Research in Marine Sciences
Volume 3, Issue 2, 2018
Pages 311- 322

Variations of vertical structure of water temperature in the coastal area of Noshahr and Lavijrood

Aziz Abdulahi[1], Somayeh Nahavandian[2,*], and Dariush Mansoury[2]

[1]Master of Science (MSc) in Physical Oceanography Department, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Mazandaran, Noor, Iran

[2]Assistant Professor of Physical Oceanography Department, Faculty of Natural Resources and Marine Sciences, Tarbiat Modares University, Mazandaran, Noor, Iran

Received: 2018-02-18 *Accepted: 2018-05-26*

Abstract

Seasonal and spatial variations of temperature vertical structure are investigated in Noshahr and Lavijrood regions. Field measurements were carried out in spring and autumn 2012 and autumn 2016, using CTD up to a depth of 70 meters. In the spring three layers, namely mixed layer, thermocline, and deep layer are clearly distinguishable, while in the autumn, the deep layer is not observed. During the spring, the mixed layer is observed up to the depth of 10 m with temperature ranges from 21.5 to 22.5 °C and the thermocline is observed at the depth between 10 - 45 m with temperature ranges between 21.5 and 8 °C, and underneath, the deep layer is located. During the autumn, the mixed layer has been observed up to the depth of 40 m with temperature range between 20 and 20.5 °C, and a thermocline between 40 and 60 m with temperature range between 14 and 20 °C. Hence, compared to the spring, the depth of the mixed layer and thermocline increase in the autumn, and as expected the temperature of these layers decreases. The seasonal and spatial comparison between Noshahr and Lavijrood shows that, while in the spring, the mixed layer depth is deeper in Noshahr, the difference is not significant in the autumn.

Keywords: Thermocline; Mixed layer; Southern Caspian Sea; Noshahr; Lavijrood.

1. Introduction

The Caspian Sea is considered as the largest water mass enclosed by the land between Iran, Turkmenistan, Kazakhstan, Russia, and Azerbaijan. The Caspian Sea is located in western Asia, eastern Caucasus, and north of the Alborz mountain range (Oey *et al.,* 2012; Gunduz and Özsoy, 2014). Regardless the Gulf of Garabogaz, the Caspian Sea is located from

* Corresponding Author: s.nahavandian@modares.ac.ir

the north and south, between the 47° 55′ N, and 36° 33′ N, and from the west to the east, between the 46° 43′ E and 54° 53′ E (Dumont, 1998). The sea area is 400,000 km^2, its coastline is about 7,500 km, and its elevation is about 27 m below the open waters level. The average and maximum depth is 208 m and 1025 m, respectively. This largest lake in the world has rich hydrocarbon reserves and very diverse biological resources, which despite the isolation and lack of direct connection with free waters have unique characteristics. Due to its vast meridional extension, the Caspian Sea has various weather conditions from the North to the South (Lebedev and Kostianoy, 2005; Jamshidi and Yousefi, 2013). The weather in the southern part of the Caspian Sea is semi-tropical, while the northern part completely freezes during the winter. The unique ecosystem of Caspian Sea along with its non-natural features such as variations in water levels is of interest to many researchers.

Understanding the physical processes help a better recognition of the resources available for the development and preservation of a sustainable marine environment in the future and will be of great importance. For example, temperature and salinity along with pressure affecting the density of seawater play important roles in controlling the dynamics and thermodynamic behavior of seas and oceans (Chand *et al.,* 2004). To optimize the usage of oceans, seas and lakes, it is vital to identify the critical physical parameters necessary. In order to achieve this purpose field sampling, and more precise analysis of these parameters is necessary. In addition, physical parameters have a significant impact on biology, air-sea interactions, marine construction and military activities (Simpson and Sharples, 2012).

Given the fact that these physical parameters vary temporally and spatially, continuous studying is important. Since, the mixed layer and thermocline as parts of the surface layer have significant effects on the biological parameters and other physical and chemical parameters in the water, their temporal and spatial investigations are important. For example, the mixed layer depth variations and disturbances in this layer and the impact of the availability of light and nutrients on phytoplankton are the main physical factors affecting their dynamics (Lavigne *et al.,* 2013). In addition, increased concern about the climate change leads increasing interest in research and development of renewable energy technologies. The ocean provides a large source of potential energy sources therefore the investment in ocean energy is growing as renewable energy technologies. Research on the conversion of the thermal energy, wave energy, tidal energy and wind energy in the seas and oceans has led to the development of technologies and, in some cases, to business development. Since these energy resources are considered as green energy sources, they can help reducing the risk of global climate change (Stewart, 2008). One of these sources is the ocean thermal energy. In order to use this energy, the temperature changes inside the oceans, such as thermohaline flows, as well as the heat exchanges between the ocean and the atmosphere muse be known. In this case, the mixed layer and the thermocline, which are the main source of these changes and exchanges in the water, are very important. The part of surface layer in the seas and oceans in which due to the turbulence in the surface layer and air-sea interactions, the physical parameters such as temperature, salinity and density are uniform, is mixed layer.

