International Journal of Engineering Trends and Technology
ISSN: 2231–5381 / https://doi.org/10.14445/22315381/IJETT-V72I5P123
Volume 72 Issue 5, 227-231, May 2024

Original Article

The Influence of the New Breakwater of Poti Port on Litho-dynamics of the Coastline

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Received: 13 December 2023 Revised: 31 March 2024 Accepted: 16 April 2024 Published: 26 May 2024

Abstract - *For several decades, anthropogenic activities caused environmental and geomorphological issues in the city of Poti, situated on the eastern Coast of the Black Sea. The construction of the Breakwater in the estuary of the northern Rioni River channel affects the transport of silt along the shore, and the paper deals with this topic. After the new Breakwater is built, all fine sediment movement in that direction will be stopped, and solid sediment will start to settle to the north of the new Breakwater. Eventually, this will cause the southern branch of the Nabada Canal to become blocked. The total flow of water from the Nabada canal will be transferred to the northern branch, and the formation of a new delta will begin there.*

Keywords - *Breakwater, Sediment, Wave, Coast.*

1. Introduction

For several years, the city of Poti and its maritime region have had environmental and geomorphological problems that are yet to be resolved, brought on by unsuccessfully designed and implemented hydro-engineering constructions in this region. Poti is located on the eastern Coast of the Black Sea in the western country of Georgia. In the southern part of the Poti coast, significant washing is threatened by the River Rioni [1]. The problems of geomorphological nature started on the coastline of Poti in 1939 when the river Rioni was completely thrown to the north of the city (Nabada Canal).

Although this measure saved the city from frequent flooding, it created an irreparable shortage of beach-forming sediment on the seashore. The sea has catastrophically washed away the coastline of Poti and pushed it back by hundreds of meters. At the same time, a delta was created at the confluence of the Nabada Channel with the sea, which is growing over time (Figure 1).

In 1959, on Rioni, seven kilometres northeast of Poti, was built the dam bridge with the regulatory sluice. Its purpose was to return the flow of the river up to 600 m3/s to the old bed of the city and in this way, fill the current deficit of sediment on the seashore (600 thousand m3/year). However, at discharges of more than 300 m3/s, due to sedimentation of the channel bed and deformations of the landlocked section, the city was again subject to flooding. To the south of the port, a sediment deficit of about 200,000 m3/year has occurred, which has caused bank washouts. Today, construction of the new port of Poti has begun. Breakwater originates at the southern branch of the Nabada delta and enters the sea at a distance of about one kilometre [2] (Figure 1).

The construction of the new Breakwater will lead to a change in the hydrological and hydrometric regimes of the sea in the coastal zone of Poti. This is directly reflected in the changes in the existing regimes of sediment transportation brought by the southern branch of the Nabada channel of the Rioni River.

In addition, the 1640-meter-long Breakwater of the new port, which enters the sea at a distance of 1 km from the 12-meter-deep isobath, will almost completely block the movement of beach-forming sediments in the southern direction [2].

Accordingly, the amount of sediment deposited from the Nabada channel of the Rion River into the canyon located southwest of the existing port (Figure 1) will be reduced. Currently, the canyon is in equilibrium. Due to a reduced sediment supply, the canyon may begin to move towards the shore and threaten the operation of the existing harbour.

The paper aims to study the impact of the new port breakwater under construction in the city of Poti on the changes in the configuration of the Nabada delta and the ongoing litho-dynamic processes along the coastline, taking into account the existing hydrological and hydrometric parameters of the Rion River and the sea coast.

