VARIATIONS OF SEAWATER PROPERTIES OF THE SOUTHWESTERN COASTAL WATERS OF THE CASPIAN SEA

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

by

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Variasi Sifat-Sifat Airlaut Di Barat Daya Perairan Pantai Laut Caspian

oleh

SIAMAK JAMSHIDI

Tesis yang diserahkan untuk
Memenuhi keperluan bagi
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TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF ABBREVIATIONS

AAB	Anomalous Algal Bloom
CEP	Caspian Sea environmental program
Chl-*a*	Chlorophyll-*a*
CTD	Conductivity, Temperature, Depth
DO	Dissolved Oxygen
IAEA	International Atomic Energy Agency
GPS	Global Positioning System
NTU	Nephelometric Turbidity Units
pH	Active Reaction
PPT	Part Per Thousand

LIST OF SYMBOLS

ρ	Density
Sigma-t (σ_t)	Density of Seawater
f	Correction Coefficient
mS/cm	Milli Siemens per Centimeter
NTU	Nephelometric Turbidity Units

VARIASI SIFAT-SIFAT AIRLAUT DI BARAT DAYA PERAIRAN PANTAI LAUT CASPIAN

ABSTRAK

Laut Caspian merupakan badan air garam dataran terbesar di dunia tetapi cuma terdapat beberapa kajian sahaja dilakukan terhadap variasi sifat-sifat airlaut di bahagian selatan perairan pantai. Kajian ini dijalankan untuk menentukan sifat airlaut dan arus laut dengan tujuan untuk menyiasat penstrataan turus air dan interaksi antara komponen fizikal, kualiti air dan komponen biologi bagi sifat airlaut. Pengukuran lapangan yang dijalankan terdiri daripada dua kaedah: profil prob CTD dikerahkan sekali pada setiap empat musim (iaitu musim bunga, musim panas, musim luruh dan musim sejuk) dan menggunakan meter arus. Data yang dikutip di analisis menggunakan fungsi polinomial dan interpolasi kubik dalam perisian Matlab dan model regressi.

Keputusan menunjukkan bahawa perubahan penting bagi sifat air laut berlaku terutamanya pada lapisan sehingga kedalaman 100m. Suhu airlaut dicatat pada julat 9–11 ^{o}C (Mac), 18–19 ^{o}C (April), 27–29 ^{o}C (Ogos) dan 19–20 ^{o}C (November) hampir dengan permukaan. Termoklin bermusim dikesan diantara kedalaman 20m dan 50 m pada musim panas dengan kecerunan suhu 16 ˚C. Ini diikuti dengan pemusnahan lapisan termoklin yang berlaku akibat penyejukan permukaan air dan mendalamkan lagi lapisan tercampur pada hujung musim luruh sehingga musim sejuk. Nilai min. kemasinan adalah 12.33 ppt, dengan nilai kemasinan yang terendah dan tertinggi dicatatkan pada bulan Mac dan Ogos. Variasi ketumpatan air laut pada bahagian atas lapisan 100m adalah agak ketara (antara 1005.78–1010.75 kg m^{-3}) tetapi di bawah lapisan ini nilainya kekal di sekitar 1010 kg m^{-3}. Variasi menegak ketumpatan didapati bersetuju dengan variasi dalam suhu turus air dan piknoklin terletak pada lokasi termoklin. Laju bunyi maksimum diperhatikan pada permukaan, iaitu sekitar 1517–1519 m s^{-1} pada musim panas. Nilai ini berkurang kepada 1453 m s^{-1} di bawah kedalaman 450 m.

Purata laju bagi arus air yang diukur dalam pelbagai musim adalah secara prinsipnya sehingga 0.5 m s^{-1}. Arah dominan bagi arus laut di kawasan kajian ialah 90^o . Dalam musim luruh dan musim sejuk laju arus yang ekstrim melebihi 1 m s^{-1} kadang kala dicerap. Nilai maksimum oksigen terlarut dicerap sekitar 7.3 mg l^{-1} dan berkurang kepada 1.2 mg l^{-1} pada kedalaman 450 m dalam musim panas dan musim luruh. Nilai tindakbalas aktif (pH) air laut berkurang dengan kedalaman. Rejim asli daripada perubahan kekeruhan air di kawasan kajian adalah dalam julat 1-10 NTU. Kepekatan chlorophyll-*a* yang direkod pada musim panas berjulat antara 0.2–3.6 mg m^{-3}.