This layer directly affects the exchange of air and sea through heat, momentum and gases. Therefore, studying the depth of mixed layer and its variations is essential to understand and interpret the thermal fields, as well as the speed of the surface layer and the processes associated with mixing (Jamshidi *et al.,* 2010).

A study by Dumont (1998) showed that in the Caspian Sea, the seasonal thermocline can be located in the water column between the surface and of 80 m. Investigation of the physical parameters such as temperature, salinity and density in the eastern part of the southern coast of the Caspian Sea in the Babolsar region showed that the seasonal thermocline in the summer is between 20 m and 50 m and at the beginning the of the autumn it located between 30 m and 45 m (Zaker *et al.,* 2007).

In 2009, Jamshidi studied the distribution of temperature, salinity, and density in the coastal waters of the south of Caspian Sea. According to the results, a seasonal thermocline was observed deeper than 30 meters (Jamshidi and Bin Abu Bakar, 2009).

In another study the parameters of temperature, salinity, and density of Caspian Sea coastal waters in the Rudsar area were examined. According to the results, the process of water layering was completed in the mid-summer and a strong thermocline was observed between 10 and 40 m (Jamshidi *et al.,* 2010).

Investigation of the temperature and salinity in different seasons in Noshahr and Noor coastal waters indicated that in the spring and summer, the depths of mixed layer in the regions were 7 and 5 m, respectively (Vahidi Ghahroodi, 2013). In autumn in Noshahr area, the mixed layer depth was 40 m and in the Noor was 38 m. The depth of the thermocline in spring was about 42 m in Noshahr and 40 m in Noor, in summer it was about 60 m in Noshahr and 80 m in Noor and in autumn was 70 m in both zones, while in winter was 68 m in Noshahr and 62 m in Noor (Vahidi Ghahroodi, 2013). Furthermore, Jamshidi and Soheilifar in 2016 studied the physical structure and summer layering in the southern coastal waters of the Caspian Sea (Rudsar, Babolsar and Kiashahr). Analyzing the field-measured data at 13 stations in the study area showed that the strongest layering of the water column was in summer and in the coastal waters of Kishashar port (Jamshidi and Soheilifar, 2016).

2. Materials and methods

The study area is the southern part of the Caspian Sea, the coasts of Mazandaran province, the coast areas of Noshahr and Lavijrood during the autumn and the spring. The location of the measurements in each transect have been shown in Figure 1. The data used in this study has been measured in spring and autumn 2012 and autumn 2016 using CTD; Idronaut Ocean Seven 316. The depths of both stations measured in the spring are 5, 10, 25, 35, and 50 m. The depths of the stations in autumn season were 5, 10, 25, 50 m in Noshahr, and 25, 35, 50, 70 m in the Lavijrood.

So far, based on the measurement many methods have been applied for estimating the mixed layer depth. Meanwhile, the threshold method as a most common method is used in this study in order to estimate the mixed layer depth (Schneider and Muller, 1990). In order to estimate the mixed layer depth threshold method is used in this study. Using profiles of temperature, salinity and density, this method can be applicable with different threshold values. Based on this method, the depth of the

Figure 1. Location of the stations

mixed layer is a depth in which the difference between the temperature, salinity or density with their related values at the reference depth (usually a depth in vicinity of the surface) exceeds a predetermined value (threshold value). The threshold method was used by Wyrtki (1964) and Schneider and Muller (1990) in order to calculate mixed layer depth based on temperature and salinity profiles.

3. Results and Discussion

Vertical variations of the temperature at four stations in spring in Noshahr and Lavijrood regions are shown in Figures 2 and 3, respectively. As can be seen in these figures, the vertical variations in water temperature was recorded between 8 and 22 °C in Lavijrood, and 8.1 and 23 °C in Noshahr. In spring the temperature variations in these two regions, were relatively similar and the largest difference was recorded near the surface. The temperature values in deep layer were similar in both regions.

Figures 4 and 5 also show the sea temperature variations in the autumn in two regions of study. According to the measurements, the temperature variation in the Lavijrood region

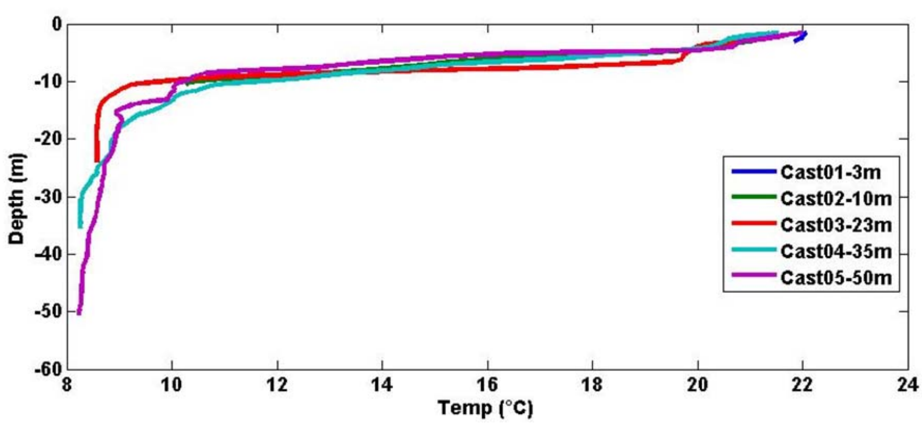

Figure 2. Temperature variations at different stations in Lavijrood in spring 2012

