Research in Marine Sciences
Volume 3, Issue 2, 2018
Pages 289 -302

Red tide development modeling in Persian Gulf and study nutrient effects on algal bloom

Madjid Abbaspour[1], and Elahe Zohdi [2,*]

[1]Professor, Sharif University of Technology, Tehran, Iran

[2]MSc of shipping engineering, Sharif University of Technology, Tehran, Iran

Received: 2018-02-22 *Accepted: 2018-05-10*

Abstract

Red tide or algal bloom occurs in estuarine, marine, or fresh water due to accumulating algae rapidly in water column and results in water coloration in high concentration and widespread serious effects on public health, fishing, and even tourism industry. Persian Gulf despite rich reserves of oil and gas, military strategic location, rich resources and valuable diverse aquatic habitats like coral reefs has been recently confronted with this phenomenon due to human, industrial and agricultural waste, oil exploration, permanent ships' traffic and shallow water, geographical and climate conditions and limited water exchange with external environment. Due to recent broad steady development of red tides that have irreparable effects on the ecosystem, economic conditions, and public health of the coastal residents, society's need for understanding is more pressing than ever. Among the investigation methods, numerical modeling has great importance due to low time and cost. MIKE software is used in this paper, considering physical, chemical and hydrodynamics factors in a zone and biological aspects of this phenomenon and temperature, salinity and nutrient effects on red tide growth. In fact predicting HABs' occurrence minimizes their damage by quick preparation of mitigation activity and prevents economic losses in aquaculture industry, desalination equipment, and also respiratory and skin irritation problems for swimmers. In this paper, the effects of pollution outflows and hydrodynamic currents of Persian Gulf on red tide development in 2008-2009 period and variation of dissolved oxygen amount to chlorophyll-A was simulated and studied by utilizing MIEK21 and ECOLAB modules. The simulation results showed that the red tide development direction was according to the Persian Gulf mainstream direction. In addition, chlorophyll-A concentration was higher near the sewage outflows and persistent in those areas at all times till nutrients present there. In addition, by increasing chlorophyll-A concentration, the dissolved oxygen concentration increased.

Keywords: Algal bloom; Chlorophyll-A; HABs; MIKE software; Red tide.

* Corresponding Author: ela.zohdi@alum.sharif.edu

1. Introduction

Land sourced marine pollution, overexploitation of living marine resources, destruction of habitat and introduction of harmful aquatic organisms and pathogens to new environment had been identified as the four greatest threats to the world's oceans. Since invasive species cannot be cleaned or absorbed in the ocean, so, their effects on the environment are irreversible. Red tide is one of the invasive species and a colloquial term used to refer to one of a variety of natural phenomena known as algal bloom, in which estuarine, marine, or fresh water algae accumulate rapidly in the water column and resulting in coloration of the surface water, varying in color from purple to almost pink, normally being red or green. These algae are not native to special area, in other word; they have various species with broad ranges. The first case of red tide occurred in 1793, British Columbia, Canada (Mohammadi, 2008; Wikipedia, 2014). Whether harmful or harmless kinds of red tide has been reported from all over the world such as Brazil, Korea, China, Japan, Chile, Canada, UK, France, Hong Kong, India, the countries of the Black Sea and the Mediterranean sea and recently the Persian Gulf and the Caspian Sea (Malaei Tavana *et al.*, 2008; Seddigh Marvasti, 2016). Blooms and their environmental effects in an aquatic ecosystem depend on the species involved, biological and ecological characteristics of the species, the scale of this phenomenon, hydrological and topographical status of environment where they are found (Bahrami Rad, 2013). According to scientists finding, the number of toxic blooms, the scale, and complexity of this natural phenomenon, the economic losses from them, the types of resources affected and the kinds of toxins and toxic species have all increased. Indeed, there is a conviction among many experts about expanding. Is this expansion real? Is it a global epidemic? Is it related to human activities? Or is it a result of increased scientific awareness and improved surveillance or analytical capabilities? (Anderson, 1994; Wikipedia, 2014) Of 5000+ microscopic algae species or phytoplankton exist worldwide, about 300 species can cause high concentration of red tides. Only one fourth of this amount is known to be harmful or toxic which include dinoflagellates, diatoms, haptophyceae, cyanophyceaes, and some of cycloflagellate. Studies indicate the presence of 21 bloom-former species, are potentially toxic, in Persian Gulf (Malaei Tavana *et al.*, 2008; Wikipedia, 2014). Damage caused by red tides is divided into two categories direct poisoning (death of marine animals, human poisoning, respiratory and skin irritation due to producing strong toxins like neurotoxin) and indirect poisoning (marine mortalities by depleting the oxygen in the water, human poisoning by eating shellfishes contaminated with red tide toxin through feeding). A bloom develops when these single-celled algae photosynthesize and multiply; converting dissolved nutrients and sunlight into plant biomass and the population of grazing zooplankton and aquatic species is small. It seems that their population is not affected only by their growth rate, but also wind or ocean currents bring them to the water surface (Anderson, 1994; Malaei Tavana *et al.*, 2008; Vahedi, 2009). The dominant mode of reproduction is simple asexual fission. When nutrients are scarce, some species switch to sexual reproduction, form cysts, and this transformation facilitates species dispersal along with currents or the other forces to new environments. Different phytoplankton species have different growth rate. Measures taken pursuant to which the average daily growth rate of dinoflagellates is almost 0.3 per day with a three-day period for regeneration. Diatoms have a daily growth rate more than dinoflagellates; 40% of them have regeneration period less than three days (Anderson, 1994; Malaei Tavana *et al.*, 2008; Taghavi and Abbaspour, 2012). Two major contributing factors in the growth of phytoplankton are temperature and nutrients, especially phosphorus and nitrogen (Wikipedia, 2014). Some of the studies, such as Vollenweider (1992), Hodgkiss and Ho (1997), Peinert *et al.* (1982), Glibert *et al.* (2010), showed eutrophication is a major contributor to HABs development in their growth period (Wong *et al.*, 2007; McGillicuddy, 2010; Sadeghi Mazidi *et al.*, 2011). Long-term studies at the local or regional level do show that red tides are increasing as coastal pollution worsens. Between 1976 and 1986, as the pollution around Tolo Harbor in Hong Kong grew six fold, red tides increased eightfold (Anderson, 1994; Malaei Tavana *et al.*, 2008).

