Temperature, Salinity and Density Measurements in the Coastal Waters of the Rudsar, South Caspian Sea

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Abstract
CTD (conductivity, temperature and depth) data collected in the coastal waters of Rudsar in summer 2008 were analyzed to identify the isothermal layers, thermocline depth and vertical structure of seawater properties. During the survey, probe was released into the seawater column down to 117 m depth. Results showed a vertical variation of temperature between 29°C at the sea surface and less than 8°C at 117 m depth. In the southern coastal waters of the Caspian Sea, stratification process of seawater is completed in mid summer. In time of measurements, a strong thermocline was present between 10 m and 40 m depths with 18°C temperature decrease across it. Below thermocline, the temperature gradually decreased and reached less than 8°C at 117 m depth. Vertical and horizontal distributions of salinity were mainly between 12.18 psu and 13.1 psu. Density variations were in agreement with the temperature changes and the variations of density in the study area were between 1005.8 kg/m³ in the sea surface and 1010.4 kg/m³ near the bottom.

Keywords: Caspian Sea, Temperature, Salinity, Density, Thermocline, Stratification.

1. Introduction
Caspian Sea (CS), the largest continental body of water on the earth, is distinguished by its special conditions: the rich hydrocarbon and biological resources, and playing an important role in the region (Dumont, 1998; Kosarev and Kostianoy, 2005; Zonn, 2005(b)). Oil industry and Fishing are major components of the economy of the littoral countries of the CS. This sea is the unique world reserves of endemic sturgeons giving 85% of world black Caviar supplies (Zaker et al., 2007; Zonn, 2005(a); Dumont, 1998). Nowadays, the CS is one of the most polluted seas and its marine environment, due to extensive human exploitation and discharge of large magnitude of human waste, is under extensive pressure. Heavy metals, hydrocarbons, pesticides, nutrients such as phosphate, nitrate and other human wastes introduced into the CS are threatening marine life and the recreational potential of the sea (Zonn, 2005(a); Zaker et al., 2007). In addition, pollution caused by industrial, agricultural and municipal wastes, offshore and coastal production of oil and gas, shipping companies and other circumstances, has lead into degradation of its biodiversity, exhaust of fish resources and increased fluctuations of the sea level.

The above-mentioned problems change the properties of seawater and environment of the Caspian basin. In this condition, the physical oceanographic studies of the CS water have become necessary (Zonn, 2005(a); Safarov et al., 2008).
These studies are among the basic requirements for environmental and any other marine related studies. By the way, they play an important role for designing the appropriate measures for reduction in pollution and sustainable development of the CS (Zaker et al., 2007). In the last decade, there has been an extensive physical oceanographic research in the southern coastal waters of the CS. The main aim of this research is to analyze and characterize the summertime structures of seawater properties over the west part of southern continental shelf of the CS. For this propose, data collections were carried out in the coastal waters of Rudsar in August 2008.

1.1 Study Area

The study area in the west of the southern coast of the CS is located at approximately N37° 15’ latitude and E50° 23’ longitude and covers a band of coastal waters with the length of 18 km and width of 16 km of coastal waters of Rudsar (Figure 1). In this area, continental shelf has a width of 11 km and a maximum depth about 50 m. Depth from the coast increases gently to about 50 m near the shelf break and after that reaches to 100 m depth at about 14 km. In addition, depth is about 200 m at 17 km off the coastline (Figure 1).

The southern coast of the CS has a warm and humid subtropical climate. The maximum and minimum air temperatures are in the August and January, respectively. In the winter, the air temperature ranges between 8-12°C and in summer the mean monthly air temperature over the entire sea equals 24-26°C. In the South Caspian, the mean annual wind speed is 3–4 ms⁻¹, and the recurrence rate of weak winds here reaches 90%. In the southern part of the sea, the number of days with storms (wind speed greater than 15 ms⁻¹) is not more than 20–30 per year (Kosarev, 2005). Due to the isolation of the CS from the World Oceans, the formation of thermohaline is under effect of atmospheric conditions over the sea and its vast drainage area. In addition, large-scale features of the thermohaline structure and its temporal variability are controlled with river runoff, the fluxes of heat and freshwater across the sea surface (Tuzhilkin and Kosarev, 2005).