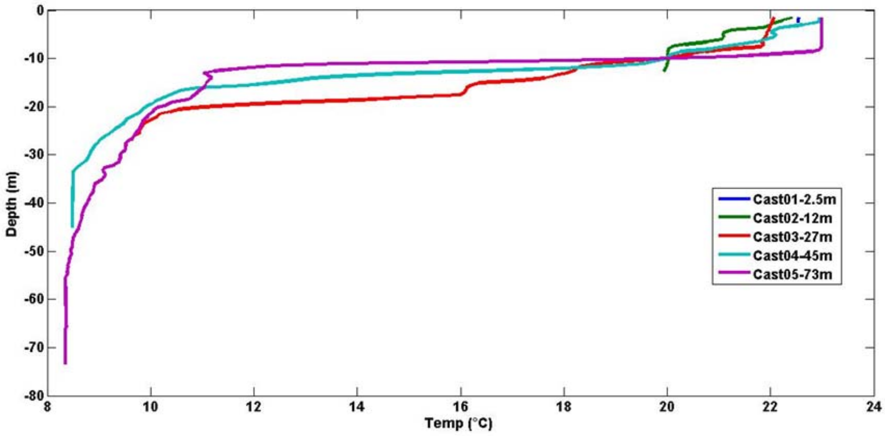

Figure 3. Temperature variations at different stations in Noshahr in spring 2012

is between 9.5 and 14.3 °C, while its variation in Noshahr is between 13 and 20.5 °C. The reason of temperature difference between these two regions may be due to the fact that the measurements were in two different years (Lavijrood data in 2016 and the data of Noshahr in 2012) and another reason can be the freshwater entrance in Lavijrood region.

The vertical sections of the temperature variations in Lavijrood and Noshahr are shown in Figures 6 and 7. The vertical axis indicating the depth and the horizontal axis represents the distance from the coast, and the colored part also shows temperature changes relative to these two axes. The maximum distance from the coast in Lavijrood is about 12 km, and its maximum depth is 50 meters. Temperature variations along the horizon at Lavijrood from the surface to the depth of about 8 meters are negligible. The isothermal lines are far from each other between depths 8 and 15 m, and they are getting close to each other at depths between 15 and 20 m. As shown in Figure 7, the surface water temperature in Noshahr is about 20 °C, which is higher than water surface temperature in Lavijrood (about 22 °C). Getting

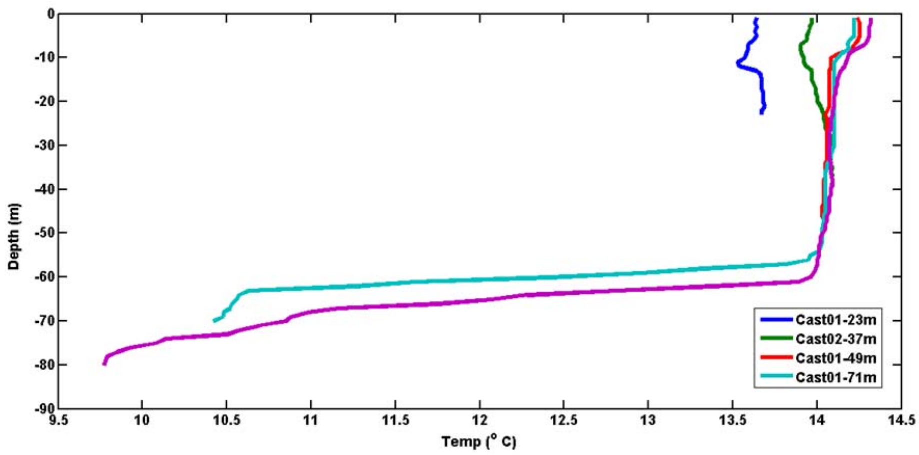

Figure 4. Temperature variations at different stations in Lavijrood in autumn 2016

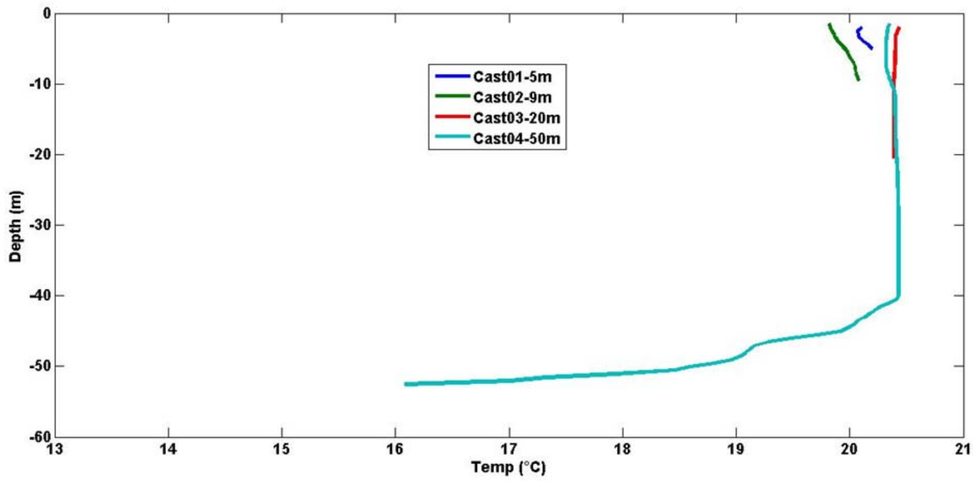

Figure 5. Temperature variations at different stations in Noshahr in autumn 2012

distance from the coast in Noshahr region, the depth of isothermal line of 22 °C increases and isothermal line of 22 °C gets close to isothermal line of 12 °C at depth of 20 m.

