Modified N-line numerical model for mapping bottom topography changes - case study Idku City, Egypt

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Sediment transport is one of the most important subjects in coastal engineering studies. The N-line numerical models for simulating changes in bed morphology are appropriate in most of the coastal engineering applications. Simplifying procedures of calibration and verification of one of these models saves time and money and increases the reliability of the model. The N-line numerical model of Perlin and Dean 1983, was modified to handle the actual contour lines as data inputs instead of using the equilibrium beach profile empirical equation. Usage of the spatial distribution of bed sediment grain size instead of the average values is considered another contribution of this paper. A comparison between the application of different types of available longshore sediment transport equations in the model is presented in the study. All these modifications were utilized to perform a sediment transport parametric study for a field case in front of Idku City in Egypt. The results show that sediment transport rate is sensitive to the small changes in activity parameter, however; the longshore transport equation factor and the breaking wave energy parameter have a little effect on it. For the case of using a wide range of wave data, CERC and Kamphuis 1991 longshore transport equations give more or less the same results. The validation of the model in the study area is also discussed.

تعتبر حركة الرسوبيات من أهم الظواهر الخاصة بهندسة الشواطئ. تصنف النماذج الرياضية كإحدى الوسائل الفعالة في حساب حركة الرسوبيات حول المنشآت ، كما تمثل النماذج أحادية البعد ومتعددة الخطوط N-line models من أهم الوسائل العملية في التطبيقات الهندسية. هذه النماذج الرياضية تحتاج إلى معايرة وتحقيق على مكان الدراسة قبل أن يتم تطبيقها، وتبسيط عملية المعايرة والتحقق يوفر الكثير من المال والجهد ويزيد من الثقة في نتائج النموذج. تم تعديل النموذج الرياضي الخاص بـ Perlin and Dean 1983 وذلك حتى نتمكن من تطبيقه على خطوط كنتور في الطبيعة بدل من استخدامه للمعادلات الوضعية للقطاع المتزن، كما تم إضافة إمكانية الاختيار من عده معادلات لحساب الحجم الكلى لحركة الرسوبيات الموازية لخط الشاطئ، وتم إدخال إمكانية التعامل مع نوعية رسوبيات القاع عند كل نقطة بدلاً من اخذ القيمة المتوسطة على كامل منطقة الدراسة. تم عمل دراسة لتأثير المعاملات المختلفة الخاصة بالمعايرة على حركة الرسوبيات وتم اختيار منطقة أدكو كنموذج حقيقي للتطبيق، وقد وجد أن حركة الرسوبيات لها حساسية عالية لأي تغير في معامل النشاط والخاص بمعادلة حركة الرسوبيات العمودية على خط الشاطئ بينما تأثير باقي المعاملات ضعيف على حركة الرسوبيات. كما وجد أن نسبة الخطأ الناتج عن استخدام متوسط حجم حبيبات القاع بدلاً من التوزيع الحقيقي على طول المنطقة صغير ويمكن التغاضي عنة، كما أنه في حالة التطبيق على كمية كبيرة من بيانات الأمواج والتي بينها تفاوت واضح في القيم وجد ان كل من معادلة CERC & Kamphuis 1991 تعطى نفس النتائج تقريباً. أخيراً تم دراسة مدى دقة تطبيق النموذج ودرجة الثقة في الاعتماد على النتائج الخاصة به وذلك بعد إتمام عملية المعايرة له.

Keywords: Coastal engineering, Sediment transport, Bottom topography, N-line numerical models, Idku City

1. Introduction

Sediment transport caused by wave and wave-induced current plays an important role in coastal engineering science. Selecting the type and the orientation of marine structures depends on distribution and rate of sediment transport in the area under investigation. Thus, the accurate evaluation of the sediment transport mechanism and quantities is an important task.

Several numerical models for simulating sediment transport and bed morphology in the coastal area have been developed during the last twenty years. The most elegant simulation for the governing sediment transport equations can be represented by a three dimensional model which is rarely used in practice due to the large operating cost of such model, Kamphuis [1]. The next lower level of sophistication is quasi three-dimensional model (Briand and Kamphuis [2], Katopodi and Ribberink [3], Rakha et al. [4] and Karambas and Koutitas [5]). Then, next class is the 2-D vertical model (Dally et al, [6] Stive [7] and Roelivink [8]) or 2-D horizontal model (Deigaard et al. [9] and Karambas [10]). The lowest level of sediment transport model is one line model (Willis [11] Hanson and Kraus [12]).

For most practical computations, the sophistication of a repeated 3-D calculation far exceeds the quality of the field data while the per-run cost does not allow for the many runs necessary to define vital problem parameters. Hence, a simpler sediment transport and shore morphology calculations which allow many and interactive calculations is very useful, Kamphuis [1].

Perlin and Dean [13] developed an implicit finite-difference, N-line numerical model to predict bathymetric changes in the vicinity of coastal structures. The wave field transformation includes refraction, shoaling, and diffraction. The model is capable of simulating one or more shore-perpendicular structures. Understanding the effect of each parameter, which affects the calibration procedures, decreases the time and the cost of modeling runs and increases results accuracy. Actual field data collected from a study area near Idku City is used in this study. The Perlin and Dean [13], N-line model was modified to use the levels of actual contour lines instead of using the equilibrium beach profile equation. Moreover, two modifications were carried out as follows:

1. Applying CERC and Kamphuis [14] equations in calculating the bulk longshore sediment transport instead of CERC equation only.
2. Applying the spatial distribution of bed sediment grain size instead of the average value along the study area.

Such procedures have been developed for calibrating the model, checking the different parameters, which affect coastal sediment transport and finding out the sensitivity of each one. The checked parameters are the activity factor, longshore transport equation factor, breaking wave energy parameter, and bed sediment grain size. The volumetric change, which represents the positive and negative sediment volume result from the comparison between the actual data and the model result, is used here as an indicator in order to get the best calibration coefficients. A computer program was developed to calculate the volumetric change between the two contour maps by using the trapezoidal rule.

2. Site description

Idku coastal area is located in Abu Quir Bay east of Alexandria City on the Mediterranean coast of Egypt, from lat. 31^{0} $20.4^{/}$ N, long. 30^{0} $18.1^{/}$ E to lat. 31^{0} $22.6^{/}$ N, long. 30^{0} $19.6^{/}$ E, fig. 1. Abu Quir Bay is a relatively sheltered, shallow and semi-circular basin boarder by the Rosetta promontory from the east and Abu Quir headland from the west. The shoreline of the bay is about 50 km long while the study area extends along shore from km 16.0 to km 11.0 west of Rosetta promontory.

3. Model description

The flow-chart of the modified N-line numerical model of Perlin and Dean [13] for simulating the sediment transport and bottom morphology is shown in fig. 2. The governing equations of the numerical model are summarized as follows:

3.1. Wave transformation model

3.1.1.Wave angle

The wave conservation equation:

$$\frac{d\sigma}{dt} + \overrightarrow{\nabla_H} * \overrightarrow{K} = O \quad . \qquad (1)$$

where, $\overrightarrow{\nabla_H}$ is the horizontal differential operator, t is the time, $\overrightarrow{K}$ is the wave number, and σ is the angular frequency.

$$\vec{\nabla} = \vec{i}\frac{\partial}{\partial x} + \vec{j}\frac{\partial}{\partial y} \quad . \qquad (2)$$

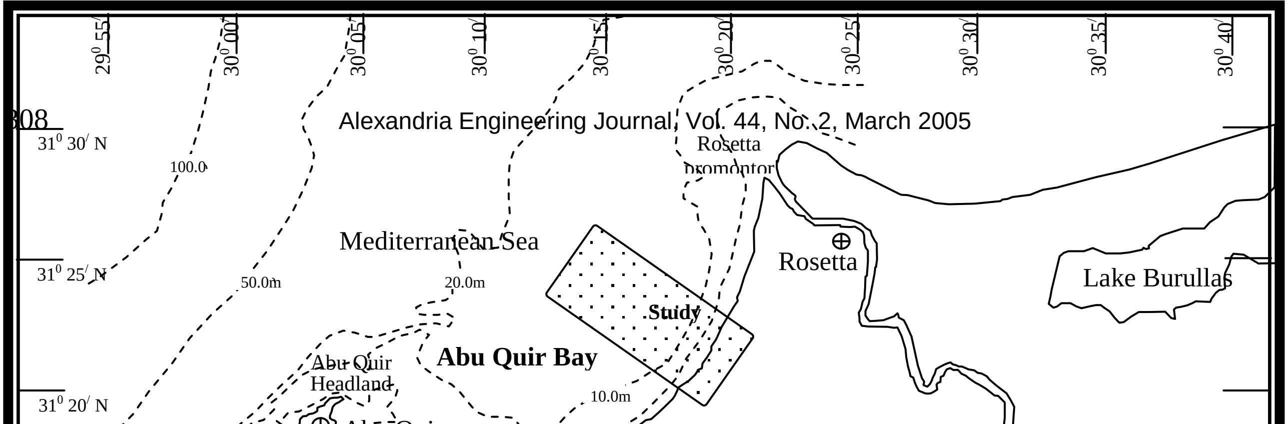


Fig. 1. General location of the study area.

