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Evaluation of the changes in the water level in the regions of Anzali Port and Lagoon influenced by the new arrangement of Anzali Breakwaters using MIKE-21

Sajjad Fathi Ozanbolagh*[1], Mohammad Hossein Nik Sokhan[2], Abdolreza Karbasi[3]

[1]*Coastal Environmental Engineering, University of Tehran, Tehran, Iran*

[2]*Civil (water) Engineering, University of Tehran, Tehran, Iran*

[3]*Environmental Geochemistry Aquatic Environments, Mangalore University, Iran*

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Abstract

The present study aimed to evaluate the modeling for the changes in the water levels of the international Anzali lagoon in Iran. Today, despite the measures for the progress of industries and commerce in human societies and increasing welfare and urbanism, the nature and ecosystem have retreated from the people's lives, causing severe damages to the environment. The changes in the breakwaters of Anzali lagoon and their new arrangements have led to the changes in the water levels of this international site. In this paper, all the required statistical data were collected initially, and changes in the water level during recent years and before the new arrangement of the breakwaters were estimated using a mathematical model. Furthermore, the MIKE-21 numerical model was used to determine the effects of improvement measures on the water level, currents and their changes in the regions of Anzali port and lagoon before and after the new arrangements. The results showed that due to the addition of new arms to the breakwaters of this region (during 2008-2012), an amount of water remained in the lagoon during all the seasons, and the water level of Anzali lagoon and pace of the currents experiences minimal, steady changes, which could have a significant effect on the sedimentation rate, and the lagoon has lower water exchange with the Caspian Sea.

***Corresponding Author:** Sajjad Fathi Ozanbolagh ✉ sajjad.fathi@ut.ac.ir

Introduction

Among different natural ecosystems, lagoons are of paramount importance. Considering their function in the preservation of biodiversity and economic, social and aesthetic aspects, lagoons have extensive effects on the environment and are among the most sensitive and fertile ecosystems on the planet Earth. Furthermore, lagoons have complex ecological attributes, which necessitate the provision of clear information and accurate assessment in terms of water level, sedimentation rate and water retention time before managerial decision-making and applications or recommendations. Anzali port (located in the north of Iran) was built in 1951 and is one of the most important commercial and fishery ports in the northern regions of Iran. In addition, this port is the section for the transport of goods via the seaway in the region, while it also is responsible for Anzali lagoon preservation, with remarkable effects on this international natural site. With this background in mind, the accurate study of this lagoon is of paramount importance.

The accurate assessment of the changes in the water level, pace and direction of the currents, pace in different directions and sedimentation rate. due to the new arrangement of the breakwaters in Anazli port is one of the leading concepts in the present study. Today, the expansion of business and industries has increased the use of seaways and coastal paths. Anzali port, which is one of the most significant ports in Iran in terms of commerce and transport, has undergone certain changes in order to develop industries and business. In order to expand Anzali port, two western and eastern breakwaters were established with the total length of 2410 meters, and the old breakwaters were rearranged. The new arrangement, which provides the required space for the anticipated activities in the port, is of economic and social significance in the city of Anzali port and the whole country.

The pond of Anzali port is connected to the Caspian Sea on one side and the Anzali lagoon on the other side.

This pond is influenced by two main mechanisms, including the border conditions in Anzali port and the inlet of the rivers into the Anzali lagoon. An important concern in this regard is whether any changes have occurred in the water level, pace and direction of the currents in Anzali lagoon as a result of these developments. Increasing the water retention time in the lagoon could positively affect the self-purification ability of water, in addition to creating odor and disrupting tourism and general living conditions in the region. The first issue in the adoption of management strategies in this regard is the thorough knowledge of the region and evaluation of the effects of the occurred changes on the hydrodynamic model of the region, which requires detailed information on its status before the development plans.

Studied region

The Anzali lagoon is a coastal wetland, which is supported by a shipping channel and two breakwaters in the Anzali port establishments and connected to the Caspian Sea. The catchment area of this lagoon is 374,000 hectares, with 11 mainstreams and 30 sub-streams, which enter the lagoon after the irrigation of farms and rice paddies with the surface currents of the lagoon's catchment area. The Anzali lagoon is located in Gilan province on the southwest margin of the Caspian Sea and has a surface of 168 square kilometers (according to the satellite documentations of IRS-PAN in 2006),. This lagoon is 25 meters below the surface of the international waters at the longitude of 14' and 20", 45" to 49, 36' and 49, and the latitude of 22' and 30", 8" to 37, 32' and 37. In the western wing of the lagoon, which has the highest depth, there is a semi-pond with a vast surface. This semi-pond is full of water, and only one river called the "Chaf Rood" streams from it, with a relatively poor vegetation. The depth of this part is approximately 3 meters, with the vastness of 50 square kilometers. The eastern wing of the lagoon has the lowest depth, which is highly fertile in terms of aqueous plant growth. The southwestern part of the lagoon is approximately one meter deep, and the central part of the lagoon directs the waters from various parts of the wetland toward the Caspian Sea.

The mainstreams that are connected to the Caspian Sea via the breakwaters of the Anzali port respectively include: 1. Sosar Roga, 2. Pir Bazar Roga, 3. Chap Khale, 4. Rast Khale (Nahang Roga), 5. Mahdi Roga (Kelvir Roga). In the regional dialect, "Roga" means canal.

On average, the depth of various areas in the lagoon could be classified as follows, and in terms of geographical position, there are four distinct areas in the Anzali lagoon: western wing of the lagoon (3 meters), eastern wing of the lagoon (0.8-1.5 meters), central part of the lagoon (0.9-1.8 meters), southern wing of the lagoon (less than one meter).

Components of modeling

In the current research, simulation was carried out in the form of a hydrodynamic model, which provides the simulations regarding the water level, pace and direction of the currents and paces in different directions. In modeling, hydrodynamic models account for the basis of every simulation process. Therefore, any errors in hydrodynamic modeling impacts the results of other models as well. This issue highlights the paramount importance of calibration in hydrodynamic models. Hydrodynamic modeling provides the other models with the data on the currents. To further clarify, the mentioned methodology has been presented in the schematic Figure 1.