Temperature profile in the Lavijrood region in spring and autumn shows that there is no mixed layer in the spring, but the thermocline and the deep layer are well visible (Figure 8). The absence of mixed layer in the spring could be due to the fact that measurements were made in late June and near the summer, and because of hot weather, the layering of water surface was intense. As shown in the figure, the thermocline is seen between the surface and 50 m depth. The deep layer, with almost constant temperature, is located below the thermocline. In the autumn, due to the increase in wind speed and the mixing mechanism, the water is well mixed, so that the layer is mixed from the surface to a depth of 60 meters and from this depth thereafter, is the thermocline layer.

Figure 9 shows the temperature profile

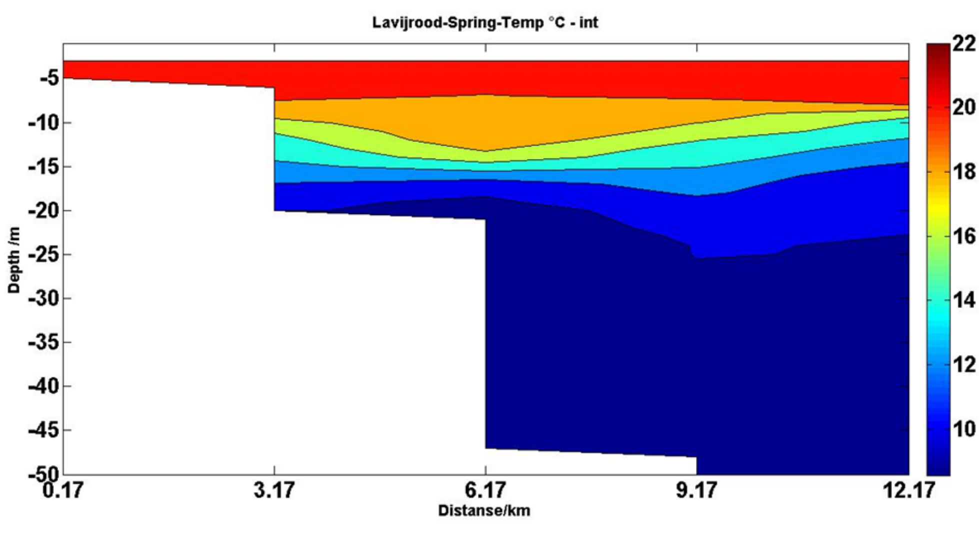

Figure 6. Two-dimensional temperature variations in the Lavijrood spring 2012

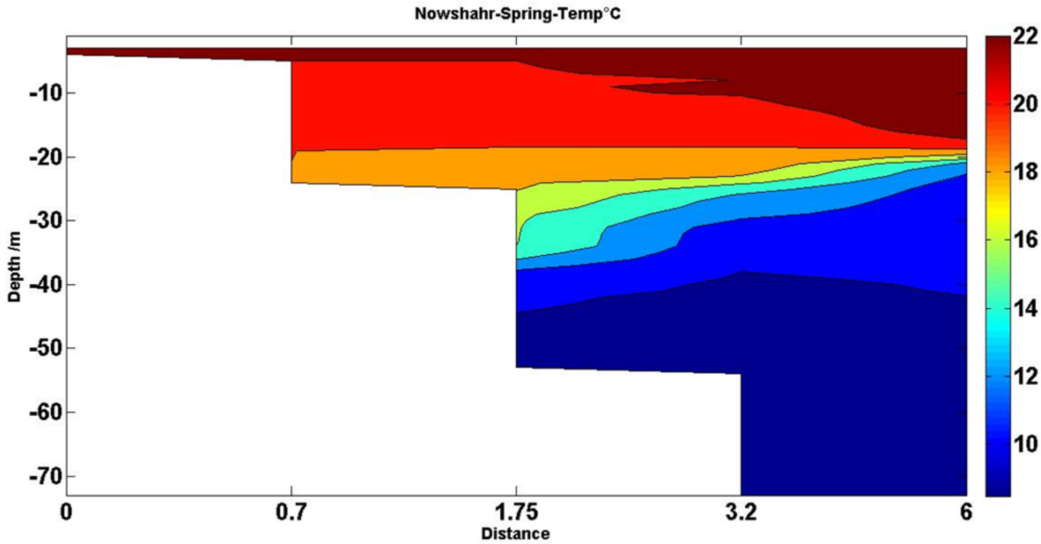

Figure 7. Two-dimensional temperature variations in the Noshahr in spring 2012

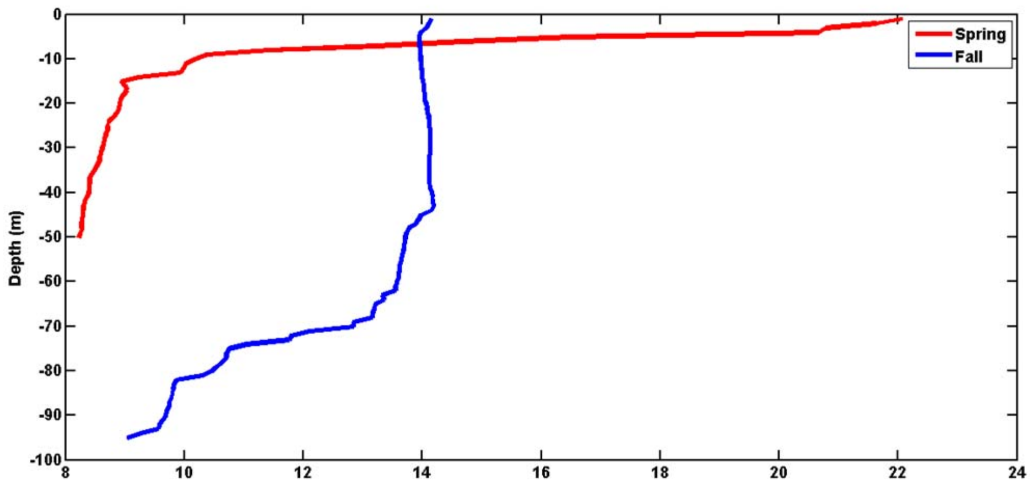

Figure 8. Temperature variations in spring 2012 and autumn 2016 in Lavijrood

variations in autumn and spring in the Noshahr area. Three layers of mixed layer, thermocline and deep are visible as well in the spring, so that the mixed layer depth is about 10 m, and below the thermocline is to the depth of about 20 m, and the deep layer is located below the thermocline. As mentioned earlier, in the autumn, the water column was well mixed up to a depth of 40 m due to winds and the mixing of water columns.

