



A Comprehensive Model Hydrodynamic and Sediment in The Gorgan Bay

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ABSTRACT

In this paper, a two-dimensional model of hydrodynamic and salinity of Gorgan Bay using Mike 21 hydrodynamic model has been proposed for calculating the water flow velocity. This model, which is a shallow water model, makes use of in-depth averaged Navier-Stokes equations alongside equations of continuity and momentum in order to determine the flow profile. Data related to temporal changes of water balance in the only open border (Ashuradeh Estuary- Bandar Torkaman), the primary water balance of the bay, and weather parameters including precipitation, evaporation, wind speed and direction, time step, heat transfer of the medium, and foam roughness coefficient within the proper range were applied to the model. Salinity was measured in nineteen different stations, and using the obtained data we accurately calibrated and validated the hydrodynamic and salinity model. Manning roughness coefficient value was equal to $0.021 \left(\frac{m}{s}\right)^{\frac{1}{3}}$. The results suggest that the optimal amount of water flow velocity is 0.029 meters per second clockwise.

Keywords: Gorgan Bay, hydrodynamic modeling, modeling of salinity, water flow velocity, Mike 21

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INTRODUCTION

The importance of water bodies is undeniable in the lives of human beings. In arid and semiarid regions of the world such as Iran, gulfs are among important water bodies which have a very sensitive and fragile ecosystem. They play an invaluable role in developing nearby residential communities and their indirect life-giving effects can be also seen in remote areas. Given their high biological importance, Gorgan Bay and Miankaleh peninsula - as wildlife sanctuaries - have been registered as one of the biosphere reserves in the world. Gorgan Bay's ecology is under the influence of Caspian Sea, adjacent rivers, and Miankaleh peninsula which plays a crucial role in the growth and proliferation of aquatic animals, bony and cartilaginous fish, as well as the attraction of winter migratory birds. The research conducted on Gorgan Bay suggests that this water body is suitable for aquaculture (Javani.2012). In the present condition, where we face water scarcity resulting from drought and rainfall deficit in our country, preserving and managing water bodies - including gulfs and ponds - is a necessity. In order to carry out any location or qualitative study, it is required that one know the status of water momentum and water flow in the water body under consideration. Therefore, one of the significant prerequisites in comprehensive studies on water bodies is performing a hydrodynamic research. Mathematical modeling of hydrodynamics and salinity simultaneously provides the possibility of calculating and determining the pattern of changes in water flow velocity and salinity changes within a desired period. Numerous studies have been conducted on hydrodynamics and salinity modeling of water bodies, and MIKE

21 is a software extensively used in this regard. Accordingly, in order to have a comprehensive and exact evaluation of the problem, it is greatly needed to acquire a sound awareness of similar studies in the field.

In Saeed Sharbati's "Studying a Three-Dimensional Model of Water Flow in the Southeast Basin of Caspian Sea Using Mike3 Software" (2013), it was observed that the flow pattern derived from the model implies the existence of currents parallel to the beach in coastline and two loop currents in the middle layer. Moving towards the depth of currents with a 180 ° phase difference from surface currents, they get out of the basin.

Esmaeily et al. in "Simulating the Pattern of Coastal Currents in Kiashahr River Mouth" (2009), (The model employed in this study is Mike 21, which is a hydrodynamic model that calculates water momentum in coastal areas.) Their study results suggested that currents resulting from eastern waves affect the mouth of the pond more than northern, northeast, and northwest waves.

David, Huntly, and Davidson (2003) applied hydrodynamic model Mike 21 to 2 kilometers of a canal and 14 kilometers of Teignmouth gulf in England. The results of sensitivity analysis, after program calibration, show that the model produced a slight error in simulating and analyzing data.

French and Kerper (2004) studied controlling salinity of sea water using Mike in Tod Reservoir and, referring to the available data, they assessed salinity control as a factor effective in the improvement of vegetation in the regions surrounding Tod Reservoir.