According to recent wide spread and persistent HABs effects, society's need for understanding these phenomena is more pressing than ever. Technological advances have expanded our capabilities for observing the ocean, providing unprecedented opportunities not only for the detection of blooms, but also for the physical, chemical, and biological factors that trigger their initiation, development, and ultimate demise. However, despite these rapidly expanding observational capabilities, HAB processes will continue to be under sampled for the foreseeable future, owing to the wide range of space and time scales relevant to these oceanographic phenomena. As such, we must rely on models to help interpret our necessarily sparse observations. To watch red tides, there are different methods: field observation and using sampling data, satellite-based studies, laboratory studies, modeling like complex numerical models, conceptual models, simple analytic formulae, semi-empirical models, aggregated box models or zero-dimensional models (McGillicuddy, 2010; Park *et al.,* 2013; Seddigh Marvasti, 2016).

1.1. Red Tide Occurrence in Persian Gulf

Persian Gulf despite rich reserves of oil and gas, military and strategic location, rich resources and important and valuable diverse aquatic habitats such as coral reefs, due to sewage and human waste, oil exploration and extraction operations, permanent ships' traffic, massive military operations and wars for several years, industrial and agricultural waste which led to the entry of organic materials like NO_3, NH_4, PO_4 and the other nutrients to this zone, and shallow water, geographical and climate conditions and limited water exchange with the external environment, has been confronted with numerous hazards. Therefore the probability of the presence of non-native species or increasing nitrification phenomenon in this area is not far-fetched. The red tide occurrence is one of the major environmental issues raised in Persian Gulf in recent years (Taghavi and Abbaspour, 2012; Ebrahimi, 2015). Related to the red tide occurrence, according to statistics of the Iranian Fisheries Science Research Institute, in short, from 1991 to 1997, close to 30 algal blooms in the Persian Gulf and Oman Sea waters are recorded but they are short-term, about 48 hours (Rezaee and Kabiri, 2009; Shakerzadeh *et al.*, 2009). Among the identified algae in this area, about 12 species can cause red tide bloom which the eight species of them, mentioned in

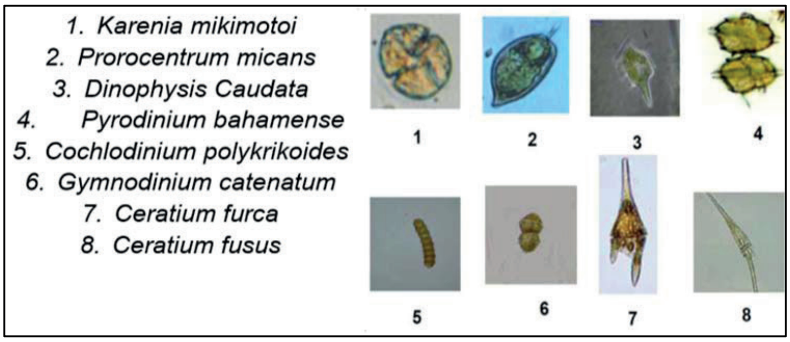


Figure 1. The dominant species of red tide phenomenon in the Persian Gulf (Taghavi and Abbaspour, 2012)

the following, have further spread (Taghavi and Abbaspour, 2012).

The most extensive red tide bloom in the Persian Gulf happened from end-August to March 2008 which was caused by Cochlodinium Polykricoides from the dinoflagellate category From late September to December 2008, red tide was observed in an area of several kilometers from Sirik port in Oman Sea to Bushehr at the center line of Persian Gulf which was covered approximately 750 km of coastline (Rezaee and Kabiri, 2009). Restriction which stop growing and blooming in the Oman Sea mainly was the lack of nutrients. Since in the north of the Strait of Hormuz, the industrial cities like Bandar Abbas and Qeshm exist and due to the defects in the urban and industrial wastewater system, the amount of organic materials in coastal waters is high during the whole of the year, and almost algal density was very high all of the 9-month period in this area. In other areas, the algal density reduced and increased periodically which these enhancement and reduction were obvious in the northern and southern regions of the Oman Sea (Hamzei, 2012). Cochlodinium, dinoflagellate with yellowish to brownish green pigment, was able to produce spherical or oval cysts and by releasing active oxygen causes oxidative fish gills and increases the amount of oxygen in the area at the time of red tide occurrence. Natural environmental conditions during the bloom for this type of algae, salinity is between 25 to 30 ppt and water temperature is between 32 to 34 ºC considering that the proper temperature range for the growth of phytoplankton in the Persian Gulf is in fall and winter, the phenomenon occurrences was in that period (Manshouri and Tabiee Yeganeh, 2009; Mohammadi Tahroodi *et al.*, 2013; Seddigh Marvasti, 2016). According to the sampling values by Persian Gulf and Oman Sea Ecological Research Institute, parameters variations at the time of blooming were in the following range: salinity (37-39.2 ppt), temperature (20.4-33.9 ºC), PH (7.96-8.6), Nitrate (0.059-0.707 mg/L), Phosphate (0.035-1.01 mg/L) and DO (3.9-9.8 mg/L). Different studies showed that the amount of dissolved oxygen (DO) in the presence of algae is increased due to photosynthesis and producing oxygen radical by Cochlodinium and salinity equal to 39.2 ppt and temperature above 30 ºC limits the Cochlodinium growth (Bahri, 2009). Based on scientific studies and field evidence, the assumptive reasons in this case are presented as follows: transport iron-rich suspended particles by wind and dust storms from the littoral states around the Persian Gulf; Surface disorganization due to sea currents; Climate changes on a large scale such as El

(a) (b) (c) (d)

Figure 2. (a) Coral reefs mortality due to suffocation and loss of light- the layer of algae covering their surface, (b) foam (sewage) due to aquatic mortality, (c) Dead fish due to red tide in the Persian Gulf, Autumn 2008, (d) Water discoloration due to Cochlodinium bloom in north of the strait of Hormuz, Qeshm in November 2008 (Rezaee and Kabiri, 2009; Taghavi and Abbaspour, 2012)

Niño; transport species through ships ballast waters; Heavy rainfall in addition to raising the temperature, reducing the amount of salt and increasing the water nutrients especially vitamin B12; Entering abundant volume of nutrients and increased water temperature due to geologic activities and upwelling (Qeshm earthquake occurrence and yearly upwelling on the east coast of Oman Sea between February and March); entering abundant volume of nutrients, urban and industrial sewage, from coastal region of Bandar Abbas. The southern cities without treatment plant pour their sewage directly into the sea more than 50 years. Discharge of Bandar Abbas sewage was equal to 300 lit/s in that time (Shakerzadeh *et al*., 2009; Vahedi, 2009; Seddigh Marvasti, 2016).