2.1 Field Measurements and Collection of Data

The data presented here were collected in a field study on the southern coastal waters of the CS that were organized by the Iranian National Center for Oceanography (INCO), in August 2008. In field measurement, the CTD probe was set in Timed Data Acquisition mode and released into the seawater column down to 117 m depth. Data collection was performed with profiler in free falling mode in every second with time interval one meter per second. The CTD probe sampled temperature, conductivity, and depth one times per second as the probe was lowered down to 117 m depth in the seawater. The observation was conducted at nine fixed stations along three transects in perpendicular to the coastline in the southern coastal waters of the CS, off Rudsar. There were three sampling stations along each transect and the distances between stations were 5 km along transects. The depth in transects from about 15 m to the southwest increased to 50 m in the middle (near shelf break) and reached to more than
100 m in the end of transect. The metrological and marine parameters such as temperatures of air and sea surface water were provided from Oceanic & Atmospheric Science Center (OASC) during January-December of 2008. Salinity values were obtained from CTD data using Peeter et al., 2000 corrections coefficient. In addition, density (sigma-t) was calculated from water temperature and calibrated salinity using Peeter et al., 2000 equation.

2. Results and Discussion

Results of analysis on seawater properties in the west part of the southern coastal waters of the CS, adjacent to Rudbar, in summer 2008 are presented. To obtain a general view of the structure of seawater properties, three transects perpendiculars to the coastline were constructed. In addition, one section parallel to the coast (away 16 km from coastline) outside the shelf was considered. Vertical distributions of seawater properties in the study area are shown in Figures 2 and 3.

2.1 Temperature Structure

Vertical temperature structure along three transects perpendicular to the coast and one section parallel to the coastline are indicated in Figures 2-3(a & b). The water temperature was found to vary between more than 29°C and 8°C with the maximal levels in the surface water. In the time of measurements, water column stratification formed from three stable structure layers; surface mixed layer and deep-water, with a strong seasonal thermocline between them. Onshore sampling stations were located in the surface mixed layer and thermocline. In the surface mixed layer the temperature was mainly more than 29°C from surface to above the thermocline in a depth of 10 m. The results showed a sharp thermocline, located between 10 m and 40 m depths with 18°C temperature gradient across it. Temperature decreased from 28°C to 10°C through the thermocline. A high level of homogeneity in the deep layer is clearly seen in offshore stations. Outside continental shelf, water temperature decreases gradually to 8°C below the thermocline at 50 m depth. Water temperature was constant around 8°C between 50 m and 117 m depths. Horizontal gradient of seawater temperature was very slight in the study area. In 2007, Zaker et al., reported forming present of a the thermocline between 20-50 m depth with 15°C temperature decrease across it, based on field observations in the east part of the southern coastal waters of the CS, off Babolsar port in summer 2003 (Zaker et al., 2007). As a result, the depth of the thermocline is significantly less than 50 m depth in summer in the southern coastal waters of the CS. Climatic fields of the water temperature in August (in the southern CS) were reported about 28°C, 21°C and 9°C at the sea surface, 30 m and 100 m depth, respectively. Annual mean temperature field at depth of 200 m varies about 7°C in the study area. (Tuzhilkin and Kosarev 2005). According to presented data and measurements (Zaker et al., 2007) in 2003, Water temperature in the deep layer varied permanently in a range colder than the upper layers. In addition, Seasonal temperature variations of deep-water layer in the southern coastal waters of the CS are slight and atmospheric processes affected two upper layers (surface mixed layer and thermocline).

The seasonal thermocline generally develops and has the strongest condition during the summer when the conditions at the sea surface are less rough in the southern coastal waters of the Caspian. Formation process of thermocline layer is completed in the study in August. During the summer, warm water, which is less dense, will sit on top of the colder, and denser water that sinks to the bottom with a thermocline separating them. Because the warm water is also exposed to the sun during the day, a stable system exists, and very little mixing of warm water and cold water occurs. One result of this stability is the less oxygen below the thermocline, as
the water below the thermocline never circulates to the surface.

