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Seasonal Variations of Seawater Properties in the Southwestern Coastal Waters of the Caspian Sea

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ABSTRACT: Seasonal variations of the seawater properties (e.g. temperature, salinity, density and chlorophyll-*a*) in western part of the southern coastal waters of the Caspian Sea near the Iranian coast were studied. A portable CTD probe was applied for profiling from sea surface to bottom at 23 stations. Maximum depth of the profiling stations was more than 470 m in the study area. Vertical structure of temperature in the southern Caspian Sea waters is characterized by a significant seasonal thermocline between 20-50 m depths in summer with a vertical gradient of 16 ^{o}C. Seasonal average of the salinity was in a range of 12.27-12.37 PSU in period of measurements. The data showed that the most chlorophyll-*a* was found below the sea surface. In general, variations of the chlorophyll-*a* concentration in the study area can be attributed to the effect of changes of seawater characteristics in various seasons, stratification and heating the sea surface layer in the warm seasons and discharge of lagoon and rivers in the study area. The range of the concentrations at the sea surface in August and November were higher than the measured values in April in the study area. Concentrations of chlorophyll-*a* were recorded in midsummer in a range of 0.2-3.4 mg m^{-3}.

Keywords: *Caspian Sea; Coastal Waters; Thermal Stratification; Chlorophyll-a Concentrations*

INTRODUCTION

The Caspian Sea

The Caspian Sea, with surface area of 400,000 km^2 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 stable and dry weather in summer (Kosarev, 2005). Based on surface monitoring in the Caspian Sea, the northern basin had larger diversity 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 freshwater 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^{o}C in winter and 27-28^{o}C in summer (Dumont, 1998). Based on International Atomic Energy Agency (IAEA) measurements near the Iranian coasts in September 1995, surface water temperature was about 27.5^{o}C with salinity of 12.24 psu (IAEA, 1996).

Southern Caspian Sea Dynamics

There is a dipole system in the deep water zone of the southern Caspian Sea like the middle part of the Caspian Sea. The system of the middle part consists of a cyclonic gyre and an anti-cyclonic gyre in its northwestern and southeastern area, respectively. In

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the southern basin, the anticyclone and the cyclonic gyre are located in the northwest and southeastern area, respectively. The current speeds at the centers of the sub-basin gyres are 0.05–0.10 ms^{-1} and reach 0.20 ms^{-1} at the boundaries of gyres. In the vertical direction, all the gyres extend down to an intermediate layer at a depth of 100 m. In deeper layers, the circulation characteristics become less distinct and the velocities reduce to 0.05 ms^{-1} (Tuzhilkin and Kosarev, 2005).

The circulation in the central basin of the sea is mainly cyclonic in the winter (January) with southward and northward current along the western and the eastern coast, respectively. The southward currents develop along the eastern boundary of the sea in the winter (February). A very strong Ekman current and upwelling can be observed in the eastern side of the sea in the summer. There is a similar current in the autumn that reaches the western coast of the southern Caspian Sea. In the southern basin, there is a cyclonic gyre in the center part which is weaker in the summer. The southward current is observed along both sides of the Southern Caspian Sea; it becomes stronger in the midsummer (August). The dominant surface currents are mainly from west to the east in the southern coastal waters of the sea (e.g. coastal area of the Anzali Port), (Birol Kara *et al*., 2010).

Hydrological Parameters (Temperature and Salinity)

Based on the measurements, water temperature at the sea surface varied in a range from 9 to 10 ^{o}C in 11 March 2008, which gradually decreased to 8 ^{o}C at 100 m depth. In that time, salinity values were between 12.2 psu and 12.3 psu at the surface and in 100 m depth respectively, in the offshore area far from the mouth of Anzali Lagoon. In 28 April 2008, the water temperature at the surface was 18-19 ^{o}C which decreased to 9-10 ^{o}C at 50 m depth. In summer (13 August), surface water temperature showed values around 27 ^{o}C with a decrease to 10 ^{o}C below the thermocline at 50 m level. The variations of salinity varied from 12.1 psu to 12.3 psu in the upper 50 m layer. In the time of measurements in the autumn (6 November), the thermocline was located between 35 and 45 m depths. The seawater temperature at the lower levels of thermocline was about 10 ^{o}C. The surface mixed layer in the autumn (November) had a thickness of 35 m with temperature of 19-20 ^{o}C. Observed data for salinity showed a value of 12.4 psu in the surface mixed layer and thermocline, which decreased to 12.3 psu at 100 m depth. Most variations of seawater characteristics are largely limited to the upper 100 m layer, over the southern continental shelf of the sea. The seasonal changes of water properties in the intermediate layer are less than in the surface layer. In the deep water layer, seasonal changes of seawater parameters were insignificant.

Based on the results of previous study in the southern coastal areas, the structure of seawater temperature indicates the existence of a thermocline located in the upper layer (varied between sea surface and 50 m depth) in midsummer. The thickness of the thermocline is reduced due to increase of turbulent kinetic energy and deepening of the surface mixed layer in the autumn (Zaker *et al*., 2007).

Chlorophyll-a in the Caspian Sea

Nowadays, one of the fundamental interests of oceanographers is the investigation on ecological characteristics of seawater. Chlorophyll-containing organisms are the first step of production in 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 thermocline affects the distribution of phytoplankton and chlorophyll-*a* concentrations. In the northern part of the Caspian Sea, interannual and seasonal variability of phytoplankton biomass is under the influence of freshwater discharges of the Volga River. 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). The seasonal pattern of chlorophyll concentration (based on SeaWiFS observations 1997-2004) shows that the maximum values in the southern Caspian Sea occurred at the surface layer in August. A maximum levels of the chlorophyll-*a* concentrations 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 authors believe that maximum levels of phytoplankton 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).

