Field Study of the 2008-2009 Red Tide in the Northern Strait of Hormuz

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Abstract: The catastrophic event of red tide has happened in the Strait of Hormuz, the Persian Gulf and Gulf of Oman from late summer 2008 to spring 2009. With its devastating effects, the phenomenon shocked all the countries located in the margin of the Persian Gulf and the Gulf of Oman and caused considerable losses to fishery industries, tourism, and tourist and trade economy of the region. In the maritime cruise carried out by the Persian Gulf and Gulf of Oman Ecological Research Institute, field data, including temperature, salinity, chlorophyll-a, dissolved oxygen and algal density were obtained for this research. Satellite information was received from MODIS sensor. Temperature and surface chlorophyll images were obtained and compared with the field data. The results obtained from the present research indicated that with the occurrence of harmful algal blooms (HAB), the Chlorophyll-a and the dissolved oxygen contents increased in the surface water. Maximum algal density was seen in the northern coasts of the Strait of Hormuz. Less concentration of algal density was detected in deep and surface offshore water. Temperature and chlorophyll satellite images were proportionate to the measured values obtained by the field method. This indicates that satellite measurements have acceptable precisions and they can be used in sea monitoring.

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1. Introduction

Harmful Algal Blooms (HABs), commonly known as Red Tide, is a sea phenomenon in which unicellular algae or cyanobacteria change the color of oceans and seas during a rapid and considerable growth. Such a phenomenon is generally harmless; however, some species endanger sea environment and human health under certain conditions. The phenomenon often broadly threatens vast areas of seas and oceans in the world.

During the last decades, an increasing number of HABs have been reported worldwide, and received a lot of attention due to their negative impact on the marine environment in which they occur (Hallegraeff et al. 2003). Over the last few decades, the coastal regions throughout the world have experienced incidences of HAB with potential threat to humans as well as marine organisms, owing to accelerated eutrophication from human activities and certain oceanic processes (Chu and Kuo, 2010).

HAB events are characterized by two main features; they are caused by microalgae and they have a negative impact on human health and/or activities such as fisheries, aquaculture, and tourism. Despite these common features, HABs are very diverse in terms of harmfulness, causative organisms, dynamics of blooms and types of impact. Other dinoflagellates can cause direct harm to or even kill marine animals, such as fish, although the precise modes of impairment to the animals are diverse and sometimes not known. One dinoflagellate which is well known for causing fish kills in Southeast Asian waters is Cochlodinium polykrikoides. Cochlodinium has been implicated in kills of wild and impounded fish around the globe (Onoue et al., 1985; Yuki, and Yoshimatsu, 1989; Guzmán et al., 1990; Qi et al., 1993; Gárrate-Lizárraga et al., 2004; Whyte et al., 2001) and has been the cause of fisheries losses exceeding $100 million in Korea (Kim, 1998; Kim et al., 1999).

Studies have also indicated that metamorphosis of oyster (Crassostrea gigas) larvae was slowed during Cochlodinium blooms (Matsuyama et al. 2001) and that mortality of larvae of the American oyster, Crassostrea virginica, was elevated by exposure to Cochlodinium (Ho and Zubkoff, 1979). The most common Cochlodinium species, C. polykrikoides, grows optimally at temperatures between 21 and 26 °C and at salinities between 30 and 36 (Kim et al 2004; Yamatogi et al., 2006). Cochlodinium is a mixotrophic alga (Larsen and Sournia, 1991; Jeong et al., 2004) and thus likely employs flexible nutrient acquisition strategies during blooms. Moreover, since this alga is noxious to some planktonic grazers (Ho and Zubkoff, 1979; Shin et al., 2003), it may escape top-down control by zooplankton which most phytoplankton experience (e.g. Gobler et al., 2002).

The phenomenon occurs through the two different methods in the Persian Gulf, the Gulf of Oman and the Strait of Hormuz in both summer and winter. Generally, native species of Nuctolica family grow in summer and native species of Dinoflagiate family grow in winter.

The phenomenon does not usually lead to loss of aquatic animals in the Persian Gulf and the Gulf of Oman; yet, it has caused the deaths of aquatic animals and wild fish in this area during recent years.