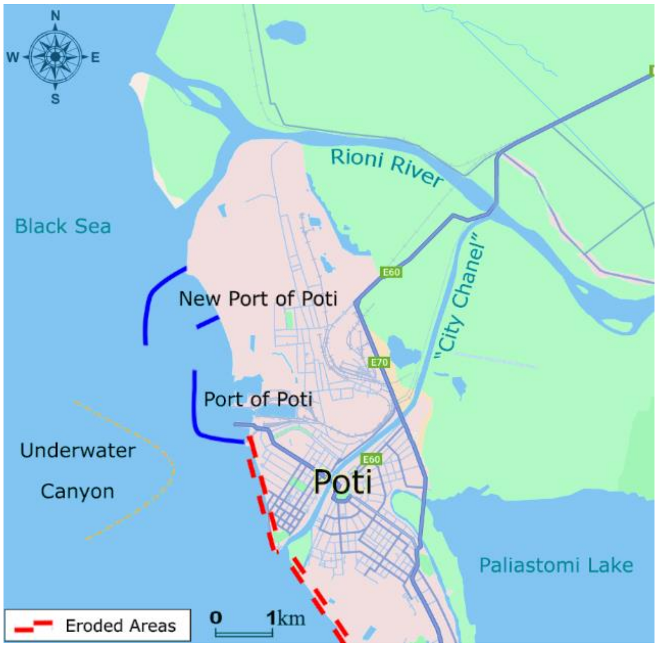


Fig. 1 Coastline scheme of Poti city

2. Main Part

The movement of waves and coastal currents along the shoreline causes shoreline change. In order to study the changes in the sediment transport and topography of the seabed in the coastal area surrounding the Nabada delta, the law of constancy of sediment mass can be used, from which the change in water depth can be obtained (Equation 1):

$$\frac{\partial h}{\partial t} = \frac{\partial q_x}{\partial x} + \frac{\partial q_y}{\partial y}, \quad (1)$$

Where x and are y horizontal coordinates, q_x and q_y are the speeds of sediment movement in the directions within the boundaries of the element. Volumetric rates of movement (q_x, q_y)) are expressed by the volume of effective sediment carried by the vertical cross-section of the element in a unit of time[3]. To determine the sediment movement speed, the following formula is used:

$$(q_x, q_y) = (q_{cx}, q_{cy}) + (q_{wx}, q_{wy}) \quad (2)$$

where(q_{cx}, q_{cy}) do mean currents cause the velocity of sediment transport, and (q_{wx}, q_{wy}) is the velocity of sediment transport caused by waves. The formula calculates the rate of sediment transport caused by currents:

$$q_{cx} = Q_c U, \;\; q_{cy} = Q_c V,$$
$$Q_c = A_c(\tau_m - \tau_{cr})/\rho g, \quad (3)$$

Where U and V are the average current velocities in the and directions, $A_c = 0.1 - 1$ is a dimensionless coefficient, the maximum value of the bottom shear stress caused by the combined action of τ_m Waves and currents are $\tau_m = \frac{1}{2}\rho f_{cw}\hat{u}_b^2$, $\hat{u}_b$ is the amplitude of the bottom orbital velocity, is the bottom friction coefficient, and is the critical bed shear stress required to drive sediment. (if $\tau \leq \tau_{cr}$, then $Q_c = 0$). The asymmetry of bottom wave velocities causes sediment movement by waves. It is more complex as it requires consideration of factors such as wave refraction, diffraction, breaking, reflection and bottom slope. The sediment transport rate caused by waves is calculated by the formula [1]:

$$q_{wx} = F_d Q_w \hat{u}_b \cos\alpha \,, q_{wy} = F_d Q_w \hat{u}_b \sin\alpha \,;$$
$$Q_w = A_w(\tau_m - \tau_{cr})/\rho g \quad (4)$$

Where A_w is a dimensionless coefficient, $\hat{u}_b$ is the amplitude of the bottom orbital velocity, α is the angle between the direction of wave propagation and the $x$axis. The coefficient is equal to:

$$A_w = B_w \frac{w_0}{(1-\lambda_v)s\sqrt{sgd}}\sqrt{\frac{f_w}{2}}, \; s = (\rho_s - \rho)/\rho, \quad (5)$$