In Figures 10 and 11, spatial comparison of temperature profiles have been shown in Lavijrood and Noshahr. The results indicate that in the Noshahr, all three layers including mixed layer, thermoclinic, and deep layer, are visible, while there is no mixed layer in Lavijrood in spring. The reason of this difference can be because of the measurements which were performed near the entrance of the river in the Lavijrood in the spring, which leads

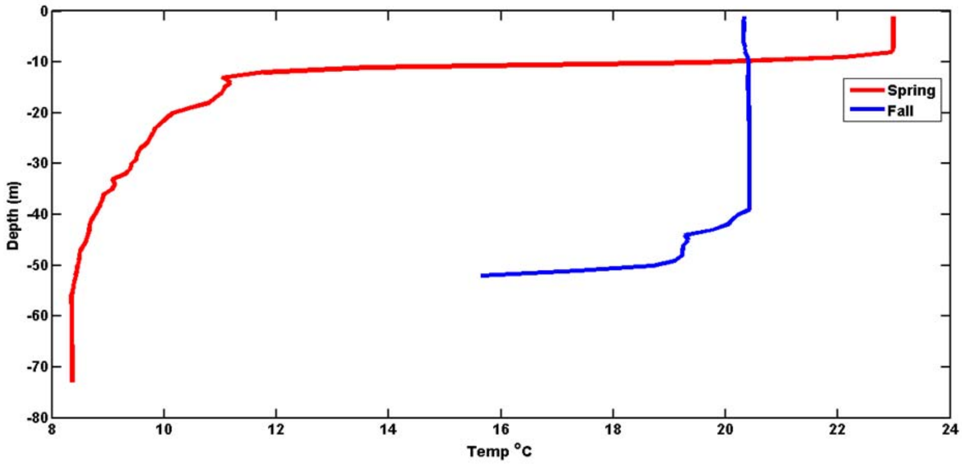

Figure 9. Temperature variations in spring and autumn 2012 in Noshahr

to stratification of surface water and decaying the mixed layer. Temperature variation range in these two regions is roughly the same. The temperature of thermochemical layer varies between 22 °C and 10 °C in Lavijrood and mixed layer temperature is about 23 °C, the thermocline is between 22.5 °C and 10 °C, and the deep layer is about 8 °C in Noshahr.

Figure 11 also shows the variations of vertical structure of the temperature in the autumn in Lavijrood and Noshahr. The similarity of these two regions is that in both regions, according to the measured depths, there are two layers of mixed layer and thermocline and there is no deep layer.

