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Assessing Chlorophyll-a in the Southwestern Coastal Waters of the Caspian Sea

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Abstract

Caspian Sea with an average depth of 27m is the largest enclosed water body in the world. Despite its enormity and valuable biotic and economic resources, investigations on the biota and seawater properties are mosaic at best. In previous studies, the monitoring of the chlorophyll-a concentrations in the Southern Caspian Sea was organized based on satellite data sets; however, vertical distribution of chlorophyll-a concentrations and its variations in deeper layers of the southern Caspian seawater are not well known. The aim of this research was to study the variations of seasonal distributions of chlorophyll-a near Anzali Port in northern Iran. Data collection was performed at 23 stations, 2 km apart, along four survey lines perpendicular to the coastline and two transects parallel to the coast every season using a research vessel. Field measurements in the study area were carried out. A portable CTD probe was applied for profiling from sea surface to bottom. Results of seasonal field measurements showed variations of the seawater properties (e.g. temperature, salinity, density and chlorophyll-*a*). Maximum depth of the profiling stations was more than 470 m and vertical structure of temperature in the southern Caspian Sea waters with a significant seasonal thermocline between 20-50 m depths in summer with a vertical difference of 16^{o}C were characterized. Seasonal average of the salinity was in the range of 12.27-12.37 PSU for the period of measurements. The highest Chlorophyll-*a* content in the range of 0.2-3.4 mg m^{-3}, was found below that of the sea surface in summer. Variations of the chlorophyll-a concentration in the study area can be attributed to the effect of changes in seawater characteristics in various seasons, stratification and heating of 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.

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

1. Introduction

The Caspian Sea, with an approximate 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

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south to north is more than 1030 km, and its width from west to east is in the 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 by southern cyclones in winter and experiences stable and dry weather in summer (Kosarev, 2005). Based on surface monitoring in the Caspian Sea, the northern basin has larger diversity and productivity than the middle and southern parts of the sea (Kasymov and Rogers, 1996). Due to the isolation of the Caspian Sea from 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, and Terek Rivers in the north (Rodionov, 1994; Mamedov, 1997). In the south, the total discharge of the Iranian rivers to the sea is approximately 4-5% of total input; from which the Sepidrood River (originating from the Elburz Mountains) is the largest (Kosarev, 2005; CEP, 2002). Surface water temperature in this part was reported to be approximately 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 approximately 27.5^{o}C with salinity of 12.24 psu (IAEA, 1996).

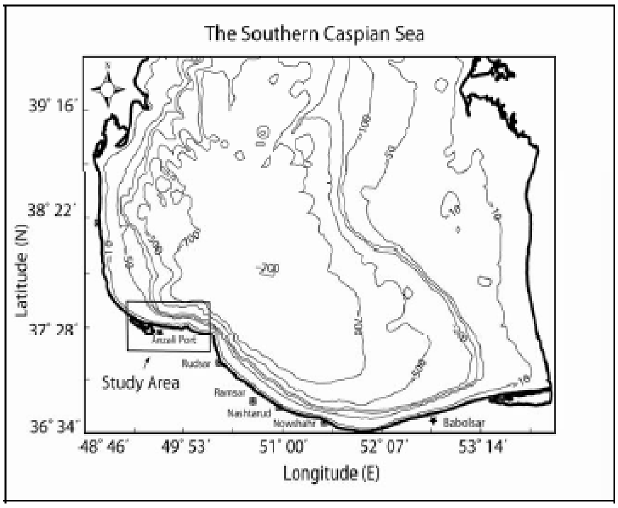
Nowadays, one of the fundamental interests of oceanographers is the investigation on ecological characteristics of seawater. Chlorophyll-containing organisms are the first step of the production in most food chains, and the health and abundance of these primary producers affect the integrity of the other 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 regulates the concentrations of chlorophyll-*a*. In this region, the seasonal thermocline affects the distribution of phytoplankton and chlorophyll-*a* concentration. 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 basins of the Caspian Sea (Nezlin, 2005). The seasonal pattern of chlorophyll concentration (based on SeaWiFS observations 1997-2004) showed that the highest values in the southern Caspian Sea through subsurface layer occurred in August. A maximum level of the chlorophyll-*a* concentrations was 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).