The Caspian environment is under high stress, due to the extensive exploitation and discharge of large magnitudes of waste such as domestic sewage waters, industrial and agricultural wastewater that threaten the Caspian ecosystems (Kosarev and Kostianoy, 2005; Zonn, 2005b; Korshenko and Gul, 2005). For example, a large scale Anomalous Algal Bloom (AAB) was observed in the southern basin of the Caspian Sea in 2005. The algal bloom was a consequence of the highly increased concentration of chlorophyll-*a* in the Caspian seawater (CEP, 2006).

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 need more investigation. The aim of the research is investigation on variations of chlorophyll-*a* concentrations in the southwestern coastal waters of the Caspian Sea. For this purpose, the seasonal distributions of chlorophyll-*a* near Anzali Port in northern Iran are evaluated by using *in situ* measured data.

MATERIALS AND METHODS

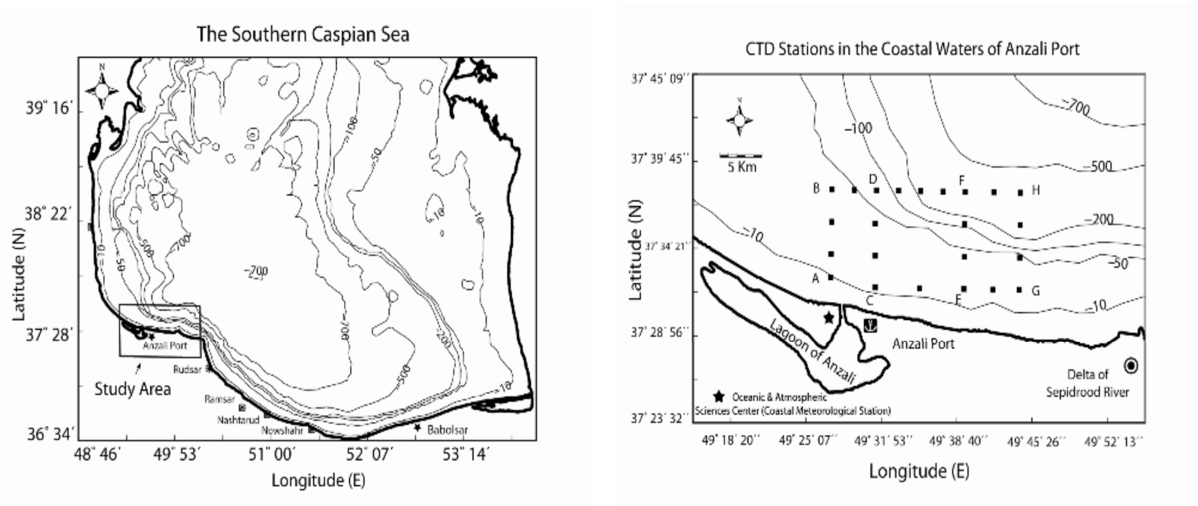
Study Area

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 N37° 29′ and N37° 39′ and between longitudes of E49° 25′ and E49° 45′. The sampling stations were located in a rectangular area of coastal waters with a length of 25 km and width of 15 km adjacent to Anzali Port and Lagoon. Fig. 1 indicates the study area and positions of sampling stations (Jamshidi and Bin Abu Bakar, 2012). The mean temperature in Anzali Lagoon was reported about 16 ^{o}C, varying from 4.5 ^{o}C in winter (February) to 27.5 ^{o}C in midsummer (August) (Asadullayeva and Alekperov, 2007). In the investigated area, depth from the west to the east increases and reaches about 500 m. In the eastern part, the continental shelf has a width of 8 km and a maximum depth about 50 m. In general, 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 offshore (Zaker, 2007).

Field Measurements

Data collection was performed in spring (April), summer (August) and autumn (November) using a research vessel. Field measurements 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. Distance between the stations reached an average of 2 km along transects.

For measuring seawater properties (such as temperature, salinity, chlorophyll-*a*) a portable CTD probe (Ocean Seven 316) developed by IDRONAUT was applied. The probe was set in *Timed Data Acquisition* mode with one-second time intervals. The chlorophyll-*a* concentrations were measured by *SEAPOINT Fluorometer* sensor on the CTD probe. The fluorometer sensor provides a method to monitor chlorophyll concentration by transmitting excitation beams of light in the blue range (around 445 nm and modulated at 1 kHz) and measures the amount of red light (with wavelength about 685 nm) emitted from the sample. Chlorophyll, when excited by the presence of an external light source, absorbs light in certain regions of the visible spectrum and re-emits a small part of this light as fluorescence at longer



(a) (b)

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

wavelengths. This technique measuring chlorophyll-*a* allows this measurement to be done *in situ* and in a time-series. The sensor was factory calibrated using especial and standard methods, instruments and references solutions. Before each field survey, the re-check procedure was performed by the standard solutions and specific methods (according to the operation manual) which were available from the IDRONAUT manufacture. The *SEAPOINT Fluorometer* sensor of the probe was calibrated for chlorophyll-*a* measurement in a scale of 0~15 mg m^{-3} range, 0.05 mg m^{-3} accuracy and 0.003 mg m^{-3} resolution.

RESULTS AND DISCUSION

Vertical Structures of Temperature, Salinity and Density

Seasonal variations in vertical profiles of seawater properties such as temperature, salinity and density at the deepest station are illustrated in Fig. 2. According to the profiles, the highest surface water temperature is observed in midsummer (August). The seawater parameters vary most through the mixed layer and thermocline. By comparing vertical profiles, the correlation between variations of temperature and density is clearly observed. Seasonal stratification patterns and vertical variations of thermocline at the deepest sampling station far from the coasts are clearly observed in the vertical profiles. In the summer and autumn, the water column is stratified to three layers; surface mixed layer, thermocline and deep water. Physical structure of seawater properties at the time of measurements showed strong thermal stratification in 13 August and 6 November 2008. The vertical structure of temperature is characterized by a significant seasonal thermocline in summer which moves down to deeper levels during autumn. The initial formation of the thermocline was first observed in the onset of spring. The feature continues to grow throughout summer and becomes fully developed in the autumn. The destruction of the seasonal thermocline occurs with the general cooling of sea surface water and deepening of the mixed layer during late autumn to winter. Seasonal variations of the thermocline are detected from the surface to 50 m depth in the spring–autumn periods. It seems that seasonal changes of the pycnocline followed the pattern of seasonal variations of the thermocline. Formation of the pycnocline starts from spring together with the thermocline in the region. The pycnocline (located in the position of the thermocline) is strongest in midsummer (August) and shifts down to around 40 m depth in the autumn. Variations of temperature, salinity and sigma-t in vertical profiles are presented in Table 1.

