Evaluation of Water Exchange between Anzali Lagoon and Coastal Waters of the Caspian Sea via Connecting Channel, North of Iran

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***Abstract*—Anzali Lagoon is a coastal liman, or wetland in the Caspian Sea near Anzali Port, in the northern Iranian province of Guilan. The lagoon divides Anzali city into two parts. Water exchange phenomenon and physical properties of seawater along connecting channel between the Caspian Sea and Anzali Lagoon were assessed. The research was based on field observation on 6 sampling stations during warm and cold seasons. Observations were performed by a portable CTD Ocean Seven 316 probe. The parameters ranges in the warm and cold seasons were different. Based on data, water temperature in vertical direction changed between 27.5-25 centigrade in June and it ranged between 9.3-7.5 centigrade in February. Mean values of water salinity in cold season were less than that in warm season in the Anzali Lagoon connecting channel. Variations of salinity were around 12 psu in warm season while salinity values in cold season observed about 7.5 psu. According to high correlation between seawater density and temperature in the Lagoon connecting channel as well as the Caspian Sea, vertical structures of water density and temperature were in agreement.**

***Index Terms*—caspian sea, anzali lagoon, physical properties, temperature, water exchange**

I. Introduction

The Caspian Sea is the largest enclosed water body in the world. It is noted by unique conditions, contains rich biological and hydrocarbon resources [1]-[4].

Anzali Lagoon is a coastal wetland in the Caspian Sea near Anzali Port, in the northern Iranian province of Guilan. Although the lagoon suffers from pollution, it is known as a good place for bird watching. The lagoon's water ranges from fresh near the tributary streams to brackish near the mouth into the harbour and the sea. Studies indicate that in the 19th and early 20th Centuries that the lagoon had a much higher salinity.

The lagoon has decreased in size since the 1930s to less than a quarter of its former extent However, in the last ten years water salinity has increased both by the rise of the level of the Caspian Sea which has caused greater interchange of waters, and due to greater salt transport in incoming "fresh" water due to increased upstream irrigation. Anzali Port is located in Guilan province, north-western Iran, on the Caspian Sea, 25 km northwest of Rasht; population (2006) 110,600. Anzali Port stands on both sides of the entrance to the lagoon, though the port is mainly on the eastern side. It is the main port for trade with Russia, and access needs to be maintained by dredging.

The southern coastal area of the Caspian Sea has warm summers and mild winters (warm and humid subtropical climate) [5]-[7]. Based on previous studies, the maximum and minimum air temperatures are in August and January, respectively. In the winter, the air temperature ranges between 8-12℃ and in summer the mean monthly air temperature over the entire sea equals 24-26℃ [7]. According to the results reported by Zenkovich, (1963) [8], water temperature in the southern Caspian Sea ranges between 9-26^{o}C during a period of winter to summer. Here, surface temperature was detected about 10^{o}C and 27-28^{o}C in winter and summer, respectively [1].

In addition, seasonal sharp thermocline forms between 20 m and 40 m depths. Based on [6] measurements, the temperature of the surface mixed layer ranged between 25^{o}C and 30^{o}C in summer and it decreased to 15^{o}C at the end of November with a seasonal thermocline between 20-50 m depths. The main sources of freshwater inputs to the Caspian Sea are the Volga, Ural, Emba and Terek Rivers in the north part, and Sepidrood River in the southern part [5], [9].

The aim of this paper is to evaluation of water exchange between Anzali Lagoon and coastal waters of the Caspian Sea via connecting channel, North of Iran. In addition, seasonal variations of physical parameters of seawater (such as temperature, salinity, and density, and stratification) of Anzali lagoon connecting channel in western part of the southern coastal waters of the Caspian Sea were studied. A special interest was placed on the physical structure of water column and horizontal changes of the seawater properties.

II. Methodology

A. Field Observations

The study area in the west part of the southern coast of the Caspian Sea is located between mouth of Anzali

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Lagoon and the sea (Fig. 1). Mean temperature in Anzali Lagoon was reported about 16°C, which varies from 4.5°C in February to 27.5°C in August. Data collection was performed during years of 2014 to 2015 using Matlaolfajr 23 research vessel in the study area. Field measurements in the study area were carried out at 6 sampling stations along a survey line. Distance between the stations reached an average of 0.2 km along transects. For measuring seawater properties a portable CTD probe (Ocean Seven 316) developed by IDRONAUT was used (Table I).