Consequences of Cochlodinium algal bloom in the Persian Gulf summarized as follows: fish mortality due to deposition in the fish gills and suffocation, increase anaerobic respiration and the depletion of DO in the water and poisoning aquatic, especially fish and benthic organisms who feed planktons (Rezaee and Kabiri, 2009; Farman Ara *et al*., 2012), injury and severe damage to light-dependent aquatic ecosystems, especially coral reef in Hormozgan waters due to suffocation and reduce light penetration (Mohammadi, 2008; Vahedi, 2009; Taghavi and Abbaspour, 2012), discoloration and changing the water quality and damage to desalination equipment and systems, especially desalination equipment (RO) of Qeshm, and ships and offshore facilities, damage to the seafood industry, especially aquacultures in Hormozgan and Bushehr (Rezaee and Kabiri, 2009; Taghavi and Abbaspour, 2012), extinction of pearl shells and sea cows of Persian Gulf (Hormozgan news, 2011), social and economic problems for lowlander and stop tourism industry in Kish and Qeshm, producing foam with fetid smell caused by bacteria decomposition which results in lowlander harassment and a sharp decline in commutes (Mohammadi, 2008; Mohammadi Tahroodi, 2013).

In general, to decrease growth of red tides different methods including physical (like spraying clay, reducing sources of nutrients, etc.), chemical (using sodium hypochlorite produced by electrolysis of seawater, etc.) and biological (using of zooplankton and anti-algae bacteria, etc.) are used. Since prevention methods in comparison to decrease methods is preferable, so it is essential to find a method for predicting red tide occurrence and observing the trend of it by considering all factors such as salinity, temperature, precipitation, current velocity and relative humidity. For this purpose, a monitoring network system can be created and used for recording the required information.

An integrated predicting model could be an important goal for research programs on ecology and algal bloom time (Vahedi, 2009; Taghavi and Abbaspour, 2012).

2. Materials and methods

2.1. Introduction to MIKE software and governing theories

MIKE software is able to simulate physical, chemical, or biological processes in lakes, estuaries, bays, coastal areas and seas with the highest reliability. For red tide modeling in MIKE software, the hydrodynamics module-MIKE21 and the biological module-ECOLAB have been used. MIKE21 is suitable tool for two-dimension (2D) simulation of physical, chemical or biological processes in coastal or marine areas and it is based on the numerical solution of the two dimensional shallow water equations - the depth-integrated incompressible Reynolds averaged Navier-Stokes equations. Thus, the model consists of continuity, momentum, temperature, salinity, and density equations. In the horizontal plane an unstructured grid is used. The spatial discretization of the primitive equations is performed using a cell centered finite volume method. MIKE 21 has different modules which are for water quality and ecological modeling, ECOLAB module is used. ECOLAB is a complete numerical laboratory for customizing aquatic ecosystem, water quality, and ecological studies by describing chemical, biological, ecological processes and interactions between state variables and physical processes. By ECOLAB exactly the required model for the specific ecosystem can be developed and its processes can be described by using standard and transform any aquatic ecosystem into a reliable numerical model for accurate predictions. The predefined ECOLAB templates containing the mathematical descriptions of ecosystems can be used as a basis and edited arbitrarily or the new template can be defined based on processes taking place in the ecosystem. The demand for tailor made ecosystem descriptions is great, because ecosystems vary. A template is independent of grid systems and the same template can be integrated with one, two and three dimensional or hydrology modeling. The template can describe dissolved substances, particulate matter of dead or living material, living biological organisms and other components. State variables included in ECOLAB can either be transported by advection-dispersion processes based on hydrodynamics, or have a more fixed nature (e.g. rooted vegetation or mussels). The description of the ecosystem state variables in ECOLAB is formulated as a set of ordinary coupled differential equations describing the rate of change for each state variable based on processes taking place in the ecosystem. Besides the pure process orientated description (Eulerian modeling), this module also supports the characterization of individual spatial entities or particles with associated attributes (agent based modeling or Lagrangian modeling). After creating or picking an ECOLAB template for the ecosystem, the ECOLAB model must be set up and run in MIKE 21 FLOW MODEL (FM). In this paper, Eutrophication 1 ECOLAB template had been used. This template considers dispersion in Eulerian framework by default, and in order to simulate the simultaneous processes of transport, dispersion and biological/biochemical processes considers a system of 12 differential equations describing the variations for 12 components (11 movable components in both hydrodynamic and biological modules and a fixed nature component belonging to the benthic system). The processes describing the variations of the components in time and space are dependent on external factors such as the salinity, water temperature, the light influx, and the discharges. In this paper, the variation of chlorophyll-A, inorganic phosphorus and nitrogen and also DO are studied. The dynamics of advective ECOLAB state variables is calculated by:

$$\frac{\partial c}{\partial t}+u\frac{\partial c}{\partial x}+v\frac{\partial c}{\partial y}+w\frac{\partial c}{\partial z}=D_x\frac{\partial^2 c}{\partial z^2}+D_y\frac{\partial^2 c}{\partial z^2}+D_z\frac{\partial^2 c}{\partial z^2}+S_c+P_c \quad (1)$$

which C is the concentration of the ECOLAB state variable; u, v, w are flow velocity components; D_x, D_y, D_z are the dispersion coefficients; S_c is sources and sinks; and P_c indicates ECOLAB processes. The mass balance for chlorophyll-A reads:

$$\frac{dCH}{dt}=production-death-sedimentation=PRCH-DECH-SECH+SECH^{n-1} \quad (2)$$

where n-1 denotes the input from the above layer (n>1). The chlorophyll-A production amount is:

$$PRCH=\left(\frac{CH_{min}}{IK}\right)\times\exp(F_3(N,P))\times PRPC \quad (3)$$

where CH_{min} is the coefficient of determining the minimum chlorophyll-A production (E/m^2/d^{-1}), CH_{max} is the coefficient of determining the maximum chlorophyll-A production in the absence of nutrient limitation, and F_3 (N) is calculated by the following formula:

$$F_3(N)=CH_{max}\times\left\{\left(\frac{PN}{PC}-PN_{min}\right)/(PN_{max}-PN_{min})\right\} \quad (4)$$