The water vertical structure in Noshahr area has two layers, a layer between the surface and a depth of 45 m and a thermocline in the underlying layer to the bed. In the Lavijrood, the mixed layer is between the surface and a depth of approximately 65 m and the thermocline is located below the mixed layer. The temperature of the mixed layer is about 14 °C and the temperature of the thermocline varies

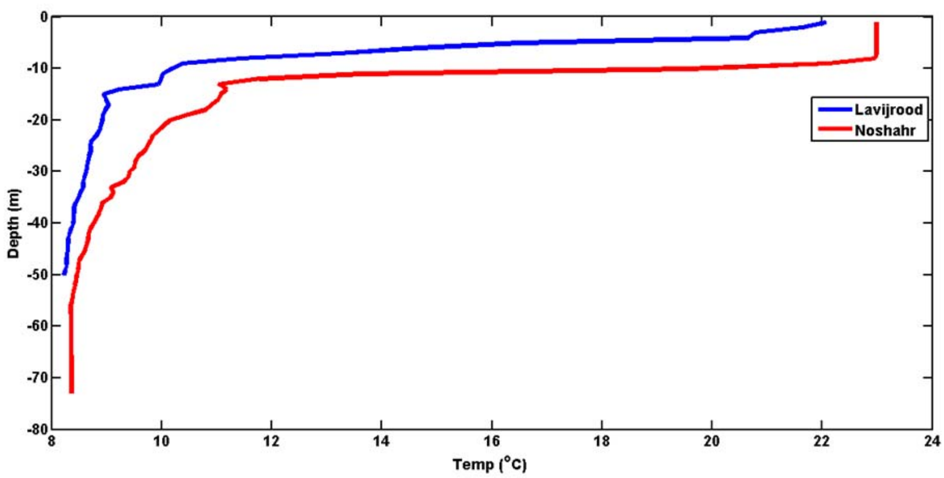

Figure 10. Temperature variations in spring 2012 in Noshahr and Lavijrood

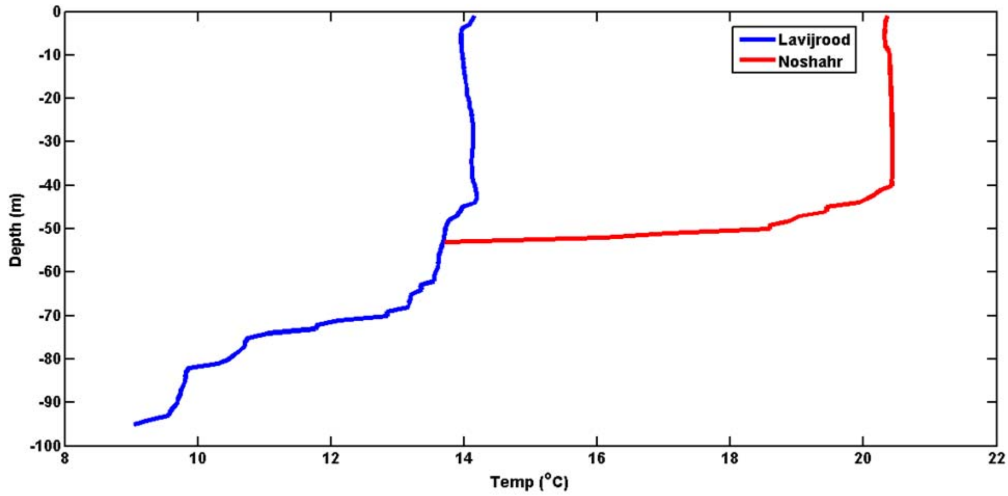

Figure 11. Temperature variations in autumn 2012 in Noshahr and Lavijrood

between 10 °C and 14 °C. In the Noshahr, the temperature of mixed layer is approximately 21 °C and the thermocline temperature ranges is between 21 °C and 12 °C.

Figures 12 to 15 show the estimation of the mixed layer depth of using different threshold values in spring and autumn in Noshahr region. The depth of mixed layer in the spring for Noshahr, calculated using threshold values of 0.01 and 0.5 are shown in Figures 12 and 13. Comparing these two figures, it can be concluded that the threshold value of 0.01 is more suitable for the spring in the area. Figure 14 shows the depth of mixed layer calculated using threshold value of 0.05 in autumn in Noshahr and with threshold value of 0.1 as well (Figure 15). Comparing these two figures represents that the best threshold for this area in the autumn is about 0.1.

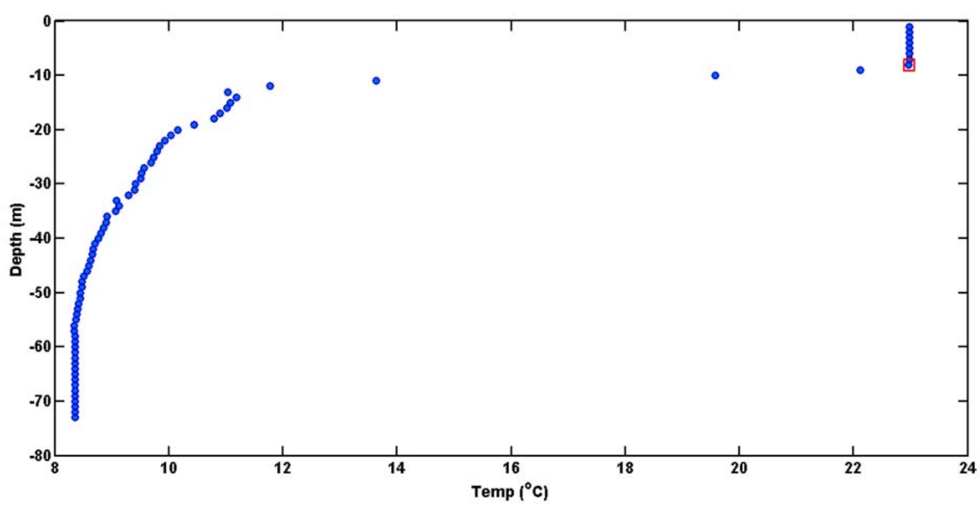

Figure 12. Estimation of the mixed layer depth using threshold value of 0.01 based on temperature profile measured in the spring in Noshahr.