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. Nowadays, 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 wastewater and agricultural run-offs 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 reflected a significant increase in 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 was 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). The aim of this research was to study the variations of chlorophyll-*a* concentrations in the southwestern coastal waters of the Caspian Sea. For this purpose, the seasonal distribution of chlorophyll-*a* near Anzali Port in northern Iran was evaluated by using *in situ* measurements.

2. Materials and Methods

2.1. Description of Study Area

The sampling was cducted in 23 station , 2 km apart in Anzali Port and lagoon with geographical coordinates located 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 (Fig. 1). The mean temperature in Anzali Lagoon was reported roughly 16°C, varying from 4.5°C in winter (February) to 27.5°C in midsummer (August) (Asadullayeva and Alekperov, 2007). In the investigated area, depth increases from the west to the east and reaches to about 470 m. In the eastern part, the continental shelf has a width of 8 km and a maximum depth of 50 m. In general, the depth increases gently from the coast to about 50 m near the shelf break and then reaches to 200 m depth at almost 12 km offshore.



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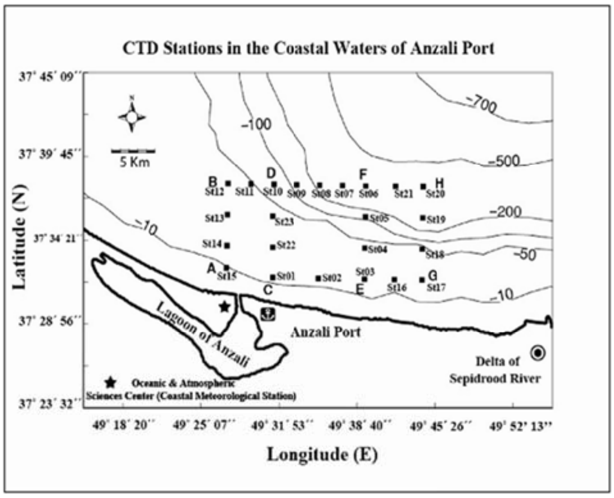


(b)

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

2.2. 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, 2km apart, along four survey lines perpendicular to the coastline and two transects parallel to the coast. For measuring seawater properties (such as temperature, salinity, chlorophyll-*a*) a portable CTD probe (Ocean Seven 316) developed by IDRONAUT was used. 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 (centered at 445 nm and modulated at 1 kHz) and measures the amount of red light (with wavelength centered at 685 nm) emitted from the sample. Chlorophyll-a, 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 wavelengths. This technique of measuring chlorophyll-a allows the 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.

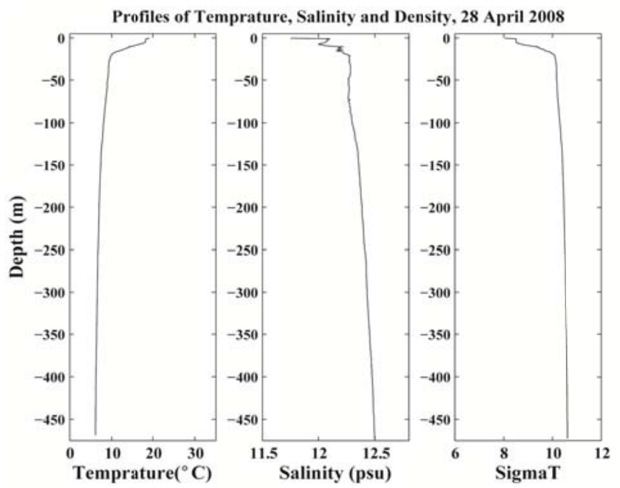
3. Results

3.1. Vertical Structures of Temperature, Salinity and Density

Based on our 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 12.2 psu at the surface and 12.3 psu in 100 m depth 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 dropped to 9-10 ^{o}C at 50 m depth. In summer (13 August), surface water temperature showed values around 27 ^{o}C with a decline to 10 ^{o}C below the thermocline at 50 m level. The 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 roughly 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 were 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 were 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 indicated the existence of a thermocline located in the upper layer (varied between sea surface and 50 m depth) in midsummer.