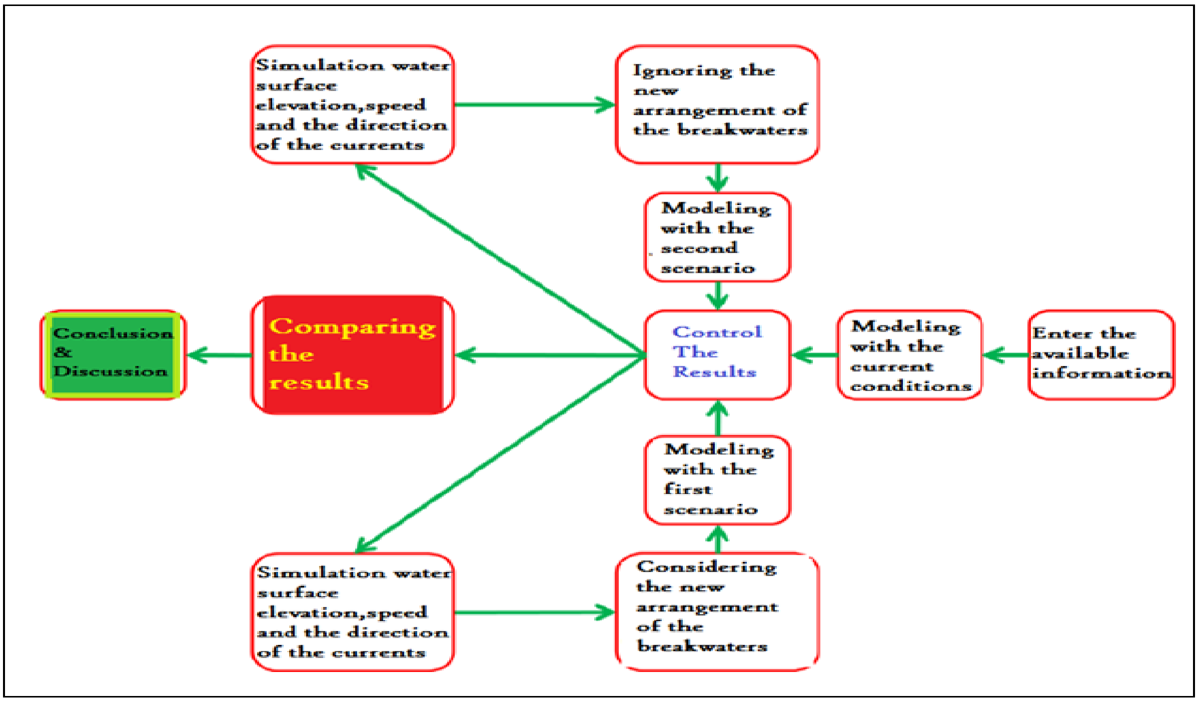

Figure 1. Flow Chart of the Modeling and Research Strategy.

Description of the model and its mathematical principles

In the present study, MIKE hydrodynamic model was used for the simulation of the currents and hydrodynamics of the investigated region. This model is a numerical modeling system for simulating water currents in ports, gulfs, coastal areas and oceans. MIKE is able to simulate unstable two- and three-dimensional currents by considering parameters such as the density of the variable, depth mapping, atmospheric effects, and changes in tide.

This model is an explicit finite volume model; therefore, it has the ability to solve the related equations on irregular networks (DHI, 2007). The mentioned model, which is a valid model on a global level and has been used in many articles and scientific projects, has been developed by Danish Hydraulic Institute and its efficacy has been confirmed in multiple models.

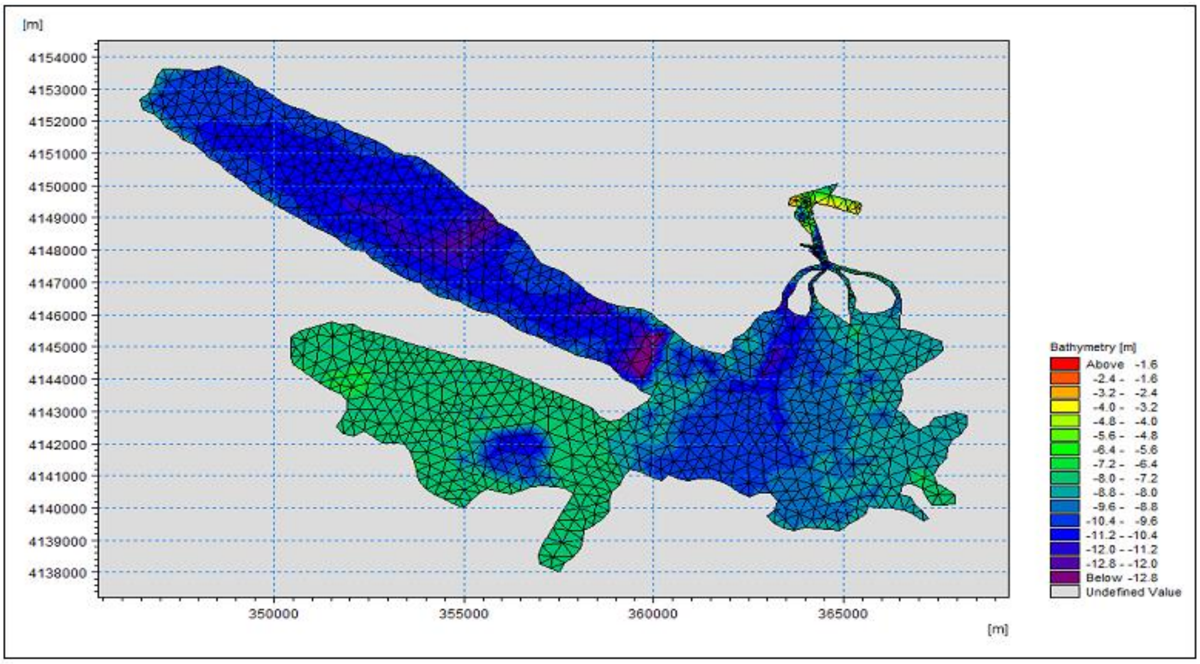

Figure 2. Mesh network and bathymetry of the region.

The following equations are required in a three-dimensional hydrodynamic model for Newtonian fluids: 1) a mass conservation equation; 2) a conservation of momentum equation; 3) an equation for conservation of salt salinity and temperature and 4)an equation of state linking density to salinity, temperature and local pressure.