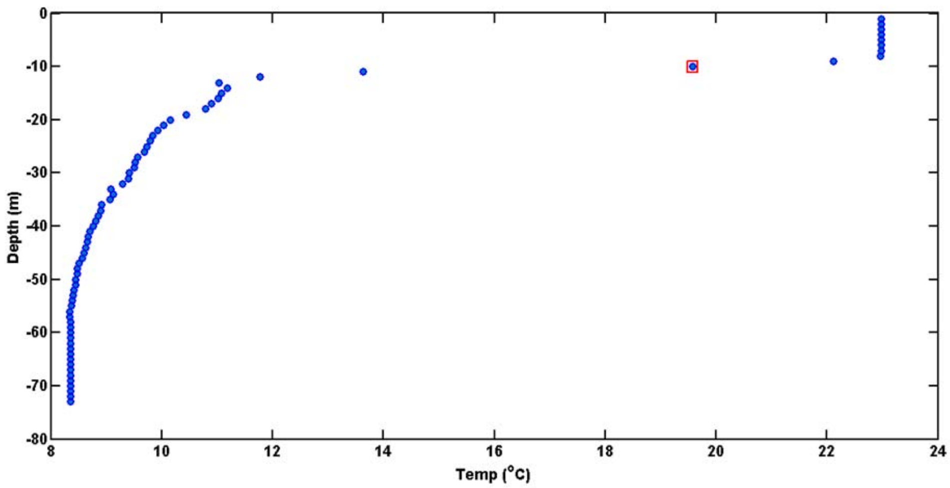

Figure 13. Estimation of the mixed layer depth using threshold value of 0.5 based on temperature profile measured in the spring in Noshahr

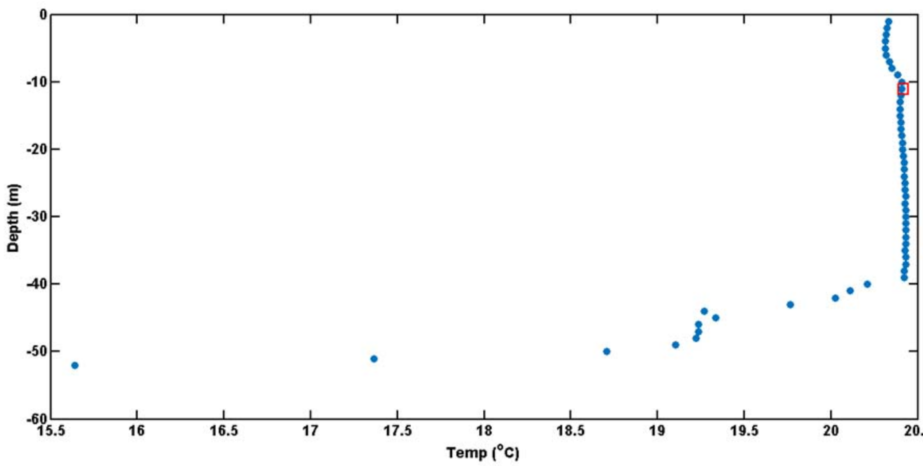

Figure 14. Estimation of the mixed layer depth using threshold value of 0.05 based on temperature profile measured in the spring in Noshahr

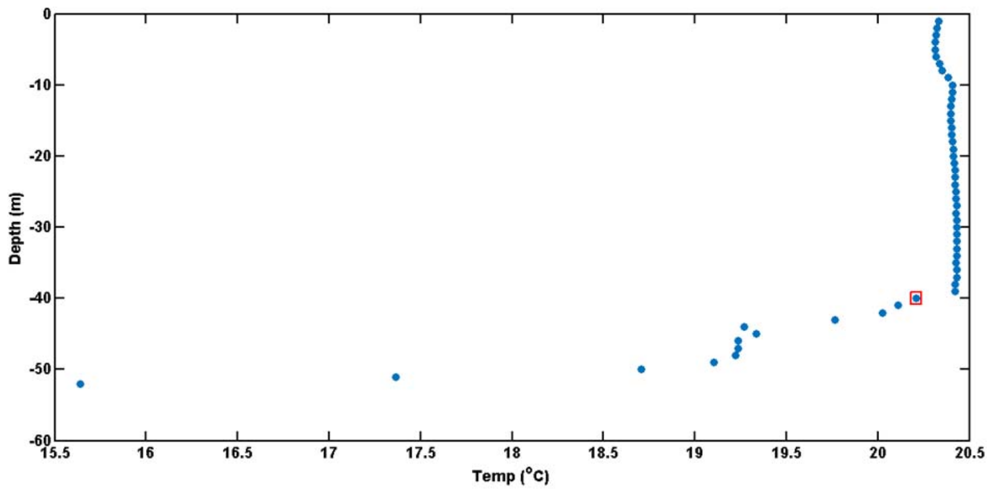

Figure 15. Estimated mixed layer depth using threshold value of 0.1, based on temperature profile measured in the spring in Noshahr

Conclusion

In this study, the vertical structure of water temperature was studied during the spring and the autumn of 2012 and 2016, in Noshahr and Lavijrood areas. The temperature range in the spring was approximately between 8 °C and 23 °C in both regions, while in the autumn, the temperature ranges had a few degrees differences.

