

Abstract

Phytoplankton as chlorophyll-containing organisms is the first step of production in most marine processes and food chains. Nutrient enhancement in the seawater due to the discharge of agricultural, industrial, and urban wastes threatens the Caspian Sea environment. Increasing concentrations of chlorophyll-*a* in seawater, in reaction to the elevation of nutrient supply can have severely damaging effects on the marine environment of the Caspian. In this research, seasonal variability of the chlorophyll-*a* concentrations in the western part of the southern coastal waters of the Caspian Sea near Iranian coast was examined using field observations. The data showed that the most chlorophyll-*a* was found below the sea surface. The thermal stratification in water column and outflow of the Anzali Lagoon affect the chlorophyll-*a* concentrations in the region. Concentrations of chlorophyll-*a* were recorded in midsummer in a range of 0.2–3.4 mg m⁻³.

1 Introduction

1.1 The Caspian Sea

The Caspian Sea, with surface area of 400 000 km² and length of coastline about 7500 km (at about 27 m depth below the ocean level) is the largest enclosed water body in the world. It contains rich hydrocarbon reserves and biological resources (Dumont, 1998; Zonn, 2005a, b; Kosarev and Kostianoy, 2005). The length of the sea from south to north is more than 1030 km, and its width from west to east is in a range of 200–400 km (Zenkovich, 1963; Klig and Myagkov, 1992; Kosarev, 2005). According to the meridional extent of the Caspian Sea, there are several climate zones over the sea. The climate in the southern Caspian Sea is subtropical which is influenced in winter by southern cyclones and a stable and dry weather in summer (Kosarev, 2005). Based on surface monitoring in the Caspian Sea, the northern basin had the largest diversity

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and productivity relative to the middle and southern parts of the sea (Kasymov and Rogers, 1996). Due to the isolation of the Caspian Sea from the open seas, its natural regime, hydrological structure and circulation are affected by external factors such as discharge of rivers and atmospheric processes (Tuzhilkin and Kosarev, 2005). About 130 rivers with various outflow volumes enter the sea. The main sources of fresh-water inputs to the Caspian Sea are the Volga (with a total volume of about 80–85% of inflow), Ural, Emba, Terek Rivers in the north (Rodionov, 1994; Mamedov, 1997). In the south, the total volume inflow of the Iranian rivers to the sea is about 4–5%; the Sepidrood River (originating from the Elburs Mountains) is the largest (Kosarev, 2005; CEP, 2002). Surface water temperature in this part was reported to be about 10 °C in winter and 27–28 °C in summer (Dumont, 1998). Based on the International Atomic Energy Agency (IAEA) measurements near the Iranian coasts in September 1995, surface water temperature was about 27.5 °C with salinity of 12.24 PSU (IAEA, 1996).

1.2 Chlorophyll-*a* in the Caspian Sea

Chlorophyll-containing organisms are the first step of production in the most food chains, and the health and abundance of these primary producers affect the integrity of the other trophic levels in the Caspian Sea. The northern region (shallow water) and deep-water zone of the Caspian Sea in the middle and southern parts are different in ecological and hydrological characteristics. Chlorophyll-*a* concentrations in various parts of the Caspian Sea are affected by some important factors such as air and seawater temperatures, wind stress anomalies over various areas of the sea, and discharge of the Volga and Ural Rivers (Nezlin, 2005). In the deep-water zone of the middle and southern Caspian Sea, thermal structure and stratification of the water column regulate the concentrations of chlorophyll-*a*. In this region, the seasonal sharp thermocline in summer acts as a barrier resulting in natural nutrient limitation for phytoplankton growth. In the northern part of the Caspian Sea, interannual and seasonal

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5 variability of phytoplankton biomass is under the influence of freshwater discharges of the Volga River. The seasonal pattern of chlorophyll concentration (based on Sea WiFS observations 1997–2004) shows that the maximum values in the southern Caspian Sea occurred at the surface layer in August. Generally, chlorophyll concentration in the northern Caspian Sea is higher than its concentrations in the southern and middle deep parts of the Caspian Sea (Nezlin, 2005).

10 The Caspian environment is under high stress, due to the extensive exploitation and discharge of large magnitudes of human waste such as discharge of domestic sewage waters, industrial and agricultural wastewater that contain nutrients, pesticides and detergents that threatens the Caspian ecosystems (Kosarev and Kostianoy, 2005; Zonn, 2005b; Korshenko and Gul, 2005). For example, a large scale Anomalous Algal Bloom (AAB) was observed for the first time in the southern basin of the Caspian Sea during August–September 2005. The algal bloom was a consequence of the highly increased concentration of phytoplankton following increased nutrient input to the Caspian sea-
15 water (CEP, 2006).