Harmful algal Blooms caused by Cochlodinium polykrikoides algae started in September 2008 from south of the Gulf of Oman, stretched to other areas of the Gulf of Oman, the Strait of Hormuz and the Persian Gulf, and lasted more than nine months. This phenomenon caused the death of so many marine species, wild fish and brood aquatic animals in this area and left catastrophic effects on the domestic economy in these regions. Red tide killed hundred tons of fish, limited fishing, damaged the coral reefs seriously, left unfavorable effects on tourism in this area, and caused disorders in marine ecosystems.

2. Method of research

Data of the present research includes the data collected from the maritime patrol performed in the Persian Gulf and Oman Sea Ecological Research Institute from 24 to 29 February 2009 at the time the red tide occurred, CTD field data preformed in the south of Gheshm Island in November 2008, and field measurements carried out before and after this phenomenon.

In this research, data of each station, including temperature, chlorophyll-a, dissolved oxygen, salinity and algal density collected in each station has been used. The data obtained from MODIS sensor satellite was used to compare with the field data of the temperature and chlorophyll.

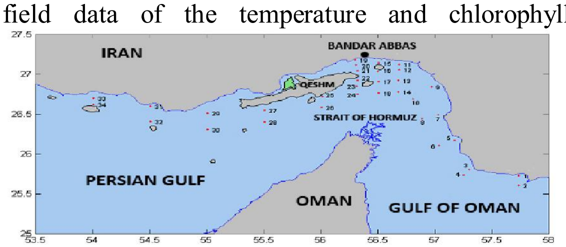


Figure 1: The Strait of Hormuz area and the stations studied in this research

Figure 1 shows the stations of the maritime patrol in the Persian Gulf, the Strait of Hormuz and the Gulf of Oman performed from 24 to 29 February 2009, considering L1, L2, L3 transects used in this research, marine parameters measurement stations in south of Gheshm Island in November 2008 and marine parameters measurement stations in Bandar Abbas coasts during HAB period. The chlorophyll and dissolved oxygen contents were obtained from the sensors installed on the CTD. Chlorophyll content and algal density were obtained experimentally in mg/m^3 and cell/l, respectively.

Finally, the field data of the stations and the satellite data were processed using Excel, Surfer and SeaDAS software. The results of the research were obtained using the assessment of diagrams and output forms of the software.

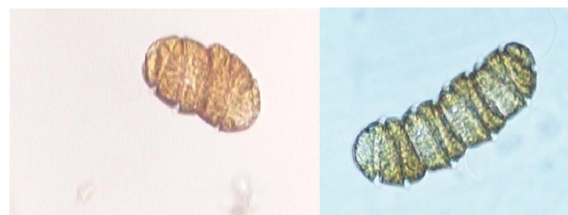


Figure 2: 2–cell and 4-cell chains of coclodinium polykorikodes caused red tide in the
Persian Gulf, the Strait of Hormuz and the Gulf of Oman in 2008-2009

Scope of study

Scope of study of the present research includes the north regions of the Strait of Hormuz. The Strait of Hormuz is where water of the Persian Gulf and water of the Gulf of Oman are exchanged.

Currents of the Strait of Hormuz are affected by the exchange of water between the Persian Gulf and the Gulf of Oman. Due to the counterclockwise movement of the current in the Persian Gulf that is generally caused by the density gradient, the current makes a reverse estuary in this area, similar to the Mediterranean Sea (Reynolds, 1993). The incoming current to the Persian Gulf runs from the north of the Strait of Hormuz and along the Iranian coasts toward the north of the Persian Gulf. There, due to the current movement of the Arvand River and the Coriolis force, the flow redirects to the south coasts of the Persian Gulf. It then moves along the Arabian coasts and toward the south of the Strait of Hormuz. During the course, due to high evaporation, its salinity increases and reaches 42psu. The high salinity of water increases water density. Consequently, the outflow of the Persian Gulf flows toward the depth and settles beneath the incoming current.