Seasonal variations in vertical profiles of seawater properties, such as temperature, salinity and density at the deepest station are illustrated in Figure 2. According to the profiles, the highest surface water temperature is observed in midsummer (August). The seawater parameters varied 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 exist 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 on 13 August and 6 November 2008.



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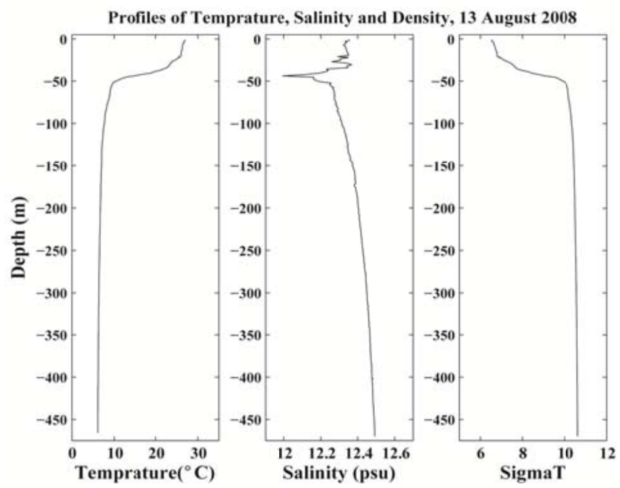

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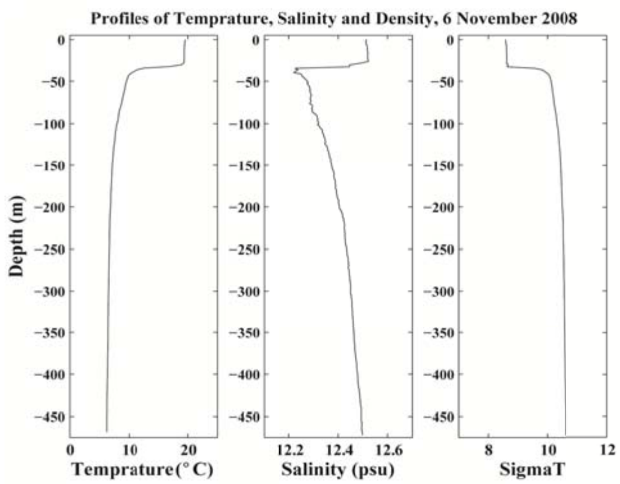

(c)

Fig. 2: Seasonal variations in water temperature, salinity and density in the deepest sampling station (Point H in Fig. 1).

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 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.

Table 1. Summary of variations in seawater temperature, salinity and σ_t in vertical profiles.

Month	Parameters	Surface layer	Thermocline layer	Deepwater
April	Temperature (ºC)	Around 19	18-10	Below 10
	Salinity (psu)	11.7-12.1	12.1-12.25	Up to 12.5
	Sigma-t (kg m^{-3})	8.04-8.51	8.51-9.98	9.98-10.63
August	Temperature (ºC)	26-27	26-10	Below 10
	Salinity (psu)	Around 12.3	12-12.35	Up to 12.5
	Sigma-t (kg m^{-3})	6.52-6.8	6.8-10	10-10.63
November	Temperature (ºC)	Around 19	18.9-9.8	Below 9.8
	Salinity (psu)	12.5	12.2-12.5	Up to12.5
	Sigma-t (kg m^{-3})	8.58-8.7	8.7-10	10-10.63

3.2. Variations of Chlorophyll-a Concentrations

Variations of chlorophyll-*a* through the upper 50 m in the study area were presented in Figures 3-5.

Distribution of chlorophyll-a along sections in the region was remarkable. Seasonal variability in chlorophyll-a concentrations over the continental shelf along transect AB near the mouth of the Anzali Lagoon (fig. 1) was indicated in Figures 3 (a, b & c). Along this section, the concentrations of chlorophyll-a increased with depth and reached a the highest concentration near the seabed in April while the maximum values of chlorophyll-a were observed in subsurface layer in August and November. In August a maximum concentration of 3.4 mg m-3 was measured at 5 m depth along this transect. 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.