In the spring, three layers of the mixed, thermocline and deep layers were observable in the water column. Based on the measurements in the spring in Noshahr, the mixed layer depth was about 10 m. The thermocline was located below the mixed layer up to a depth of 45 m and underneath of the deep layer. In Lavijrood during the spring there was no mixed layer and the thermocline was located between the surface and depth of 50 m, and the deep layer were visible below the thermocline.

During the autumn, the deep layer decayed and only mixed layer and the thermocline was visible. In Noshahr, the mixed layer was between the surface and 40 m and the thermocline was beneath up to the depth of 40 m. While, in Lavijrood the depth of the mixed layer is about 60 m and below the thermocline was located. It can be said that although the depth of the thermocline varied locally, its depth was in the average of 30 and 40 m. The mixed layer depth has been calculated using threshold method. Since suitable threshold values varied spatially and seasonally, it can be concluded that it's difficult to use a unique threshold value in order to estimate the mixed layer depth.

Acknowledgements

The authors would like to thank Dr. Nematollah Mahmudi and Dr. Mehdi Gholamali Fard, who provided this study valuable data.

References

Chand, S., Aung, T., and Rao, S. 2004. Physical properties of southern Fiji waters. The South Pacific Journal of Natural and Applied Sciences, 22(1): 57-61.

Dumont, H. J. 1998. The Caspian Lake: History, biota, Structure, and Function, Limnology and Oceanography, 43(1): 44–52.

Gunduz, M, and Özsoy, E. 2014. Modeling seasonal circulation and thermohaline structure of the Caspian Sea. Ocean Science, 10(3):459-71.

Jamshidi, S., and Bin Abu Bakar, M. N. 2009. Distribution of Temperature, Salinity and Density on the Southern Continental Shelf of the Caspian Sea, off Babolsar; during the Fall Season, In Asian and Pacific Coasts 2009, 22-28.

Jamshidi, S., Bin Abu Bakar, M. N., and Noordin, M. 2010. Temperature, Salinity and Density Measurements in the Coastal Waters of Rudsar South Caspian Sea. Journal of the Persian Gulf (Marine Science), 1(1): 27-36.

Jamshidi, S., and Soheilifar, M. 2016. Evaluation of physical structure and summer layering in the water column of the southern Caspian Sea coastal zone. Two Scientific Journal Series - Marine Techniques Research, 1: 111-101.

Jamshidi, S., and Yousefi, M. 2013. Seasonal Variations of Seawater Properties in the Southwestern Coastal Waters of the Caspian Sea. International Journal of Marine Science Engineering, 3(3): 113-124.

Lavigne, H., D'Ortenzio, F., Migon, C., Claustre, H., Testor, P., and et al. 2013. Enhancing the comprehension of mixed layer depth control on the Mediterranean phytoplankton phenology. Journal geophysical research, 118: 3416–3430.

Lebedev, S.A., and Kostianoy, A.G. 2005. Satellite altimetry of the Caspian Sea. Sea, Moscow, 366.

Oey, L., Chang, Y.L., Lin, Y.C., Chang, M.C., Xu, F., and Lu, H.F. 2012, ATOP-The advanced Taiwan Ocean Prediction System based on the mpiPOM, Part1: Model Descriptions, Analysis and Results. Terrestrial Atmospheric and Oceanic Sciences; 24(1): 137-158.

Schneider, N., and Muller, P. 1990. The meridional and seasonal structures of the mixed-layer depth and its diurnal amplitude observed during the Hawaii-to-Tahiti Shuttle experiment. Journal of physical oceanography, 20(9): 1395-1404.

Simpson, J. H., and Sharples J. 2012. An Introduction to the Physical and Biological Oceanography of Shelf Seas, Cambridge: Cambridge University Press.

Stewart, R.H. 2008. Introduction to Physical Oceanography, (Department of Oceanography Texas A & M University, USA, 2008 Edition: 345 P.

Vahidi Ghahroodi, M. 2013. Temperature, salinity and velocity changes in coastal waters of the south of the Caspian Sea (northern and Noshahr areas), Master thesis in marine physics, Faculty of Marine Sciences, Tarbiat Modares University.

Wyrtki, K. 1964. The thermal structure of the eastern Pacific Ocean. Dtsch. Hydrogr. Z., 8A, 6–84.

Zaker, N.H., Ghaffari, P., and Jamshidi, S. 2007. Physical Study of the Southern Coastal Waters of the Caspian Sea, off Babolsar, Mazandaran in Iran. Journal of Coastal Research, 50: 564-569.