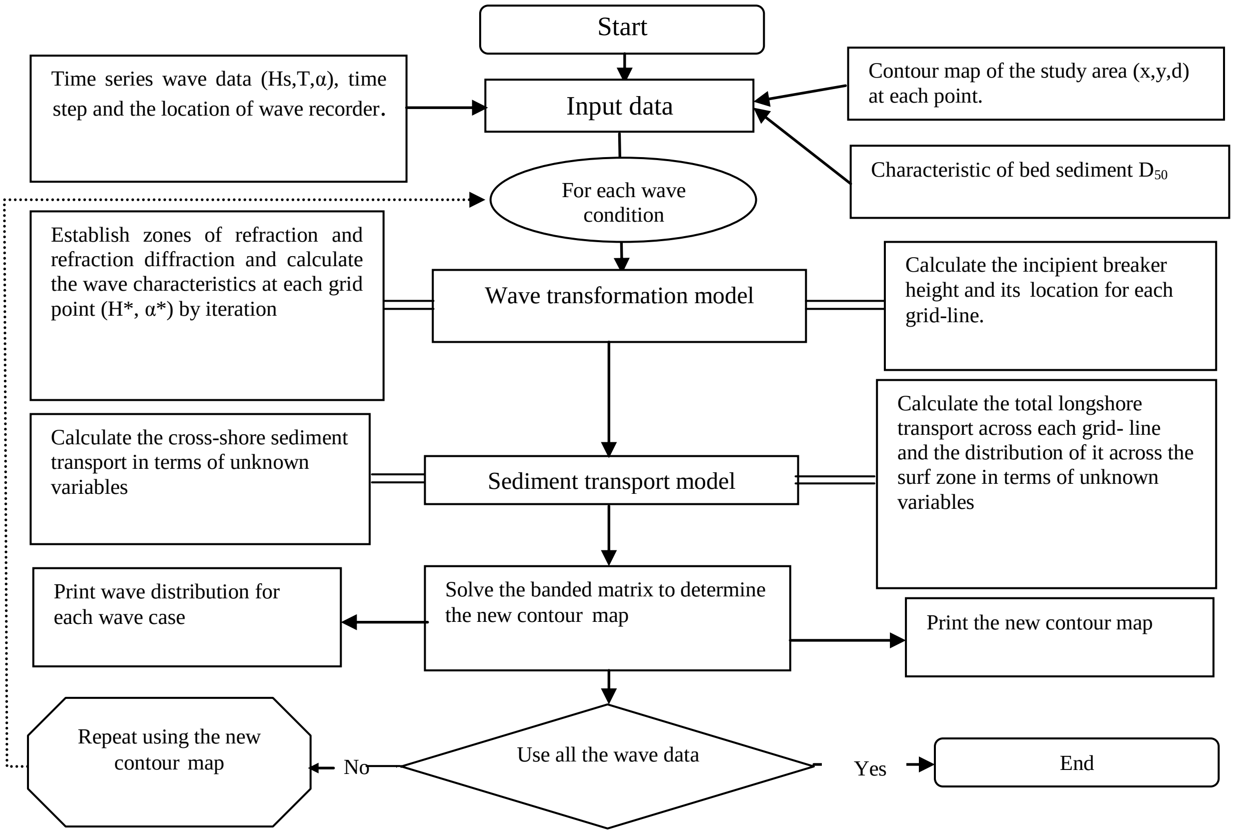


Fig. 2. Flow chart of the sediment transport numerical model.

Where $\vec{i}$ and $\vec{j}$ are the unit vectors in the x and y directions, x is the longshore direction, and y the offshore direction. Fig. 3 shows the definition sketch.

$$\vec{K} = \vec{i} * K_x + \vec{j} * K_y \quad . \qquad (3)$$

For the steady – state case, eq. (1) yields:

$$\frac{\partial}{\partial x} K_y - \frac{\partial}{\partial y} K_x = 0 \quad . \qquad (4)$$

Where K_x and K_y are the wave number in the x and y directions, respectively.
The equation can be written in final form as:

$$\frac{\partial}{\partial x} K \cos\theta - \frac{\partial}{\partial y} K \sin\theta = 0 . \qquad (5)$$

Where θ *is* the wave angle.

The numerical solution introduced by Noda [15] is used to solve eq. (5). This equation was initiated with Snell's law to specify the boundary conditions on the offshore boundary and on the wave angle approach side. Numerical smoothing is used at the conclusion of the wave field calculation to simulate the lateral transfer of wave energy along the wave.

3.1.2. Wave height

The governing equation for wave height calculations is the conservation of energy equation. By neglecting dissipation of energy due to friction percolation and turbulence, this equation can be expressed as:

$$\vec{\nabla}(E\overrightarrow{C_G}) = 0 \quad . \qquad (6)$$

Where E is the average energy per unit surface area and $\overrightarrow{C_G}$ is the group velocity. Eq. (6) can be written in final form as:

$$\frac{\partial}{\partial x}\left(\frac{\ell g H^2}{8} C_G \sin\theta\right) + \frac{\partial}{\partial y}\left(\frac{\ell g H^2}{8} C_G \cos\theta\right) = 0 \quad , \qquad (7)$$

where ℓ is the mass density of water, g is the gravitational constant, H is the wave height, and θ is the wave angle. C_G is determined by the linear wave theory.

$$C_G = \frac{C}{2}\left(1 + \frac{2Kd}{\sinh(2Kd)}\right) \quad . \qquad (8)$$

The finite difference form of eq. (7) can be easily solved by iteration with wave height boundary conditions along the same boundaries as the wave angles using linear theory shoaling and refraction coefficients, in which d is the water depth and C is the wave celerity. The local wave heights are limited by the value of .78 of the water depth.

4. Sand transport model

The continuity equation is used to simulate the sediment transport and bathymetry changes.

$$\frac{\partial y}{\partial t} + \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y} = 0 \quad . \qquad (9)$$

Fulford [16], based on laboratory data from Savage [17], developed a distribution of longshore sediment transport across the surf zone for the case of straight and parallel contours. A more general form of the equation is:

$$q_x(y) = B(y+a)^2 \, e^{\left(-\left[\frac{y+a}{C\, y_b}\right]\right)^3} \quad , \qquad (10)$$

where:

y_b is the distance to the point of breaking,

a is the constant to allow sediment transport above mean water level to be represented and equal the breaking height divided by beach slope.

C is a constant, which represents the width of the curve which analytically represent Fulford distribution, taken 1.25, Perlin and Dean [13], and

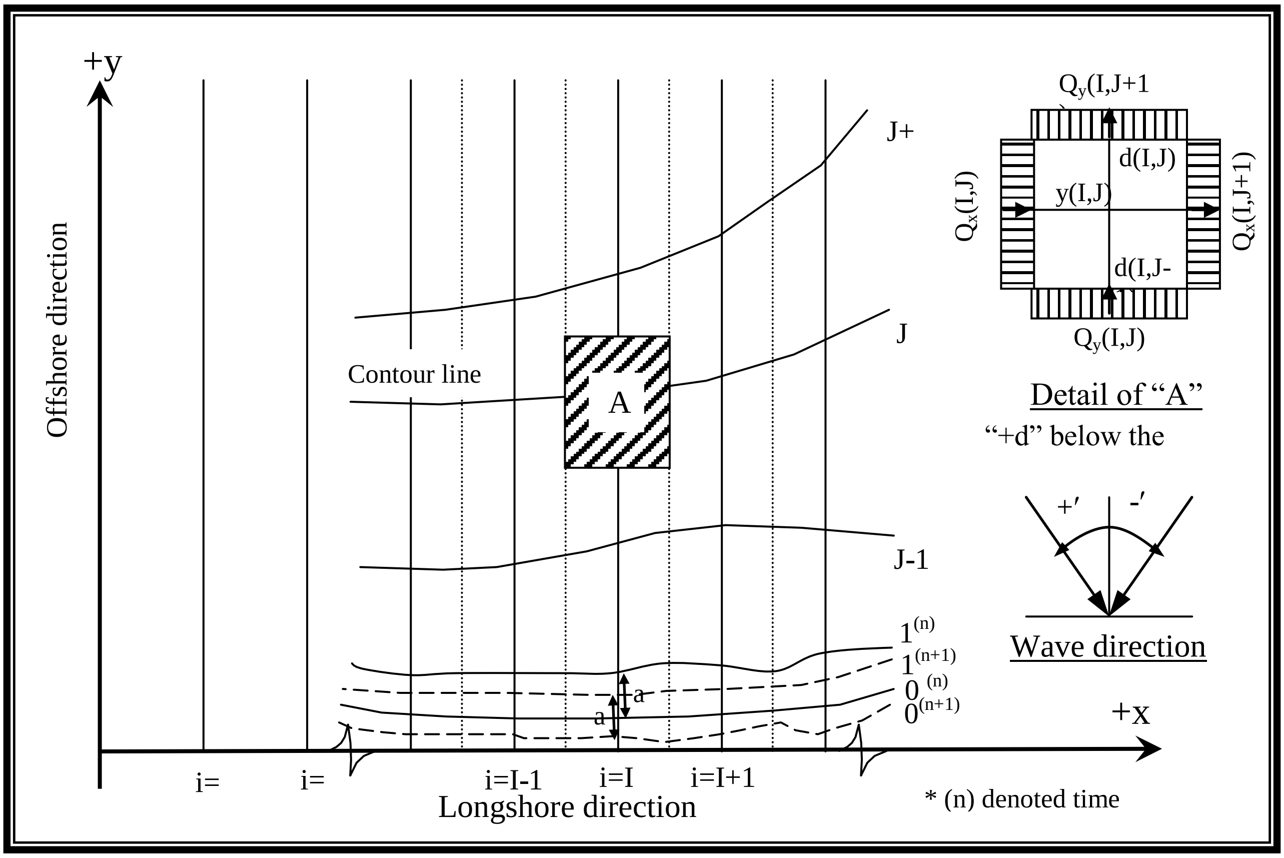


Fig. 3. Definition sketch for the numerical model.