Bathymetry preparation and computational grid of the model

Bathymetry and computational grid used in this research are shown in Figure 2. To prepare the bathymetry, hydrographs applied by the national cartographic center of the country is 2012 with a 1.10000 scale was used. The deepest hole (26.5) was three kilometers away from the shore.

Figure 3. Location of synoptic station and its resulted wind rose.

The final applied grid contained 1258 knots and 2042 elements. Determinant of the size of elements was the required accuracy for modeling in the first place and time-step selected for modeling in the second place, so that sustainability of the model and condition of courant number were provided. Sensitivity analysis tests indicated that model outputs were extremely sensitive to the size and resolution of the computational grid. It should be noted that decreased size of the grid leads to increased accuracy of hydrometric file and computing cost. Therefore, selection of the computational grid must be carried out according to the accuracy and expense of the calculations. Following some stages of increasing the model resolution, model outputs were insensitive to the magnitude of the grid.

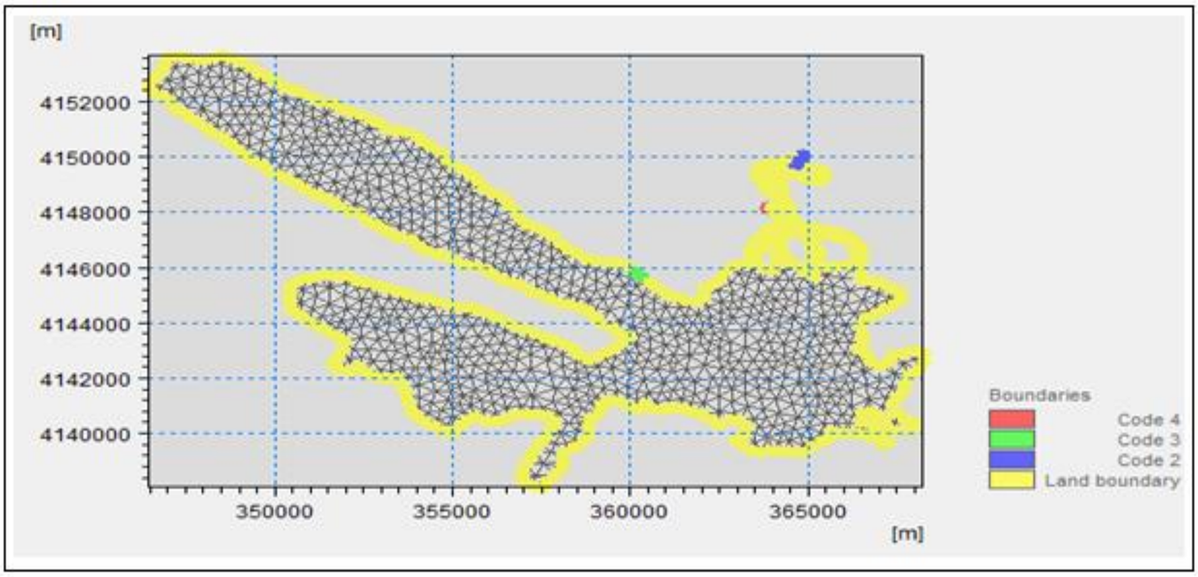

Figure 4. General location of open borders.

In this paper, the time-step was selected based on various considerations. The selected time-step could have an impact on increase or decrease of accuracy in computing. Performing of sensitivity analysis determined that selection of time-steps shorter than five seconds would not increase the accuracy of calculations.

Therefore, the time-step of five seconds was seelcted as the final time-step. In addition, given the presence of restrictive factors, such as stability control of the model, the time-step must be selected in a way that the courant number is smaller than one. Along with the selected time-step, the size of elements of the model can determine the courant number . In a computational grid with larger elements, longer time-steps can be selected. In the MIKE model, the courant number can be calculated for shallow water equations and transfer equations in various ways.

For shallow water equations, the courant number is estimated, as follows:

$$CFL_{HD} = \left(\sqrt{gh} + |u|\right)\frac{\Delta t}{\Delta x} + \left(\sqrt{gh} + |v|\right)\frac{\Delta t}{\Delta y} \quad (1)$$

Simulation accuracy can be controlled by selecting the degree of calculations in numerical equations. In this research, low-grade calculations with higher speed of algorithm was applied for numerical solving of equations. It is noteworthy that duration of stimulations is directly associated with the selection of the numerical technique. In other words, selection of higher-grade calculations can double the running time of the model.

Density

In modeling of an aquatic environment, variability of density in water column or total environment during simulation must be considered for optimal results.

Barotropic modeling leads to stability in salinity and temperature during simulation, which will be associated with constant density as well. On the other hand, baroclinic modeling results in the solving of transfer equations for salinity and temperature, which will be associated with updated density during the simulation. Given the fact that the salinity of water in Bandar-e Anzali canal (the junction of Anzali Lagoon to Caspian Sea) is different, compared to salinity of water in the pond of the harbor, baroclinic modeling was carried out.

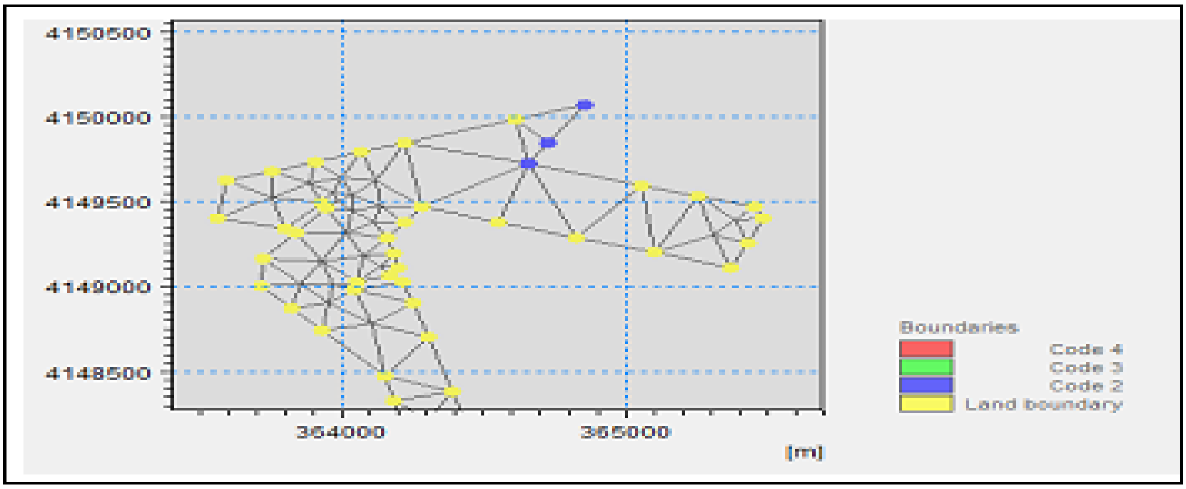

Figure 5. Location of the first open border (entrance of the Caspian Sea).

