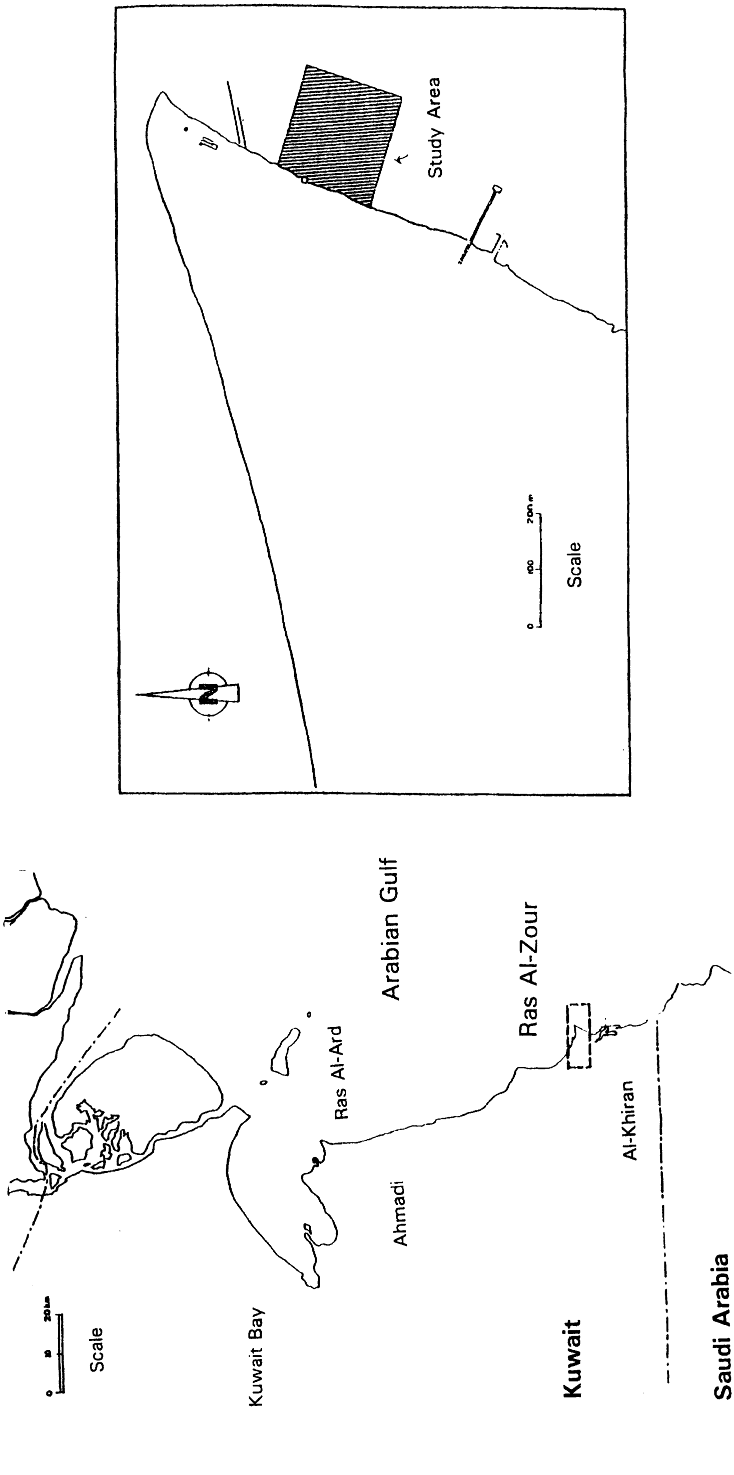

Fig. 1 The location map of the study area at Ras Al-Zour.