To set the integral of eq. (10)to be one, B is taken $3/(C^3 y_b^3)$ and to determine the value of the sediment transport at any location across the surf zone, the integral result at this point is multiplied by the value of bulk longshore transport.

The final form of sediment transport of "y" location in the surf zone results for a shoreline with straight and parallel contours:

$$q_x(y) = \frac{3}{(1.25)^3 (y_b)^3} (y + \frac{d_b}{\partial d/\partial y})^2 e^{\{-[(y+\frac{d_b}{\partial d/\partial y})/(1.25 y_b)]\}^3} \quad . \tag{11}$$

To obtain the fraction of transport between two y coordinates the integral of equation from y_1 to y_2 must be used.

$$Q_x = Q\int_{y_1}^{y_2} q_x(y)\ dy \quad . \tag{12}$$

Q is the total longshore transport.

Two empirical equations are used to calculate the total longshore sediment transport.

CERC equation:

$$Q = \frac{K_l}{(\ell_s - \ell)\, g\, (1-p)}\ E_b\, C_{Gb}\, Sin\,(2\alpha_b) \quad . \tag{13}$$

Kamphuis equation [14]

$$Q = K_l^* \frac{\ell}{(\ell_s - \ell)(1-p)} (\frac{g}{2\pi})^{1.25} H_s^2 T^{1.5} m^{.75} D_{50}^{-.25} Sin^{0.6}(2\alpha_b) \quad . \tag{14}$$

Where

K_l, K^*_l is the are dimensionless coefficient,

G	is the gravitational acceleration,
ℓ_s	is the sediment mass density,
p	is the prosity,
E_b	is the average energy in the breaking point per unit surface area,
C_{Gb}	is the group velocity at the breaking point,
H_s	is the significant wave height,
α_b	is the wave angle at breaking point,
T	is the wave period,
m	is the beach slope across the surface zone, and
D_{50}	is the medium sediment size.

In order to compensate for the nonparallel nature of the contour the term $Sin(2\alpha_b)$ is replaced by $Sin(2\alpha_l)$ where α_l represents the angle between the local wave angle and local contour.

Bakker [18] developed cross-shore sediment transport equation:

$$Q_{y_{i,j}} = \Delta x\, K_{c_{i,j}} [y_{i,j-1} - y_{i,j} + W_{EQ\,i,j}]. \qquad (15)$$

Where:

Kc	is an activity factor.
$W_{EQ(i,j)}$	is the positive equilibrium profile distance between $y(i,j)$ and $y(i,j-1)$.

$$K_c = 10^{-5} \quad ft/sec \quad for\ d < d_b \ , \qquad (16\text{-a})$$

$$K_c = \frac{D_{2out}}{\Gamma(D_1 + D_{2b})} * 10^{-5} \quad ft/sec \quad for\ d > d_b \ . \qquad (16\text{-b})$$

Where

D_1	is the energy dissipation by wave breaking.
D_{2b}	is the energy dissipation by bottom friction inside the breaking zone,
D_{2out}	is the energy dissipation by bottom friction outside the breaking zone
Γ	is a parameter relating the efficiency with which breaking wave energy mobilizes the sediment bottom.

An implicit scheme of the finite difference form of the longshore and cross-shore sediment transport equations was used to circumvent the stability problem of the model.

5. Boundary conditions

To solve the Finite-difference form of the continuity equation boundary values –left side, right side, onshore, and offshore boundary of the study area- are required. The “*y*“ values along the left and right side boundary are assumed to be fixed at their initial locations. It means that the sediment transport quantity along these boundaries is zero.

The onshore boundary is treated by assuming that the berm and beach face move in conjunction with the shoreline position, fig. 3.

$$y^{n+1}_{i,O} = y^{n}_{i,O} + [y^{n+1}_{i,1} - y^{n}_{i,1}] \ . \qquad (17)$$

The required sediment transport is then computed by the change in position of the shoreline.

$$Q^{n+1}_{y_{i,1}} = -[\frac{Berm * \Delta x}{\Delta t}][y^{n+1}_{i,1} - y^{n}_{i,1}] \ . \qquad (18)$$

The offshore boundary is treated by keeping the contour beyond the last simulated one fixed until the bed slope transcends the angle of repose then resetting it to a position such that the slope equals to the angle of repose.

6. Site investigation and data processing

One year of field data collection program was executed in the study area during the period from October 2001 to September 2002. This program is a part of the plan of British Gas International Company and their Partners, Egyptian General Petroleum Company and Edison International, to develop a liquefied natural gas export project in Egypt, HR Wallingford [19]. Collected data include measurements of seven cycles of bathymetry and beach profiles. The survey was covering about 4.5 kms. in longshore direction and about 10 kms. in cross shore direction to depth of 15.0 m below M.W.L. The measurements include sedimentation, time serious wave data collected by using the ADCP "Acoustic Doppler Current Profile" multidirectional wave gauge mooring within the study area at a depth of 13.0m below M.W.L., and sea surface elevation. The positions were measured with accuracy of ±1.0 m, the depths were measured with accuracy of ±0.1m and the sea surface elevations were measured with accuracy of ±0.01 m.

Choosing the boundaries of the study area was mainly depending on the previous studies. The direction analysis of the available longshore current data revealed that the nodal point was found more or less near the eastern border of the study area, UNDP/UNESCO [20]. Analysis of ten years hydrographic profile survey showed that the shoreline of Abu Quir bay in general is accreting except for some specific locations, fig. 4. There is a recession of the coastline on both sides of Rosetta promontory, Fanos [21]. The source of the sediment along the Abu Quir bay was Rosetta Nile Branch and Rosetta promontory, Frihy et al. [22] Gewilli [23], and beyond 5-6m depth below M.W.L. Frihy et al. [22] The tidal range varies between .05 and .40 m with an average value of .22 m, Debes [24]. The noticed tidal currents along the study area are believed to be less than .05 m/sec and can be neglected, El-Gindy et al. [25].The statistical analysis of the available wave data from January 2002 to April 2002 at 13.0 m water depth is shown in fig. 5. From the results, it is clear that:

1- The significant wave height is 1.9 m and the average wave period is 5.0 sec.
2- The predominant wave directions are from the sector of NNW and WWSW.
3- The maximum wave height is 3.0 m with corresponding wave period and wave direction 9.8 sec and 278^0 , respectively.
4- The distribution of waves along the study area due to the significant and maximum wave height is shown in figs. 6 - 7.

Analysis of the available five years of wave data from 1985 to 1990, cleared that wave characteristics are changed from season to season and from year to year without a definite trend, Fanos et al. [26].

7. Sensitivity analysis

7.1. First module

This module is used to simulate sediment transport along the study area during the period from January 2002 to April 2002 using CERC empirical equation in calculation of the bulk sediment transport rate.

Three groups of computer experiments were executed in this module. For each group, one parameter of the following three parameters was varied, and the others were kept constant. The variable parameters are, activity factor, longshore transport equation factor, and breaking wave energy parameter.

For each run, the net sediment volume was calculated by comparing the field measurement of April 2002 and the corresponding model result. A parametric analysis was presented through a group of graphs showing the effect of each parameter on the corresponding net sediment volume, as shown in fig. 8. The above calculation was repeated with taking into consideration the surf zone only to depth 3.0 m, fig. 9. From the graphs and results summarized in table 1, it is clear that:

1. Sediment transport rate is sensitive to the small changes in the activity parameter.
2. The longshore transport equation factor and the breaking wave energy parameter have a little effect on sediment transport rate.
3. The best value of the activity parameter is .00005 and .000004 for the whole area and the surf zone, respectively.
4. The recommended value for longshore transport equation factor is .60 and 1.1 for the whole area and the surf zone, respectively.
5. The best value of the breaking wave energy parameter is equal one.
6. The net sediment volume, which calculated by comparing the observed and the estimated contour maps in all trials, is within the field data accuracy.
7. For the whole area, the best values of the three parameters are within their recommended ranges.