Wind effect and its mathematical principles

The nearest synoptic station to the evaluated region belongs to Bandar-e Anzali station, located at 49°27'56,76" east and 37°28'46,68" north. It should be noted that wind data cannot be used when they have been influenced by dry climate.

In the present study, data of Bandar-e Anzali station were selected as statistics of studied basics due to the short distance between Bandar-e Anzali station and sea shore. Information (i.e., speed and direction of wind) were provided from this station by referring to the meteorological organization of the country for one year. In Figure 3, a one-year wind rose was prepared according to the data, along with the location of the synoptic station in Anzali. Wind blowing creates tension on the surface, which can be calculated by the following equation:

$$\bar{\tau}_w = \rho_a c_d |u_w| \bar{u}_w \qquad (2)$$

In this station, the speed of wind was changed to meter per second, and turned into wind speed at 10-meter height by applying the following equation with regard to synoptic height above sea level:

$$V_{10} = V_Z \left[\frac{10}{Z}\right]^{\frac{1}{Z}} \qquad (3)$$

In this equation, Tw is surface tension caused by wind, ṗa is air density, Cd is empirical coefficient of air friction and uw is 10-meter height from ground surface. In the MIKE-21 model, the Cd coefficient is determined based on empirical relations (Wu 1980, 1994). Therefore, we have:

$$c_d = \begin{cases} c_a W_{10} < W_a \\ c_a + \frac{c_b - c_a}{W_b - W_a}.(W_{10} - W_a) W_a \leq W_{10} \leq W_b \\ c_b W_{10} < W_b \end{cases} \qquad (4)$$

Where Ca, Cb, Wa and Wb are empirical coefficients and W10 is wind speed at 10-meter height above the ground level.

Bed resistance

Bottom tension is determined by quadratic friction law:

$$\frac{\overline{T_b}}{p_o} = c_f . \overline{u_b} . |\overline{u_b}| \quad (5)$$

Where Cf is drainage coefficient, Ub is the flow rate at the top of the bed and Po is water density.

In two-dimensional computations, Ub is speed in average depth and Cf can be obtained from Manning or Chezy numbers.

$$c_f = \frac{g}{C^2}$$
$$c_f = \frac{g}{(Mh^{1/6})^2} \quad (6)$$

In equations, h is the total depth of water and g is acceleration of gravity. Range of changes in manning number is 20-43, whereas it is 30-50 for Chezy number.

Border conditions

The evaluated region ends at the Caspian Sea from the north and Anzali Lagoon from the south with five canals (Roga in local language). Ghazian bridge at the south of Anzali canal is the connecting point of the four main rogas, which enter the water of rivers that pass the lagoon into Anzali canal. “Shanbeh Bazar” is the name of another roga, which is the bridge that connects the West Rivers of the lagoon with Anzali canal. Therefore, three open borders are considered in the model, one of which is located at the entrance of breakwaters, and the other two are at the entrance of “Shanbeh Bazar” river to Bandar-e Anzali and entrance of the mentioned river to Anzali Lagoon. Level changes of the Caspian Sea must be considered at the open border with the sea. Since the water level was recorded with a tide gauge device in 2003 by ports and maritime organization, the related data were obtained from this organization. Locations of the open borders are determined in Figures 4, 5 and 6.

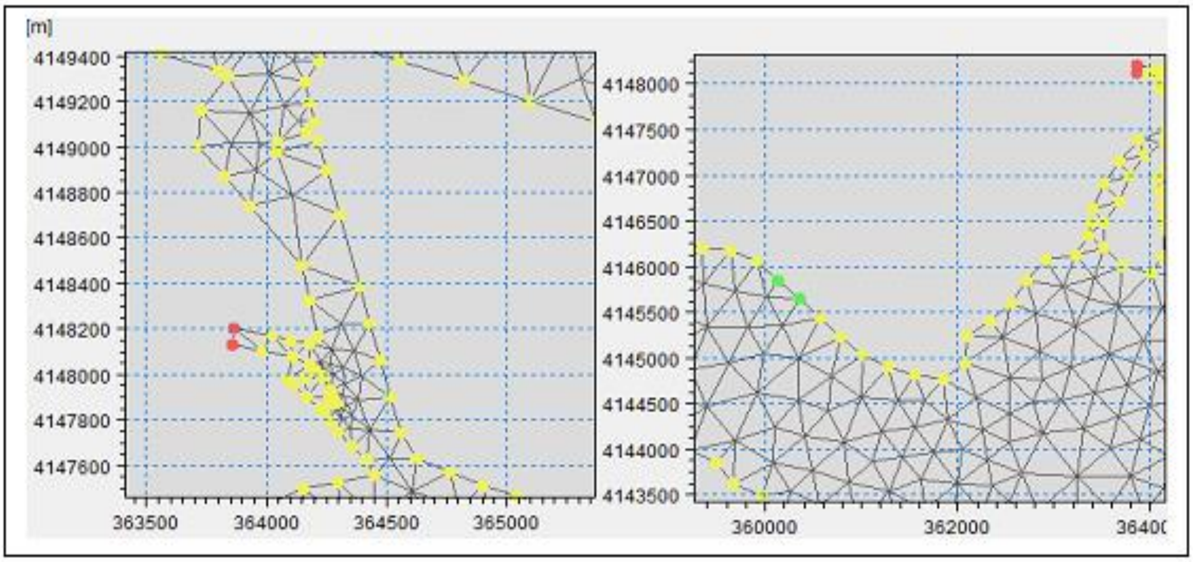

Figure 6. Locations of the second and third borders (entrance of “Shanbeh Bazar” river).