SECH and DECH read:

$$SECH=SEPC\times\left(\frac{CH}{PC}\right) \quad (5)$$

$$DECH=(DEPC+GRPC)\times\left(\frac{CH}{PC}\right) \quad (6)$$

Based on the above, red tide modeling in Persian Gulf has been done (MIKE manuals, 2012).

2.2. Red Tide Modeling Process

Generally, the steps to carry out an environmental project consist of: project analysis (analysis and evaluation of the ecosystem problem and solution strategy); collection of data, field measurements, and laboratory analysis; set up and run the model; calibration; solution (running the production simulations and presenting the results). For red tide modeling in MIKE software, the hydrodynamics module-MIKE21 and the biological module-ECOLAB have been used (MIKE manuals, 2012). Red tide modeling process in Persian Gulf zone is divided into four sections:

1) Define Persian Gulf topography by using shoreline and water depth data of Persian Gulf in Longitude/Latitude projection between 23.7 to 33 ºC north and 47.7 to 58 ºC east in xyz format of ETOPO-1 website including Longitude/Latitude position and depth of every point and generate proper mesh for computational grid: import shoreline data, modify boundaries, define specifications of boundaries for the area by creating closed domain, define position of Jask (Lat.=25/63، Long.=57/77) and Majis (Lat.=24/518، Long.=56/606) and draw arc, and define a unique integer value for boundaries (open boundaries and land boundaries mark 2 and 1, respectively) to create a mesh, define polygons for closed domains and exclude the small islands from the mesh domain, import scatter data to interpolate water depths in mesh elements, generate depth-independent mesh, then smoothing and refining and analyzing the mesh to ensure that the mesh is optimal, carry out mesh-interpolation by interpolating scatter

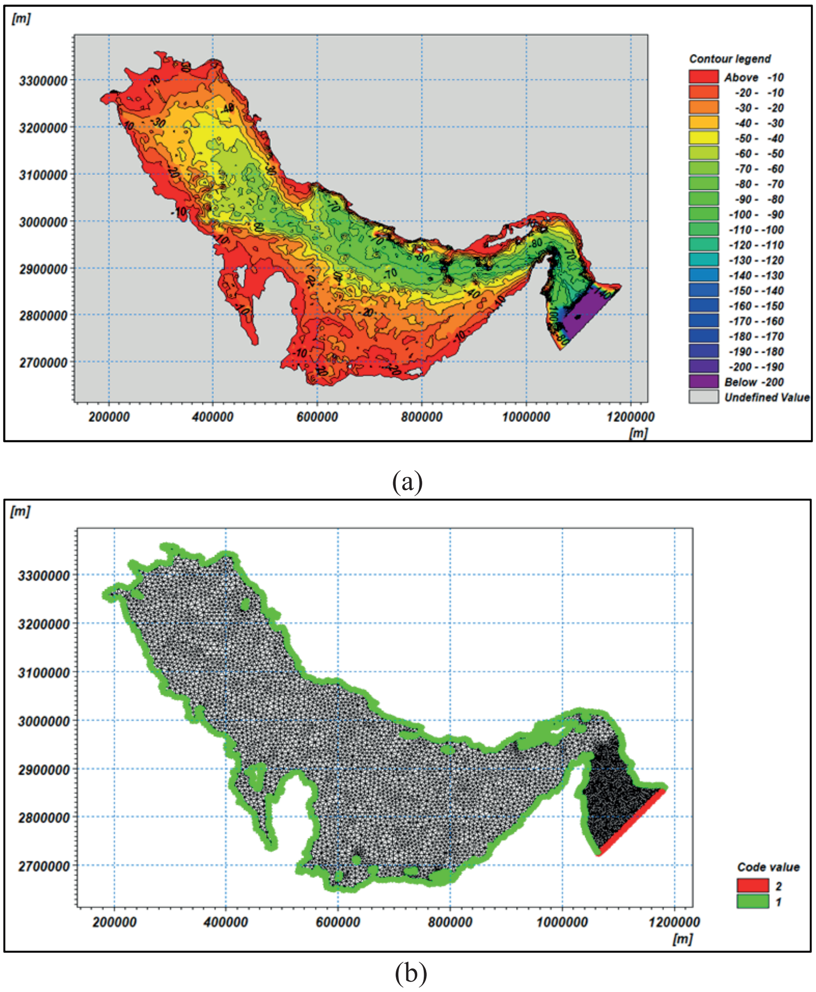
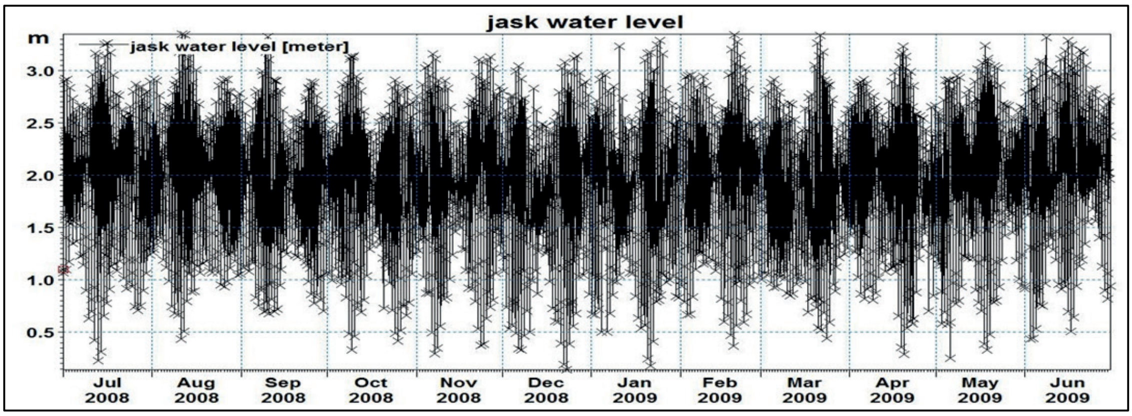