7. 2. Second module

This module is used to simulate sediment transport along the study area during the period from January 2002 to April 2002 using Kamphuis empirical equation in calculation of the bulk sediment transport rate. With the same technique used above, different values of the activity factor and the longshore transport equation factor were checked out to get the best value which gives a closer image to the observed contour lines. The results are shown in fig. 10. From the graphs, it is clear that:

1. The best value of the activity parameter is .000047 and .0000035 for the whole area and the surf zone, respectively.
2. The longshore transport equation factor has a little effect on sediment transport rate compared with the activity parameter.
3. In all runs, the different in sediment volume which, calculated by comparing the observed and the model's estimated maps is within the field data accuracy.

The effect of using the average value of the bed sediment grain size instead of the actual size distribution in longshore sediment transport calculations was checked. The second module runs were repeated using the actual values of sediment grain size in each point. Fig. 11, shows the results. It is clear that:

Table 1
Summary of the parametric study using the recent numerical model

Parameter / Model	*Kc*		*Kl* for CERC		*Kl* for Kamphuis		*Γ*	
	Surf zone	Whole area	Surf zone	Whole area	Surf zone	Whole area	Surf zone	Whole area
Range*	.00001-.0001		.57-.77		.0013-.0016		0-1.0	
First module	.000004	.00005	1.1	0.60	----	-----	1.0	1.0
Second module	.0000035	.000047	------	-----	No exact value		1.0	1.0

* These ranges are recommended by previous studies.

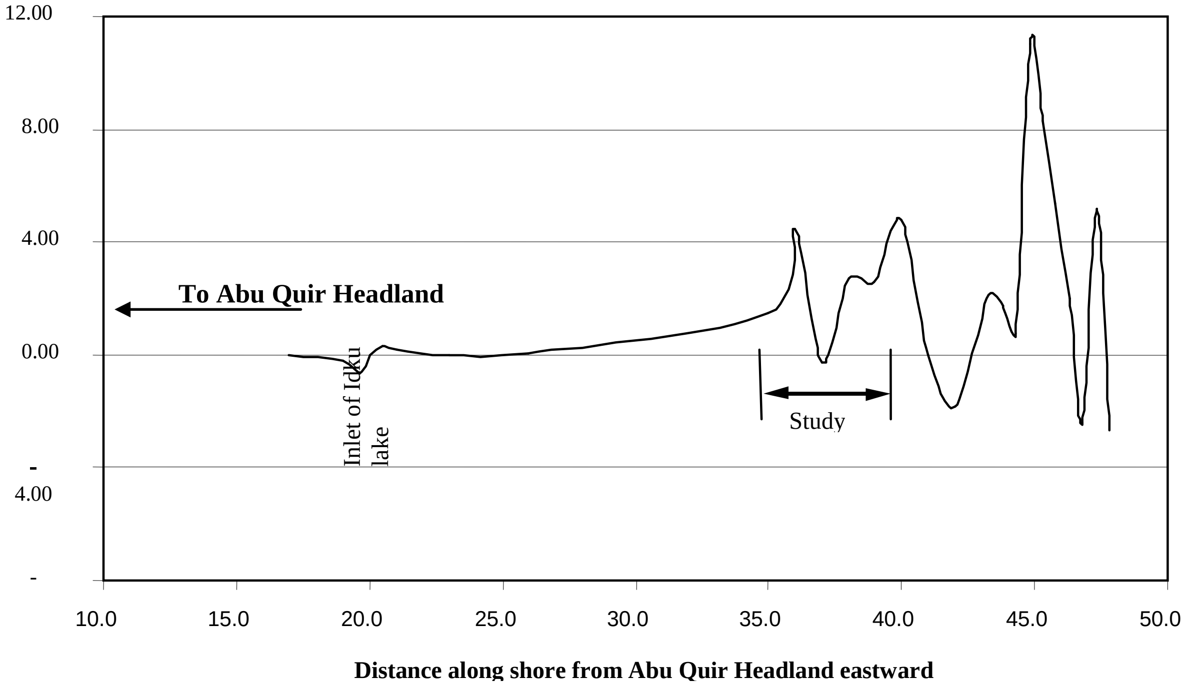


Fig. 4. Rate of shoreline change using field data collected during the period from 1990 to 2000, (After Fanos [21]).

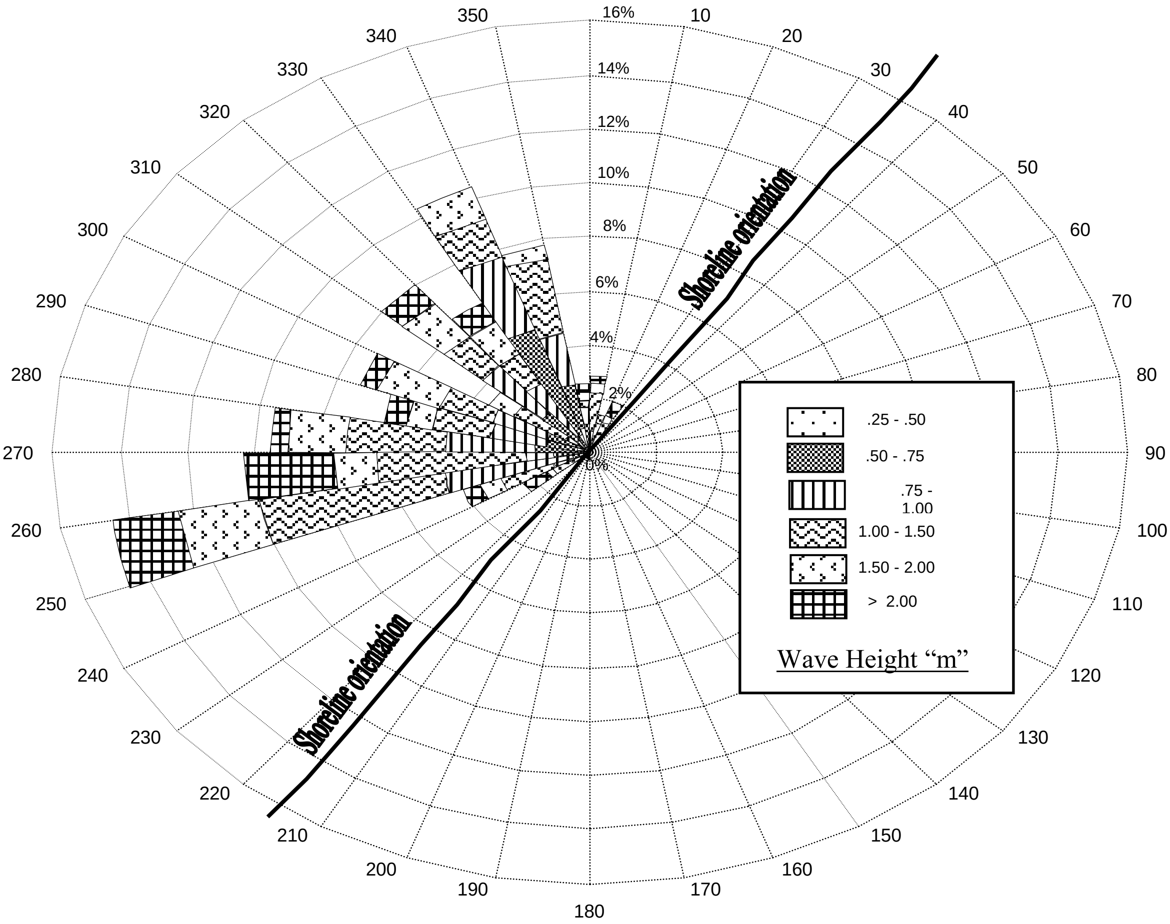


Fig. 5. wave rose of the field data collection in front of idku city at depth 13.0 m below M.W.L-during the period from January 2002 to April 2002.