Calibration and sensitivity analysis

Hydrodynamic model has a limited number of physical parameters, which must be adjusted at the calibration phase. Various sensitivity evaluation tests were performed to detect the effect of changes in different parameters, such as border conditions, eddy viscosity, bed friction, resolution (size of the flexible grid of the model), and time-step in the hydrodynamic model. Sensitivity analysis demonstrated that the model is sensitive to time-step. According to the results, selection of time-steps shorter than five seconds added no significant accuracy to the calculations. In addition, the sensitivity analysis showed that model outputs were extremely sensitive toward the size and resolution of the computing grid.

After the increase of model resolution in a few stages, model outputs were insensitive to the grid size. Therefore, model grid was selected as the final grid at this phase. In this stage, other calculations were done independently from time-step and grid size. As a result, extension of other parameters was considered for better adaptation of model results with field data.

In addition, sensitivity tests demonstrated that bed friction was the most effective parameter in the results of the hydrodynamic model. In MIKE model, bed friction can be calculated in two ways: 1. roughness height, and 2. square roughness coefficient.

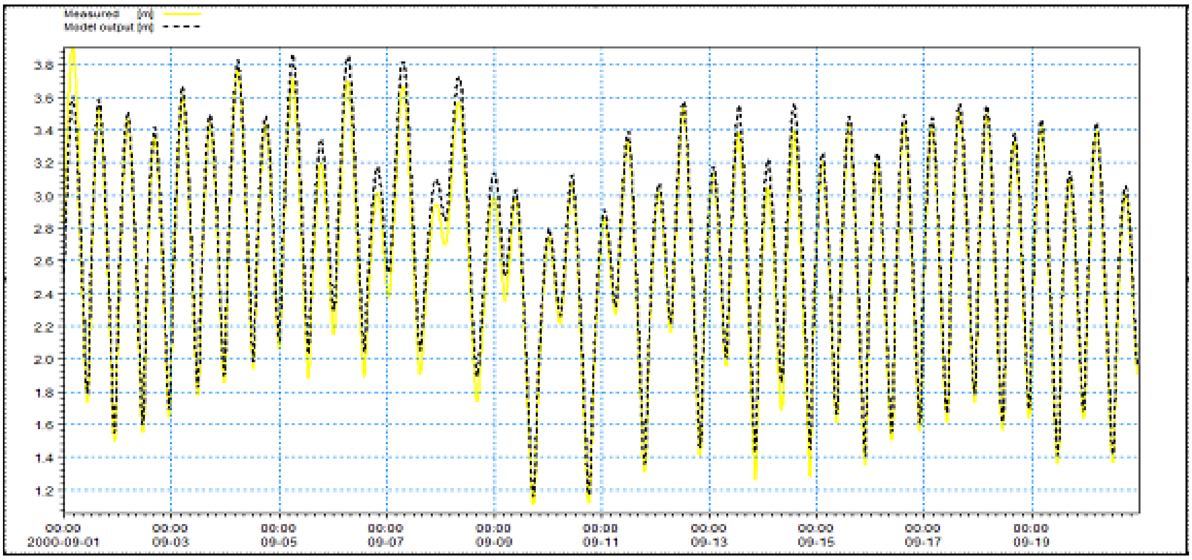

Figure 7. Comparison of model output and field data in one month.

In this article, bed friction was applied to the model by defining roughness height. Different amounts within the range of 0.001-0.3 meters were tested, leading to the selection of 0.01 as the final option.

The coefficient of vertical eddy viscosity is another parameter that determines disorder and chaos in water. In general, eddy viscosity is large at regions where there is a large velocity gradient.

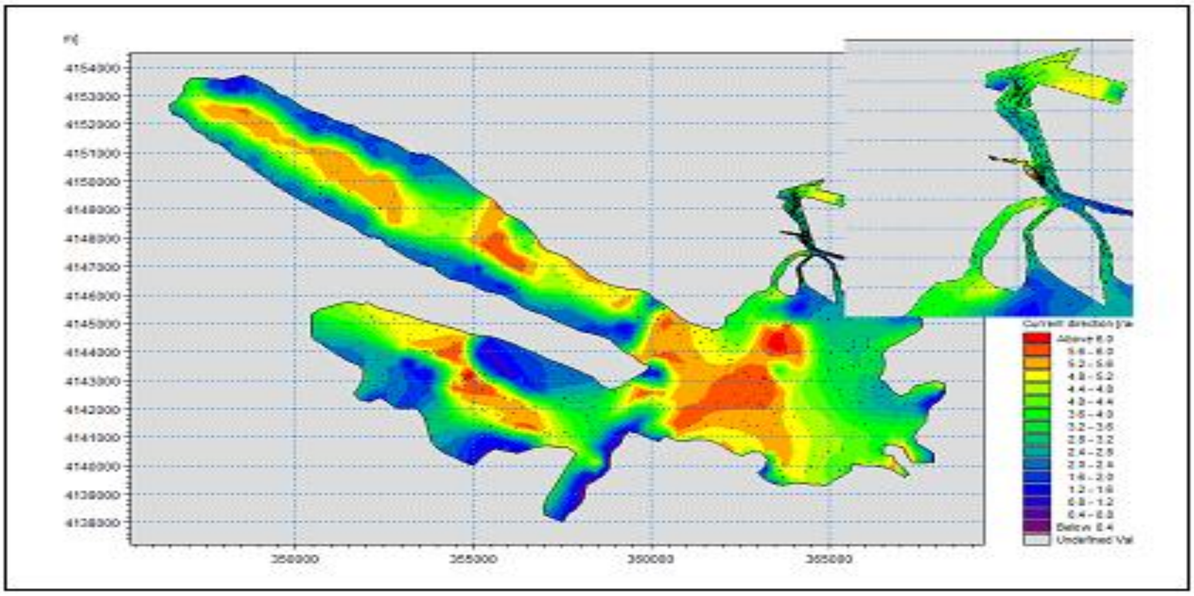

Figure 8. Direction of flows and speeds at Bandar-e Anzali and Anzali Lagoon (the first scenario).