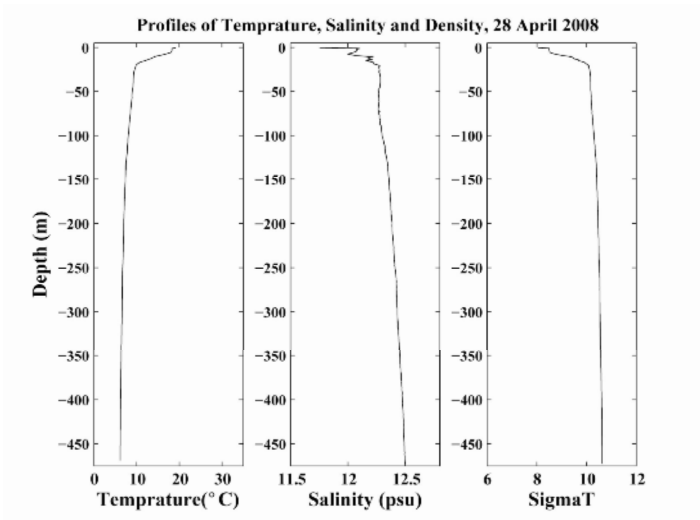
Variations of Chlorophyll-a Concentrations

Variations of chlorophyll-*a* through the upper 50 m in the study area are presented in Fig.s 3-5. Distributions of chlorophyll-*a* concentrations along sections in the region are remarkable.

Transect AB: Seasonal variability in chlorophyll-*a* concentrations over the continental shelf along transect AB near the mouth of the Anzali Lagoon is indicated in Fig.s 3(a, b & c). Along this section the concentrations of chlorophyll-*a* increased with depth and reached a maximum concentration near the seabed in April while the maximum values of chlorophyll-*a* were observed in subsurface layer in August and November. A maximum concentration of 3.4 mg m^{-3} at 5 m depth along this transect in August is notable. The mean values at 5 m depth along transect AB in April, August and November were 1.32 ± 0.05 mg m^{-3}, 2.27 ± 0.99 mg m^{-3} and 2.32 ± 0.15 mg m^{-3}, respectively (Table 2). Vertical variations in concentrations at onshore stations were more than those at the offshore stations, especially in April and August.

Table 1: Summary of variations in seawater temperature, salinity and sigma-t in vertical profiles.

Month	Parameters	Surface layer	Thermocline layer	Deepwater
April	Temperature (°C)	Around 19	18-10	Below 10
	Salinity (psu)	11.7-12.1	12.1-12.25	Up to 12.5
	Sigma-t	8.04-8.51	8.51-9.98	9.98-10.63
August	Temperature (°C)	26-27	26-10	Below 10
	Salinity (psu)	Around 12.3	12-12.35	Up to 12.5
	Sigma-t	6.52-6.8	6.8-10	10-10.63
November	Temperature (°C)	Around 19	18.9-9.8	Below 9.8
	Salinity (psu)	12.5	12.2-12.5	Up to12.5
	Sigma-t	8.58-8.7	8.7-10	10-10.63



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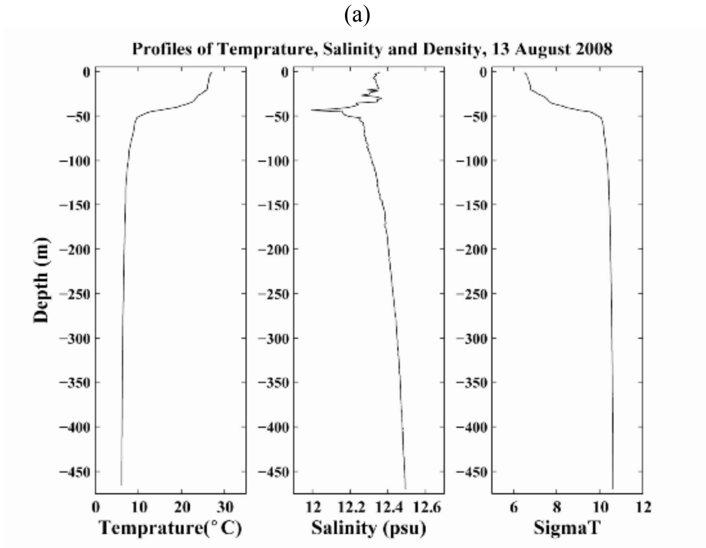

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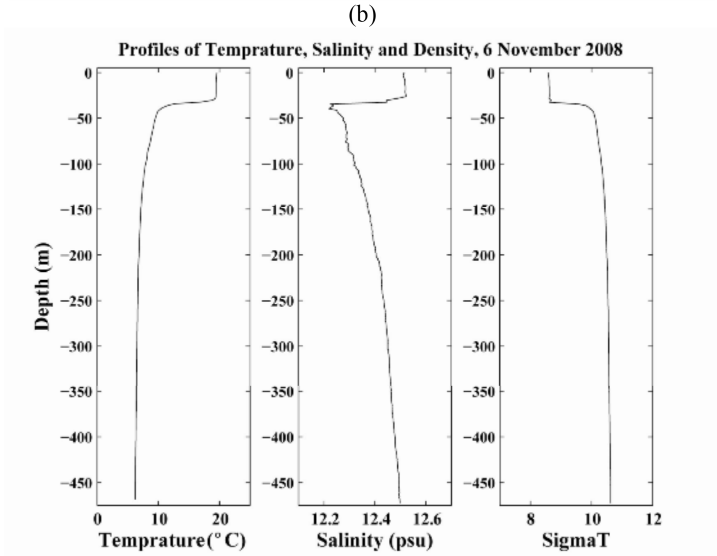


(c)

Fig. 2: Seasonal variations in water temperature, salinity and density in deepest sampling station.