The lagoon outflow mainly influenced the seawater properties and their structures over transect CD. In the surface layer of transect in April and November, concentrations hiked from the coast towards the offshore stations (Fig. 3 d, e & f). 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 was observed. Seasonal changes of chlorophyll-a concentrations along transect EF were displayed in Figures 4 (a, b & c).

The concentrations at the sea surface layer (well mixed layer) over the continental shelf and outside the shelf in November were approximately uniform. The highest 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 of 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. Seasonal variability of chlorophyll-a along transect GH were designated in Figures 4 (d, e & f). In midsummer (August) horizontal gradient of chlorophyll-a concentration was 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). Distribution of chlorophyll-a along transect AG (parallel to the coastline) is shown in Fig. 5 (a, b & c). Vertical differences of chlorophyll-a in the eastern part of transect at the time of measurements in all seasons were insignificant (left side of the Figures 5 (a, b & c)). Seasonal distributions of chlorophyll-a concentration along transect BH are presented in Figures 5 (d, e & f). The concentrations along this section clearly represented 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 mg m-3, 2.28 ± 034 mg m-3 and 2.25 ± 0.16 mg m-3, respectively.

In order to make a better comparison between concentrations of chlorophyll-a along different transects, the maximum, minimum, average and standard deviation at the sea surface and subsurface layers (5 m, 10 m and 15 m depths) as well as statistical analysis 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 concentration are presented in Table 3.

In general, the greatest concentrations of chlorophyll-a were observed throughout the upper 50 m layer.