In addition, maximum levels of the chlorophyll-*a* concentration (i.e. phytoplankton biomass) were observed in the middle and southern parts of the Caspian Sea in summer 2001 (Kideys et al., 2008; Nezlin, 2005). This phenomenon was not related to the changes in physical conditions such as water temperature or wind stress. Some au-
20 thors believe that maximum levels of phytoplankton (maximum values of chlorophyll-*a* concentrations) was due to the invasion of *Mnemiopsis Leidyi*, which was observed in the middle and southern basin of the sea (Kideys et al., 2008; Kideys and Moghim, 2003; Nezlin, 2005).

25 Very low and high levels of concentrations of chlorophyll-*a* can be harmful to marine biota. Chlorophyll concentration is one of the key indices in the study of the health status of any natural marine ecosystem. Therefore, the investigation on variations of chlorophyll-*a* is very important to the study of water quality and marine pollution in the Caspian Sea. Variability of chlorophyll-*a* concentrations determines the ecological conditions of marine systems such as the changes in the physical and chemical

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characteristics of the environment. One of the fundamental interests of oceanographers is the investigation of ecological characteristics of seawater.

In previous studies, the monitoring of the chlorophyll-*a* concentrations in the Southern Caspian Sea is organized based on satellite data sets (e.g. Nezlin, 2005; Kideys et al., 2008). The vertical structure of chlorophyll-*a* concentrations and its variations in deeper layers of the southern Caspian seawater are not well known (Kideys et al., 2008; Nezlin, 2005) and needs more investigation.

The objective of the study is an investigation on the concentrations and structure of chlorophyll-*a* in the southern coastal waters of the Caspian Sea. For this purpose, the seasonal distributions of chlorophyll-*a* near to Anzali Port in north of Iran were evaluated using in situ measurements.

2 Material and methods

The analysis conducted in this work was based on experimental observations in the southern part of the Caspian Sea. Data collection were performed in spring (April), summer (August) and autumn (November) in the southern coastal waters of the Caspian Sea by using a small research vessel. The study area was located in the west part of the southern coastal waters of the Caspian Sea near the Iranian boundary between latitudes of 37°29' N and 37°39' N and between longitudes of 49°25' E and 49°45' E. The sampling stations were located in a rectangular area of coastal waters with the length of 25 km and width of 15 km adjacent to Anzali Port and Lagoon. Figure 1 indicates study area and positions of field survey stations. Mean temperature in Anzali Lagoon is reported as about 16°C, which varies from 4.5°C in winter (February) to 27.5°C in midsummer (August) (Asadullayeva and Alekperov, 2007). In the investigated area, depth from the west to the east increases and reaches to about 500 m. In the eastern part, continental shelf has a width of 8 km and a maximum depth about 50 m. Here, the depth from the coast increases gently to about 50 m near the shelf break and after that reaches to 200 m depth at about 12 km (Zaker, 2007). Field

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observations in the study area were carried out at 23 stations along four survey lines perpendicular to the coastline and two transects parallel to the coast in year 2008. Distance between the stations reached to an average of 2 km along transects. A portable Ocean Seven 316 CTD probe developed by IDRONAUT was applied. Probe was set in *Timed Data Acquisition* mode for profiling. The profiler was used in free-fall mode at one metre per second recording at one-second time intervals.

3 Results

Chlorophyll-*a* concentrations can act as an indicator of phytoplankton abundance and biomass in the coastal waters. It is natural for levels of chlorophyll-*a* to fluctuate over the different seasons. In this paper, variations of chlorophyll-*a* in upper layers of Iranian coastal waters of the Caspian Sea are presented. Seasonal variability in the vertical distribution of chlorophyll-*a* along transects AB and CD perpendicular to the coastline and near to mouth of the Anzali Lagoon are presented in Fig. 2. Here at the time of measurements in early spring (April), the concentrations of chlorophyll-*a* increased with depth. Concentrations at the sea surface mainly varied between 1.3–1.4 mg m⁻³ along transect AB while in transect CD the values were in range of 1.1–1.4 mg m⁻³. Maximum value of chlorophyll-*a* was recorded around 2.1 mg m⁻³ at depth of 20 m in both transects (Fig. 2a and d). Vertical gradient of concentrations in transects AB and CD in midsummer (August) was more than early spring (April). According to the measured data in summer, maximum value of chlorophyll-*a* in transect AB was around 3.4 mg m⁻³ at 5 m depth while minimal was 0.4 mg m⁻³ between 15–20 m (Fig. 2b). In transect CD, maximal and minimal chlorophyll-*a* were 2.4 mg m⁻³ around 5 m depth and 0.2 mg m⁻³ below 25 m depth, respectively (Fig. 2e). In August horizontal gradient of chlorophyll-*a* in 2 m upper layer at the sea surface was very slight and contour line of 0.6 mg m⁻³ concentration was horizontal (Fig. 2b). In November, concentrations near the sea surface in transect AB were recorded between 2–2.1 mg m⁻³. As it can be seen in Fig. 2c, the concentrations enhanced to 2.4 mg m⁻³ from the sea surface to depth