Transect CD: The lagoon outflow mainly influences the seawater properties and their structures over transect CD. In the surface layer of transect in April and November, concentrations increased from the coast towards the offshore stations (Fig.s 3d, 3e and 3f). The average concentrations of chlorophyll-*a* at 5 m depth of transect in April, August and November were 1.25 ± 0.17 mg m^{-3}, 1.92 ± 0.56 mg m^{-3} and 2 ± 0.53 mg m^{-3}, respectively. In the deeper layer of these transects in August a considerable drop in recorded values is observed. Seasonal features along transect CD (and section AB) determine how much biological production occurs in area in front of the lagoon mouth.

Transect EF: Seasonal changes of chlorophyll-*a* concentrations along transect EF are displayed in Fig.s 4 (a, b & c). The concentrations of chlorophyll-*a* along this section were not affected by the lagoon discharge. The concentrations at the sea surface layer (well mixed layer) over the continental shelf and outside the shelf in November were approximately uniform. The maximum level of concentrations was recorded at 10-15 m depths in August. The mean concentrations at 10 m depth along transect EF showed the values 1.35 ± 0.23 mg m^{-3}, 2.2 ± 0.37 mg m^{-3} and 2.02 ± 0.29 mg m^{-3} respectively in April, August and November.

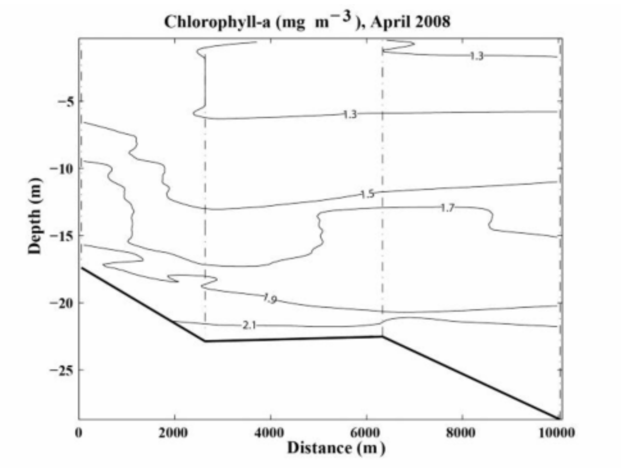
Transect GH: Seasonal variability of chlorophyll-*a* along transect GH were shown in Fig.s 4 (d, e and f). In midsummer (August) horizontal gradient of chlorophyll-*a* concentrations are less than those in April and November. The values along section GH were 1.25 ± 0.17 mg m^{-3}, 2.52 ± 0.23 mg m^{-3} and 1.82 ± 0.28 mg m^{-3} in April, August and November, respectively. The range of chlorophyll-*a* values along this section in August was more than in April and November (Table 2).

Transect AG: Distribution of chlorophyll-*a* along transect AG (parallel to the coastline) are shown in Fig.s 5 (a, b & c). This section is close to the coastline and concentrations at the beginning part of transect (left side of the Fig.s 5 (a, b & c)) are under the influence of the lagoon influx (freshwater discharge). Vertical differences of chlorophyll-*a* in the eastern part of transect at the time of measurements in all seasons were insignificant.

Transect BH: Seasonal distributions of chlorophyll-*a* concentration along transect BH are indicated in Fig.s 5 (d, e & f). The concentrations along this section clearly represent the range of chlorophyll-*a* values in the offshore area. the concentrations at 10 m depth along this transect in April, August and November were 1.35 ± 0.28, 2.28 ± 034 and 2.25 ± 0.16, respectively.

In order to make more comparison between concentrations of chlorophyll-*a* along different transects, minimum, maximum, average and standard deviation at the sea surface and subsurface layers (5 m, 10 m and 15 m depths) were calculated. Statistical summaries of chlorophyll-*a* concentrations along various transects at the times of the measurements are presented in Table 2. In addition, sea surface temperature, mixed layer depth, depth of the subsurface chlorophyll maximum and surface and subsurface chlorophyll-*a* concentrations are presented in Table 3.

Regarding the measured data, it seems that temporal changes in the horizontal, vertical and seasonal distribution of chlorophyll-*a* were associated with changes in water column stratification (mixing), seawater properties and Lagoon freshwater inflows. In general, the greatest concentrations of chlorophyll-*a* were observed throughout the upper 50 m layer.



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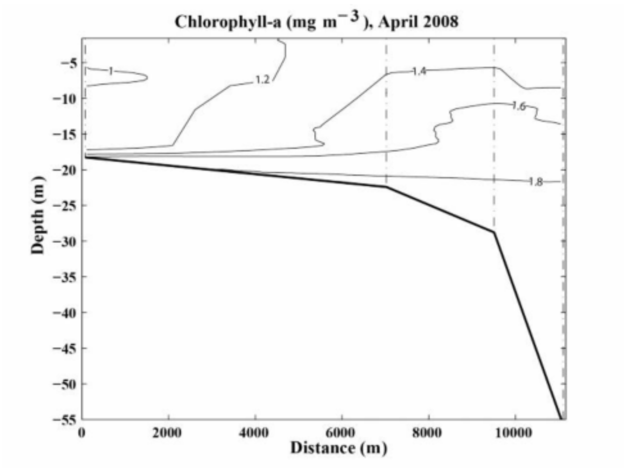

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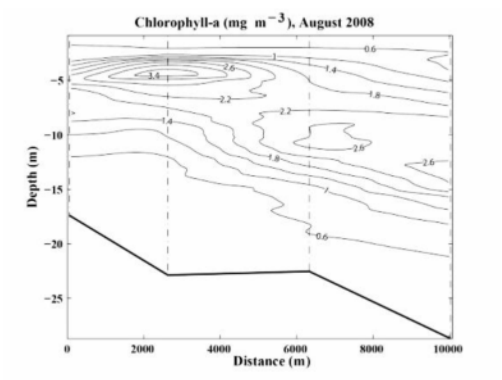