Kajian interaksi antara pelbagai komponen bagi sifat air laut di barat daya perairan pantai Laut Caspian menunjukkan beberapa penemuan yang menarik. Suhu air laut, penstrataan dan arus di kawasan kajian memberi kesan besar terhadap kualiti air dan komponen biologi pada struktur menegak dan mendatar. Pemalar korelasi (R^2) untuk tindakbalas aktif-suhu dan oxygen terlarut-suhu menunjukkan nilai melebihi 0.8 dalam pelbagai musim di rantau ini. Sirkulasi am air laut di selatan perairan pantai Laut Caspian mempamerkan pergerakan arah lawan jam. Sirkulasi ini memainkan peranan penting terhadap perubahan ciri-ciri air, termasuk juga dalam pengangkutan air lagun Anzali sedimen dan komponen yang berkaitan (seperti muatan terampai dan sedimen), merentasi pentas benua yang cetek ini. Struktur suhu, iaitu stratifikasi terma dan arus-janaan percampuran semasa musim sejuk, sangat mempengaruhi variasi pada kualiti air dan komponen biologi air laut.

VARIATIONS OF SEAWATER PROPERTIES OF THE SOUTHWESTERN COASTAL WATERS OF THE CASPIAN SEA

ABSTRACT

The Caspian Sea is the largest inland saltwater body in the world, but only a few studies have been conducted on the variations of seawater properties in its southern coastal waters. This study carried out to determine seawater properties and sea currents for the purpose of investigating the stratification in water column and interactions among the physical, water quality, and biological components of the seawater properties. Field measurements were conducted using two methods: CTD probe profiling deployed once during each of the four seasons (i.e., winter, spring, summer, and autumn) and using current meter. The collected data were analyzed using polynomial functions and cubic interpolation techniques in Matlab programming and regression modeling.

Results showed that the significant changes in seawater properties occurred primarily within the upper 100 m layer. The seawater temperatures recorded were 9–11 °C (March), 18–19 °C (April), 27–29 °C (August), and 19–20 °C (November) near the surface. A seasonal thermocline was detected between 20 and 50 m depth in summer at a temperature gradient of 16 °C. The subsequent destruction of the thermocline layer occurred with the general cooling of the surface water and deepening of the mixed layer toward the end of autumn and winter. The mean value of the seawater salinity was 12.33 ppt which its lowest and highest values were recorded in March and August, respectively. The variations in seawater density within the upper 100 m layer were considerable (between 1005.78 and 1010.75 kg m^{-3}), but below this layer, the value remained around 1010 kg m^{-3}. The vertical variations in density agree with variations of temperature in water column, and a pycnocline was observed at the location of the thermocline. The maximum speed of sound in seawater was observed at the surface layer, between 1517–1519 m s^{-1} in August. This value decreased to about 1453 m s^{-1} below 450 m. The average speed of the water current, measured in

various seasons, was principally up to 0.5 ms^{-1}. The water currents in autumn and winter were stronger than those during the spring. The dominant direction of the sea current in the study area was approximately 90°. In autumn and winter, extreme current speeds of more than 1 m s^{-1} were sometimes observed. The maximum dissolved oxygen was observed to be around 7.3 mg l^{-1}, which decreased to 1.2 mg l^{-1} at 450 m in summer and autumn. The active reaction (pH) of the seawater decreased with depth. The natural regime of the turbidity variations in the study area was between 1 and 10 NTU. The chlorophyll-*a* concentration recorded in August ranged from 0.2 to 3.6 mg m^{-3}.

The study of the interaction between the various components of the seawater properties of the southwestern coastal waters of the Caspian Sea presented interesting findings. The seawater temperature, stratification, and water currents had remarkable effects on the variations in water quality and biological components in the vertical and horizontal structures. The correlation coefficients (R^2) of active reaction-temperature and dissolved oxygen-temperature were more than 0.8 in various seasons in the region. The general circulation of seawater in the southern coastal waters of the Caspian Sea exhibited counterclockwise movement. This circulation plays a significant role in changing the water characteristics, as well as in transporting Anzali lagoon water and its associated components (e.g., suspended load and sediment), over the shallow continental shelf. Temperature structure, i.e. thermal stratification, and current-generated mixing during cold seasons, significantly influenced the variations in the water quality and biological components of the seawater.