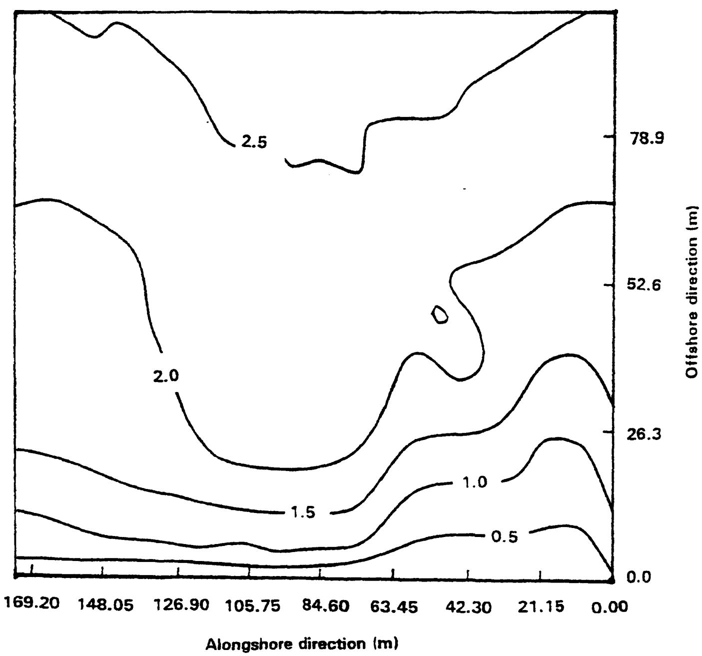

Fig. 2 The bathymetry map of the study area.

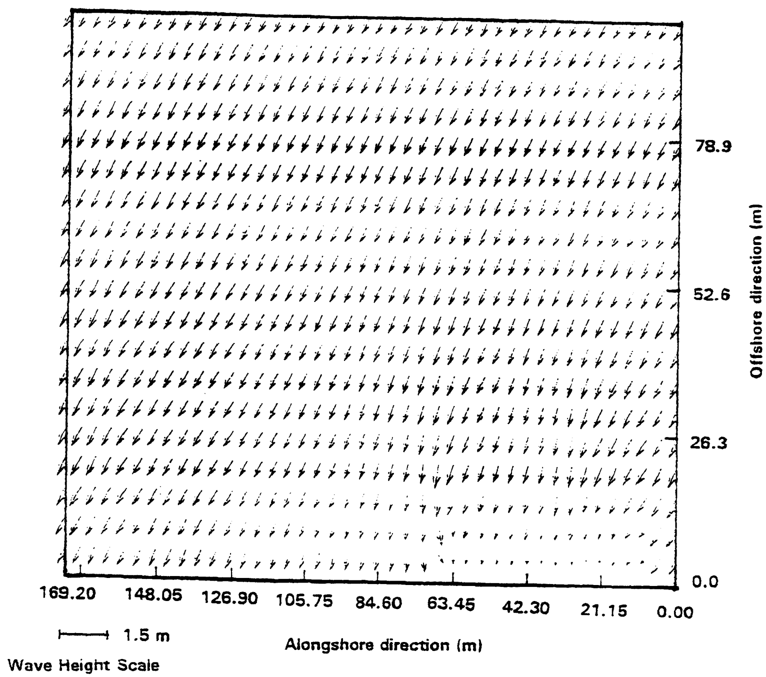

Fig. 3 Nearshore wave field of the study area predicted by the nonlinear nearshore circulation numerical model.