Time series of daily air and surface water temperature of 2008 in a coastal station in western part of the southern coasts of the CS are given in Figure 4. The daily air and surface water temperature was calculated by averaging between records at 9.5 am and 3.5 pm in local time (6 and 12 in Greenwich Time). This data were obtained for 366 days from 1st of January to 31st of December 2008. The daily air temperature ranged from -1.5°C to 30.1°C. The minimum and maximum values of the daily surface water temperature were 1.7°C and 30.15°C, respectively. Figure 4 clearly shows that variations in the seawater and air temperatures have a high correlation.

Fig 2. Vertical structure of temperature, salinity and density in the study area in summer (August) 2008, Left panel: in a transects located in the north. Right panel: in a transect located in the middle of the study area, left side of the plot is to the sou
2.2 Salinity Structure

Vertical distributions of salinity in the study area in summer are presented in Figures 2-3(c & d). The annual distribution of the evaporation intensity affects the seasonal features of the surface salinity field over the entire deep-water part of the CS. Climatic fields of the water salinity (psu) in the surface layer of southern basin of the CS ranges between 12 and 13.5 psu (Tuzhilkin and Kosarev, 2005). Zaker et al., measurements in 2003 showed a very small variation of salinity between 12.1 psu and 12.35 psu in east part of the southern coastal waters of the CS (Zaker et al.,

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Fig 3. Vertical structure of temperature, salinity and density in the study area in summer (August) 2008; Left panel: in a transect located in the south of the study area, left side of the plot is to the southwest. Right panel: outside of the shelf in an alon
In the time of present observations, salinity was found to vary between 12.18 psu and 13.1 psu in the study area. The salinity was patchy and its structure indicated a gradient of salinity about 0.9 psu in the region. At the surface mixed layer, vertical gradient of the salinity was slight. The Salinity in the surface mixed layer ranged between 12.4-12.5 psu. Over the continental shelf, the salinity was mainly recorded between 12.2-12.5 psu. Variations of salinity across the thermocline were found higher than surface mixed layer and deep waters. Below thermocline, the salinity was mainly averaged around 12.4 psu. Outside the shelf, the salinity varied between 12.2 psu and 13.1 psu (Figure 3d). The maximum value of salinity (more than 12.6 psu) was observed in 30 m depth.

Vertical structure of density of seawater in the study region is given in figures 2-3(e & f). In the study area, a strong pycnocline is detected at the place of thermocline between 10-40 m depth. In time of measurements, density varied between 1005.8 kg/m³ and 1010.4 kg/m³ from sea surface to bottom, respectively. In the surface mixed layer the density ranged between 1005.8 kg/m³ and 1006.0 kg/m³. The density increases with decrease in temperature. Across the pycnocline, density changes from 1006.0 kg/m³ to 1010.1 kg/m³ between 10 m and 40 m depths. Below thermocline, the density was 1010.2 kg/m³ and with a small gradient increased to 1010.4 kg/m³. In the southern coastal waters of the CS, density variations are highly in agreement with temperature variations.

Density of water in the southern coastal waters of CS mainly depends on water temperature. In the time of measurements, vertical gradient of density was about 4.6 kg/m³ in the study area. However, horizontal density difference along transects was low. It seems that, the density-driven current, driven by the difference between onshore station and outside of the shelf is weakened in the study region.

### 2.4 Stratification

As summer progresses, the temperature (and density) differences between upper and lower water layers become more distinct. The sea generally becomes physically stratified into three identifiable layers, known as the surface mixed layer, thermocline, and deep layer. The surface layer is the upper, warm layer, and is typically well mixed. Below the surface mixed layer is the thermocline region, a layer of water in which the temperature declines rapidly with depth (18°C through 30 m depth). The deep water is the bottom layer of colder water, isolated from the surface layer by the thermocline. Usually, air temperature reaches the highest in August during the year in the southern coasts of the CS. Therefore, seawater of surface layers is in the warmest condition in this month. Water temperature difference between sea surface and deeper layers is maximum and thermocline has the strongest condition in August during the year. Stratification is most developed in
August due to large sea surface heating and weak sea surface wind.