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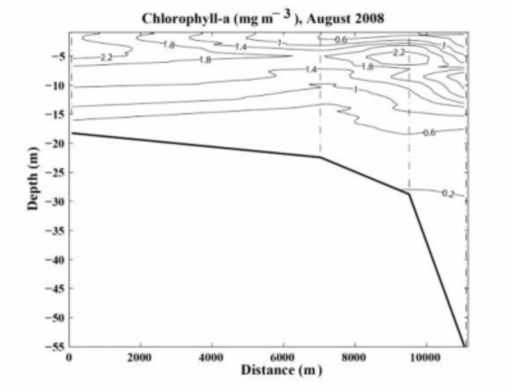

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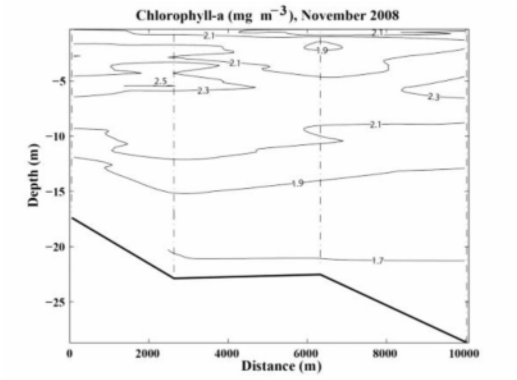

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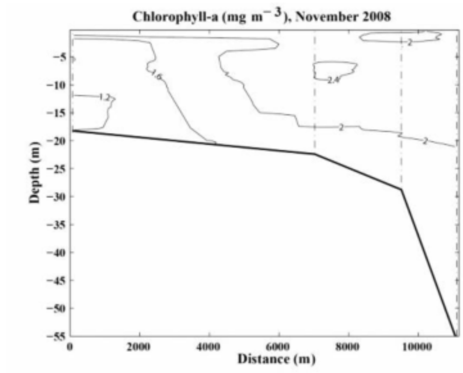

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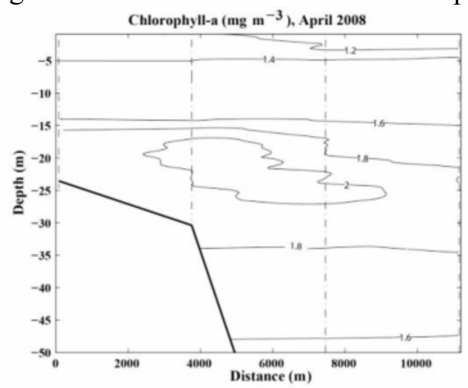
Fig. 3: Seasonal variations of the chlorophyll-a along transects AB (left panel) and CD (right panel)



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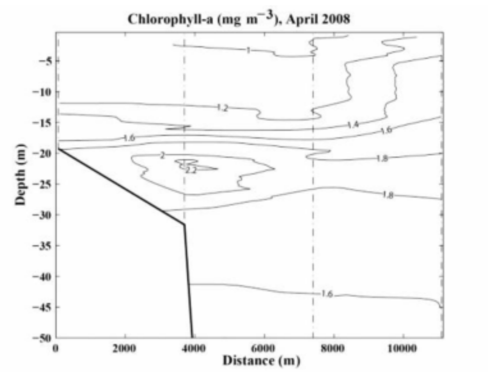

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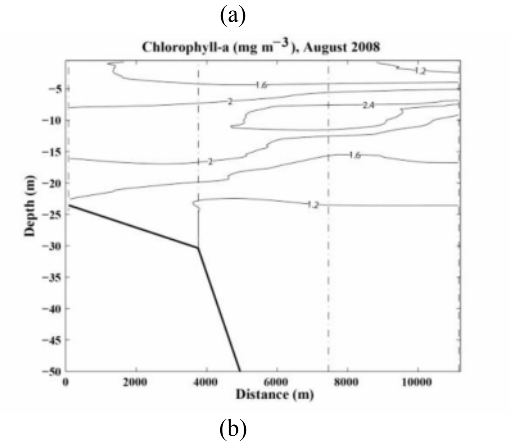

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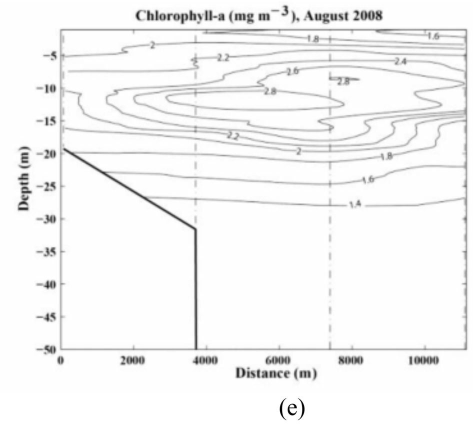