Babu et al. (2005), in "Simulating Tidal Currents Using Numerical Hydrodynamic Model Mike 21 in the Gulf of Kutch Located in Southwest of India," noted that the coefficient of

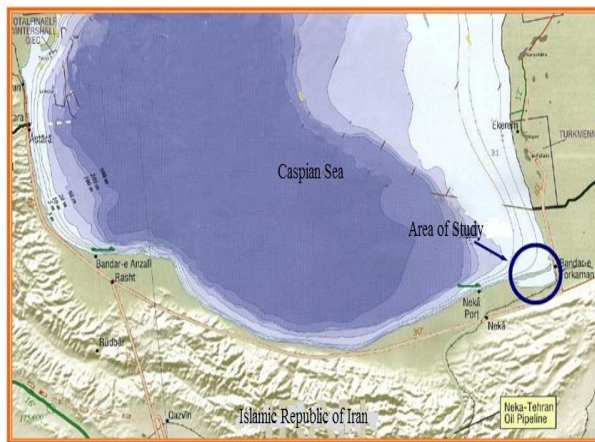
friction against wind was calibrated as 0.0026, Manning number was $38 \frac{m^{1/3}}{s}$, and rotational viscosity was equal to $0.5 \frac{m^2}{s}$. This research made it clear that the power of wind is vital in determining hydrodynamics and transporting sediments of the region, such that the speed of flooding tidal currents increases about 20 percent for the southwest winds during January and July and the speed of ebbing tidal currents decreases by the same amount.

Modeling waves emitted from the earthquake which led to the Tsunami in the northern coast of Sumatra in Indonesia, Petersen and Rasch (2005) studied the formation of waves resulting from earth vibration and proposed a three-dimensional simulation for that phenomenon using MIKE 21. They assessed the operation of waves and the manner of their collision with the aforementioned coasts.

2- METHOD

1-2- Study region

Gorgan Gulf, with an extent of approximately 521 square kilometers, is located in the southeast of Caspian Sea and is considered the biggest gulf of the Caspian Sea coastline. The only open border of this gulf is the border of Ashuradeh which is located in the northeast of the gulf and connects it to the Caspian Sea. The average length of this region is approximately 40 kilometers and its average width is around 10 kilometers. its geographical coordinates are of $53^{\circ} 30'$ to $54^{\circ} 03'$ Eastern and $36^{\circ} 46'$ to $36^{\circ} 54'$ northern respectively. One part of this gulf is located in Golestan Province and the other is located in Mazandaran Province. Gorgan Gulf has a digital level gauge station, in Ashuradeh region, which reports water balance once in every 10 minutes. The study area is shown in (Fig.1).



(Fig. 1) Area of study

2-2- Equations used in MIKE 21

MIKE21 is a two-dimensional (longitudinal and transverse) model developed by Danish Hydrodynamic Institute, which is one of the most important and notable research centers in the world. This software can perform hydrodynamic modeling in three ways: kinematic wave, diffusion, and completely dynamic. In this model it is presumed that no change occurs in the ordinate dimension; therefore, such a presumption seems reasonable and appropriate for Gorgan Bay whose water depth is very small in comparison to its surface. On the other hand, salinity modeling of gulfs and estuaries is one of the important

capabilities which has been integrated into MIKE 21. Once a hydrodynamic model is created using MIKE21, the created model could be easily used in salinity modeling. Mike21 hydrodynamic model based on discrete finite difference method for the equations of continuity, momentum and salinity model based on the transport equation and diffusion equation works. Hence, considering the capabilities of MIKE 21 model, we have used it for hydrodynamic and salinity simulation in the course of this study.

Table 1 represents the equations used in hydrodynamic and salinity model, and Table 2 presents the parameters employed in hydrodynamic and salinity relations.