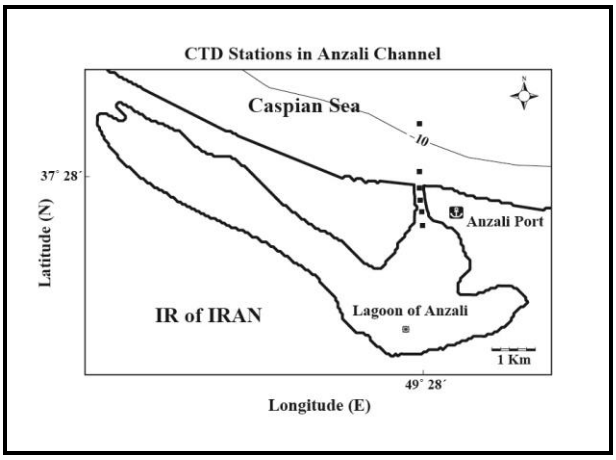

Figure 1. The southern Caspian sea and study area

The probe was set in Timed Data Acquisition mode with one-second time intervals. The accuracy of pressure, temperature and conductivity sensors of Ocean Seven 316 probe was 0.05 full-scale, 0.003°C and 0.005 mS cm^{-1}, respectively. Data collection was performed with profiler in free falling mode into the seawater column down with a time interval of one meter per second.

TABLE I. SPECIFICATIONS OF CTD PROBE

Parameter	Range	Accuracy	Resolution
Pressure	0-1000 dbar	0.05 % full scale	0.002% full scale
Temperature	-3 to +50 °C	0.003 °C	0.00020 °C
Conductivity	0-70 mS cm^{-1}	0.003 mS cm^{-1}	0.00025 mS cm^{-1}
Oxygen	0-50 mg l^{-1}	0.1 mg l^{-1}	0.01 mg l^{-1}
	0-500 % sat.	1 % sat.	0.1 % sat.
pH	0-14 pH	0.01 pH	0.001 pH
Turbidity	0-25 NTU	0.1 NTU	0.005 NTU
Fluorometer	0-5 mg m^{-3}	0.02 mg m^{-3}	0.002 mg m^{-3}

B. Field Observations

In field measurements, the depths ($P_{(z)}$) of profiling instruments are mainly derived from measured hydrostatic pressure, p (in dbar). Due to linear relationship between hydrostatic pressure, p = p(z), and geometric depth (z) that is possible [10].

$$p(z) = -g\int_z^0 \rho(z)dz$$

For the World Oceans, the pressure calculated in Pascal as follow:

$$P_{(pascal)} \approx 1.025\times10^3 \times (9.81)z_{(m)} = 10055.25z_{(m)}$$

Moreover, pressure in dbar

$$P_{(dbar)} \approx \frac{1.025\times10^3\times(9.81)z_{(m)}}{10^4} = 1.005525z_{(m)}$$

where, $g = 9.81, (\frac{m}{s^2})$ and $\rho = 1.025\times10^3, (\frac{kg}{m^3})$

The used value of density

$$\rho = 1.010\times10^3, (\frac{kg}{m^3})$$

Therefore, correction coefficient for calculation the depth from pressure data was obtained as follows:

$$P_{(dbar)} \approx \frac{1.010\times10^3\times(9.81)z_{(m)}}{10^4}$$

During the sampling, the sensed parameters by CTD probe were calibrated by UNESCO formulas. Due to the difference between the compositions of the Caspian Sea from the world ocean waters, some correction coefficients needed to be used. Some of the experimental, empirical and chemical equations were used for calculation of salinity and density of the Caspian Sea water. Millero and Chetirkin, (1980) carried out density laboratory measurements using some samples collected in the near shore surface waters of the southern part [11]. In the current research, the coefficients that were presented by Peeters *et al.*, (2000) on IAEA data (1996) for calibration the salinity and density values is used [12].

$$S_{Caspian} = 1.1017S_{CTD}$$

$$\rho_{Solution}(T,S,p) = \rho_{Sea}(T,0,p) + f(T,p)(\rho_{Sea}(T,S,p) - \rho_{Sea}(T,0,p))$$

where,

- $\rho_{Sea}(T,S,P)$ is the density of water from UNESCO formulas using in situ temperature, pressure and salinity and $f(T,p)$ is the correction factor.
- $\rho_{Sea}(T,0,P)$ is the density of the water from UNESCO formulas using in situ temperature and pressure, S = 0.

In computations presented by Peeters *et al.*, (2000) for the ionic composition of the CS and for S = 12.3, T = 25°C and P = 0 was given by f = 1.0834 [12].

III. RESULTS AND DISCUSSION

Physical structures, water exchange phenomenon and TSD analysis results along the connecting channel were presented and discussed in the section.

A. Vertical Structures of Temperature, Salinity and Density

Fig. 2 shows vertical structures of physical properties of the connecting channel water in June 2014. Near the surface, some changes of water temperature and density were observed. Based on data, below 10 m depth in deepest station near the coastal area, changes of temperature, salinity and density were slight. Variations of water salinity between surface and bottom were very low. According to high correlation between water density and temperature in the channel as well as the Caspian Sea, vertical structures of water density and temperature were in agreement. With heating the surface waters in early spring, vertical gradient of temperature increased in consequence of enhancement the air temperature.