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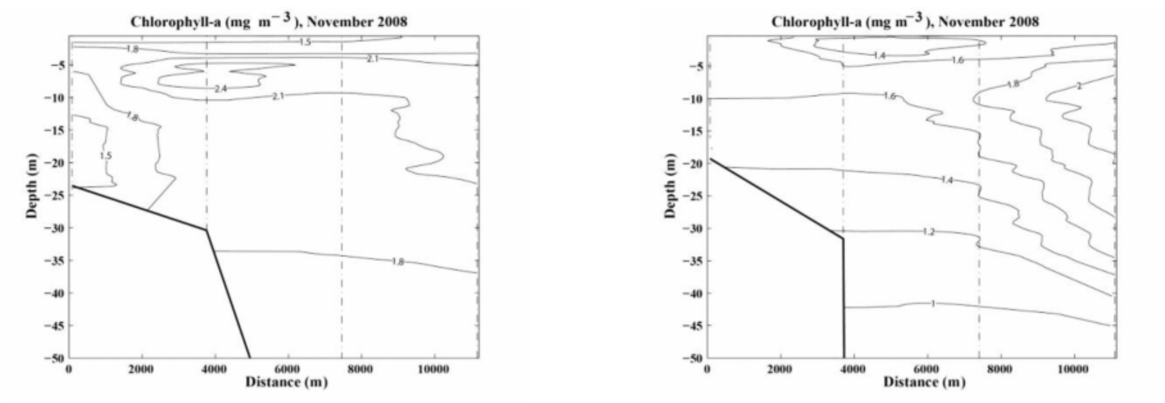
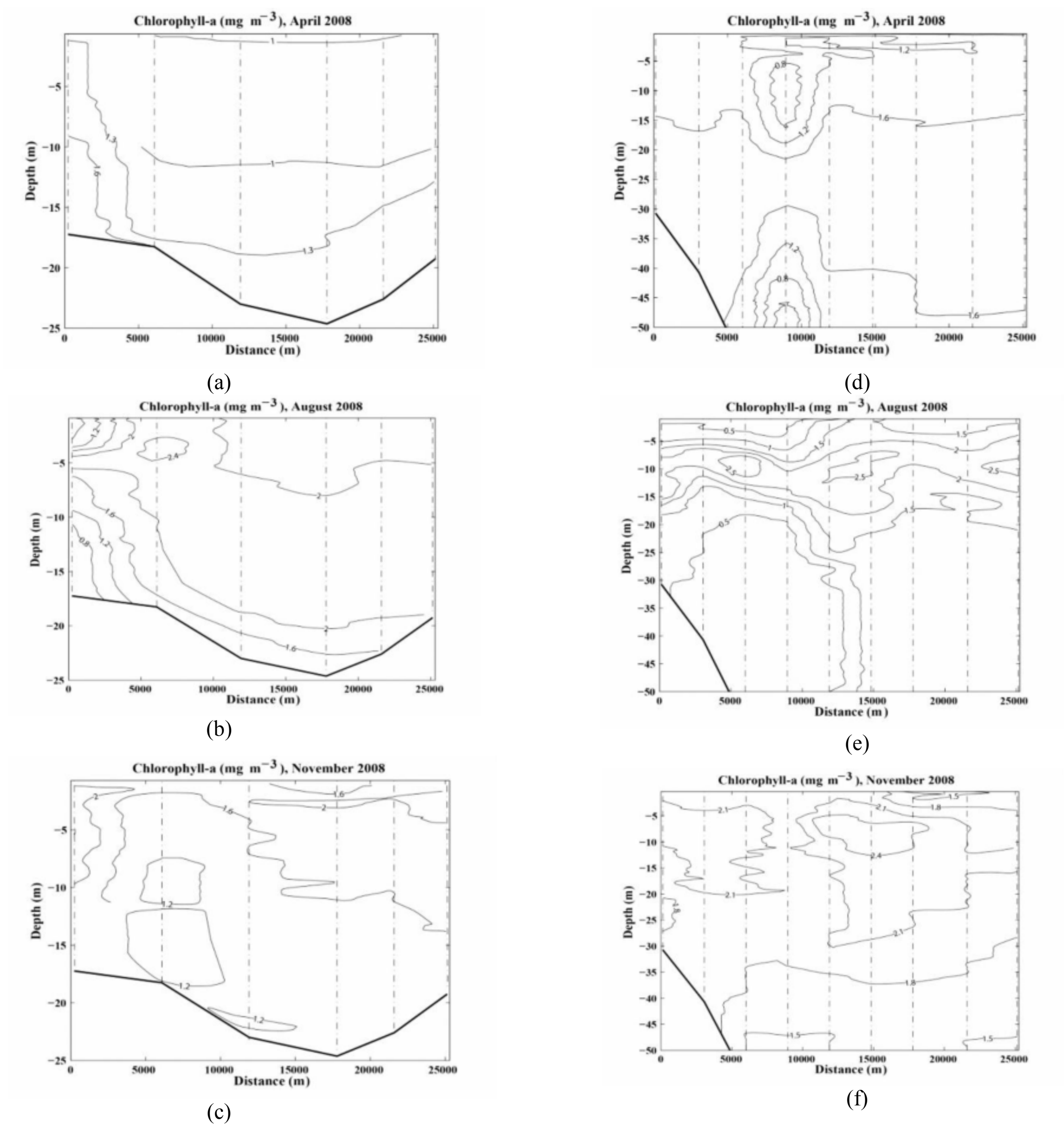


(c) (f)

Fig. 4: Seasonal variations of the chlorophyll-a along transects EF (left panel) and GH (right panel)



(c) (f)

Fig. 5: Seasonal variations of the chlorophyll-a along transect AG (left panel) and BH (right panel)

Table 2: Summary of chlorophyll-*a* concentrations along transects in April, August and November 2008