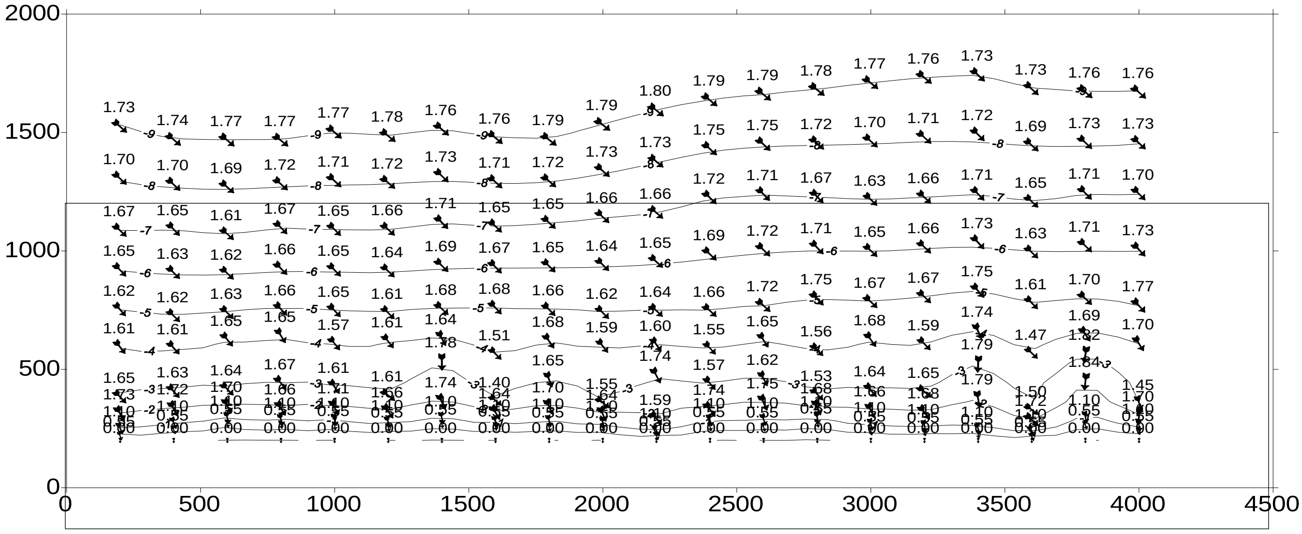


Fig. 6. Wave distribution along the study area due to single wave with *Hs* = 1.9m, *T*=5.0 sec, local direction = 50° at water depth 13.0 m.

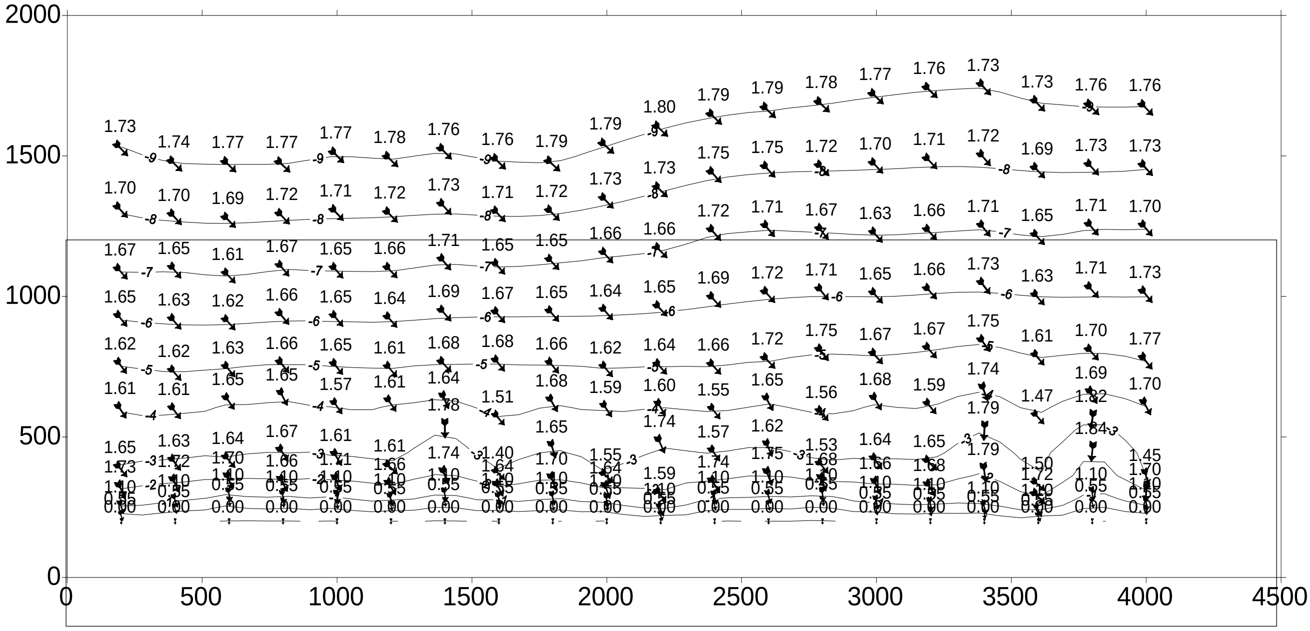


Fig. 7. Wave distribution along the study area due to max. measured wave of H = 3.0m, T=9.8 sec, local direction = 27° at water depth 13.0 m.

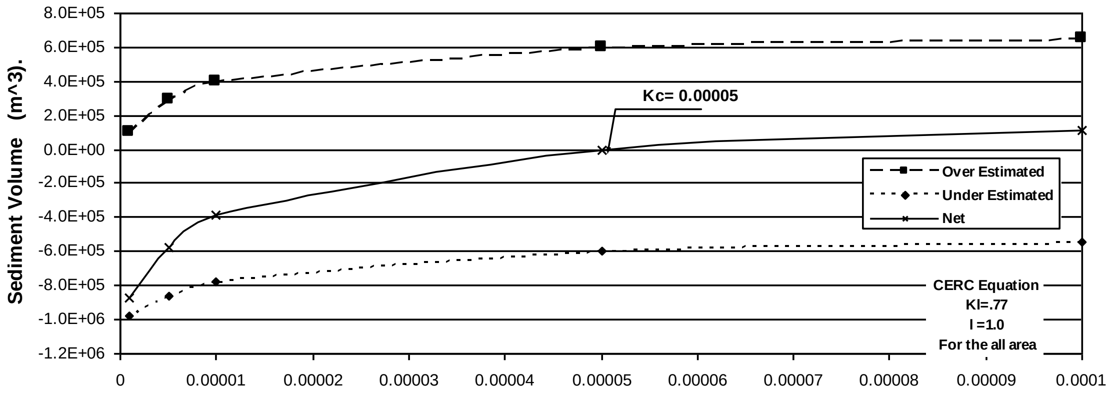
1. The sediment grain size along the study area is ranged from 0.1 to 0.2 mm while the weighted average value equals 0.14 mm.
2. In this case, the error caused by using the average value of the bed sediment grain size along the study area instead of the actual distribution is ranged between 0.5% and 1.5% for the surf zone and along the whole area, respectively.

A comparison between results of using CERC and Kamphuis equation was conducted by using the recommended value of longshore transport equation factor for each equation. The relationship between the net sediment volume, which calculated by comparing the field measurements and the model simulation results, and the activity parameter, was obtained, as show in fig. 12. From the results it is cleared that:

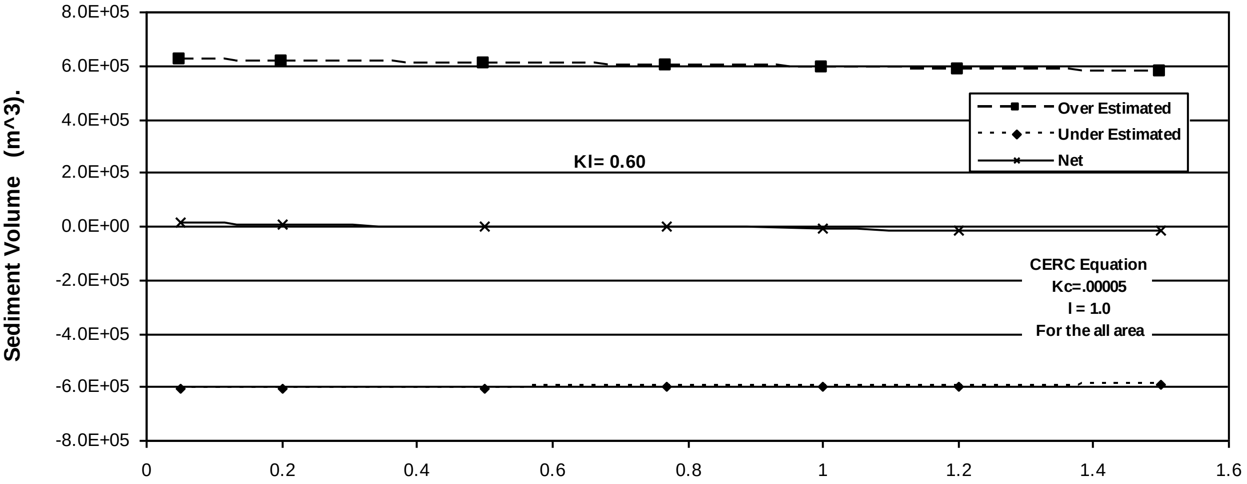
1. Along the whole area, Kamphuis equation gives better results for activity factor less than .00005; however, CERC equation gives better results for activity factor greater than .00005.
2. For the surf zone only with depth of 3.0 m, CERC equation gives better results for whole value of activity factor except for a small range less than .0000035.
3. The usage of Kamphuis [14] or CERC equation gives more or less the same results. This case is related to the wave condition, which specified in this period of year, from January to April, by a group of storms with relative calm conditions in between. Related to each other, CERC formula predicts longshore sediment transport rates during storms reasonably well, Miller [27, 28]; however, Kamphuis [14] formula gives better estimation for lower wave condition (less than 1m in height), Wang et al. [29]. Mixed the two cases of wave storm and low wave condition guide the two equations of Kamphuis and CERC to the same result.