3. Results

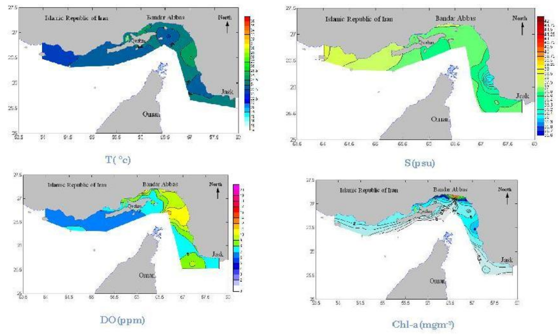


Figure 3: Surface distribution of temperature, chlorophyll, dissolved oxygen and salinity using the data obtained from the maritime patrol performed from 24 - 29 February in the north of the Strait of Hormuz

Figure 3 shows the surface temperature of the seawater measured in the maritime patrol performed 24 - 29 February. According to the Figure, the surface steady temperature is between 24°C to 25°C. Flowing toward the Persian Gulf, the surface temperature decreases. The surface chlorophyll of the seawater at the north coasts of the Strait of Hormuz is high. Flowing toward the Persian Gulf, The Gulf of Oman and central areas of the Strait of Hormuz, the temperature decreases. The dissolved oxygen in the north of the Strait of Hormuz is more than 10 ppm, which decreases in the surface water of the Persian Gulf and north water of the Gulf of Oman to 7ppm and 8ppm, respectively. Within the area under study, salinity of the Gulf of Oman is less than the one of the Strait of Hormuz and the Persian Gulf.

Density of Cochlodinium polykrikoides algae, the agent responsible for creating the red tide, has the most algal density in the north of the Strait of Hormuz. The density decreases in the north of the Persian Gulf and the Gulf of Oman.

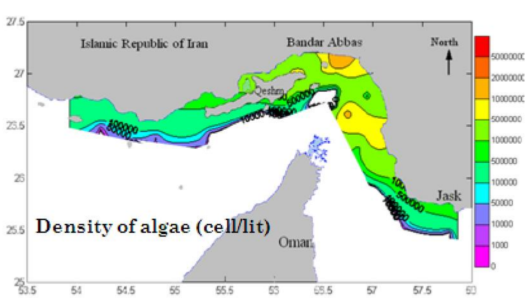


Figure 4: Surface distribution of the algal density of Cochlodinium polykrikoides using the data obtained from the maritime patrol of 24 - 29 February in the north of the Strait of Hormuz

The most algal density of the surface of water measured in the southeast of Bandar Abbas coast and east of the Hormuz Island is 20 * 10^6 cell/l. In these surface images, one is able to see the conformity of the surface chlorophyll distribution with the surface algal density distribution and surface oxygen.

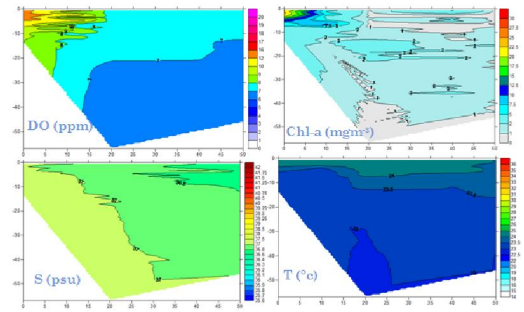


Figure 5: L1 transect, section of temperature, chlorophyll, dissolved oxygen and salinity using the data obtained from the maritime patrol of 24 - 29 February in the north of the Strait of Hormuz, Stations 19 to 24

Figure 5 shows the vertical section from the north of the Strait of Hormuz to the center of the Strait of Hormuz. In Figure 5, the vertical section, is shown by L1 transect. The Figure shows the steady distribution of water temperature with little thermocline gradient toward the bed in which the temperature varies from 23°C to 24°C. By moving from the north of the Strait of Hormuz to the depth of water and moving toward the center of the Strait of Hormuz, chlorophyll content decreases. It indicates that HAB density is extremely high in the north of the Strait of Hormuz. Water chlorophyll decreases in deep areas, which indicates that Cochlodinium polykrikoides algae content in deep water is more than the one in the surface water. Nevertheless, the differences in different regions of this transect indicates that distribution of HAB agent algae in different surface and deep regions is different. In addition, the chlorophyll content in water with the depth of 20 to 30 meters is more than the one in the surface water.