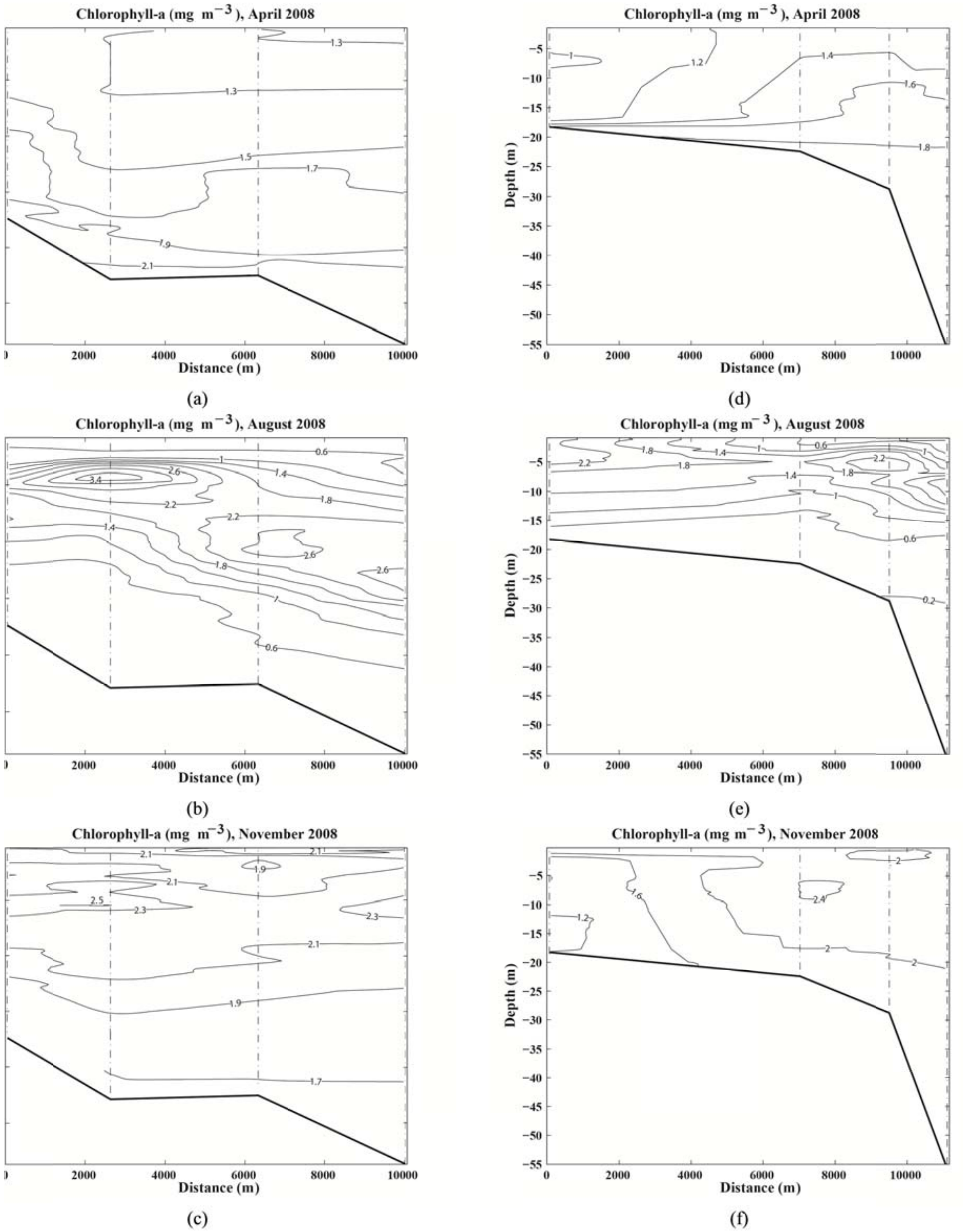

Fig 3: Seasonal variations of the chlorophyll-*a* along transects AB (left panel) and CD (right panel)