8. Model validation

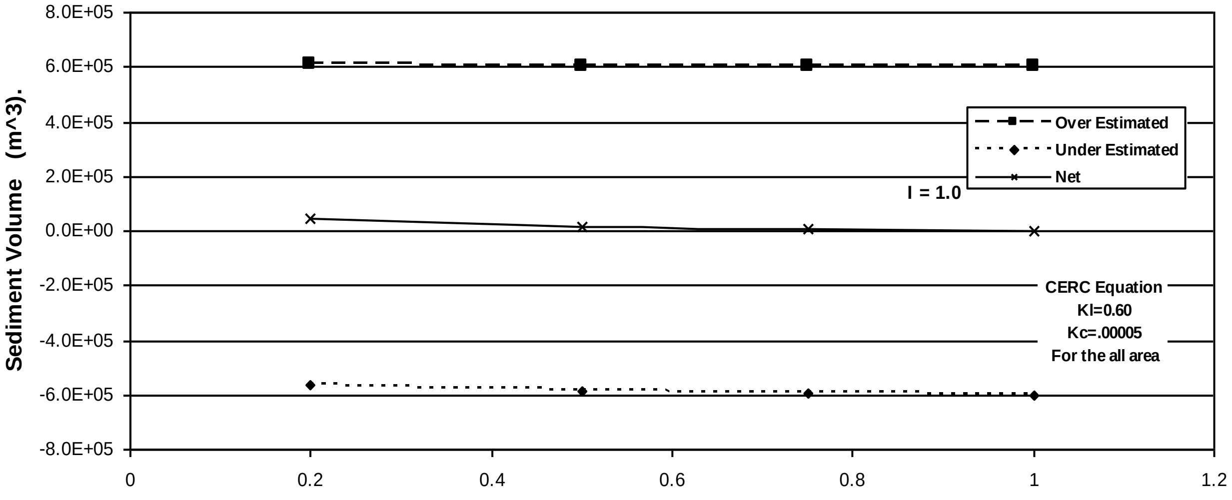
An application to the second modules with its final parameters for the whole area and surf zone with usage of the spatial distribution of bed sediment grain size was held during the period from January 2002 to Marsh 2002. The results are shown in fig. 13, and the results of topography changes are illustrated in figs. 14-15. From the results it is clear that:



(a) Activity Factor Kc



(b) Longshore Sediment Transport Equation Factor Kl



(c) breaking wave energy parameter

Fig. 8. Distribution of the difference in sediment volume between the field measurement & model simulation with different parameters affected the coastal sediment transport.

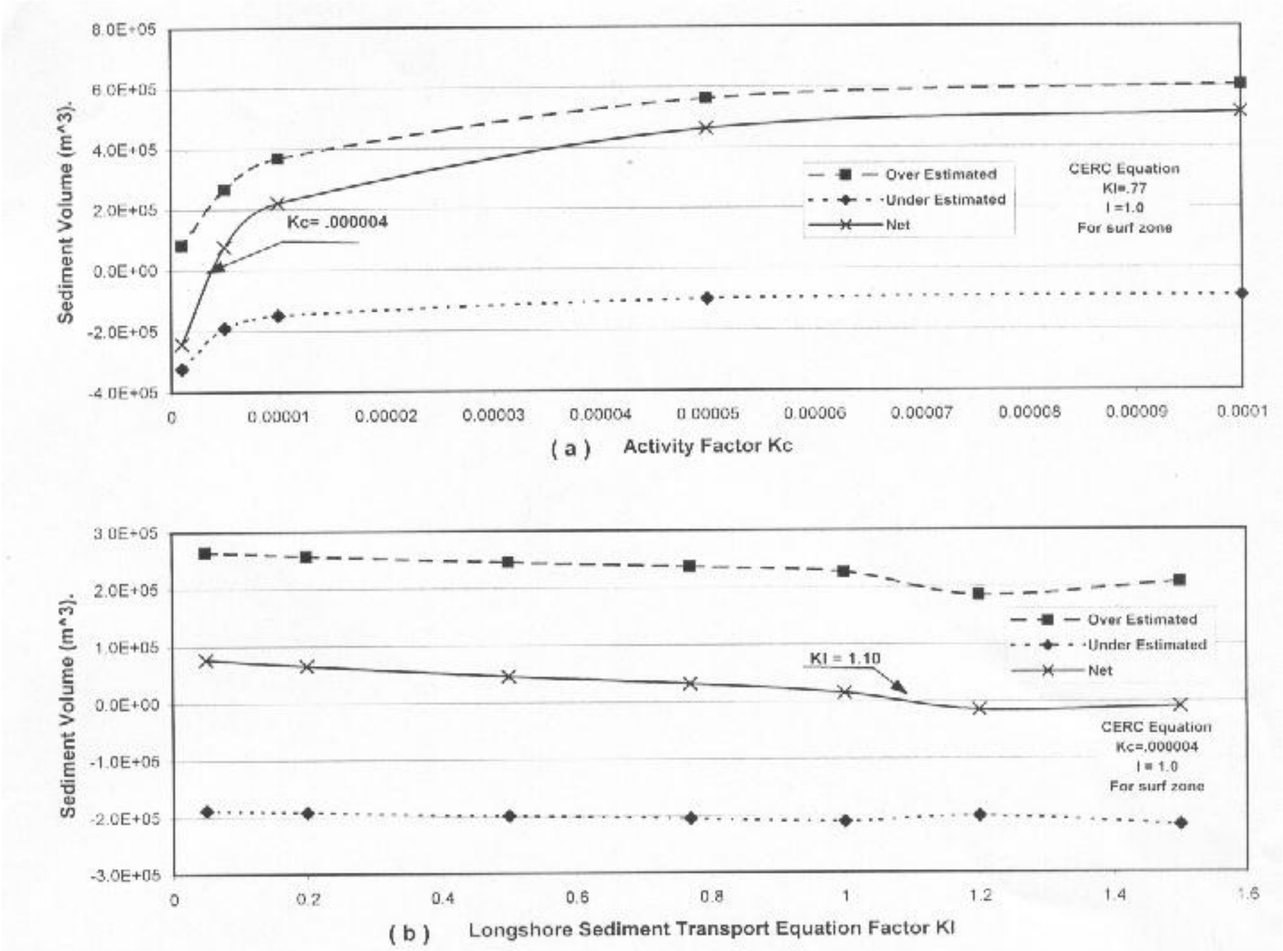


Fig. 9. Distribution of the difference in sediment volume between the fiel measurements & model simulation with different parameters affected the coastal sediment transport.

1. From contour 4.0 m below M.W.L. seaward, the model simulation gives the same trend of the field measurements; however, the model simulation is underestimated.
2. Case of using the suitable calibration coefficients for the surf zone gives better result than the other case, which used the suitable coefficients for the whole area.
3. In general, the model simulation gives magnitudes lower than the measured values. It may be due to outer source of sediment not considered in the model simulation.
4. The expected volume of outer source for sediments along the study area was estimated as 1100000 m^3 during the study period.

9. Conclusions

Using the net sediment volume as an indicator in calibrating the morphodynamic models simplifies the calibration process and helps in estimating the value of the outer sources of sediment transport. Checking the different parameters that affect the calibration procedures shows that:

1. Sediment transport rate is sensitive to the small changes in activity parameter so it is recommended to start the calibration procedures with this factor.
2. The longshore sediment transport equation factor and the breaking wave energy parameter have a little effect on sediment transport rate.
3. For the case of uniform grain size distribution without rocky pocket, using the representative averaged value of bed sediment grain size instead of the spatial distribution is acceptable.