There are two methods for applying eddy viscosity in MIKE-21 model: 1. constant eddy viscosity and 2. Smagorinsky eddy viscosity, which is a function of the velocity gradient. Smagorinsky eddy viscosity with coefficient of 0.28 was selected for simulation in this model.

Moreover, field data of velocity of flows at the point of Ghazian Bridge were used for calibration of the model. Comparison of the measured field data and model output are presented in Figure 7. As observed, the results are indicative of good accordance between field data and simulation.

Water level for the existing scenarios and lack of new arrangement of break waters can be observed in figures 9 and 10.

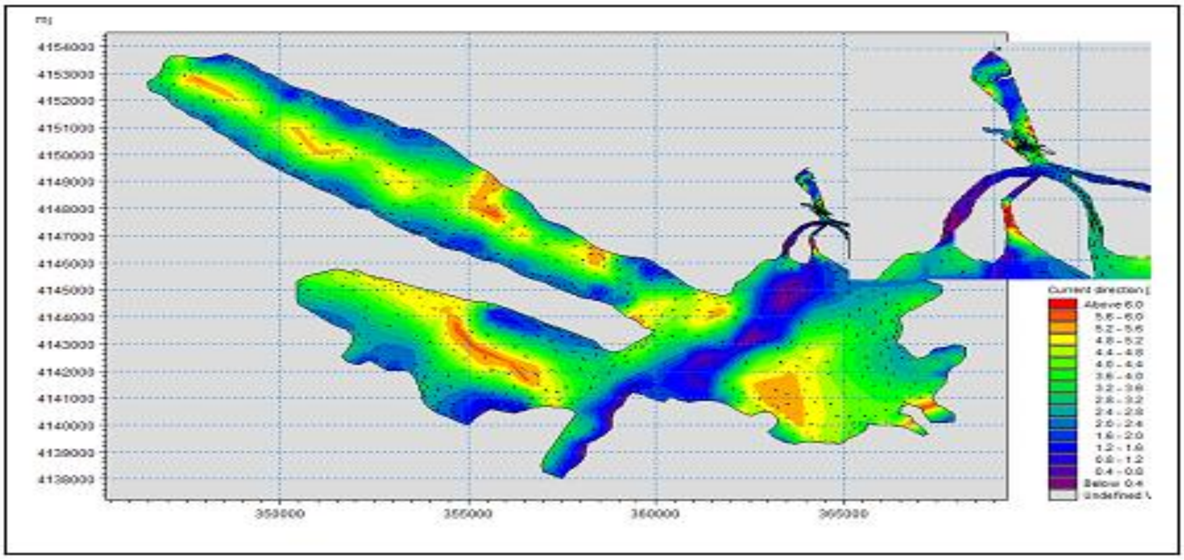

Figure 9. Direction of flows and speeds at Bandar-e Anzali and Anzali Lagoon (the second scenario)

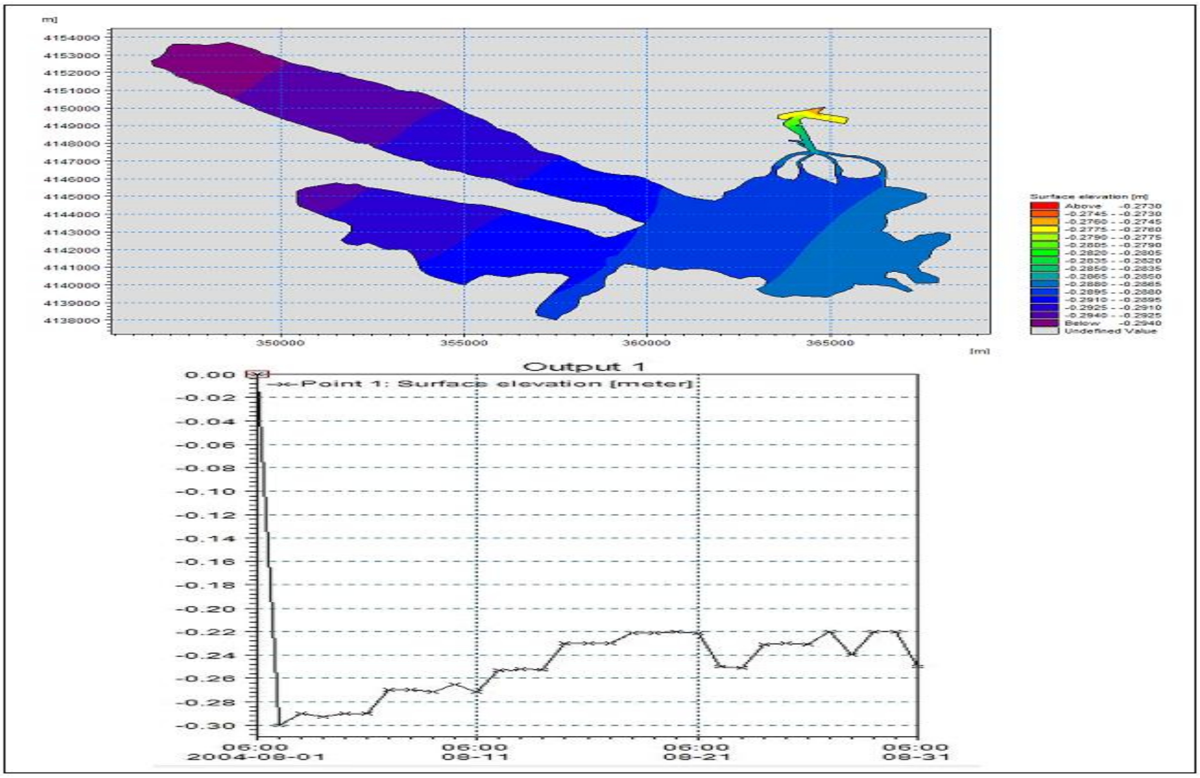

Figure 10. Water level of the region for the first scenario.

Therefore, the modeling results can be trusted. After model calibration and ensuring the accuracy of results, we referred to the mentioned modeling processes and simulated the flows and water level and speeds in various directions based on the current status of the region, which means considering the new arrangement of breakwaters.