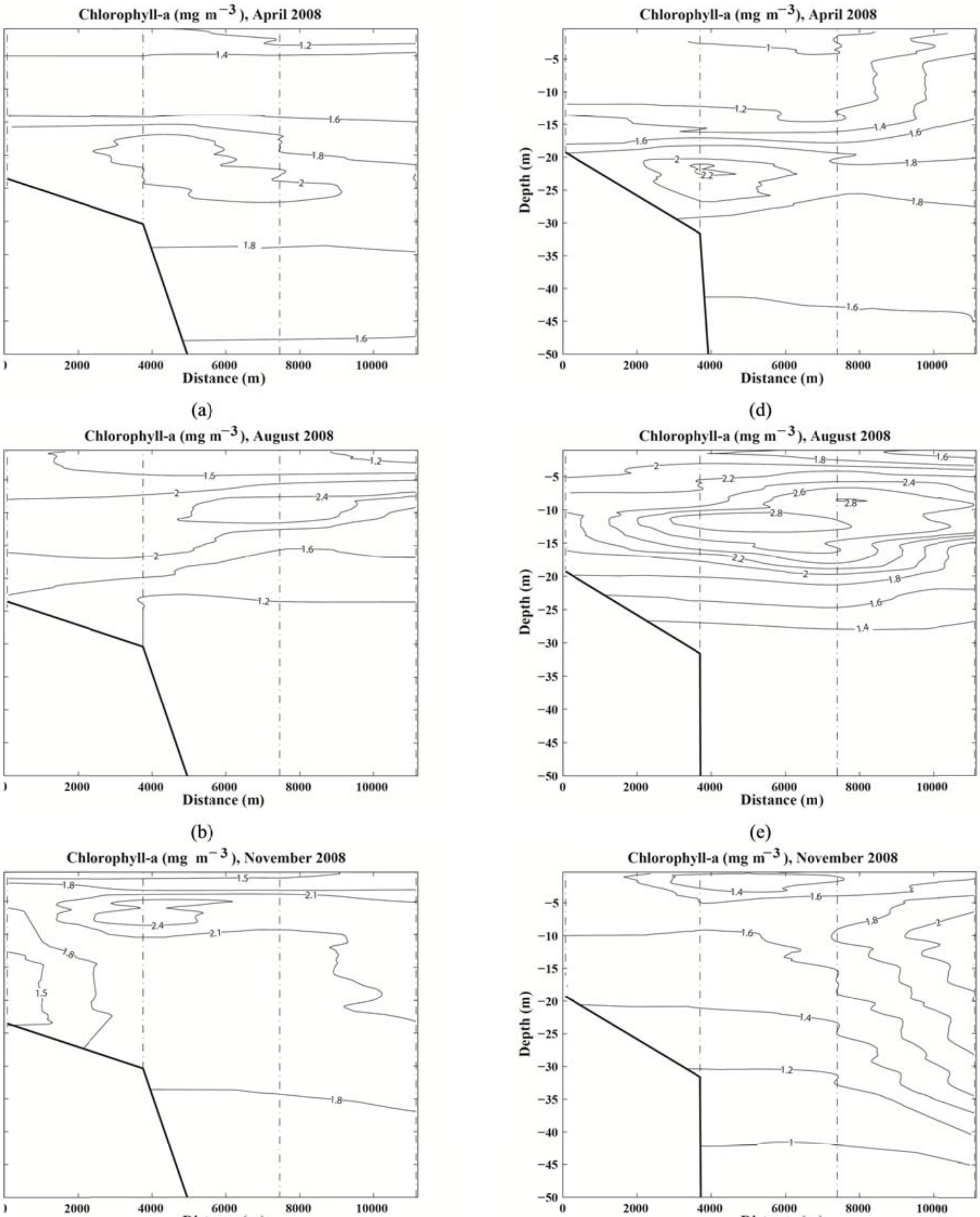

Fig 4: Seasonal variations of the chlorophyll-*a* along transects EF (left panel) and GH (right panel)