Oxygen distribution in this transect is similar to the one of chlorophyll. The only difference is that oxygen distribution is steadier. The oxygen content in the north of the Strait of Hormuz is high; however, its content in the center of the Strait of Hormuz is normal. The high concentration of oxygen in the north of the Strait of Hormuz can be attributed to the production of oxygen due to the photosynthesis of the red tide algae during the day. Such measurements have already been carried out during the day.

Distribution of salinity shows that water of north of the Strait of Hormuz is a little saltier than the one of the central parts of the strait. The amount of salinity increases in deeper areas. The incoming current flowing into the Persian Gulf has made water of the central area of the Strait of Hormuz less salty.

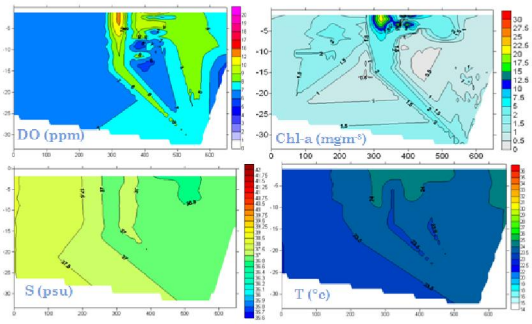


Figure 6: L2 transect, a vertical section of temperature, chlorophyll, dissolved oxygen and salinity using the data obtained from the maritime patrol of 24 - 29 February in the Persian Gulf toward the Gulf of Oman in stations close to the coastal regions of the north of the Strait of Hormuz

Figure 6 shows L2 transect which is a vertical section of the Persian Gulf toward the Gulf of Oman in stations close to the coastal regions of the north of the Strait of Hormuz. In this transect, temperature distribution shows that temperature of the coastal regions of the Persian Gulf close to the north of the Strait of Hormuz is less than the other regions. A gentle gradient of thermocline with little temperature changes is seen in some areas of the Strait of Hormuz.

Chlorophyll content in the regions close to the north coasts of the Strait of Hormuz exceeds 20 mg/m^3 whereas in the other regions of this transect in the Persian Gulf and the Gulf of Oman, the content of chlorophyll decreases. Chlorophyll content decreases in deep regions.

The dissolved oxygen content in the north surface regions of the Strait of Hormuz exceeds 12 ppm, which is the most amount of the dissolved oxygen. The dissolved oxygen content in the Persian Gulf, the Gulf of Oman, and deep waters decreases to 7 ppm, 8 ppm, and 5 ppm, respectively. In the center of the Strait of Hormuz, at the depth of 10m to 20m, there is a region in which the oxygen content reaches less than 6ppm. The region is located in an area where the oxygen content is high; the reason may be lack of photosynthesis of algae, as the algae of the upper layers prevent sunlight to reach the beneath layers. As oxygen is consumed during the day, the phenomenon requires the least amount of oxygen early morning.

L3 transect shows the vertical section of the Persian Gulf to the Gulf of Oman in the offshore stations of the north of the Strait of Hormuz.