τ_m do waves and currents cause the maximum shear stress, λ_v is the bottom porosity and f_w is the wave coefficient of friction. The value of f_w depends on the amplitude and period of the orbital velocity as well as the characteristics of the bottom. For example, if the bottom consists of sand $d =$ 0.2mm, $w_0 = 2.4$cm/s, $\lambda_v = 0.4$, $s = 1.65$, $B_w = 7$and $f_w =$ 0.01~0.2, then the value of A_w changes in the range$A_w =$ 0.1~1. A_w is constant during calculations. In formulas (4):

$$F_d = \tanh\left(k_d \frac{\Pi_c - \Pi}{\Pi_c}\right),$$
$$\Pi = \psi' \frac{h}{L_0} = \frac{\hat{u}_b^2}{sgd}\frac{h}{L_0}, \quad (6)$$

Where Π represents the critical value at the zero point (where the lateral movement of the sediment is zero). $\Pi_c$is a unit order value and is specified in the calculation processes. The values of the Π parameter will be specified if the replace $\psi'$with the shields parameter. Equation (4) depends on bottom friction (critical stress), the value of which must be determined under the influence of waves and currents. The critical condition for sediment movement is determined by the critical value of the Shields parameter, which is equal to $\psi_c = \tau_{cr}/(\rho_s - \rho)gd$. For fine sand, the value of $(d = 0.1\sim0.4)$ the Shields critical parameter is equal to 0.11, and for large sand, it is equal to 0.06. The bottom slope factor is not taken into account in the formulas used to determine (q_x, q_y). It is taken into account:

$$q_x' = q_x + \varepsilon_s|q_x|\frac{\partial h}{\partial x},$$
$$q_y' = q_y + \varepsilon_s|q_y|\frac{\partial h}{\partial y}, \quad (7)$$

Moreover, instead of (1), it becomes:

$$\frac{\partial h}{\partial t} = \frac{\partial q_x'}{\partial x} + \frac{\partial q_y'}{\partial y} \quad (8)$$

2.1. Algorithm of the Solution

Entry of the notations in equation (7):

$$A = q_x \,, \quad B = \varepsilon|q_x|\,, \quad C = q_y \,, \quad D = \varepsilon|q_y|$$

and (8) rewrite as follows:

$$\frac{\partial h}{\partial t} = \frac{\partial}{\partial x}\left(A + B\frac{\partial h}{\partial x}\right) + \frac{\partial}{\partial y}\left(C + D\frac{\partial h}{\partial y}\right) \quad (9)$$

The task can be generalized and call it the generalized solution of Equation (9) the Sobolev's function $h \in \widetilde{W}_2^{(1)}$, which satisfies the equation [1, 3]:

$$\iint_S \frac{\partial h}{\partial t}\omega_{i,j} dS = \iint_S \frac{\partial}{\partial x}\left(A + B\frac{\partial h}{\partial x}\right)\omega_{i,j} dS + \iint_S \frac{\partial}{\partial y}\left(C + D\frac{\partial h}{\partial y}\right)\omega_{i,j} dS \quad (10)$$

For any $\omega_{i,j} \in W_2^{0(1)}$, here $W_2^{0(1)}$ is a space of quadratically summable functions with its first-order derivative, which is zero on the boundary B and takes any fixed value inside. Applying Green's equation in (10), the result is the following [5]:

$$\iint_S \frac{\partial h}{\partial t}\omega_{i,j} dS = -\iint_S \left(A + B\frac{\partial h}{\partial x}\right)\frac{\partial \omega_{i,j}}{\partial x} dS - \iint_S \left(C + D\frac{\partial h}{\partial y}\right)\frac{\partial \omega_{i,j}}{\partial y} dS \quad (11)$$

Subsequently, in the area S, it must be drawn a grid rectangular area with the size $\partial x = a$ and $\partial y = b$. To construct the projection-difference scheme, the Courant function is applied to each node of the grid in the area, which is equal to one in the given node and zero in the rest of the grid nodes [6].

$$\omega_{m,n}(x_i, y_j) = \begin{cases} 1, (i,j) = (m,n) \\ 0, (i,j) \neq (m,n) \end{cases} \quad (12)$$

The function has a hexagon, which is depicted in Figure 2.