CHAPTER ONE

INTRODUCTION

1.1 Background

Study on seawater properties and their variations in the water column are important in oceanographic studies. In the coastal areas, such research is of considerable interest not only because of its influence on the various physical processes on the shelf region but also due to close relation to the marine environment and ecosystems (Thurman and Trujillo, 2001). The need for coastal water research is further justified, particularly with recent urban and industrial developments and dramatic increase of population near the coasts of the seas and oceans in the world.

The first study on Caspian Sea water characteristic such as determination of pH in the seawater was performed by Bruevich in the early 1930s. The result of the study showed that the values of active reaction (pH) in the Caspian Sea water were significantly greater than pH values in the World Ocean (Tuzhilkin et al., 2005). One of the early good reports about the Caspian Sea characteristics such as water temperature was published in 1963 by Zenkevitch (Khoshravan, 2007). He reported that the surface water temperature data record important variation during the year. The temperature regime of the Caspian Sea is rather unusual. On the one hand, it is characterized by considerable temperature differences in wintertime between its northern and southern areas, and on the other hand, leveling of the temperature regime between mentioned part in the summertime. The less saline water at the surface of the northern part of the sea freezes during December to march. In the southern part of the sea, surface water temperature varies from 9 ^{o}C in winter to 26 ^{o}C in summer (Tuzhilkin and Kosarev, 2005).

The thermal stratification and thermocline structure in the Caspian Sea water is subject to significant interannual variability, including multiannual trends that dominate other kinds of variability in the intermediate and abyssal layers. According to enhanced river discharge in the last decades, a hydrostatically stable in vertical salinity stratification formed in the Caspian Sea deep-water areas. It is expected that the mentioned occurrence caused changes in the thermal structure, pattern of stratification and vertical distributions of salinity in the seawater. The multiannual trends in the variability of the thermohaline structure of the Caspian Sea waters may exert significant influence upon other components (abiotic and live) of its ecosystem (Tuzhilkin and Kosarev, 2005).

The results of some studies until the beginning of the 1990s show that the long-term changes in the thermohaline structure of the seawaters along significant changes in nutrient supply to the Caspian Sea with the river discharge that occurred in the second half of the twentieth century this led to a profound transformation of the natural dissolved oxygen regimes of the Caspian Sea waters. Following the recent changes (such as in the riverine runoff regime and sea-level) that have occurred in the Caspian Sea environment at the end of 20^{th} century, close attention and further monitoring requires, especially in the southern part of the sea (Tuzhilkin and Kosarev, 2005).

1.2 Statements of problem

To date there are few studies on the distributions of seawater properties and currents in the southern coastal waters of the Caspian Sea. The hydrological studies of the Caspian Sea (in the north part) were performed at the beginning of the twenty century under supervision of Lebedintsev, Knipovich, and Bruevich. Their principal results stated that the Caspian Sea significantly differs from other regions of the world ocean in its salt composition and density. The salt composition of the waters of the Caspian Sea was formed as a result of transformation of the initial oceanic water under the influence of the continental runoff after the isolation of the Caspian Sea from the World Ocean (Tuzhilkin et al., 2005).

In last decades, intensity of Caspian studies has been decreased and many coastal monitoring and hydro-meteorological stations have been closed. In addition, significant events have occurred in the Caspian Sea such as riverine runoff regime and sea level fluctuations have caused in essential transformation in hydrological structure and distribution of seawater parameters. The Caspian Sea and specially its southern coastal waters is the most unknown region from oceanographic viewpoint due to deficiency of field measurements data. Performed previous studies were mostly done at the surface layer of the sea or for a short time in the region. There is no suitable and adequate data and knowledge about the southern coastal water of the Caspian Sea. Vertical structure of seawater parameters, stratification, current pattern and their variations were not studied and presented obviously. Therefore, study of variations in seawater properties, thermal stratification and sea current in the region is very important.

1.3 Objectives of the study

The objectives of this study are:

1- To determine the variations of physical components of seawater properties (e.g. temperature, salinity, density and sound speed) in the continental shelf and deep waters;

2- To determine regime of the current over the continental shelf in various measurements;

3- To investigate on the pattern of thermal stratification in the water column and determine the behavior of seasonal variations of thermocline; and

4- To investigate on variations of active reaction (pH), dissolved oxygen, turbidity (water quality components) and chlorophyll-*a* (biological component) in various seasons. Interaction between these parameters with some physical parameters is also established.