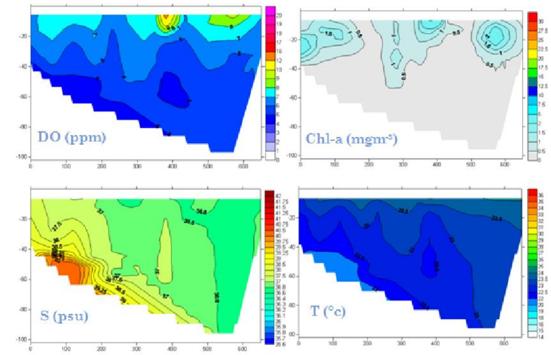


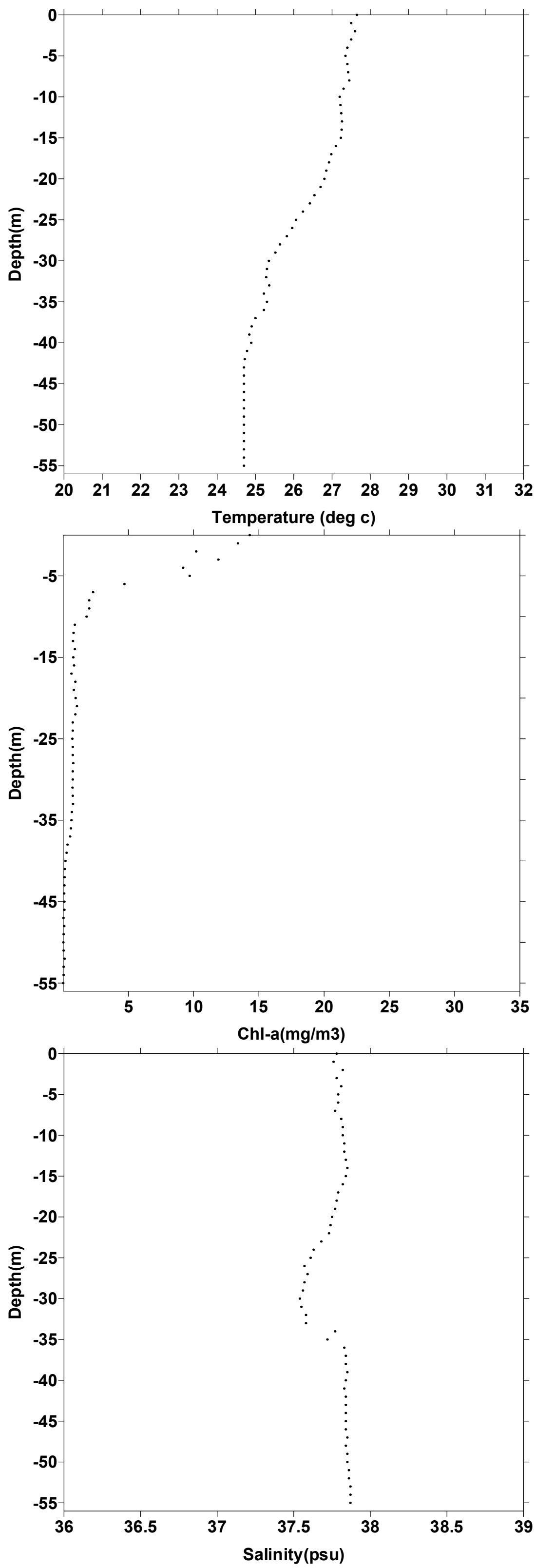
Figure 7: L3 transect, a vertical section of temperature, chlorophyll, dissolved oxygen and salinity using the data obtained from the maritime patrol of 24 - 29 February in the Persian Gulf toward the Gulf of Oman in the offshore stations of the north of the Strait of Hormuz

Temperature distribution in this region is in a way that the steady stratification is seen in the temperature. With the increase of depth, the compressed temperature stratification in the Persian Gulf is stretched to the extended stratification in the Gulf of Oman and thermocline becomes weaker and deeper.

The chlorophyll content in this transect is less than the one in L2. Regions with high amount of chlorophyll are only seen in a scattered way in the Persian Gulf, Strait of Hormuz and the Gulf of Oman which is consistent with the satellite images in Figure 8.

The dissolved oxygen content is higher in the surface water; however, it is lower in deep water of this transect. The most concentration of the dissolved oxygen is in the center of the Strait of Hormuz, which exceeds 12ppm. The oxygen and chlorophyll contents are consistent. In this vertical section, by moving from the Persian Gulf to the Gulf of Oman, the amount of salinity decreases. By moving from the depth of the Persian Gulf to the depth of the Gulf of Oman, salinity decreases severely; it decreases from 40 psu at the depth of the Persian Gulf to 36.8 psu at the depth of the Oman Sea.