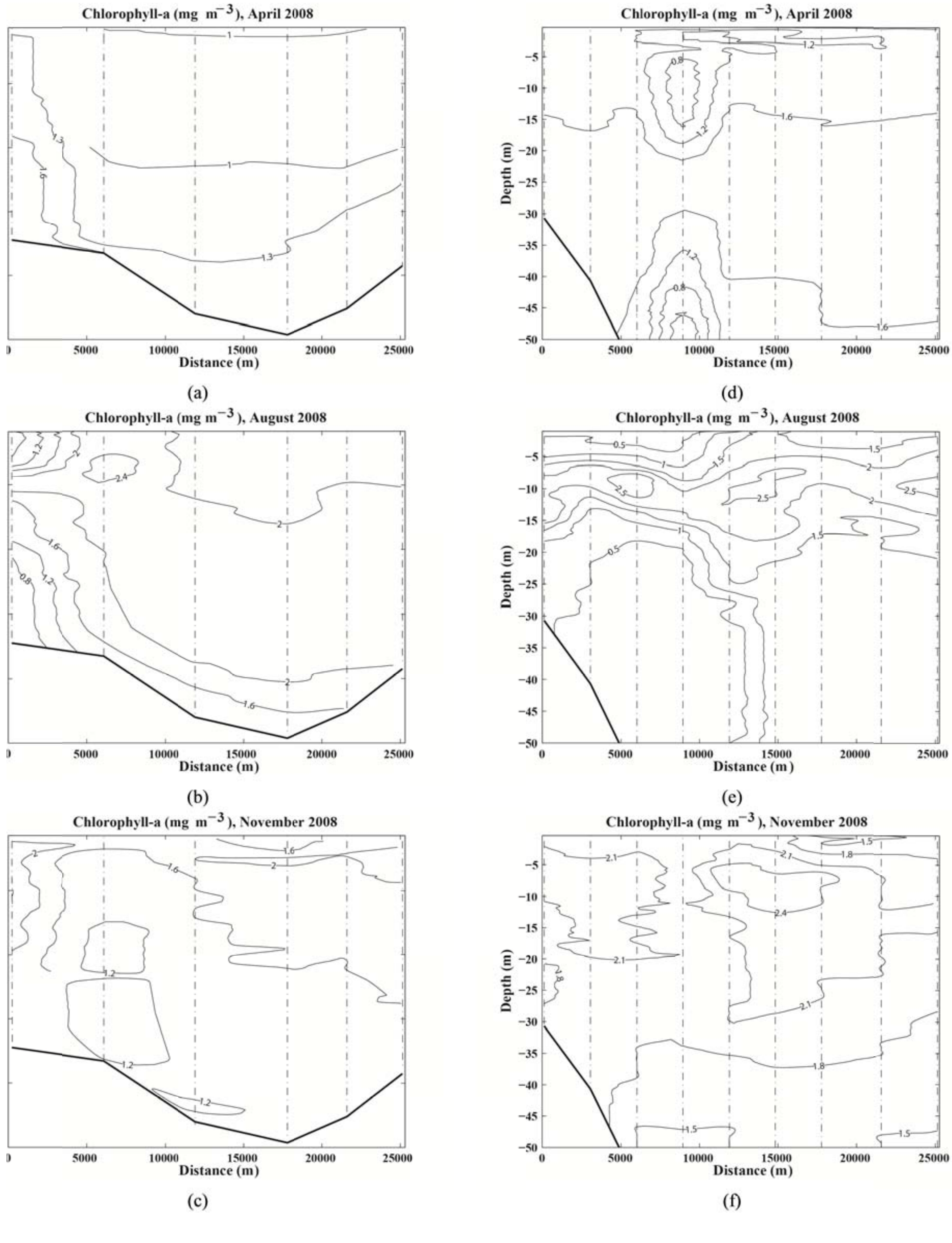

Fig 5: Seasonal variations of the chlorophyll-*a* along transect AG (left panel) and BH (right panel)

Table 2: Minimum, maximum, average and standard deviation of chlorophyll-*a* concentrations through four levels along transects in April, August and November.

Transect	Depth	Minimum Chlorophyll-*a* (mg m^{-3})			Maximum Chlorophyll-*a* (mg m^{-3})			Average Chlorophyll-*a* (mg m^{-3})			Standard Deviation (mg m^{-3})		
		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: Sea surface temperature, mixed layer depth (recognisable based on the vertical structures of temperature, salinity and density) and chlorophyll-*a* concentrations in the sampling stations in April, August and November.

Stations	**Sea surface temperature (C)**			**Mixed layer depth (m)**			**Subsurface max. chl-*a* (mg m^{-3})**			**Depth of 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

4. Discussion

The results of seasonal distributions of chlorophyll-a concentrations in the southern coastal waters of the Caspian Sea were analyzed. In the study area, Chlorophyll-a concentration was higher in midsummer than other times. Several factors, such as stratification, mixing, and seawater temperature affect the concentrations of chlorophyll-a. This is because, the sea surface layers in the region receive high 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 the phytoplankton growth and enhance the concentration of chlorophyll-a due to increase in nutrient values in water column. The thickness of the thermocline reduced due to increase of turbulent kinetic energy and deepening of the surface mixed layer in the autumn (Zaker et al., 2007).

In spring, the vertical gradient of chlorophyll-*a* especially over the continental shelf was less than that in summer. The maximum value of chlorophyll-*a* was 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 values in the eastern area. Overall, the concentrations of chlorophyll-a in summer and autumn were larger than corresponding 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 available at deeper levels. 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 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). According to the field measurements in the coastal waters of Rudsar and Anzali, 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 study carried out by Nezlin (2005) confirmed similar behavior in the southern coastal waters of the Caspian Sea (Iranian coastal areas; such as Anzali, Kiyashahr, Rudsar).

The pattern of the seasonal distributions of chlorophyll-a concentrations demonstrated that the range of variations in concentrations near the mouth of the lagoon was lower than that in the offshore stations in the study area. In offshore stations (deepwater zone), concentrations of chlorophyll-*a* were mainly affected by thermal stratification of the water column. As can be seen in Figures 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 acts as a natural boundary separating the warm and well-illuminated surface 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 early 1980s. Thus, simultaneous hikes in nutrients contributed to increases in chlorophyll-*a* values (Kideys et al., 2008; Kideys and Moghim, 2003; CEP, 2006; Kopelevich et al., 2008). Because of 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. Based on to the discharges 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. Based on the results presented by Nasorllahzadeh et al. (2008) the high nutrient concentrations can explain the Anomalous Algal Blooms and maximum phytoplankton densities attained in the region.

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. Based on the current study and comparison with the results of previous researches, it seems that the variations of the chlorophyll-*a* concentration in the study area can be attributed to the effect of changes of seawater characteristics in different seasons, stratification, heating of the sea surface layer in the warm seasons and discharge of lagoon and rivers in the study area.

5. Conclusions

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 close to 5 m depth in summer. Below the thermocline, values of chlorophyll-a rapidly declined and its concentrations were relatively small near the bottom. Seasonal average of the salinity was in a range of 12.27-12.37 PSU in the period of measurements. The highest Chlorophyll-*a*. content in the range of 0.2-3.4 mg m-3, was found below the sea surface in summer. 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 of the sea surface layer in the warm seasons and discharge of lagoon and rivers in the study area.

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