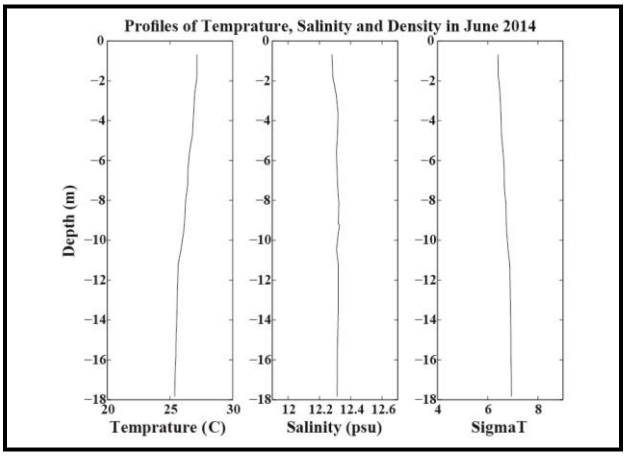

Figure 2. Vertical structures of temperature, salinity and density in the channel in June 2014.

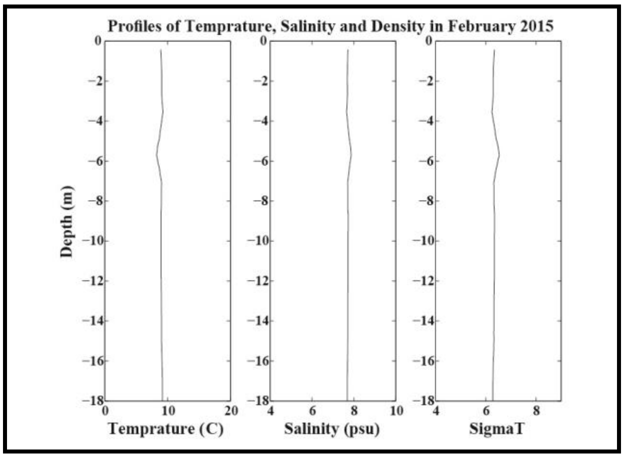

Figure 3. Vertical structures of temperature, salinity and density in the channel in February 2015.

Fig. 3 shows physical structures of the channel water in February 2015. Based on the collected data in mid-winter, values of the salinity varied below 8 psu from sea surface to the bottom. A vertical gradient can be seen in structures of physical and chemical properties of water in. There was no strong thermal stratification in the water column in the channel such as southern coastal waters of the Caspian Sea in winter. Just there was a weak daily variation between surface and deeper layer around 6m depth. Due to low salinity of the Caspian Sea water, vertical structure of density and its variations were in agreement with the temperature, thus, a small density change was detected in the position of thermocline around 6 m depth during time of measurements.

The natural regime of structures of seawater parameters in the Caspian Sea is under effect of external factors such as riverine and lagoon runoff and atmospheric activity. Study on the mentioned factors shows that they define a rapid and significant variability in the hydrological structure and circulation of the waters of the Caspian Sea relative to the other open seas. Therefore, comprehensive monitoring of the natural environmental conditions of the Caspian Sea and changes in its main parameters is necessary. Anzali lagoon as a part of the southern basin of the Caspian Sea follows this sea characteristics under above mentioned factors.

B. TSD Diagrams

Temperature- Salinity- Density (T–S–D) diagram referred to all data gathered from the study area in June 2014 were presented in Fig. 4. The density of collected data in June changed between 1004.9 and 1006.8 kg/m^3 and crossed four isopycnal. It means that a weak thermal and density stratification was in water column in the time of measurements. Vertical profiles of temperature and density in May, presented in Fig. 2, also showed a weak layering of water column. There are two layers including; a surface weak thermocline and a subsurface layer, from sea surface to bed. Measured data from surface layer and thermocline were condensed. Dispersion of collected data from two upper layers was high. Salinity values were often concentrated between 6.5 psu and 7 psu. According to T–S–D diagram, a water mass correspondence to the water column from surface to bed can be seen.

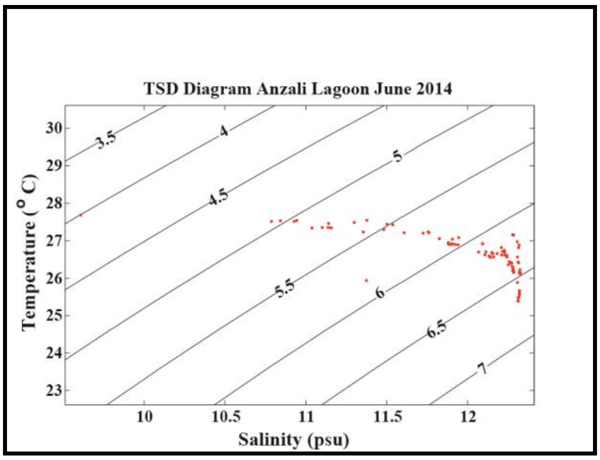

Figure 4. TSD diagram on all data collected from the channel, June 2014.