1.4 Scope of the study

Scopes of this study are:

1. The continental shelf and deep waters of the southwestern coastal waters of the Caspian Sea refers to the seawater through 50 m upper layer and below this depth, respectively. The variations of seawater properties were investigated in water column in continental shelf and deep waters in the region in the southern Caspian Sea. The study area covered a rectangular shape with the length of 30 km and width of 15 km in the southwestern coastal waters of the southern Caspian Sea. Two important features of the southern Caspian Sea are narrow continental shelf, and deep water. The measurements were carried out in several stations in the continental shelf and deep water zone in the study area throughout the water column. Thus the outputs of this study in the investigated area can represent seawater characteristics in whole region of the southern coastal waters of the Caspian Sea.

2. Temporal regime for the study of variations in seawater properties represented the four seasons i.e. winter, spring, summer and autumn. For measuring the seawater properties, the data were collected in the months of February, April, August and November, which provide the best statistical reliability and characterizing through each season. The single date measurements of the seawater properties in the mentioned months were able to represent the characteristics of water in each season. In addition, the high costs of field measurements, and weather and sea conditions were some of limitations in this study. Therefore, seawater properties were measured in the study area on 11 March, 28 April, 13 August and 6 November. Attempt was made to conduct the first measurements in February but weather and sea conditions were not appropriate for field measurements. Thus, the first profiling operation was delayed and can be performed in early March, necessarily.

3. Seawater properties were divided into three components; physical, water quality and biological. Physical components of the seawater properties consist of temperature, salinity, density and sound speed. Water quality components include of active reaction (pH), dissolved oxygen and turbidity. Chlorophyll-*a* was measured as biological component of seawater properties.

4. For the measurement of the seawater parameters a CTD probe was used. For data collection the equipment was sent down the water column using a winch and a cable in each sampling station. UNESCO techniques and algorithms for computation of fundamental properties of seawater were applied for data processing and analysis. The prepared data was utilized to determine the variations of seawater properties, thermal stratification. In addition, the prepared data, used algorithms and analyzed methods were used to approach to determine the interaction between different components of seawater properties in the southern coastal waters of the Caspian Sea in various seasons.

5. Regime of the sea current in the southwestern coastal waters of the Caspian Sea was determined using current meter (Self Recording Current Meters, RCM9-MKII), manufactured by AANDERAA, Norway. The current meter was used according some limitations such as equipment batteries, high cost of measurements and fishing activities in the region.

1.5 Outline of the thesis

This thesis presents a description on variations of seawater properties of seawater in the southern coastal waters of the Caspian Sea, near to the Iranian Coast based on observational data collected. Special attention is paid to study on variations of the vertical structure of seawater properties, thermal stratification and current. Chapter one gives an introduction about the study characteristics, current situations, problems in the region and objectives in definition of the research. Chapter two is devoted to a literature review of the previous oceanographic studies in the Caspian Sea, particular near to the southern boundaries. Chapter three presents the methodology of the research, including set up the experimental application and field measurements and data analysis. Chapter four included of study of seawater properties such as temperature, salinity, density, sound speed and current as physical components of seawater properties in the investigated area. Chapter five explained the results of variations in the water quality and biological components of seawater properties such as active reaction (pH), dissolved oxygen, turbidity and chlorophyll-*a* in the seawater. Chapter six shows the interaction between components of seawater properties in the study area. Chapter seven concluded the summary and conclusion of the study. At the end references of the study and appendix are provided.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The chapter presents a review on general structures of temperature and salinity in the ocean. In addition, characteristics of the Caspian Sea and range of variations in seawater properties are represented. Methods of measurements of seawater properties, data analysis and some examples of graphs for presentation the variations of seawater parameters are provided. At the end part of chapter, significant of the study and its importance are explained.

2.2 Structures of temperature and salinity in the ocean

Generally, the water temperature of the oceans and seas decrease with depth. The decrease in water temperature is more rapid near the surface than the deeper layers. Usually, vertical variations of temperature shows a surface mixed layer and thermocline at the upper layers. Deep water area is located below these two layers until bottom. For providing a general view and comparison, variation of water temperature in the Pacific Ocean from Antarctic to Alaska is shown in Figure 2.1 (Knauss, 1997).

The total amount of dissolved material in seawater is introduced with salinity. It is given in unit of parts per thousand (ppt). The most part of dissolved salts in seawater are sodium chloride. Vertical variation of salinity in ocean and sea waters is not very much (Knauss, 1997). A longitudinal section of salinity in the western basin of the Atlantic Ocean is presented in Figure 2.2 (Emery and Thomson, 2001).