Formula	Equations
$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t}$	Continuity
$\frac{\partial p}{\partial t} + \frac{\partial}{\partial x} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial x} + gp \frac{\partial \zeta}{\partial y} + \sqrt{\frac{p^2 + q^2}{c^2 h^2}} - \left[E_x \frac{\partial^2 p}{\partial x^2} + E_y \frac{\partial^2 p}{\partial y^2} \right] - \Omega q = 0$	Momentum in x direction
$\frac{\partial p}{\partial t} + \frac{\partial}{\partial y} \left(\frac{p^2}{h} \right) + \frac{\partial}{\partial x} \left(\frac{pq}{h} \right) + gh \frac{\partial \zeta}{\partial y} + gp \frac{\partial \zeta}{\partial x} + \sqrt{\frac{p^2 + q^2}{c^2 h^2}} - \left[E_x \frac{\partial^2 p}{\partial x^2} + E_y \frac{\partial^2 q}{\partial y^2} \right] - \Omega p = 0$	Momentum in y direction
$\frac{\partial}{\partial t} (hc) + \frac{\partial}{\partial x} (uhc) + \frac{\partial}{\partial y} (vhc) - \frac{\partial}{\partial x} \left(h \cdot D_x \frac{\partial c}{\partial x} \right) - \frac{\partial}{\partial y} \left(h \cdot D_y \frac{\partial c}{\partial y} \right) - Qs(cs - c) - R = 0$	Transmission and diffusion

(Table 1) Hydrodynamic and salinity equations used in MIKE 21 model

Parameter symbol	Parameter definition	Parameter symbol	Parameter definition
E	Viscosity coefficient	h	Water depth
C	Chezy coefficient	$\zeta(x,y,t)$	Water level
Ω	Coriolis parameter	$d(x,y,t)$	Temporal changes of water depth
D_x	Penetration coefficient in x direction	u	Speed in x direction
D_y	Penetration coefficient in y direction	v	Speed in y direction
g	Gravitational constant	$p,q(x,y,t)$	Flux density in y and x directions
		t	Time

(Table 2) The parameters employed in hydrodynamic and salinity relations

3-2-RESEARCH ALGORITHM

Given that the researchers collected and measured data during a span of one year, this same period (2012) was adopted for modeling. The research algorithm is presented in Fig. 2. In the following, the represented stages in Fig. 2 are described briefly.

1. To obtain information relevant to Water boundary, Mark Line and water depth of Gorgan Bay for modeling, we conducted hydrographic and field geodetic operations in the research region. The points of water border and Mark Line were recorded using two Nivo Total Station cameras and a manual

GPS device. The base level used for all recorded points in hydrographic and geodetic field operations is the precise benchmark leveling used in the National Cartographic Center whose base level balance is equivalent to -23.32 meters from sea level (Yarinasab, 2012).

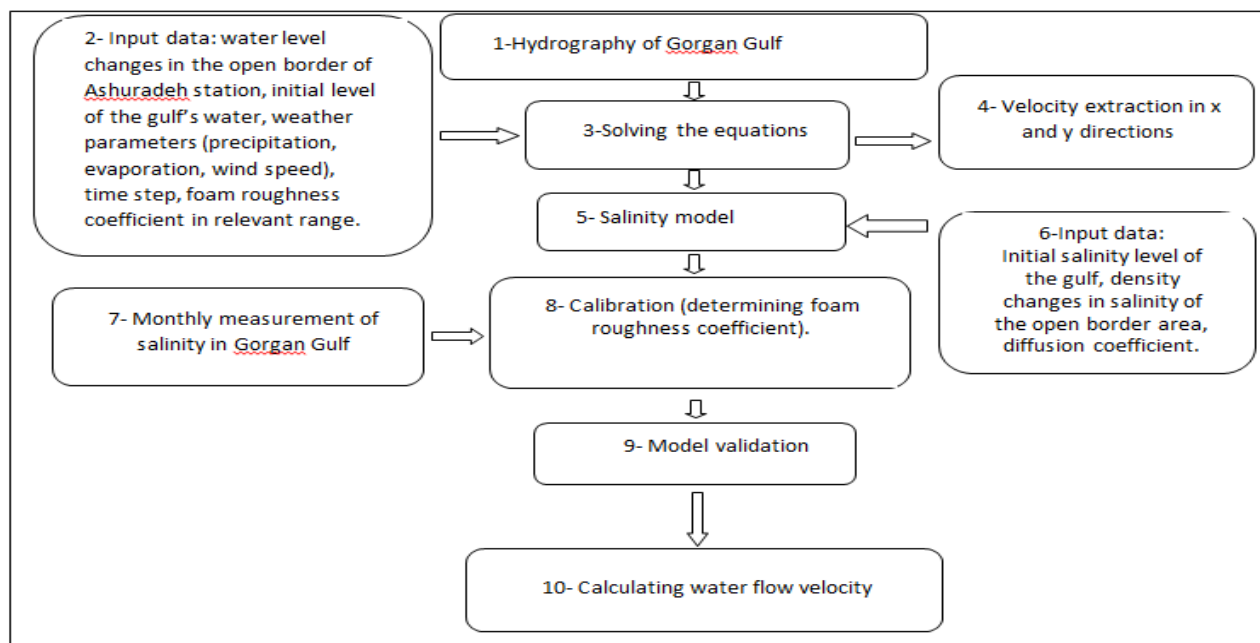
2. Input data and information given to the model include:

- Temporal changes in water balance of Gorgan Bay's open border in 2012 which were recorded by a digital level gauge of Ashuradeh every 10 minutes.

- Due to Bandar Torkaman's proximity to the gulf, the temporal changes of wind were recorded every 10 minutes from this town's synoptic station.

-Temporal changes of effective rainfall (difference between rainfall and evaporation) were collected from a rainfall gauge station and an evaporation station which recorded data every 10 minutes.

-Time step of model implementation was considered 600 seconds, which matches Courant number (0.7)



(Fig.2) Research algorithm

3 and 4. After creating input data files and putting them into hydrodynamic model alongside a Manning coefficient, the researchers extracted the velocity of water flow in two directions: X and Y.

5 and 6. Hydrodynamic model is the base of salinity model; therefore, hydrodynamic model alongside Manning roughness coefficient will be introduced to the salinity model as an initial conjecture. In this phase, the file of salinity parameters will be created. The most important parts which have to be introduced in this phase are: initial conditions of salinity, salinity border, and diffusion coefficient. These values should be introduced into the software. In this study, salinity in the initial phase of modeling, as the initial conditions of salinity, was given to the model with a value equal to 10.45 psu. Besides, the conditions of salinity border, including Ashuradeh station's monthly salinity information in 2012, were introduced into the model.

7. To conduct calibration and validation operations, we needed a series of real values of salinity parameter during modeling. These data are the result of monthly measuring salinity parameters in 19 different stations of Gorgan Bay.

Geographical coordinates	Station number
54 ° 02' 00"	1
36 53 29	
54 01 36	2
36 50 00	
54 00 09	3
36 53 07	
54 00 00	4
36 51 00	
53 57 00	5
36 54 00	
53 58 00	6
36 53 00	
53 58 00	7
36 49 00	
53 56 00	8

36 51 00	9
53 54 00	
36 53 00	10
53 54 00	
36 48 00	11
53 52 20	
36 51 00	12
53 50 00	
36 52 33	13
53 50 00	
36 48 00	14
53 47 45	
36 51 28	15
53 45 00	
36 52 00	16
53 45 00	
36 48 00	17
53 43 00	
36 51 00	18
53 40 00	
36 51 00	19
53 40 00	
36 49 00	