Figure 3. (a) Persian Gulf bathymetry, (b) mesh file and the defined boundary codes

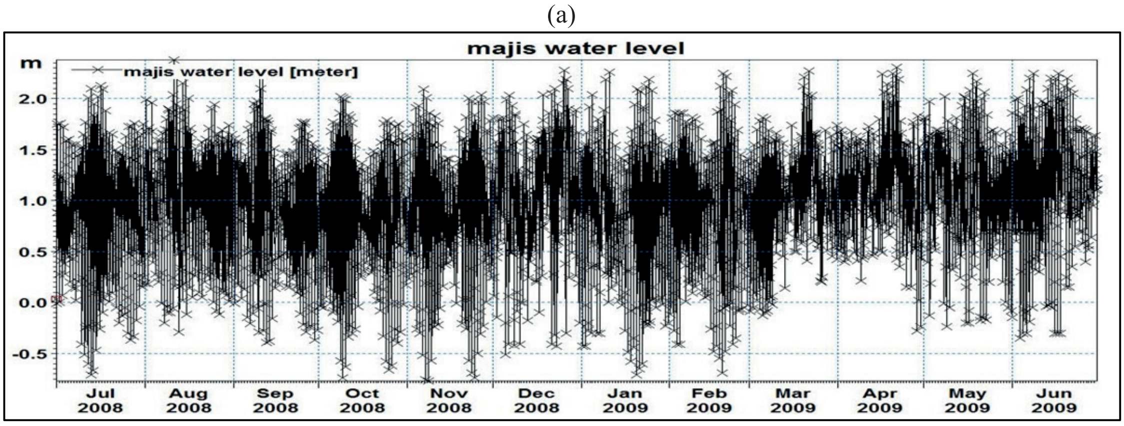
data amounts and represent the bathymetry in mesh nodes according to the input data, and finally export the mesh file in order to use it in MIKE21 hydrodynamic module. According to the above steps, the results of this part are shown in Figure 3.

2) Definition of hydrodynamic flow in the Persian Gulf, according to water level data in the open boundary between Jask and Majis from IOC website in the period of 1 July 2008 till 30 June 2009, and prevailing hydrodynamic forcing including wind force data in station (long.=56, lat.=26) from Coastal and Port Engineering Department of Ports and Maritime Organization in the form of time series and wind rose plot for during the year, hydrodynamic sources data like the average flow of Mond, Dalaki, Arvand rivers respectively equal to 4.39, 5.13, 1750 cubic meter per second and inputting wastewater flow of Bandar Abbas equal to 300 liter per second: in this modeling Evaporation-precipitation over the Persian Gulf, the dominant wave system and density variations based on salinity and temperature are ignored. Thus, time series and wind rose plot are as Figure 4.

The wind rose in Figure 5 is in accordance with the studies about winds pattern over the Persian Gulf that states this area is in the pattern of the summer monsoon winds (southwest) and winter

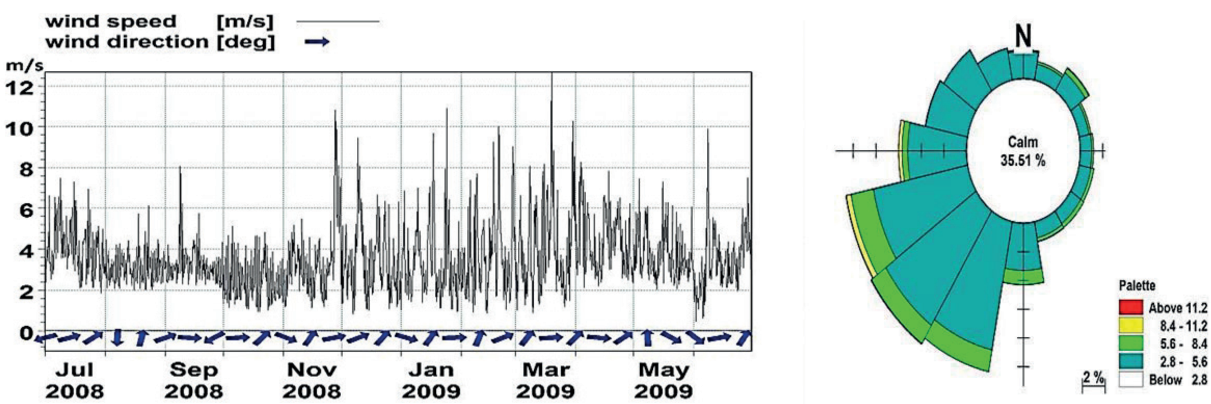


(a)



(b)

Figure 4. Water level time series (m) in (a) Jask and (b) Majis stations



(a) (b)

Figure 5. (a) Wind time series [speed (m/s) and direction (deg)], (b) wind rose plot in station (Long =56, Lat = 26)

monsoon winds (northeast) and the strength of winter monsoon winds are much less than the summer monsoon winds (Seddigh Marvasti, 2016). After defining water level boundary condition, wind forcing, rivers, topography and determining initial conditions in MIKE 21