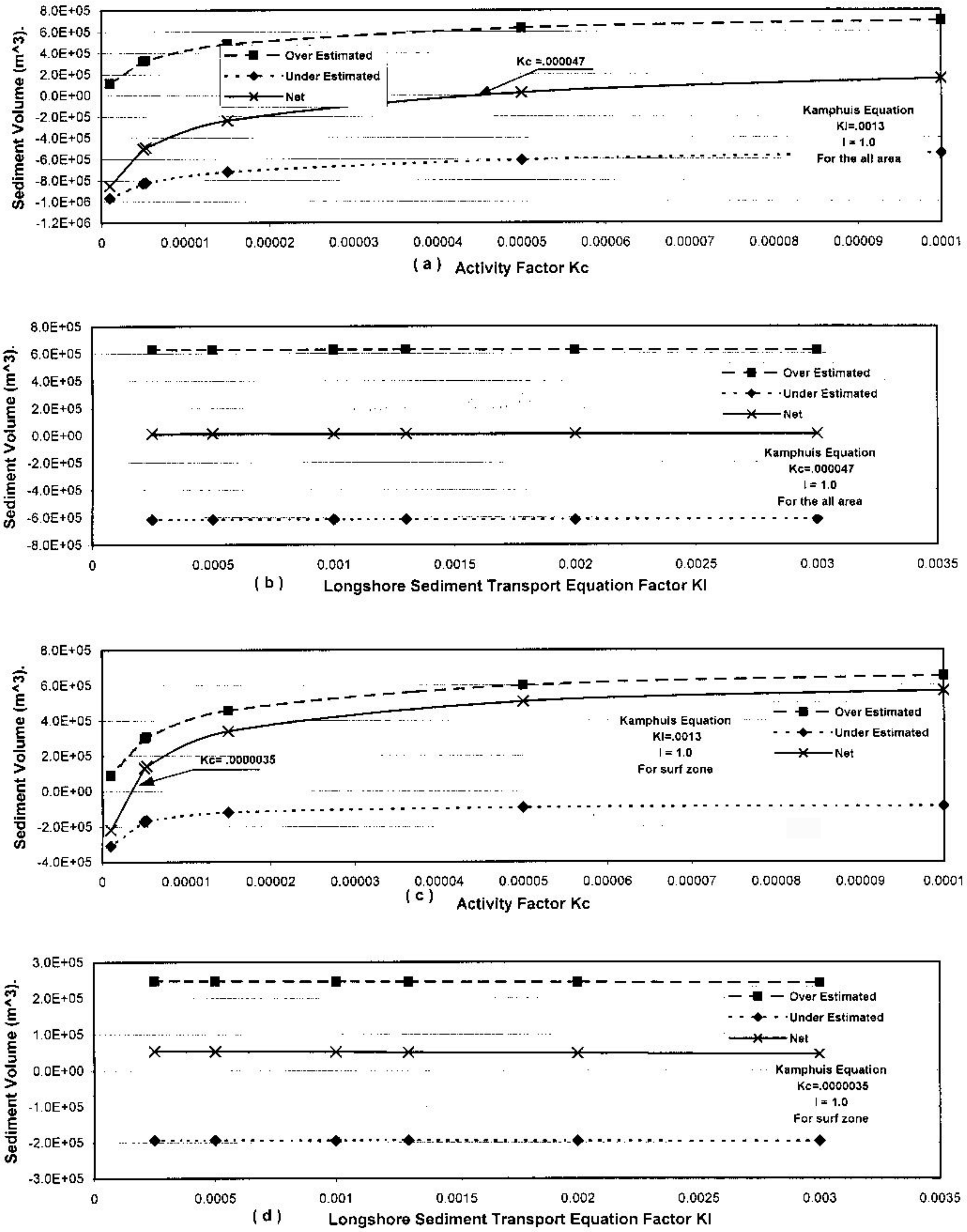
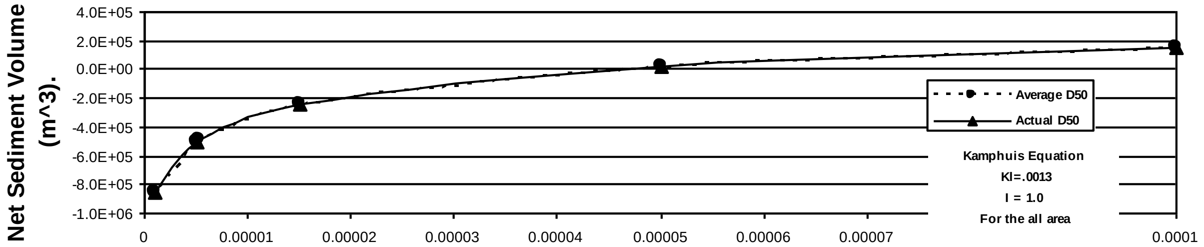
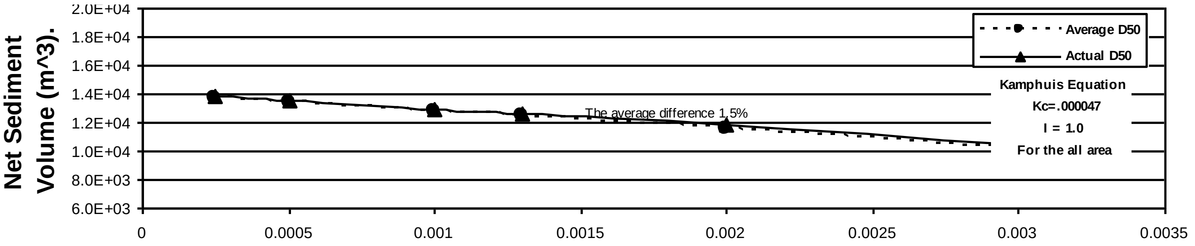


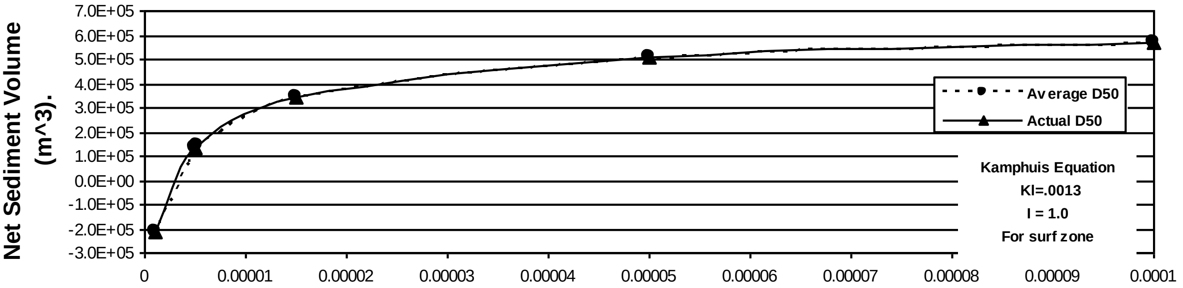
Fig. 10. Distribution of the difference in sediment volume between the field measurements & model simulation with different parameters affected the coastal sediment transport.



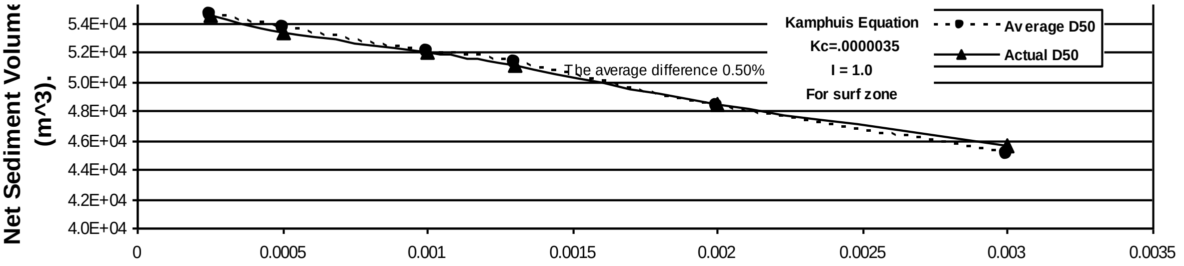
(a) Activity Factor Kc



(b) Longshore Sediment Transport Equation KI

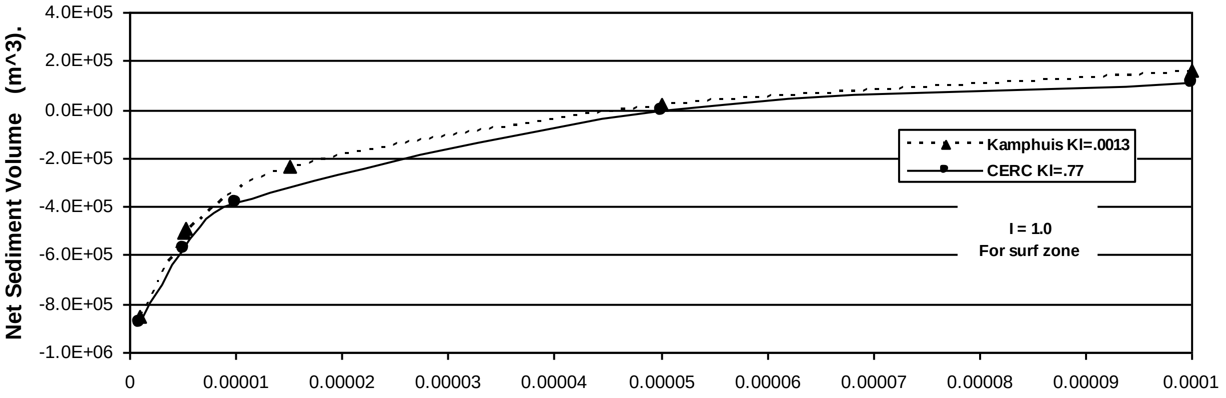


(c) Activity factor Kc

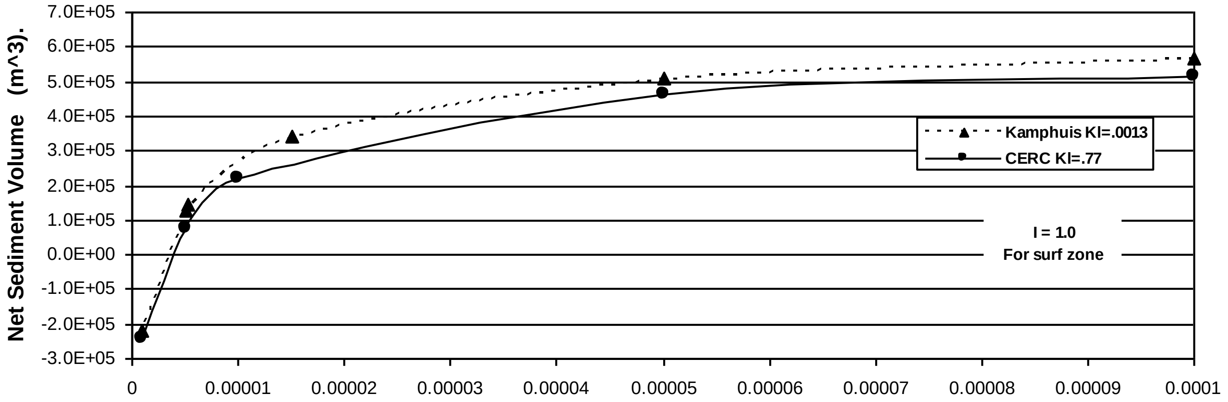


(d) Longshore Sediment Transport Equation Factor KI

Fig. 11. Distribution of the difference in sediment volume between the field measurements & model simulation with different parameters affected the coastal sediment transport.