(Tab. 1) Location of stations of Gorgan Bay

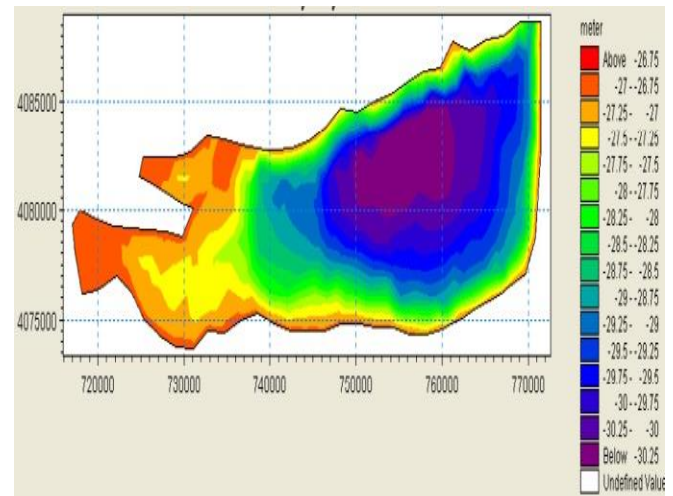
8. In this phase, hydrodynamic and salinity model calibration must be performed and the optimal Manning roughness coefficient and diffusion coefficient for Gorgan Bay be determined. During the calibration operation, hydrodynamic and salinity modeling was repeated for different values of Manning roughness coefficient and diffusion coefficient within the ranges of 0.02-0.025 and 30-100, respectively. Then, the results of modeling with different values of Manning roughness coefficient and diffusion coefficient were determined in 19 different stations in Gorgan Bay. It has to be added that salinity data obtained from 19 stations in Gorgan Bay were employed so as to perform calibration.

9. After calibrating hydrodynamic and salinity model, models have to be validated. To this end, data gathered in October and November of 2012 were used. After validating the models, the optimum values of Gorgan Bay's Manning roughness coefficient and diffusion coefficient were specified. The results of model validation confirm the appropriateness of the proposed calibrated model. Hence, if the hydrodynamic model developed for Gorgan Gulf with a Manning roughness coefficient value equal to 0.021 and the salinity model with a diffusion coefficient of 50 are validated, one could utilize them for the entire Gorgan Bay at any time period.

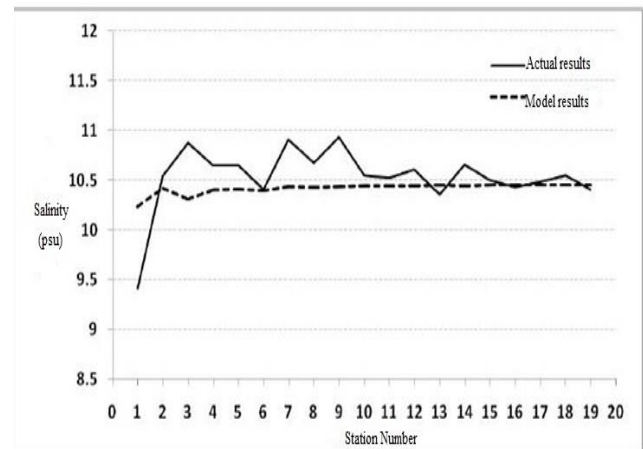
3. DISCUSSION AND CONCLUSION

Through field geodetic and hydrographic operations, the Water boundary and Mark Line of Gorgan Bay were obtained using MATLAB, ILWIS, and Google Earth software. Interpolating

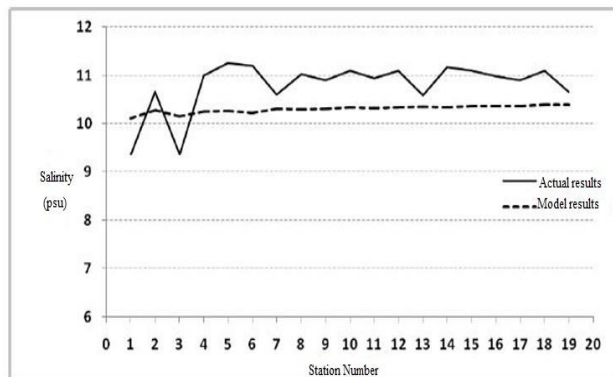
hydrographic data in ILWIS environment and entering data into MATLAB, we extracted Gorgan Bay's seabed data in the form of a file containing depth and geographical latitude and longitude (Fig. 3) (Yarinasab, 2012). Modeling was conducted using different values of Manning roughness coefficient and diffusion coefficient; the optimal values of Manning roughness coefficient and diffusion coefficient were 0.021 and 50, respectively. Figures 4 to 6 compare salinity values taken from the model to the salinity values recorded from the gulf during three months of calibration. Examining the figures, it can be suggested that model calibration has been conducted appropriately.