Figure 8 shows the data measured in south of the Gheshm Island in November 2008. The Figure 8 shows the decrease of temperature from 27.5°C at the surface to 25.5°C at the depth of 40 meters. Chlorophyll content is 14 mg/m^3 at the surface; it reaches 2 mg/m^3 at the depth of 10 meters and closes to zero at more depths. Water salinity is 37.8 psu at the surface of water. Due to the incoming current into the Persian Gulf, salinity decreases to 37.5 psu. At the depth of 40m, it increases again and reaches 38 psu.



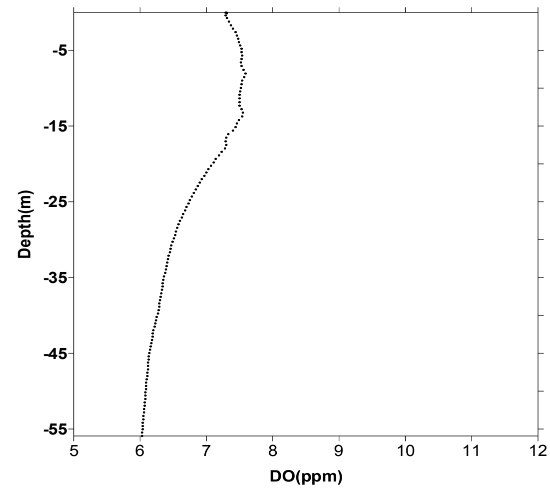
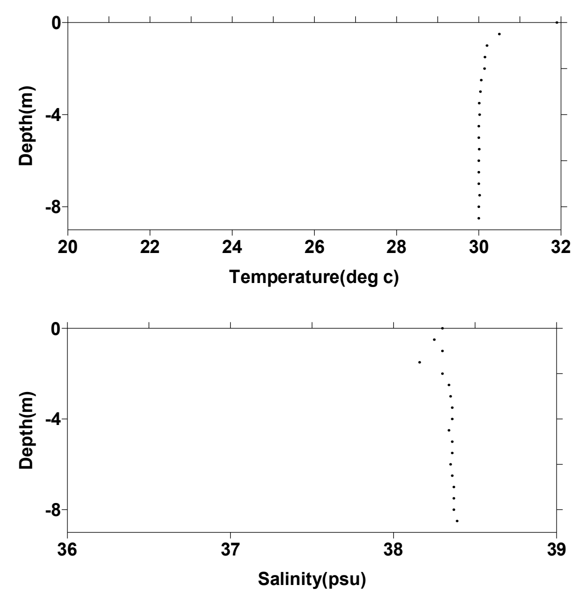


Figure 8: Measured CTD data in south of the Qeshm Island in November 2008

Parameters measured in an area close to the Bandar Abbas coasts show that water temperature at the surface of water decreases from 31.5°C to 30°C at the depth of 2m. The same temperature (30°C) is maintained to the bed.

Chlorophyll contents of the seawater decrease to 34 mg/m^3, 2 mg/m^3, and 6 mg/m^3, respectively. The dissolved oxygen at the surface of water, at the depth of 2m and 4m are 10.8 ppt, 8 ppt, and 6 ppt, respectively; this trend is proportion to chlorophyll. Salinity of the seawater slowly increases from the surface to the depth.