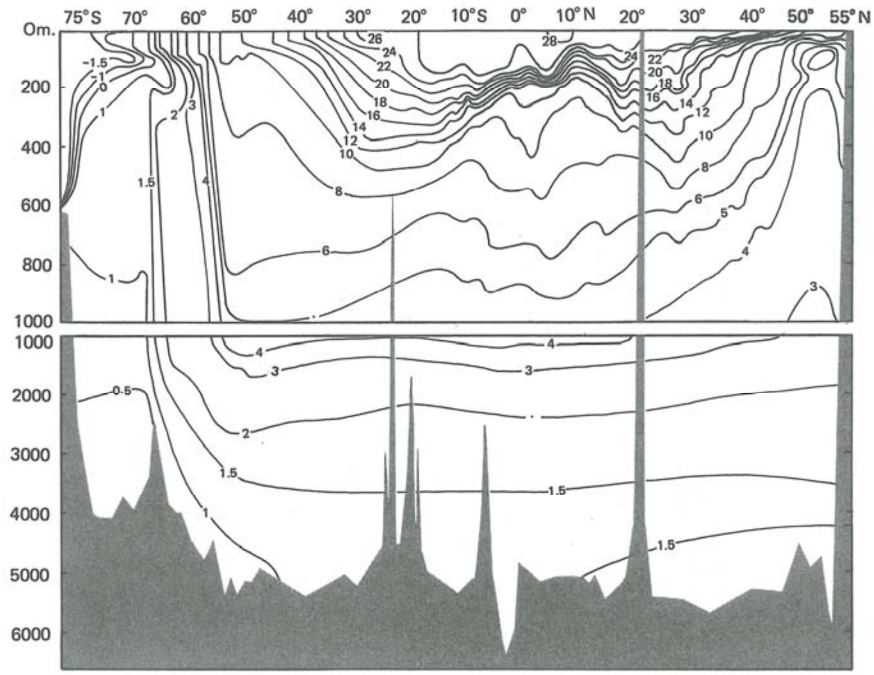

Figure 2.1. Water temperature along 160° W in the Pacific Ocean from Antarctic to Alaska (Knauss, 1997).

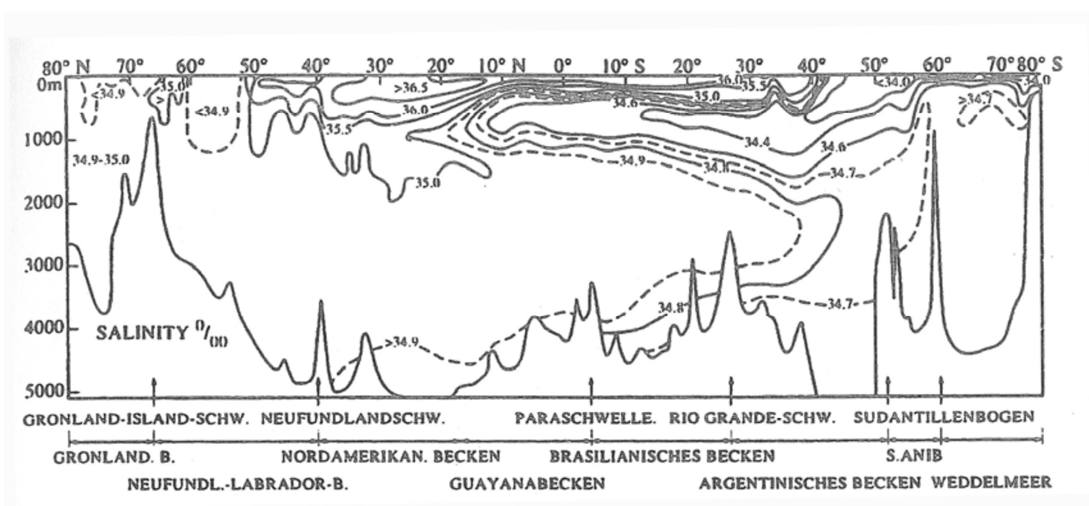

Figure 2.2. Longitudinal section of salinity in the western basin of the Atlantic Ocean (Emery and Thomson, 2001).