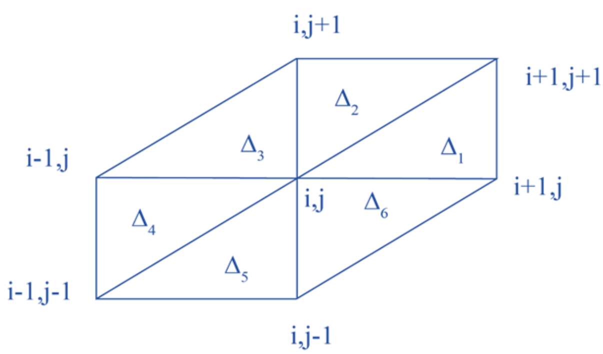


Fig. 2 Finite element

$$\omega_{i,j}(x,y) = \begin{cases} \left(x_{i+1,j} - x\right)/a, \text{.....................when } (x,y) \in \Delta_1; \\ \left(y_{i,j+1} - y\right)/b, \text{.....................when } (x,y) \in \Delta_2; \\ \left(x - x_{i,j}\right)/a + \left(y_{i,j+1} - y\right)/b, \text{ when } (x,y) \in \Delta_3; \\ \left(x - x_{i-1,j}\right)/a, \text{.....................when } (x,y) \in \Delta_4; \\ \left(y - y_{i,j-1}\right)/b, \text{.....................when } (x,y) \in \Delta_5; \\ \left(x_{i+1,j} - x\right)/a + \left(y - y_{i,j}\right)/b, \text{ when } (x,y) \in \Delta_6. \end{cases} \quad (13)$$

After transformations for each $(i,j) \in S^n$ (11) the equation will take the form

$$\theta\frac{dh_{i,j}}{dt} + E_1 h_{i,j} - E_2 h_{i+1,j} - E_3 h_{i,j+1} - E_4 h_{i-1,j} - E_5 h_{i,j-1} = F \quad (14)$$

Where:

$$E_1 = \frac{b}{6a}\left(4B_{i,j} + 2B_{i+1,j} + B_{i+1,j+1} + B_{i,j+1} + 2B_{i-1,j} + B_{i-1,j-1} + B_{i,j-1}\right) + $$
$$+\frac{a}{6b}\left(D_{i+1,j+1} + 2D_{i,j+1} + D_{i-1,j} + D_{i-1,j-1} + 2D_{i,j-1} + D_{i+1,j}\right);$$
$$E_2 = \frac{b}{6a}\left(2B_{i,j} + 2B_{i+1,j} + B_{i+1,j+1} + B_{i,j-1}\right);$$
$$E_3 = \frac{a}{6b}\left(2D_{i,j} + D_{i+1,j+1} + 2D_{i,j+1} + D_{i-1,j}\right);$$
$$E_4 = \frac{b}{6a}\left(2B_{i,j} + B_{i,j+1} + 2B_{i-1,j} + B_{i-1,j-1}\right);$$
$$E_5 = \frac{a}{6b}\left(2D_{i,j} + D_{i-1,j-1} + 2D_{i,j-1} + D_{i+1,j}\right);$$
$$F = \frac{b}{6}\left(A_{i+1,j} + A_{i+1,j+1} - A_{i,j+1} - A_{i-1,j} - A_{i-1,j-1} + A_{i,j-1}\right) + $$
$$+\frac{a}{6}\left(C_{i+1,j+1} + 2C_{i,j+1} + C_{i-1,j} - C_{i-1,j-1} - 2C_{i,j-1} - C_{i+1,j}\right).$$