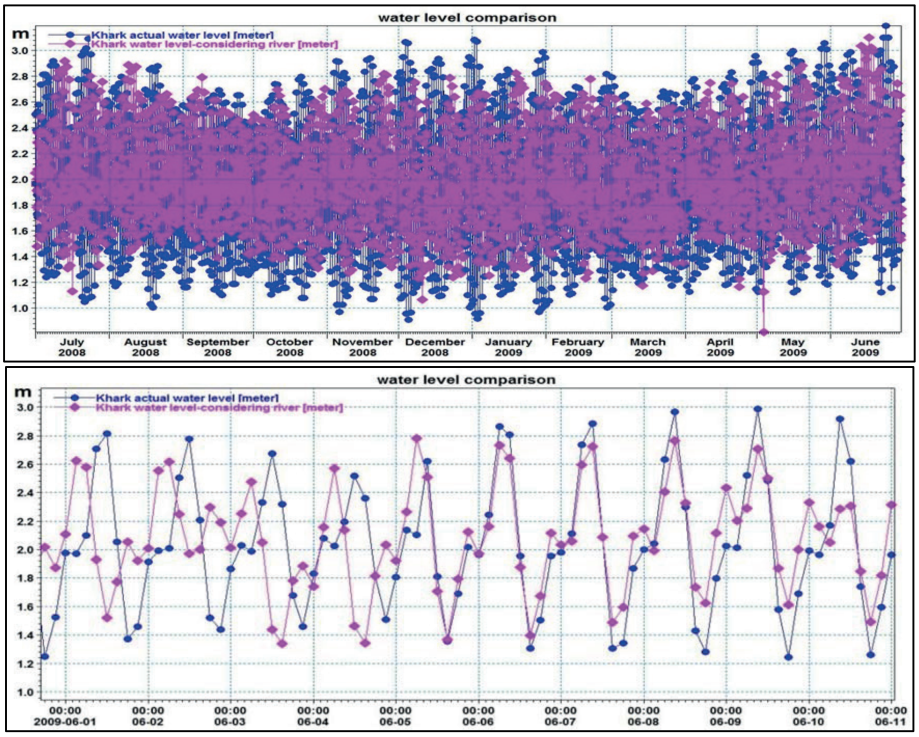


Figure 6. Comparison of simulated water level (m) with actual water level data in Kharg station (eddy viscosity=0.34, bed resistance=50)

Flow Model (FM), the hydrodynamic model is created and a two-dimensional output and a point output in Kharg station are defined. In order to convergence and stability of the model during solving partial differential equations using explicit method, Courant number is defined as 0.5. The simulation time step is equal to 10800 seconds, and the number of time steps due to cover the year is defined as 2919. Low order method is selected to solve the equations. Two-dimensional results show counterclockwise flow of the Persian Gulf.

3) Persian Gulf hydrodynamic model calibration by using actual water level data of Kharg station which received from Coastal and Port Engineering Department of Ports and Maritime Organization: in order to model calibration, bed resistance and eddy viscosity values during the simulation have been changed. Finally, the optimal values of them respectively equal to 50 and 0.34 which are used in the ultimate hydrodynamic model to define red tide.

The observed difference in the figures may be due to consider only the wind force. In general, four factors are important in the Persian Gulf Stream circulation: wind, tides, water density variation and turbulent diffusion caused by vertical mixing processes. (Taghavi and Abbaspour, 2012) This difference can be due to not consider other factors like tides, water density variation.

4) Defining trend of algal bloom in Persian Gulf zone by utilizing data variation in salinity, temperature, chlorophyll-A, nutrient concentration (nitrate and phosphate) and DO in form of average monthly in open boundary, ECOLAB forces including solar radiation equal to constant value 26.5 E/m^2/d, ECOLAB loading concentration including concentration of Bandar Abbas sewage pollution equal to 300

lit/s in eutrophication 1 ECOLAB template: Horizontal diffusion coefficients, growth and death rate, sedimentation and grazing rate, the growing rate dependence on temperature, salinity and nutrients are changeable to investigate the effect and calibrate the model. This template only considers diatoms and green algae. In this modeling diatoms growth rate equal to 0.8 per day and green algal growth rate equal to 1.4 per day, sedimentation rate in the depth of less than 2 meters equal to 0.25 m/day and in the depth of greater than 2 meters equal to 0.5 m/day and maximum grazing rate equal to 1.5 per day and death rate equal to 0.02 per day are defined. In output part of the simulation, a two-dimensional output including chlorophyll-A, inorganic nitrogen and phosphorus, and DO variation is defined.