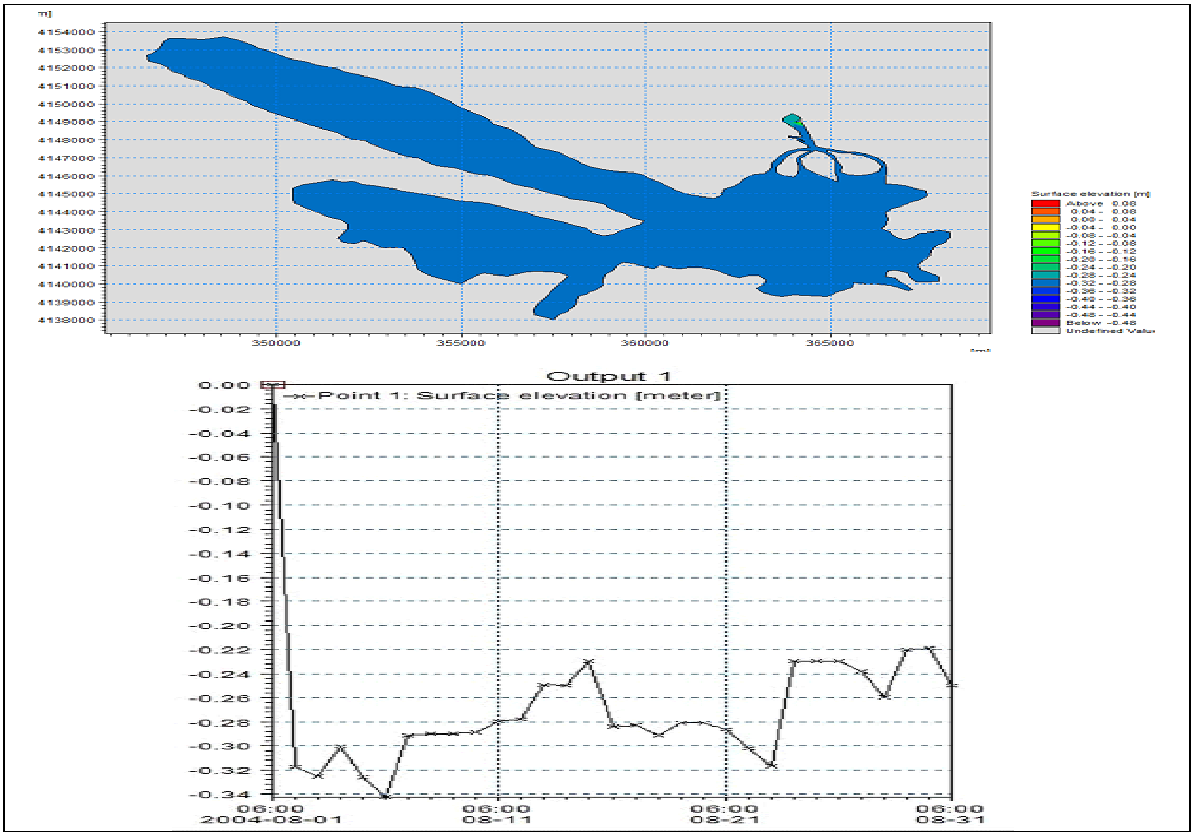

Figure 11. Water level of the region for the second scenario.

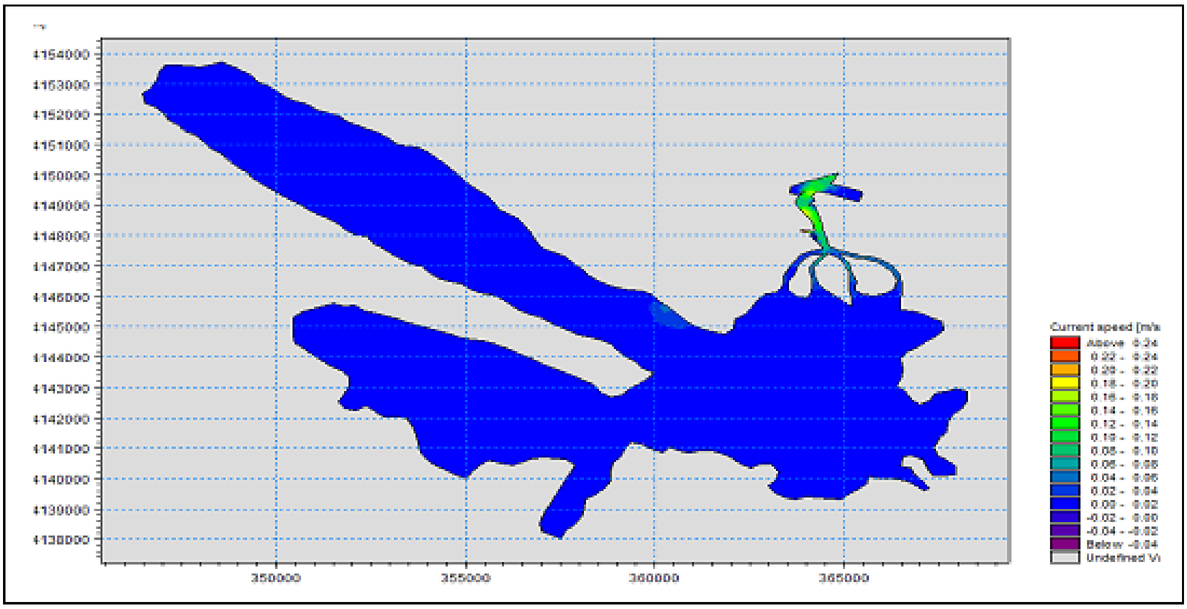

Figure 12. Flow speeds in the region for the first scenario.

Results

Simulation was carried out for one month. As explained before, two factors of wind and river flow create flow.

Flow speed and direction vectors in the middle of the month are presented in figure 7 and 8 for the first and second scenarios.

Flow speeds for the existing scenarios and lack of new arrangement of breakwaters in the region can be observed in figures 11 and 12.