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largest chlorophyll-*a* concentrations were found near the sea surface, because there is less light at depth. In other words, the highest values of the chlorophyll-*a* concentrations were often located just below the surface between 5–20 m depths.

Based on measurements in the coastal waters of Rudzar (Fig. 1) in summer 2008, the amounts of the chlorophyll-*a* concentrations varied from 3.8 to 0.1 mg m⁻³ with the maximal levels at 15 m depth. In addition, chlorophyll-*a* concentration sharply decreased with depth and reached around 0.5 mg m⁻³ and 0.1 mg m⁻³ at 60 m and below 80 m depths, respectively (Jamshidi et al., 2010). Therefore, it is found that the largest concentrations of chlorophyll-*a* in the study area were limited to the upper layers including the surface mixed layer and thermocline (around 50 m surface layers). The seasonal variations of the chlorophyll-*a* in the region were described by one obvious maximum in midsummer. Nezhlin (2005) reported similar phenomenon in the South Caspian Sea.

Investigation on vertical, horizontal and seasonal structures of the chlorophyll-*a* found that the changes in chlorophyll-*a* concentrations far from the mouth of the Anzali Lagoon were slight. While near to the mouth of the lagoon, chlorophyll-*a* concentrations showed a greater range. In offshore stations (deepwater zone), concentrations of chlorophyll-*a* and process of phytoplankton growth were mainly under effect of thermal stratification of the water column. As it can be seen in Figs. 3 and 4, the most changes of the concentrations outside the shelf were in surface mixed layer and thermocline. In the southern coastal waters of the Caspian Sea, pycnocline was established in position of thermocline layer in warm seasons (Zaker et al., 2007). The formed pycnocline acts as a natural boundary separating the surface warm and well-illuminated layer from the near bottom layer, which is rich in nutrients.

Southern lagoons and coastal regions of the Caspian Sea have been steadily polluted with anthropogenic sources (fertilizer and pesticides used in agriculture and increased nutrient load of river flows due to deforestation of woodland) since the early 1980s. Thus, simultaneous rises in nutrient contributed to increases in chlorophyll-*a* values (Kideys et al., 2008; Kideys and Moghim, 2003; Kopelevich et al., 2008). Due

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to the location of the investigated region near the mouth of the Anzali Lagoon, the chlorophyll-*a* concentrations in the area were high, especially in midsummer. Because of the entrance of pollutant, the environment of the Caspian is under pressure. According to the discharge of local rivers and lagoons in the coastal waters, seawater in the near mouth areas has different conditions from deep water zone as shown by the enhanced chlorophyll-*a* concentrations. The marine environment of the Caspian Sea needs serious measures to prevent the entrance of the degradable wastes, nutrients and industrial pollutants.

5 Conclusions

Presented data in this manuscript provide a preliminary knowledge on the distributions of chlorophyll-*a* in the coastal waters of Anzali Port in the southern Caspian Sea. The results showed that the maximum concentrations of chlorophyll-*a* were observed around 5 m depth in summer. Below the thermocline, values of chlorophyll-*a* rapidly decreased and its concentrations were slightly near the bottom.

Higher chlorophyll-*a* concentrations were recorded during summertime (August) measurements when the water temperature and light levels in the region were higher. The average of the concentrations of chlorophyll-*a* is an important indicator for the state of the marine environment of the region in the southern Caspian Sea. The structure of the variations of chlorophyll-*a* in the coastal area and near mouth of estuaries, rivers and lagoons was different in comparison to offshore area. The chlorophyll-*a* concentrations in the western part of the study area and near mouth area were higher than in the eastern region.