Transect	Depth	Minimum Chlorophyll-*a*			Maximum Chlorophyll-*a*			Average Chlorophyll-*a*			Standard Deviation		
		Apr.	Aug.	Nov.	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.
AB	Surface	1.3	0.4	2	1.6	0.7	2.1	1.4	0.5	2.05	0.14	0.14	0.05
	5 m	1.3	1.3	2.1	1.4	3.6	2.4	1.32	2.27	2.32	0.05	0.99	0.15
	10 m	1.4	0.8	1.9	1.8	2.6	2.3	1.52	1.62	2.1	0.17	0.86	0.16
	15 m	1.5	0.4	1.8	1.9	1.8	1.9	1.72	1.62	1.82	0.17	0.66	0.05
CD	Surface	1	0.6	2.2	1.3	2.4	2.3	1.2	1.12	2.22	0.14	0.86	0.05
	5 m	1	1.2	1.2	1.4	2.2	2.3	1.25	1.92	2	0.17	0.56	0.53
	10 m	1	1	1.1	1.5	2.7	2.3	1.32	1.77	1.97	0.22	0.74	0.58
	15 m	1.1	0.5	1	1.7	1.9	2.2	1.5	1.05	1.85	0.28	0.59	0.56
EF	Surface	1.1	1	1.4	1.3	1.2	1.5	1.17	1.3	1.45	0.09	0.34	0.05
	5 m	1	1.8	1.8	1.4	2	2.5	1.3	1.92	2.15	0.2	0.09	0.28
	10 m	1	2.1	1.7	1.5	2.7	2.4	1.35	2.2	2.02	0.23	0.37	0.29
	15 m	1.4	1.6	1.3	1.8	2.2	2.3	1.62	1.87	1.9	0.17	0.27	0.42
GH	Surface	1	1.5	1.3	1.9	1.8	1.9	1.3	1.67	1.55	0.42	0.12	0.26
	5 m	1.1	2	1.6	1.6	2.3	1.8	1.25	2.2	1.75	0.23	0.14	0.12
	10 m	1.1	2.2	1.5	1.5	2.7	2.2	1.25	2.52	1.82	0.17	0.23	0.28
	15 m	1.4	1.9	1.5	1.7	2.6	2.1	1.5	2.25	1.7	0.14	0.35	0.27
AG	Surface	1	0.7	1.2	1.4	2.4	2	1.13	1.65	1.71	0.17	0.55	0.38
	5 m	1	1.9	1.2	1.4	2.4	2.4	1.11	2.08	1.76	0.16	0.19	0.40
	10 m	0.9	0.8	1.1	1.8	2.2	1.9	1.15	1.88	1.6	0.33	0.53	0.28
	15 m	1.1	0.4	1	1.9	2.1	1.8	1.41	1.73	1.4	0.27	0.65	0.27
BH	Surface	1.1	0.4	1.4	1.9	1.6	2.2	1.33	0.96	1.74	0.25	0.47	0.29
	5 m	0.8	0.8	1.9	1.6	2.3	2.6	1.25	1.62	2.18	0.21	0.46	0.22
	10 m	1.4	1.8	2	1.5	2.7	2.5	1.35	2.28	2.25	0.28	0.34	0.16
	15 m	0.8	0.7	1.8	1.7	1.9	2.3	1.55	1.61	2.11	0.29	0.53	0.13

Table 3: Surface and subsurface chlorophyll-a concentrations in the sampling stations in April, August and November 2008.

Stations	Sea surface temperature (C)			Mixed layer depth (m)			Subsurface max. chl-*a* (mg m^{-3})			Depth subsurface chl-*a* max. (m)			Surface chl-*a* (mg m^{-3})		
	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.	Apr.	Aug.	Nov.
St01	18.17	28.56	16.94	8	20	35	1.6	2.5	2.2	18.26	3.15	1.16	1.0	2.4	2.1
St02	18.16	28.37	17.59	8	20	35	1.4	2.1	2	22.3	6.85	2.60	1.0	1.5	1.6
St03	18.03	28.36	17.72	8	20	35	1.5	2.1	2.1	24.59	9.11	2.69	1.1	1.8	1.4
St04	18.28	28.42	19.92	8	20	35	2.2	2.3	2.6	19.37	11.24	6.99	1.2	1.2	1.5
St05	18.41	27.55	20.05	8	20	35	2.1	2.7	2.3	24.83	8.92	4.77	1.1	1.2	1.4
St06	18.54	27.88	19.92	8	20	35	2	2.4	2.5	29.11	6.8	7.39	1.3	1	1.5
St07	18.12	27.64	20.32	8	20	35	1.9	2.6	2.5	23.54	7.92	7.48	1.1	1.6	1.5
St08	18.35	27.78	20.15	8	20	35	2	2.5	2.6	24.29	9.89	5.55	1.2	0.4	1.6
St09	18.66	27.71	20.18	8	20	35	1.6	2.4	2.1	21.41	12.75	11.18	1.2	0.3	1.8
St10	17.82	28.39	20.15	8	20	35	1.9	2.9	2.5	20.46	8.33	8.31	1.2	0.9	2.2
St11	18.08	28.02	20.12	8	20	35	1.8	2.2	2.7	19.45	7.42	17.97	1.3	0.5	2
St12	17.66	28.56	19.37	8	20	35	2	2.9	2.4	21.03	12.98	5.41	1.6	0.4	2.1
St13	18.26	28.39	19.27	8	20	35	2.1	2.7	2.2	22.41	10.79	5.78	1.3	0.5	2
St14	18.07	29.28	19.11	8	20	35	2.8	3.6	2.5	22.35	4.34	5.47	1.3	0.3	2.1
St15	18.88	29.32	18.31	8	20	35	2.2	2.4	2.4	16.44	5.02	4.86	1.4	0.7	2
St16	17.80	28.31	17.76	8	20	35	1.6	2.4	2	22.60	13.19	2.10	1	1.8	1.2
St17	17.64	28.35	19.48	8	20	35	1.5	2.2	2.4	14.37	7.48	3.63	1.3	1.7	1.9
St18	17.90	27.82	19.40	8	20	35	2.2	2.9	1.6	21.05	11.08	4.48	1	1.8	1.4
St19	18.15	27.30	19.63	8	20	35	1.9	2.8	1.8	22.62	11.53	9.08	1	1.7	1.3
St20	19.19	27.00	19.58	8	20	35	1.9	2.6	2.2	23.85	9.27	9.62	1.9	1.5	1.6
St21	18.00	26.84	19.74	8	20	35	1.9	2.4	2.2	26.44	8.70	13.45	1.2	1.2	1.4
St22	18.80	28.71	19.17	8	20	35	2.1	1.8	2.4	22.42	5.05	4.22	1.3	0.6	2.3
St23	17.79	28.62	19.61	8	20	35	1.9	2.5	2.3	24.02	5.13	6.07	1.3	0.6	2.2

The results of seasonal distributions of chlorophyll-*a* concentrations in the southern coastal waters of the Caspian Sea were analyzed. In the study area several factors such as stratification, mixing, and seawater temperature affect the concentrations of chlorophyll-*a*. Chlorophyll-*a* concentrations were higher in midsummer than other times. It is can because the sea surface layers in the region receive more sunlight and heating in summer. In autumn with seasonal changes in seawater conditions, destruction of the seasonal thermocline and pycnocline starts. This process can stimulate phytoplankton growth and enhance the concentration of chlorophyll-*a*. On the other hand, due to the location of the study area near the mouth of Anzali Lagoon, the chlorophyll-*a* concentrations in the area are under the influence of the lagoon outflow.