(a) Activity Factor Kc



(b) Activity Factor Kc

Fig. 12. Distribution of the difference in sediment volume between the field measurements & model simulation with different value of activity factor.

4. For the ordinary case of wave conditions with periods of storms and calm weather, using CERC or Kamphuis [14] equation of longshore sediment transport gives more or less the same results; however, CERC equation gives more stable numerical calculations.

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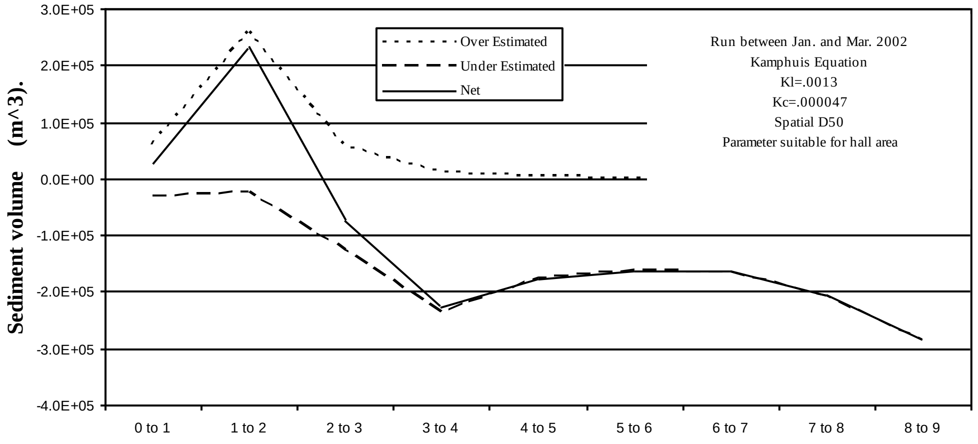
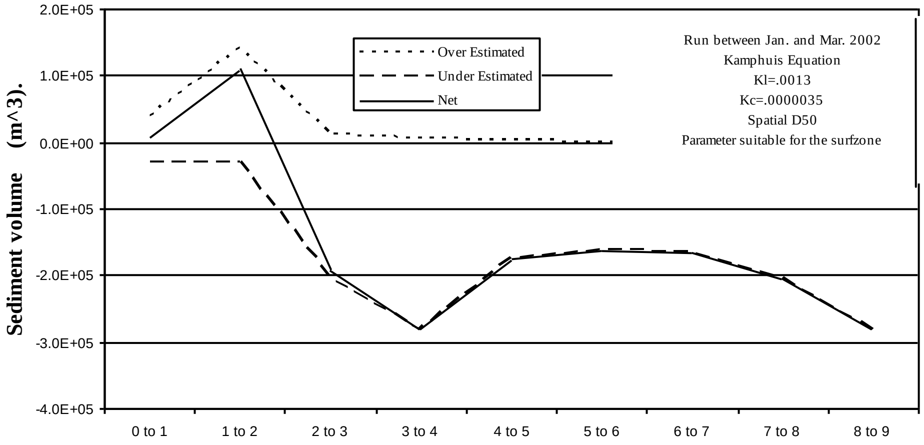


(a) Contours Lines (m).



(b) Contours Lines (m).

Fig. 13. Distribution of the difference in sediment volume between the field measurement & model simulation.

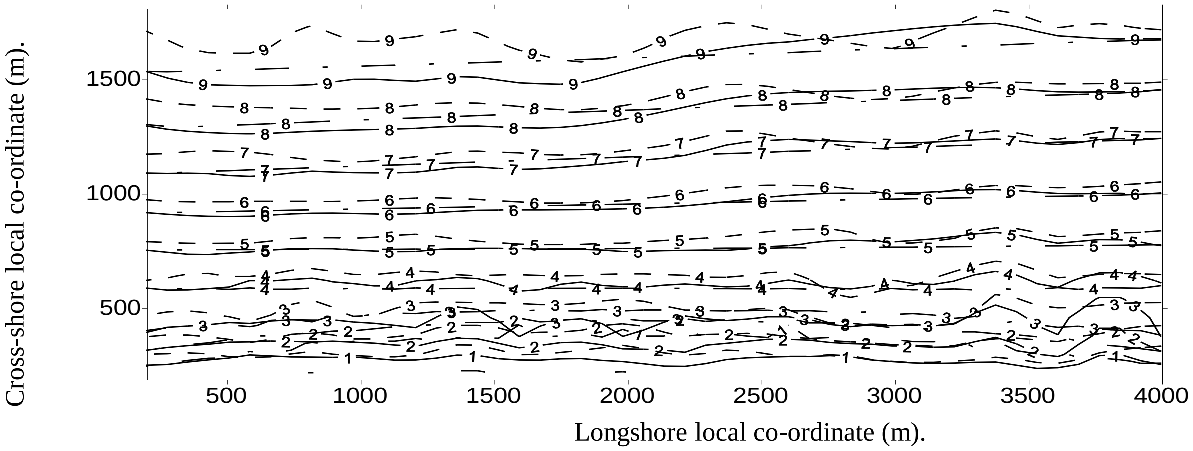


Fig. 14. Simulation of Edku topography during the period from Jan. 2002 to Mar. 2002 using the following parameters; K_L=.0013, Kc=.000047, Γ=1.0 for Kamphuis equation.

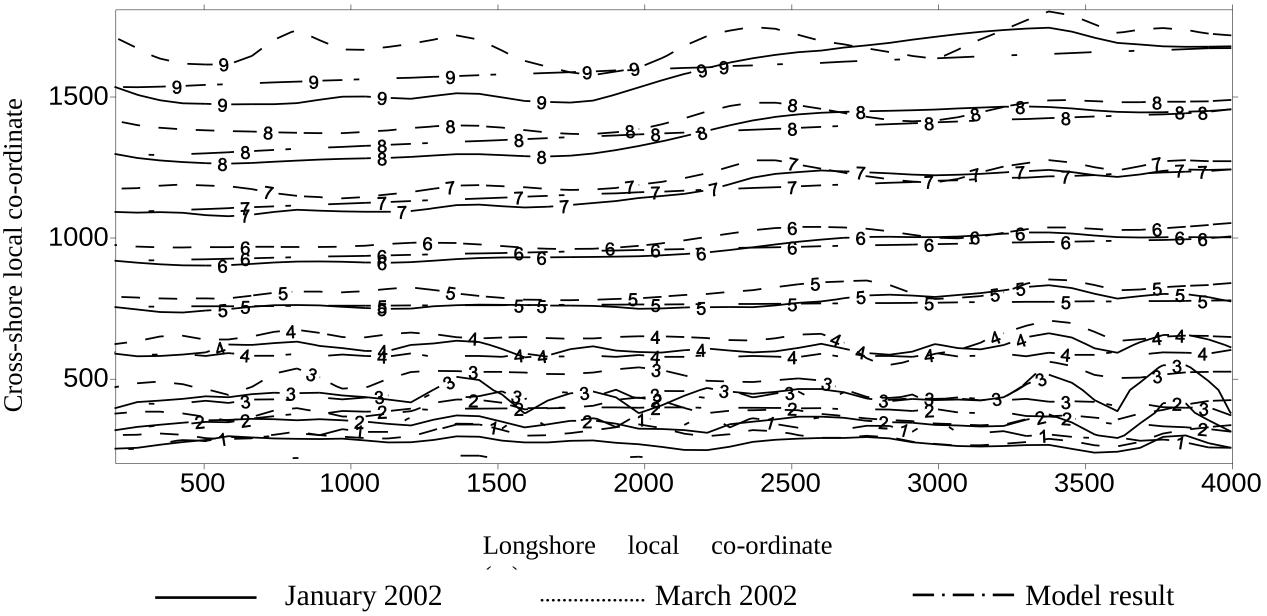


Fig. 15. Simulation of Edku topography during the period from Jan. 2002 to Mar. 2002 using the following parameters; K_L=.0013, K_C=.0000035, Γ=1.0 for Kamphuis equation.

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