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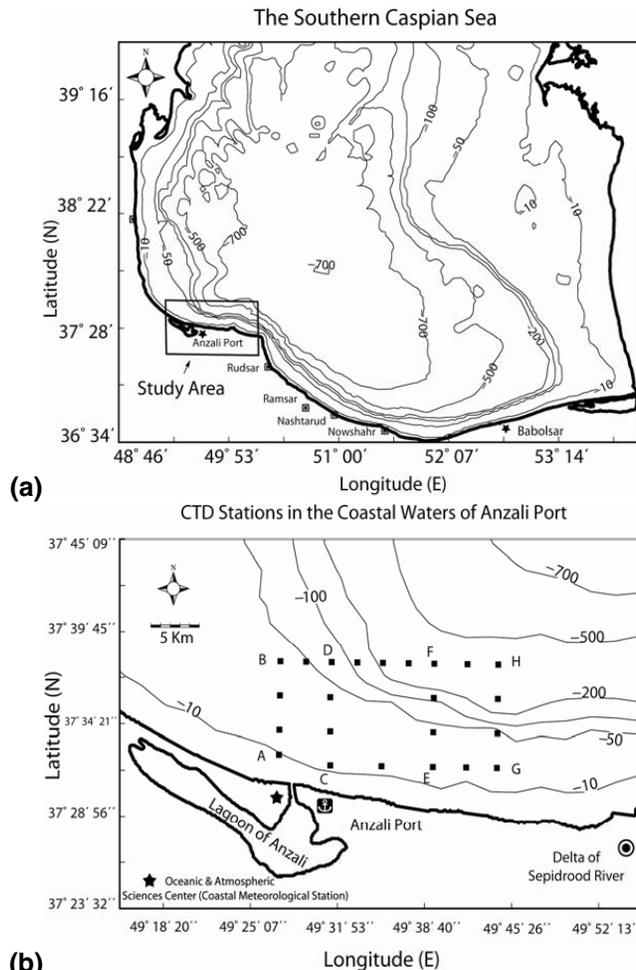
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Fig. 1. (a) Study area in the southern Caspian Sea and (b) positions of sampling stations.

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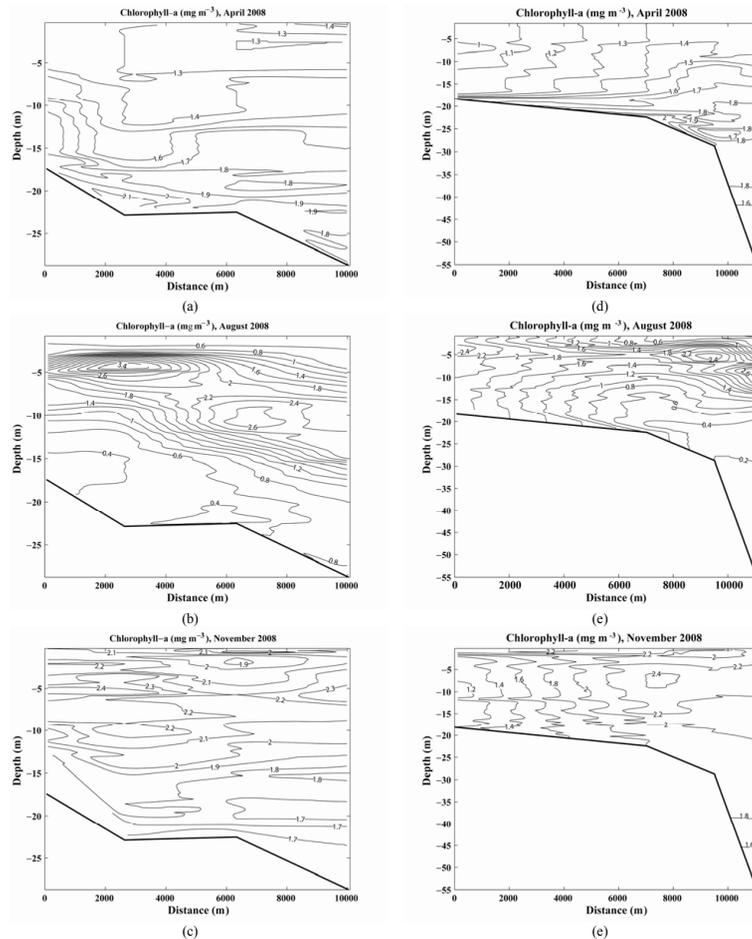
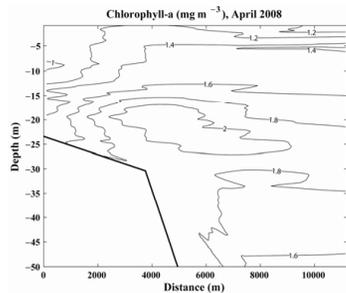
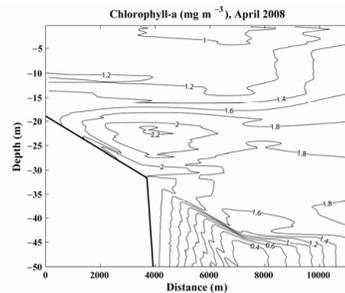