In spring, the vertical gradient of chlorophyll-*a* especially over the continental shelf was less than that in summer. The maximum values of chlorophyll-*a* were observed in midsummer. In August, levels of the chlorophyll-*a* measured near the coastline (at the onshore stations) in the western part of the study region (near mouth of the lagoon) were more than in the eastern area. Overall, the concentrations of chlorophyll-*a* in summer and autumn were larger than recorded values in early spring. The distribution of chlorophyll-*a* indicated a gentle decrease with depth in the area. The largest chlorophyll-*a* concentrations were found near the sea surface, because there is less light at depth. The highest values of the chlorophyll-*a* concentrations were often located just below the surface at 5-20 m depths.

In comparison, the measurements in the coastal waters of Rudsar (see Fig. 1a) in summer 2008 showed that chlorophyll-*a* concentrations varied from 3.8 to 0.1 mg m^{-3} with the maximum 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 seems 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. The previous studies carried out by Nezlin (2005) confirmed similar behavior in the South Caspian Sea.

Investigation of vertical, horizontal and seasonal structures of the chlorophyll-*a* found that variations in chlorophyll-*a* concentrations far from the mouth of the Anzali Lagoon were smaller. Near to the mouth of the lagoon, chlorophyll-*a* concentrations showed a greater range. In offshore stations (deepwater zone), concentrations of chlorophyll-*a* were mainly affected by thermal stratification of the water column. As can be seen in Fig.s 3 and 4, the largest variations of the concentrations outside the shelf were in surface mixed layer and thermocline. In the southern coastal waters of the Caspian Sea, the pycnocline was established in position of a thermocline layer in warm seasons (Zaker *et al.,* 2007). The stratification (pycnocline) may be 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 from anthropogenic sources 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 to the location of the investigated region near the mouth of the Anzali Lagoon, the chlorophyll-*a* concentrations in the area were considerable, especially in midsummer. According to the discharge of local rivers and lagoons in the coastal waters, seawater in the near mouth areas has different conditions from the deep water zone as shown by the enhanced chlorophyll-*a* concentrations.

Increase in chlorophyll during algal blooms (reducing light due to self shading) imply increases in organic matter that is then fed into the microbial loop, which can cause a rapid drawdown in dissolved oxygen concentrations. Therefore, it is the indirect effect of enhanced phytoplankton (and chlorophyll-*a*) that can have a deleterious effect on the marine environment and aquatic ecosystems. As mentioned in the literature, a large scale Anomalous Algal Bloom (AAB) occurred near the Iranian coasts over a region of 20,000 km^2. This unprecedented phenomenon developed in the beginning of the second half of the August 2005 and existed until the end of September 2005. The concentrations of chlorophyll-*a* in this AAB exceeded 50 mg m^{-3} (CEP 2006). According to the reported data in previous studies (e.g. CEP, 2006; Kideys *et al*., 2008; Kideys and Moghim, 2003) it seems that the threshold value of chlorophyll-*a* concentrations probably can be in a range of 8-10 mg m^{-3} for developing a bloom in the sea. This could be useful to satellite oceanographers monitoring coastal regions for harmful algal blooms.

Kosarev and Yablonskaya (1994) reported that in the Caspian Sea, the phytoplankton species are mainly brackish and freshwater with less variety compared to the world's ocean. Diatom species from the Chrysophyta group were reported to form the most abundant and widespread species throughout the Caspian Sea. A study was performed by Nasorllahzadeh *et al.* (2008) in the southern coastal waters of the Caspian Sea in two phases (1996-1997 and 2005). Based on their results; in terms of number of species and abundance, both sets of data show that the diatoms (Chrysophyta) were dominant during all seasons of the year before the introduction of an alien species. During year of 2005, the diatoms (Chrysophyta) were still the dominant group in terms of number of species, but the Cyanophyta recorded higher abundance (especially during summer and autumn). Kideys and Moghim (2003) reported that changes in phytoplankton species abundance and biomass can be associated with increase in abundance of the ctenophore. The changes in chlorophyll-*a* concentration over a seasonal cycle can be due to a change in species composition rather than an increase in one phytoplankton group. In addition, based on the results presented by Nasorllahzadeh *et al.* (2008) the high nutrient concentrations can explain the blooms and maximum phytoplankton densities attained in the region.

In general, variations of the chlorophyll-*a* concentration in the study area can be attributed to the effect of changes of seawater characteristics in various seasons, stratification and heating the sea surface layer in the warm seasons and discharge of lagoon and rivers in the study area. In a previous study, Nezlin (2005) reported that the variations of chlorophyll-*a* concentrations in the Caspian Sea can be related to some factors such as discharge of the rivers and seawater temperature over different region of the sea.

Chlorophyll-*a* concentration is one of the key indices in the study of the health status of any natural marine ecosystem. Variability of chlorophyll-*a* concentrations may be an indicator of ecological conditions in marine environment. Therefore, the investigation of variations of chlorophyll-*a* is very important in oceanographic studies in the Caspian Sea.

CONCLUSION

Data presented in this study provide preliminary knowledge of 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 relatively small 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 variations of chlorophyll-*a* in the coastal area and near mouth of estuaries, rivers and lagoons was different in comparison to the offshore area. The chlorophyll-*a* concentrations in the western part of the study area and in near-mouth area were higher than in the eastern part of the region.

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