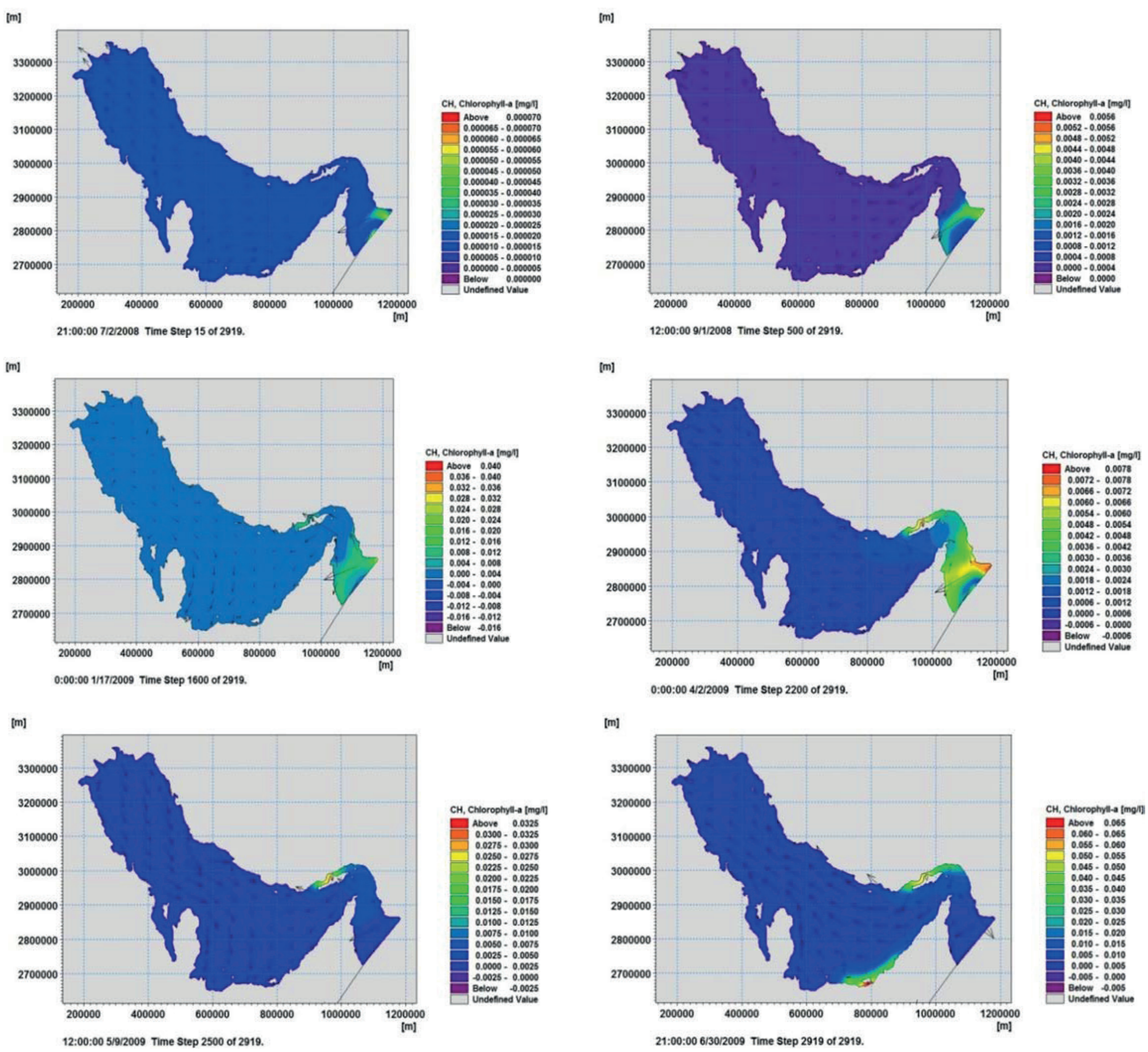


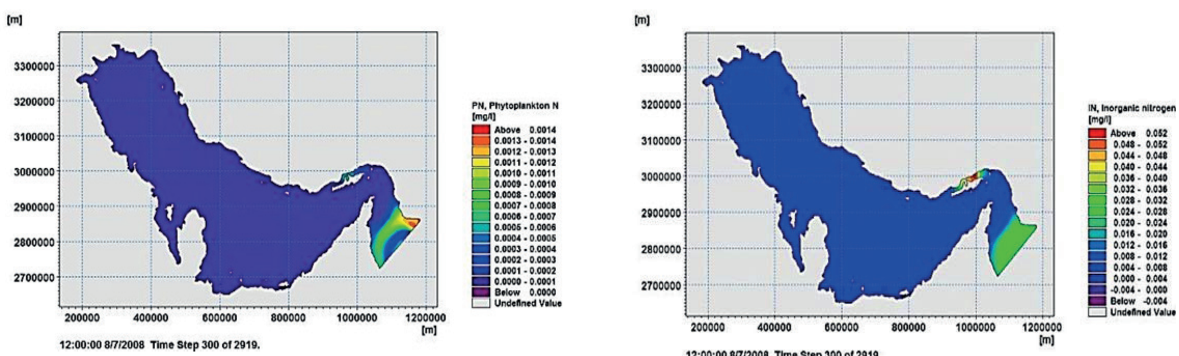
Figure 7. The trend of chlorophyll-A (mg/l) by utilizing eutrophication 1 template and dominant stream in Persian Gulf (chlorophyll-A dispersion and diffusion is in accordance with main direction of dominant stream and also location of contamination sources)

3. Results and Discussion

Finally, the results of simulation show that chlorophyll-A concentration is increased by enhancing the amount of nitrate and phosphate, and increasing in chlorophyll-A concentration causes increasing in DO concentration. Also the trend of chlorophyll-A development is according to Persian Gulf stream circulation as well as increasing growth rate due to nutrient concentration.

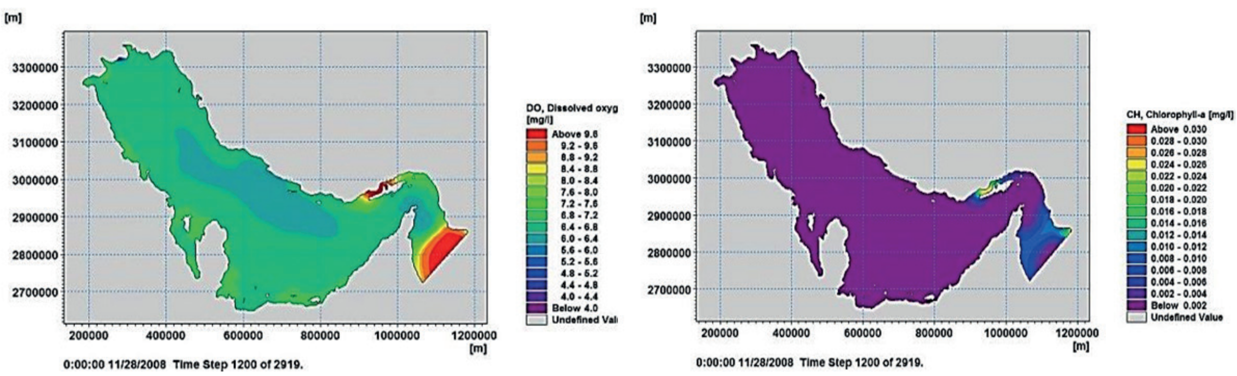
Conclusion

In the recent years, Persian Gulf due to special geographical and climate conditions has been confronted with red tide phenomenon and it gives seriously impact on ecosystem, public health and economy condition. Due to the facts that through the investigating methods of this phenomenon, numerical modeling has great importance because of the need to lower time and cost, in this paper, the effects of pollution outflows and hydrodynamic currents of Persian



(a) (b)

Figure 8. Comparison the proceed of (a) chlorophyll-A (mg/l) to (b) nitrogen and phosphorus dispersion (mg/l)



(a) (b)

Figure 9. Comparison of (a) DO variation (mg/l) to (b) chlorophyll-A concentration (mg/l) by utilizing eutrophication 1 template

Gulf on Red Tide development in 2008-2009 period and variation of amount of DO to chlorophyll-A was simulated and studied by utilizing MIEK21 FLOW MODEL (FM) and EUTROPHICATION 1 ECOLAB TEMPLATE modules. The simulation results showed that the direction of red tide development was in accordance with the mainstream direction of Persian Gulf. Considering nitrate concentration (0.059-0.707 mg/l) and phosphate concentration (0.035-1.01 mg/l) in hydrodynamic boundary and Bandar Abbas swage pollution equal to 300 lit/s, chlorophyll-A concentration was increased with increasing nitrate and phosphate as well as persistent in those areas at all times till the presence of nutrients over there. In addition, due to increasing chlorophyll-A concentration, the dissolved oxygen concentration increased.