2.3 The Caspian Sea

The Caspian Sea is the unique and largest inland water body on the earth that is situated between Europe and Asia. The volume of the Caspian Sea is 78,000 km^3 and its surface area is close to 400,000 km^2 (Dumont, 1998). It is very important marine environment for the world and in particular for the lateral countries around it. It is bordered on the west by Azerbaijan and Russia, on the northeast and east by Kazakhstan, on the east by Turkmenistan, and on the south by Iran. The Caspian Sea is situated between latitudes 47^o, 07′ N and 36^o, 33′ N and longitudes 45^o, 43′ E and 54^o, 20′ E. The sea is characterized with containing rich hydrocarbon reserves and biological resources (Mamedove, 1997; Dumont, 1998; Shaw et al., 1998; Zonn, 2005a,b; Kosarev and Kostianoy, 2005). There are extensive oil fields within and close to the Caspian Sea. The oil industry in the Caspian region is developing fast and the oil carrying has become an important issue. Fishing and caviar production is the second largest industry in the Caspian Sea. The Caspian Sea is the only water body in the world that is included a large stock of sturgeon, producing in recent years about 85% of the world's black caviar supplies. The sturgeon of the Caspian Sea as living fossils, are of high biological, ecological, genetic and commercial importance (Dumont, 1998, Zonn, 2005b). The chief ports (fisheries and commercial ports) of the Caspian Sea are Astrakhan (Russia), Baku (Azerbaijan), and Anzali Port (Iran).

The history of the Caspian Sea begins 50-60 million years ago, when it was the Paratethys Gulf (bay) and part of the ancient Tethys Ocean (Figure 2.3). In the other word, the Caspian Sea is the last part of the Tethis Ocean (Ancient Ocean) or more exactly of its Paratethys bay. In the past, the Tethis Ocean linked the Pacific and the Atlantic Oceans. However, because of gradual move of continental platforms its connection was vanished with the Pacific Ocean and later on with the Atlantic Ocean. Therefore, the Caspian Sea became isolated from the other oceans on the earth (Nevesskaya et al., 1986; Dumont, 1998). Due to the isolation of the Caspian Sea from the open seas, its natural water structure is under direct effect of external factors such as discharge of rivers and atmospheric processes.

The hydrological structure and circulation of the Caspian Sea water are defined by these factors (Kosarev and Kostianoy, 2005).

Figure 2.3. The Caspian Sea as remain of the Paratethys Gulf (source: http://www.zin.ru/projects/caspdiv/biodiversity_report.html)

The Caspian Sea with a surface water level of 27 m below the world ocean level located in a large continental depression. Its linear dimensions from north to south and from east to west are 1030 and 435 km, respectively (Klige and Myagkov, 1992). The mean depth of the sea is about 170 m (about 550 ft) and its deepest area located in the southern basin. The southern and south-western shorelines of the Caspian Sea are bordered by the Elburz Mountains and the Caucasus Mountains. About 130 rivers, different in size, enter the Sea, notably the Volga, Ural, and Zhem rivers, all of which flow into it from the north. Other tributaries include the Gorgan (Gurgan) and Atrek rivers, flowing from the east, and the Kura River, flowing from the west. In the southern coasts of the sea, the Sepidrood (Sefidrud) River is located. The Caspian Sea is connected to the Baltic Sea, the White Sea, and the Black Sea by a network of internal channels, chief of which is the Volga River. These waterways make available an outlet to northern part of Europe for the oil fields of the Sea (Klige and Myagkov, 1992; Kosarev, 2005).

The Caspian Sea contains of three parts: north, middle and southern (Figure 2.4). The northern part contains about 25% of the total surface area, while the middle and southern parts cover around 37% each. However, the water volume in the northern part accounts for a mere 0.5%, while the volume in the middle part make up 33.9%, and the southern basin holds 65.6% of Caspian Sea water. These volumes are an indication of the bathymetry of each part. The northern Caspian is very shallow, with mean depths of less than 5 m. In the middle division, the main feature is the Derbent depression with depths of over 500 m. The southern part includes the South Caspian depression with a maximum depth of 1025 m (Dumont, 1998; Kosarev, 2005).

In the past, there have few studies (e.g. Roohi et al., 2008; Nasrollahzadeh et al., 2008) about seawater properties in the southern Caspian Sea. But the results of the field observations on seawater specifications and their changes in the southern Caspian Sea are limited. Although, some field measurements were carried out in the region for investigation on the seawater properties, but these observations were mainly focused either on variations of water properties at the sea surface layers or were done at a short time and in a small area. So there is not enough and accurate knowledge of the variations of seawater properties in various seasons and in deep water layers, especially in the southern part.