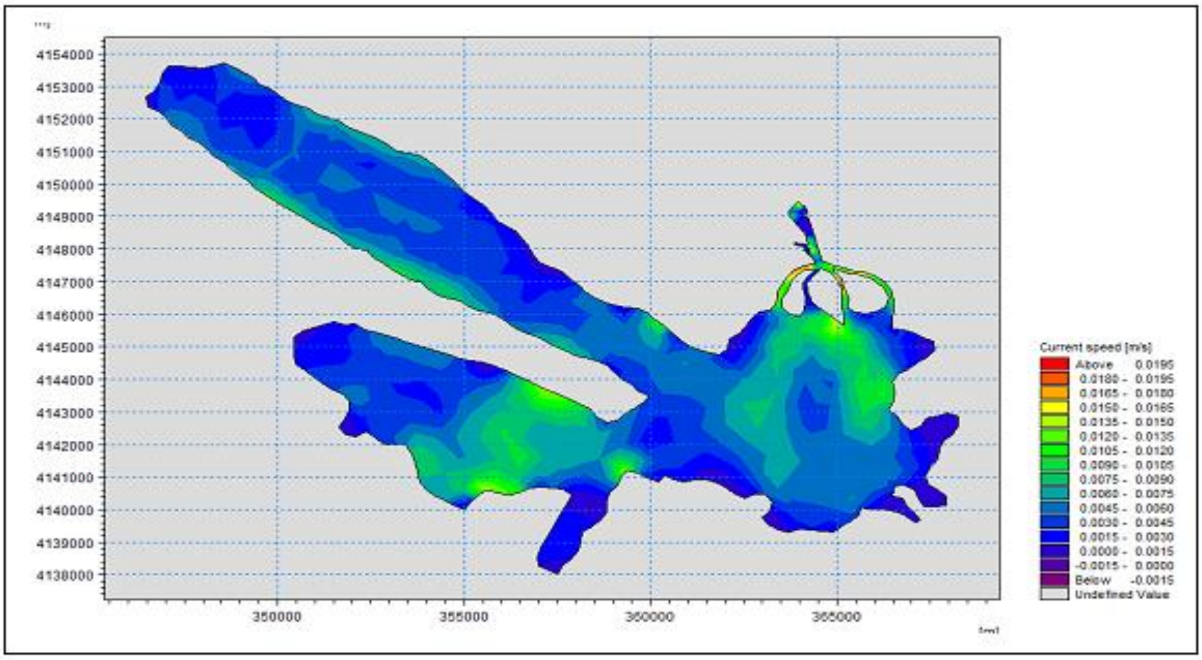

Figure 13. Flow speeds in the region for the second scenario.

Discussion

The present study is the result of evaluating the available information and observations, field measurements and hydrodynamic modeling in Bandar-e Anzali and Anzali Lagoon by the international model of MIKE-21. With regard to the results of the two scenarios, it could be concluded that new arrangement of breakwaters (i.e., arms added to the structure) changed the flow speed and water level. According to the performed assessments, Anzali Lagoon is fed by several rivers, which are locally known as roga.

These rivers are the main source of sediments and water discharge, which enter the Anzali Lagoon. As observed in Figure 14, the point of entrance of rivers to the lagoon are determined. In these calculations, the average water discharge of rivers from Boustani studies (2006) were applied.

After adding new arms to breakwaters and creating a new arrangement for them, a longer water-stay occurred at the entrance water to the lagoon, compared to the time when there was no added arm to the breakwaters.

This has led to maintenance of water in the lagoon during all seasons. Therefore, flow speed at the evaluated region was at a constant level due to adding structures.

This is indicative of the fact that Anzali Lagoon has less water exchange with the Caspian Sea and speed is almost at a fixed rate in various directions in different locations of the region. In the second mode, flow speed was significantly changed due to lack of new structures in breakwaters of Anzali Lagoon. This is indicative of the fact that Anzali Lagoon and the region of Bandar-e Anzali has a more suitable water exchange, compared to the first mode.

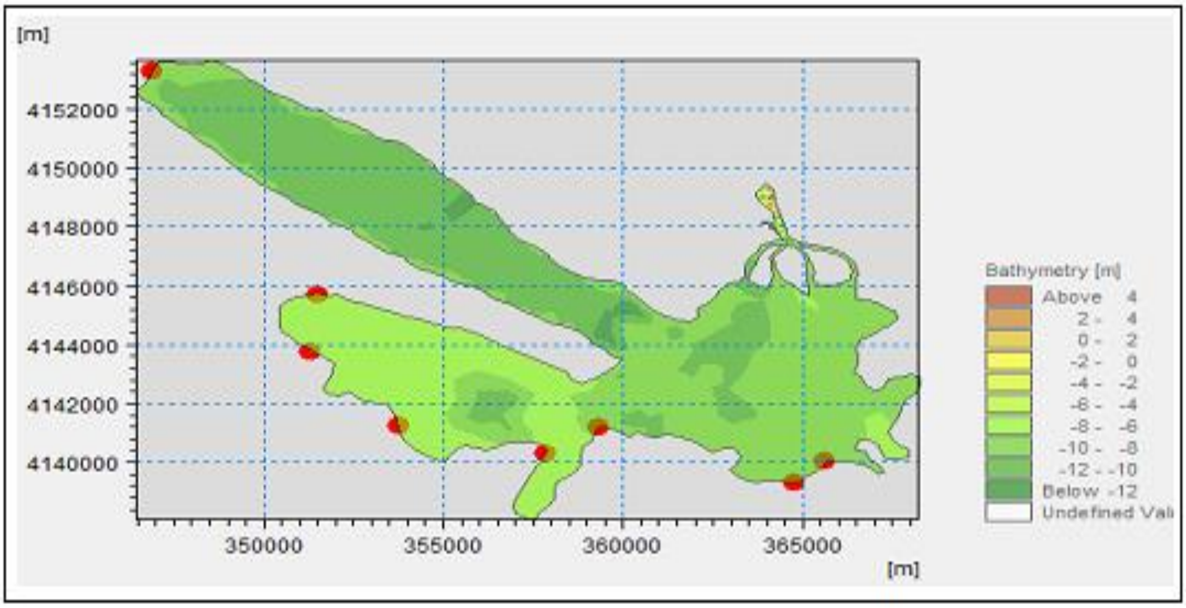

Figure 14. Location and entrance of important rivers of the lagoon.

In addition, significant and various changes were observed in speeds at different directions and regions of the lagoon. Therefore, it could be stated that increased bottom level of Anzali Lagoon and decreased water depth over the past years had no association with the mentioned issue.

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