The coefficients included in Equation 14 are determined as a result of solving the wave and coastal current equations in the same area. When solving it, we'll use the Crank-Nicholson scheme, which provides a second-order approximation in time:

$$h_{i,j}^{m+1}\left[\frac{ab}{\Delta t} + \frac{E_1}{2}\right] - h_{i+1,j}^{m+1}\frac{E_2}{2} - h_{i,j+1}^{m+1}\frac{E_3}{2} - h_{i-1,j}^{m+1}\frac{E_4}{2} - h_{i,j-1}^{m+1}\frac{E_5}{2} = h_{i,j}^{m}\left[\frac{ab}{\Delta t} - \frac{E_1}{2}\right] + h_{i+1,j}^{m}\frac{E_2}{2} + h_{i,j+1}^{m}\frac{E_3}{2} + h_{i-1,j}^{m}\frac{E_4}{2} + h_{i,j-1}^{m}\frac{E_5}{2} + F. \quad (15)$$

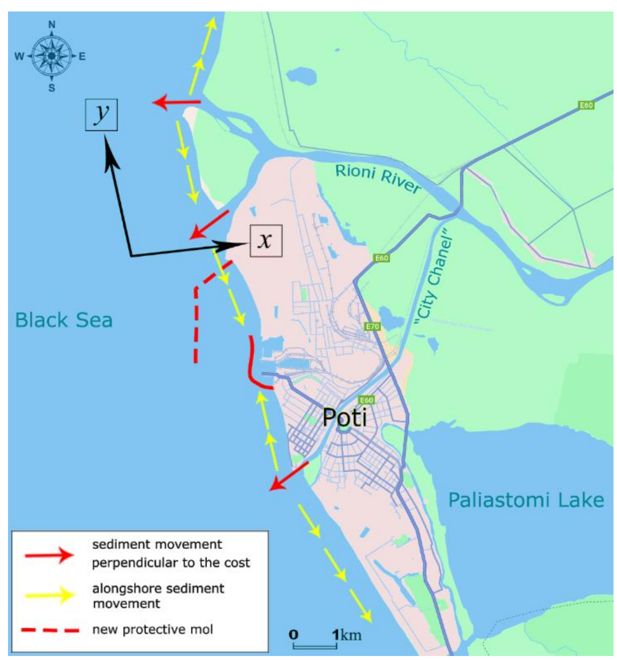
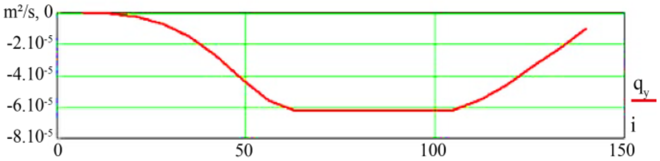
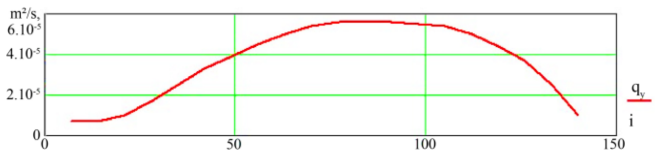


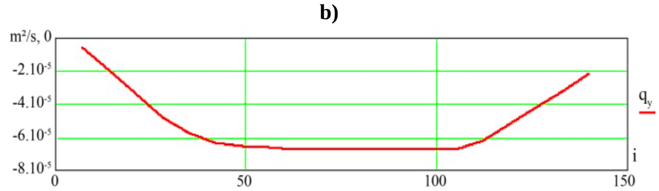
Fig. 2 Sediment flow scheme and integration area



a)



b)



c)

Fig. 3 Sediment transportation speeds: a) q_y m²/s, when i=1-141; j = 10; b) q_y, m²/s, when i=1-141; j = 70 c) q_x m²/s, when i=1-141; j = 40.

Equation (15) under the appropriate boundary and initial conditions are effectively solved by the upper relaxation method [4]. The flow chart of Rioni River sediment along the bank and the integration area is shown in Figure 3. The dimensions of the integration are 4000 meters along the shore (in steps - $\partial y = b = 50m$) and 980 meters in the direction of the shore (in steps - $\partial x = a = 7m$) (Figure 3). Characteristics of the waves are: $H_s = 2.5m$, $T_p = 7s$. The results of numerical experiments are shown in Figure 4.