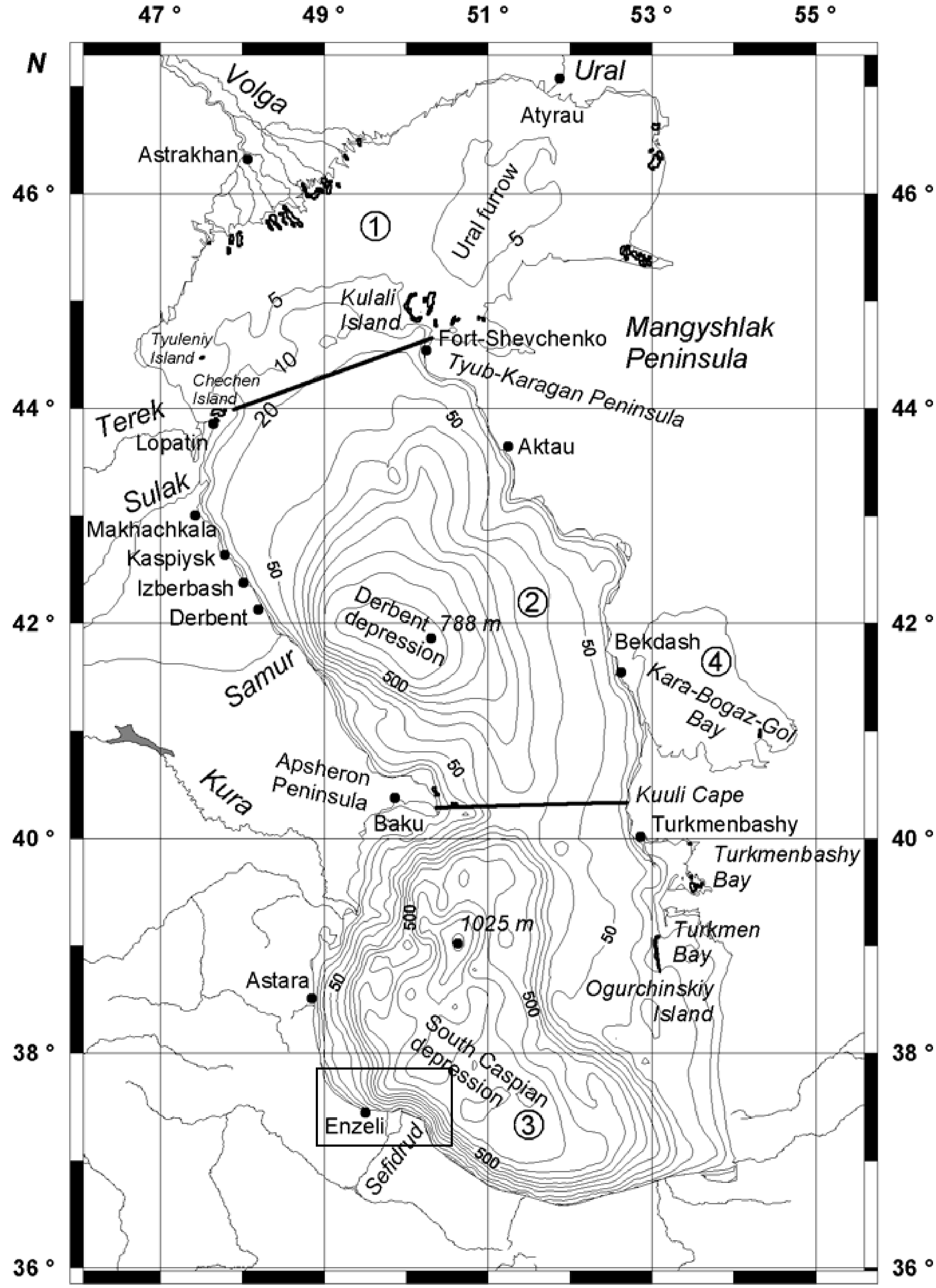

Figure 2.4. The north, middle and southern basins of the Caspian Sea (Kosarev, 2005) and study area illustrated by the rectangular area.