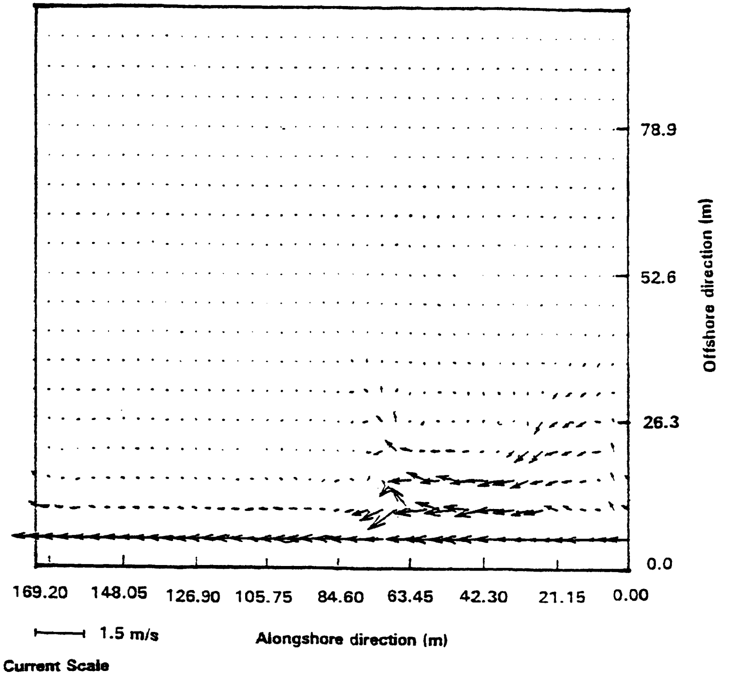

Fig. 4 Nearshore current field of the study area predicted by the nonlinear nearshore circulation numerical model.

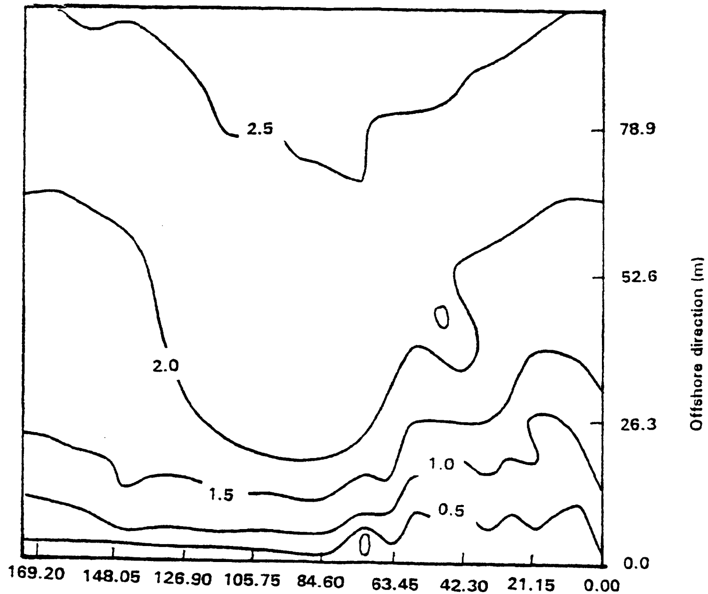

Fig. 5 Predicted bathymetry map of the study area after 30 min of wave action.

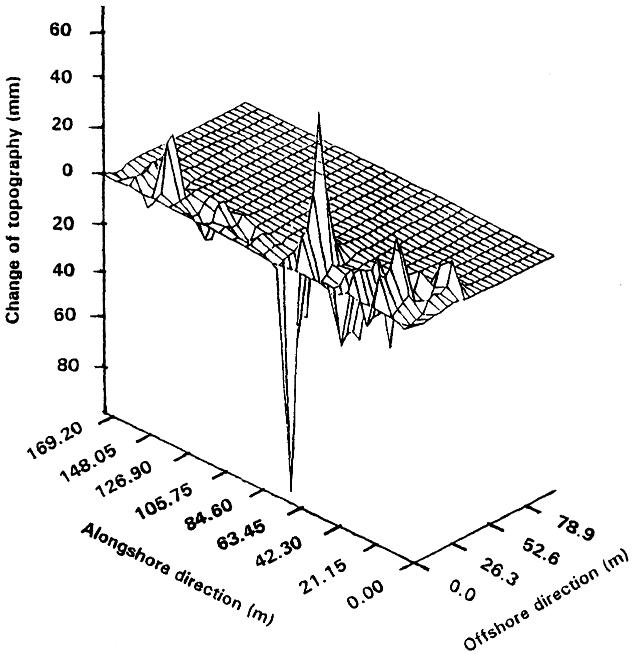

Fig. 6 Predicted deposition and erosion patterns of the study area.