4. Analysis of the Results

During the numerical solution, the waves of the western directions are taken, namely the west, northwest, and southwest. Figure 4 shows the southward transport rates of sediment in the Nabad delta at different points. From a) it follows that the sediment transport speed in the south direction is significant 100 meters from the shore in an 800-meter strip $(i = 15,\dots,130)$ and its maximum value is equal to - $q - 5_{ymax}$m²/s.

On average, the volumetric velocity of sediment transport to the south of the delta is 0.027 m³/s, and the annual volume of sediment transported in the south direction is 850,000 m³. Figure 4 (b) shows the northward sediment transport rates at different points. It follows from this that the northward transport velocity of sediment is significant 100 meters from the shore in an 800-meter strip $(i = 15,\dots,130)$and its maximum value is equal to – $q - 5_{ymax}$m² / sec. On average, the volumetric velocity of sediment transport to the south of the delta is 0.021 m³/s, and the volume of sediment transported per year is 650,000 m³.

Figure 4 (c) shows the velocities of the bank-directed (westward) sediment transport at different points. It follows that sediment transport rates in the western direction are important from a distance of 70 meters to 1000 meters from the shore. Assuming that the average slope of the underwater slope is $\alpha = 0.011$, then the water depth at a distance of 1000m from the shore will be 11 meters. i.e., The main mass of solid sediment in the area of the Nabada delta is moved along the shore to a depth of 11 meters.

The maximum sediment transport speed is equal to $q - 4_{xmax}$m²/s. The amount of beach-forming sediment introduced by the Nabada channel is about 4 mln. m³ per year [2]. Calculations show that 1.5 mln. Sediment with a volume of m³ is subjected to coastal migration in the area of the new delta, 0.65 mln m³ in the north of the delta to Khobiskalli, and 0.85 million m³ south of the delta to the harbour. Therefore, the remaining 2,500,000 m³ transported westward will be deposited on the seafloor, and the sea floor will rise by an average of 11 cm per year. According to these data, in 10 years, the Nabada Delta will advance into the sea by about 100-110 meters.

In total, the new delta completely covered 13 kilometres of coastline, from the harbor to the river to the mouth of river Khobi. Everywhere on the mentioned Coast, the trend of shore growth is noticeable. Since 1939, the increase in land within the new delta has amounted to about 1300 ha. At the same time, the volume of accumulated sediment amounted to almost 240 mln. m³ [2].

Currently, the advance of the shoreline in the central part of the new delta is 10–11 meters per year. 6–8 m/year near the harbour on the southern flank and the river on the northern flank. 2-3 meters per year at the Khobi estuary. As it is known, the construction of breakwaters on the accumulative coasts significantly hinders the free movement of sediment. Because on both sides of the embankment, sediment migrates along the shore in opposite directions, sediment will accumulate on both sides of the embankment.

After the construction of the new embankment, the impact of southwesterly waves will be weakened in its north, the movement of sediment in the southern direction will be completely blocked, and 0.85 mln. m³ of solid sediment will additionally begin to settle in the north of New Breakwater. In the case of the currently available hydrological and hydrometric data of the River Rioni, the accumulation of a large amount of sediment over time (approximately 5-6 years) will lead to the blocking of the southern branch of the Nabada channel.

Accordingly, the total flow of water from the Nabada channel of the Rion River will be shifted to the northern branch and the formation of a new delta will begin there. The delivery of solid sediment to the underwater canyon south of the

Breakwater will be stopped, which is currently in equilibrium. A reduction in the supply of sediment may cause it to move towards the shore, which will interfere with the normal operation of the harbour.

Acknowledgments

This research was supported by the Shota Rustaveli National Science Foundation (SRNSF) of Georgia (Grant number YS 21-108).

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