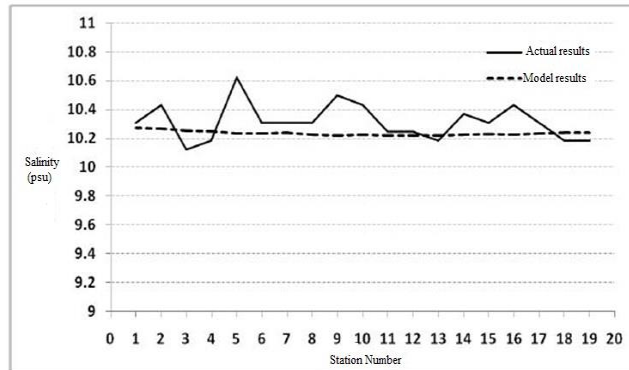
(Fig. 3) Water boundary information and align the bottom of Gorgan Bay in MIKE21



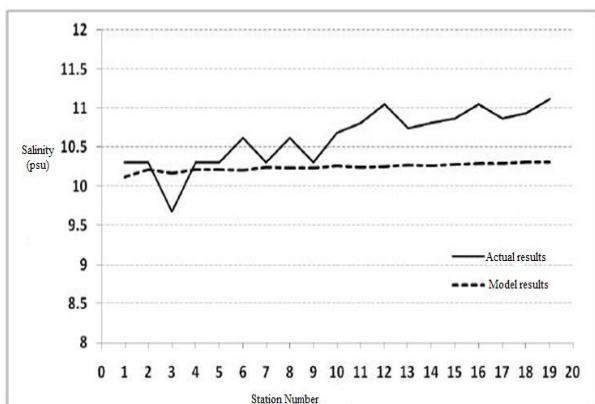
(Fig. 4) Salinity of the stations obtained from model analysis and real salinity values in July



(Fig. 5) Salinity of the stations obtained from model analysis and real salinity values in August

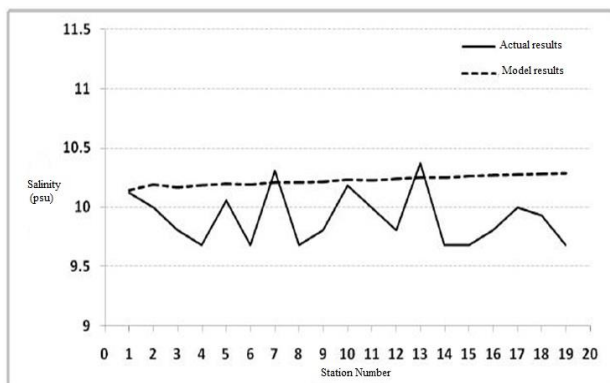


(Fig. 8) Salinity of the stations obtained from model analysis and real salinity values in November



(Fig. 6) Salinity of the stations obtained from model analysis and real salinity values in September

After model calibration, we have to make sure whether the model is valid or not. In figures 7 and 8, salinity values derived from the model are compared with the real salinity values in Gorgan Gulf recorded during two months of validation. Generally, the results point to a rather well conducted modeling. The optimal values of Manning roughness coefficient and diffusion coefficient of Gorgan Bay are respectively 0.021 and 50.



(Fig. 7) Salinity of the stations obtained from model analysis and real salinity values in October

Now that an appropriate model for hydrodynamic and salinity has been developed, the situation of water flow velocity can be derived from the hydrodynamic model. The conditions of water flow velocity during the first and the second half of the year as well as the whole year are given in the following table.

The average of water flow velocity (m/s)	Time period (monthly)
0.0290	First 6 months of year
0.0299	Second 6 months of year
0.0294	12 months

(Table 4) Average water flow velocity of Gorgan Bay within 6 and 12 months (2012)

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