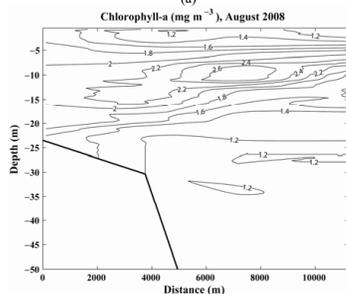
Fig. 2. Seasonal variations of the chlorophyll-*a* along transects AB (left panel) and CD (right panel).



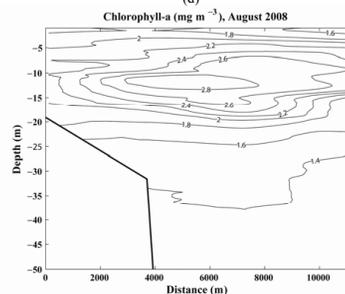
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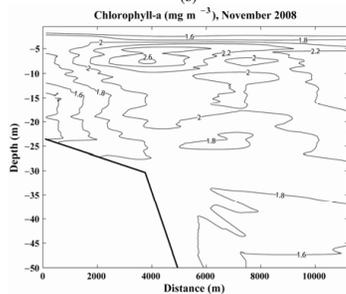
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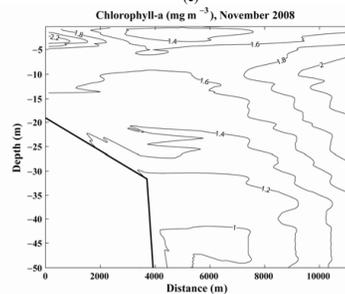
(b)



(e)



(c)



(f)

Fig. 3. Seasonal variations of the chlorophyll-*a* along transects EF (left panel) and GH (right panel).

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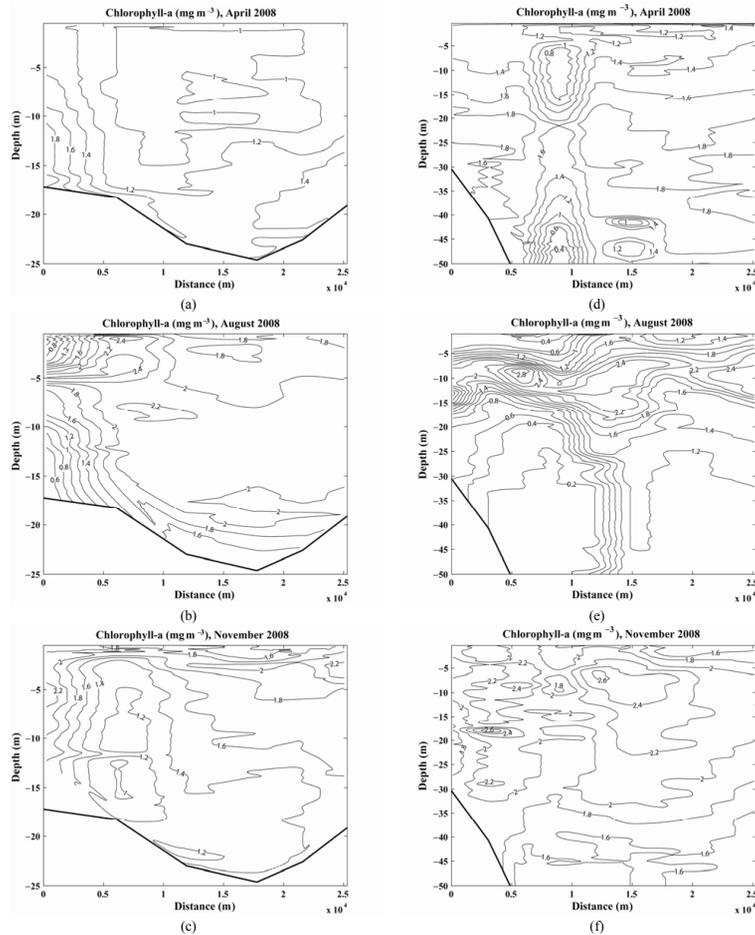


Fig. 4. Seasonal variations of the chlorophyll-*a* along transect AG (left panel) and BH (right panel).