References

Anderson, D. M. 1994. Red tides. Scientific American Journal, 271(2): 52-58.

Bahrami Rad A. 2013. Algae bloom and its importance in aquatic ecosystems, http://www.newposeidon.blogfa.com/post-57.aspx.

Bahri, A. 2009. Bloom and its importance in aquatic ecosystems, Persian Gulf and Oman Sea Ecological Research Institute. Available at: http://pgoseri.ac.ir [Accessed on March 2017].

Ebrahimi, M. 2015. Monitoring algae bloom in coastal waters of Persian Gulf and Oman Sea (Hormozgan coastal waters), Persian Gulf and Oman Sea Ecological Research Institute.

Farman Ara M., Hosseini Balam F., and Hasanzade E. 2012. Numerical simulation of subsurface flow effects on the distribution of red tide phenomenon in the Persian Gulf, the 10th International Conference on Coasts, Ports and Marine Structures, Tehran, Iran.

Glibert, P. M., Allen, J.I., Bouwman, A. F., Brown, C.W., Flynn, K. J., and et al. 2010. Modeling of HABs and eutrophication: Status, advances, challenges. Journal of Marine Systems, 83(3-4): 262-75.

Hamzei, S. 2012. Field Observation and numerical modeling of red tide development in the north part of Hormoz Strait, Science and Technology University, Iran.

Hodgkiss, I.J., and Ho, K.C. 1997. Are changes in N: P ratios in coastal waters the key to increased red tide blooms? Hydrobiologia, 352: 141e147.

Hormozgan news. 2011. Available at http://www.hormozgannews.com/Pages/News-2325.html [Accessed on July 2017].

Malaei Tavana, H., Behpoor, S., Changizi, M., and Karimi, H. 2008. Investigate the reinforcing factors in forming and occurrence of harmful algal bloom, National Conference on Human, Environment and Sustainable Development, Hamedan, Iran.

Manshouri, M., and Tabiee Yeganeh, S. 2009. Investigate the red tide causes and controlling it in Persian Gulf, 12th National Congress on Environmental Health, Shahid Beheshti University, Tehran, Iran

McGillicuddy, D.J. 2010. Models of harmful algal blooms: conceptual, empirical, and numerical approaches, Preface to a Special Issue of Journal of Marine Systems, DRAFT MANUSCRIPT.

MIKE manuals. 2012. ECOLAB Short Scientific Description; MIKE 21 - FLOW MODEL FM-Particle Tracking Module; MIKE21/3 PARTICLE TRACKING; GEODESY IN MIKE ZERO-Map Projection and Datum Conversion; MIKE21

FLOW MODEL FM-ECOLAB/OIL SPILL; MIKE ZERO-PREPROCESSING& POSTPROCESSING; MIKE ZERO-Project Oriented Water Modelling; MIKE ZERO-mesh generator; MIKE ZERO-The Common DHI User Interface for Project Oriented Water Modelling, available at https://www.mikepoweredbydhi.com [Accessed on March 2017].

Mohammadi, H. 2008. Red tide, http://hamedmohamadi63.blogfa.com/post-27.aspx

Mohammadi Tahroodi, M. Fatemi, S. M., Nabavi, S.M., and Kazemi Tabar, S. M. 2013. Study the occurrence of Cochlodinium algal bloom and environmental parameters in the coastal waters of Qeshm-Hormozgan, International Congress on Environmental Crises and its Solutions, Kish Island, Iran

Park, S., Lee, Y., and Lee, S.R. 2013. Forecasting Red Tide using Ensemble Method. International Journal of Software Engineering and Its Applications, 7(5): 145-152.

Peinert, R., Saure, A., Stegmann, P., Stien, C., Haardt, H., and Smetacek, V. 1982. Dynamics of primary production and sedimentation in a coastal ecosystem. Netherlands Journal of Sea Research 16: 276-289.

Rezaee, H., and Kabiri, K. 2009. Study red tide phenomenon tracking in the Bandar Abbas coastal waters and Qeshm and Hormuz Islands, Research Project of National Ocean Graphic Center.

Sadeghi Mazidi, S., Ahmadi, M.R., and Taherizadeh, M.R. 2011. The seasonal changes in phytoplankton population and environmental factors in winter and spring in Bandar Abbas coastal waters. Fisheries and Aquaculture Journal, 5: 13-21.

Seddigh Marvasti S. 2016. Numerical simulation to study effective factors and different mechanisms of red tide in Oman Sea, Physical Oceanography PhD thesis, Islamic Azad University, Science and Research Branch, Tehran, Iran.

Shakerzadeh, F., Bavandi, S., Bahmanmanesh, A., and Hedayatifard, M. 2009. Red tide and its destructive effects on the marine environment with emphasis on marine mollusks, The International Conference of Persian Gulf in Islamic Azad University of Bushehr, Iran.

Taghavi, L., and Abbaspour, M. 2012. The determinative factors for modeling and management of red tide in the Persian Gulf, The First International Conference of Environmental and Geopolitical Persian Gulf.

Vahedi, M. 2009. Red tide threat. Port & Sea magazine, 23: 116-119.

Vollenweider, R.A. 1992. Coastal marine eutrophication. In: Vollenweider, R.A., Marchetti, R., Viviani, R. (Eds.), Marine Coastal Eutrophication. London: Elsevier.

Wikipedia. 2014. Red tide, https://en.wikipedia.org/wiki/Red_tide.

Wong, K.T., Lee, J. H., and Hodgkiss, I. J. 2007. A simple model for forecast of coastal algal bloom. Estuarine, Coastal and Shelf Science, 74(1-2): 175-196.