T–S–D diagram presented for collected data in February showed that vertical gradient of water temperature was not very high (around 2 degree) (Fig. 5). Due to Anzali lagoon and local rivers discharge in the area, the salinity amounts in the study area were slight. There were mainly one water masses identified in water column, which consists of water influence by local river and lagoon less saline water. Lesser salinity waters of the surface layer were located at left side of the diagram (temperature between 7.5 ℃–8 ℃, salinity between 0.5-7.5 psu). A compact part of data with temperature between 10-11.5 ℃ and salinity between 8.5-9.5 psu can be seen in top of diagram.

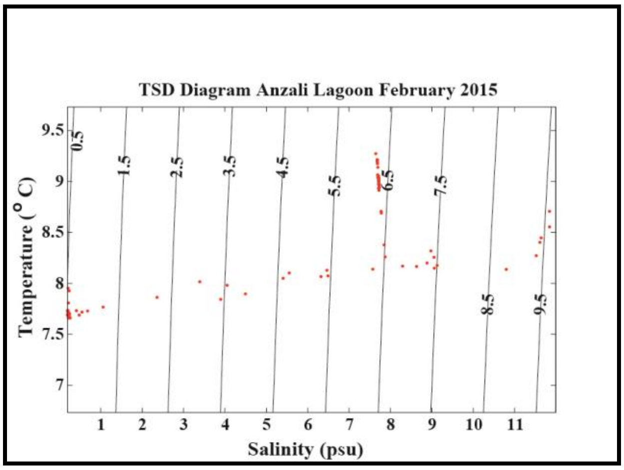

Figure 5. TSD diagram on all data collected from the channel, February 2015.

According to the climate change in autumn and increasing kinetic energy of atmosphere and seawater column in the region, deepening surface mixed layer phenomenon is occurred and thickness of the thermocline layer decreases below the surface mixed layer. Due to low salinity of the Caspian Sea water, vertical structure of density and its variations were in agreement with the temperature, thus, pycnocline was detected in the position of thermocline during time of measurements. Formation process of the seasonal thermocline started in early spring in the region. In midsummer, it was observed to be in strongest and highest thickness. In autumn with climate change and increasing kinetic energy in the water column, deepening the surface mixed layer is occurred. Vertical structure of sea water in winter showed that the stratification of water column is destructed.

The results of the study represent preliminary information on vertical structure and variability of seawater characteristics in the region during the warm and cold seasons in the year. The physical and chemical characteristics of the channel water were different in comparison to the other part of the Caspian Sea shallow waters area. The formation and destruction of thermocline affect the distribution of the parameters in water column along the area. Moreover, characteristics of channel water was one of the important factors for changing other properties such as active reaction and dissolved oxygen regimes in seawater over the continental shelf near the mouth of the lagoon in the investigated area. Discharge of large amounts of industrial, agricultural and urban wastes threats the Anzali Lagoon and adjacent area in the southern boundary of the Caspian Sea. With regard to the elevation of pollutants and nutrient contents in the Caspian Sea, it is expected that average values of dissolved oxygen concentrations in the deeper layers of the Caspian Sea was reduced. The results indicated the need of serious efforts for reducing entrance of human activities wastes and pollutants into the Caspian Sea environment and lagoons and bays in its coastal area.

Based on analysis additional information from some previous studies [13], [14] in the study area, local factors and human activities changed the natural structure of active reaction. The bays, lagoons, rivers discharge, port activities can be mentioned as important sources for entrance the urban and industrial wastes and other pollutants into the coastal waters and changes the natural regime of chemical properties including active reaction and environmental parameters of the seawater.

IV. Conclusions

Water exchange between Anzali Lagoon and coastal waters of the Caspian Sea via connecting channel, North of Iran were evaluated. In addition, regime of the physical structure and characteristics of water in the connecting channel in the western part of the southern Caspian Sea was presented and discussed. Furthermore, horizontal and vertical structure of the mentioned parameters was studied and major conclusions are as follows:

In all cases, the parameters range in the warm and cold seasons were different. The mean values of water salinity in the cold season were more than that in the warm season in the lagoon. Thermal stratification is not strong in the connecting channel. Almost daily thermal stratification of water column was observed. The results show no wide range of variations in the seawater properties based on TSD diagram in the time of measurements.

Due to increasing the depth near the mouth of the lagoon and water changes between the lagoon and the sea, characteristics of physical and chemical properties of water in this area was like the adjacent coastal seawater.

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