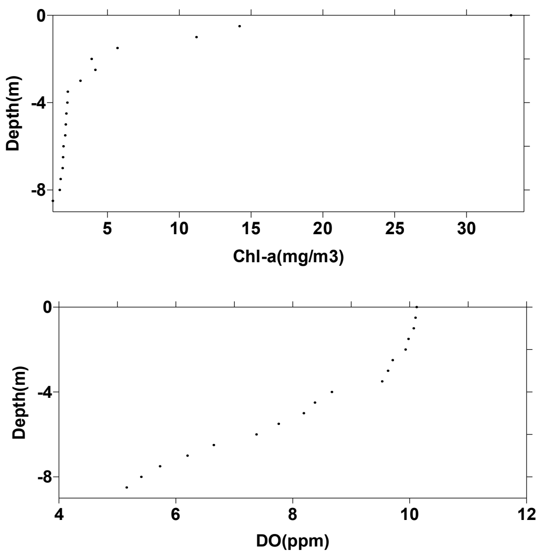


Figure 9: Measured CTD data in south of the Bandar Abbas coast in November 2008

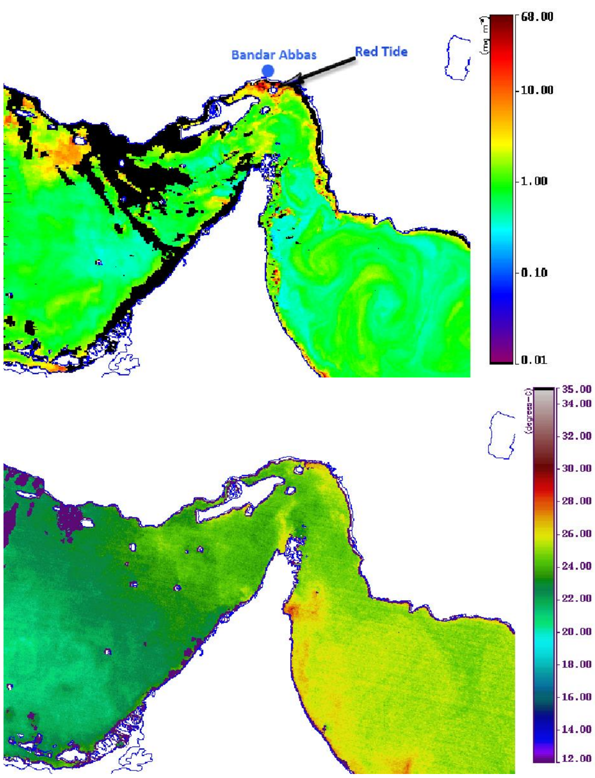


Figure 10: Satellite images of temperature, and surface water chlorophyll, on 29 February 2009 using MODIS sensor data

In addition, satellite images drawn by SeaDAS software shows that the highest temperature of the surface water in the north water of the Strait of Hormuz belongs to the east of Badar Abbas coasts where the chlorophyll content is high. By moving toward the Persian Gulf, temperature drops and chlorophyll content decreases. In the eastern regions of the Strait of Hormuz, the temperature is lower than the one of the center of the Strait of Hormuz. However, high chlorophyll content in the eastern coasts located in the north of the Strait of Hormuz can be seen as a narrow strip on the coastline. This issue shows that the algae concentration in the eastern coast of the Strait of Hormuz is more than the other regions, which may be due to more nutrients in this region and entering such materials through the industrial and urban sewage.

4. Conclusion

With respect to the results obtained in this study, one is able to conclude that consistency of the chlorophyll-a distribution, dissolved oxygen and algae (the agent responsible for creating the red tide) in the studied stations and satellite sensor chlorophyll images can be studied. The achieved consistency can be attributed to the availability of chlorophyll in algae, photosynthesis action, and oxygen generation.

The most distribution of algae and chlorophyll-a can be seen in the surface water of the north of the Strait of Hormuz and south and east of Bandar Abbas. This indicates that nutrients are abundant to feed algae and there are appropriate physical and biological conditions for them to grow in this area.

Chlorophyll content and algae distribution were measured by the stations. Satellite images confirm that algae density in nearshore area is more than the one in offshore areas, which indicates that the growth conditions of the algae in the water close to the coastline is more appropriate, as nutrients and oxygen contents are more.

Chlorophyll distribution in the vertical section and surface to depth diagram indicates that HAB density decreases from surface to depth. Because light, nutrients and oxygen contents in deeper waters are far less than the surface water. These conditions limit the growth and living of the algae.

The oxygen content in the north of the Strait of Hormuz and in areas with high concentration of HAB is high. This can be attributed to the generation of oxygen due to the photosynthesis of algae, which is responsible to create red tide during the day. However, the similar measurements carried out during night and early morning prove the opposite and indicate that the algae consume oxygen during the night. Consequently, the oxygen content is reduced.

In the central areas of the Strait of Hormuz, the chlorophyll content at the depth of 20 to 30 meters is a little more than the surface of water. This indicates that there is a limited area, which is appropriate for the algae to grow and there are some constraints for their growth.

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