The comparison between present study and the earlier surveys in the southern coastal waters of the CS indicated that atmospheric processes and local rivers inflow mainly affected vertical stratification of seawater in the coastal area. The thickness of the thermocline in autumn (November) was approximately half of its thickness in the mid summer (August). In autumn, with climate change and decrease of air temperature in the region (Figure 4), temperature of seawater decreases below 20°C. Therefore, deepening the surface mixed layer and destruction of the thermocline occurs in water column. As the weather cools during autumn, the surface layer cools too, reducing the density difference between it and the deep layer. As time passes, winds mix the sea to greater depths, and the thermocline gradually deepens. When vertical temperature and density differences between surface and bottom waters approach the slight values, autumn winds can mix the entire sea. In this case, the stratification of southern coastal waters of the CS is much less stable, because the density difference between layers is small. Therefore, the layering persists throughout the winter. The stratification is weakened in autumn, and vanished in winter.

Profiles of temperature, salinity and density referred to all data are shown in Figure 5. From this figure, we can understand the characteristic of variation in the study area. High association between temperature and density of the data is clearly illustrated in vertical profiles. Across thermocline, salinity variation was higher than mixed surface layer and deep layer and values were appeared scatter. This suggested that the sea surface heating and wind did not govern the horizontal distribution of bottom cold-water masses. A high correlation among data in each profiles of temperature, salinity and density could be seen below 40m depth.

Fig 5. Vertical profiles of temperature, salinity and density in the study area in summer (August) 2008.

2.5 Water Mass

Temperature and salinity form an important tool in identifying water masses in the sea. A T-S diagram for all observed temperature and salinity data is shown in Figure 6. The T-S relationship is used to identify the different water mass properties in the region. There are three water masses identified in the area; the first is surface mixed layer, which consists of warm water, second is thermocline and below that heavy water of deep layer. The water of mixed sea surface, thermocline and deep water layers are clearly seen in the upper, middle and lower part of graph. Warm waters of the mixed layer were located at top of the diagram (10 m upper layer). In the surface mixed layer, water masses undergo property changes in response to atmospheric conditions. The temperature and salinity of light surface water were mainly lower than 30°C and about 12.4 psu, respectively. The measured data of thermocline layer is scattered in the middle of T-S diagram. Across thermocline (10-40 m depths), water mass is less homogeneous in comparison with the two other layers which were mentioned above, and it occupies regions on the T-S plot. In the lower part of plot, heavy water of deeper layer with low temperature (less than 10°C) and salinity less than
12.4 psu are located. Dispersion of data was low at surface mixed layer as well as in the deep layer data. Water mass was very homogeneous in the deep layer (below thermocline) and was almost point on the plot. This condition could be seen for water mass of surface mixed layer (upper 10 m) in the study area.

Fig 6. Temperature- Salinity diagram in the study area, August 2008.

3. Conclusion

The results of field measurements of temperature, salinity, density and their vertical variations in the coastal waters of the southern CS, off Rudsar in August 2008 were briefly analyzed. In time of measurements vertical structures of physical properties of seawater indicated a strong thermal stratification in the water column that included surface mixed layer, thermocline and deep-water layer. Temperature varied between more than 29°C at the sea surface and less than 8°C at 117 m depth. A strong thermocline located between 10 and 40 m depths with 18°C temperature decrease across it. In the surface mixed layer, the temperature ranged between more than 29°C at the sea surface water and 28°C above the thermocline in a depth of 10 m. Below thermocline, the temperature decreased gradually to less than 8°C near the sea bed. Thickness of thermocline is maximal in the summer with the greatest vertical gradient. Gradient of water temperature between surface and deeper layers in the summer was more than its gradient in autumn and winter. Therefore, there was a strong thermocline and high stability in the water body. Distributions of salinity were 12.18-13.1 psu between sea surface and bottom. Vertical and horizontal Variations of salinity across thermocline were higher than sea surface mixed and deepwater layers. Density variations were in agreement with the temperature changes and the variations of density in the study area were between 1005.8 kg/m³ in the sea surface and 1010.4 kg/m³ near bottom at 117 m depth. There was a seasonal pycnocline layer that existed in place of thermocline.

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References