2.4 Characteristics of the Caspian Environment

2.4.1 The southern coastal area

The country of Iran is located in the southern boundary of the Caspian Sea with length of 800 km coastline. The southern coast of the sea is limited by Alborz Mountain ridge (with the mean height about 2000 m) which is extended from the northwest to the northeast of Iran (Figure 2.5). At some areas, the mountains are located close to the sea about 2-5 km and at other places they are 30-50 km away from the coastline. The Alborz Ridge plays role as a separator between the narrow coastal area with humid climate near to the southern coastline of the Caspian (in northern part of the ridge) and central part of Iran with dry and warm climate (in southern part of the ridge, Figure 2.6). Several rivers originated from the Alborz Mountains flow to the sea through the coastal area of the Caspian Sea. The total volume inflow of Iranian rivers to the sea is about 4-5%, which Babol, Gorgan and Sepidrood River with most contribution are distinguished (Kosarev, 2005; CEP, 2002). The Sepidrood River is a river, approximately 670 km (416 mi) long, rising in north-western Iran and flowing generally northeast to meet the Caspian Sea at Guilan province. This river is Iran's second longest river. The Sepidrood River with depth of 1.5-2 m and width of 100-120 m run to the Caspian Sea near the Kiyashahr Port. In the western part, Sepidrood River delta is characterized with area of 1800 km^2.

The coastal and shelf regions along the southern boundary of the Caspian Sea are interesting areas for oceanographers. The western part of the southern coastal waters of the Caspian Sea near to the Anzali Port is located near the mouth of Anzali Lagoon and Sepidrood (Sefidrud) River. Several factors such as freshwater discharge from the lagoon and river, seasonal and atmospheric variations and general circulation can affect the structure of seawater properties, thermal stratification and hydrodynamics in the region.

Figure 2.5. The Caspian Sea in the north part of Iran (source: http://www.google.com/earth/index.html).

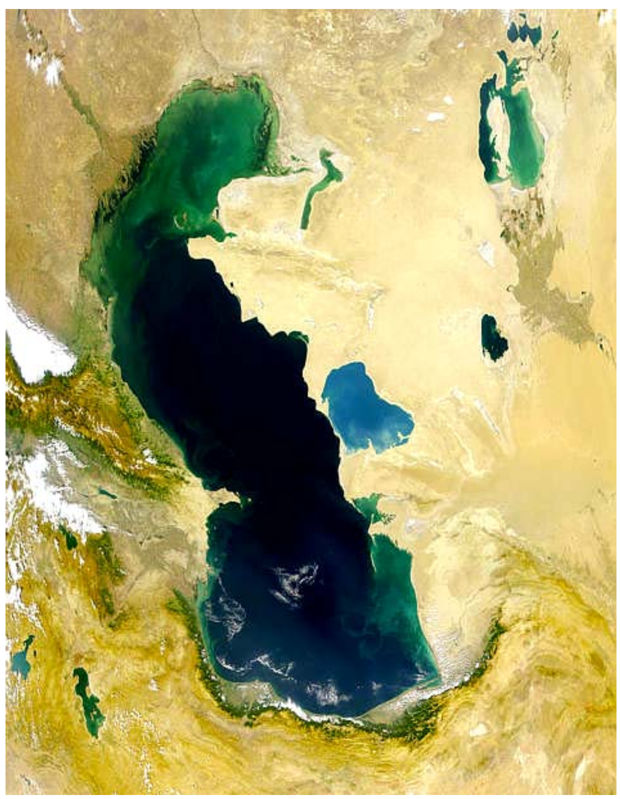

Figure 2.6. The Caspian Sea contains shallow part in the north and deep basins in the middle and southern part (source: http://www.google.com/earth/index.html).

2.4.2 Bathymetry

The southern basin of the Caspian Sea is located in a geosyncline region that a significant abnormality is seen in its topography. In the western part of the southern basin, the shelf width varies from 15 to 60 km and breaks at variable depths between 60 m to 150 m. The eastern shelf with maximum width of 190 km is wider than the western shelf. The break of the eastern shelf is located in 100-130 m depth. The continental shelf in the southern coastal waters is very narrow with 5-10 km width (Figure 2.7). The deepest point of the sea is placed in the central region of the southern basin with 1025 m depth (Kosarev, 2005). The seabed sediments of the Caspian Sea are characterized with terrigenous and calcareous deposits. The bottom of the deepwater zones of the southern basin is covered with weakly calcareous clayey silts (Kosarev, 2005). The shores of the Caspian Sea mainly made of Quaternary deposits. In the southern part, the shore is mountainous and rugged. The coast of the Caspian Sea in the study area (Anzali) is classified as coasts with coarse well-stored sediments and high percentages of heavy minerals (Khoshravan, 2007).

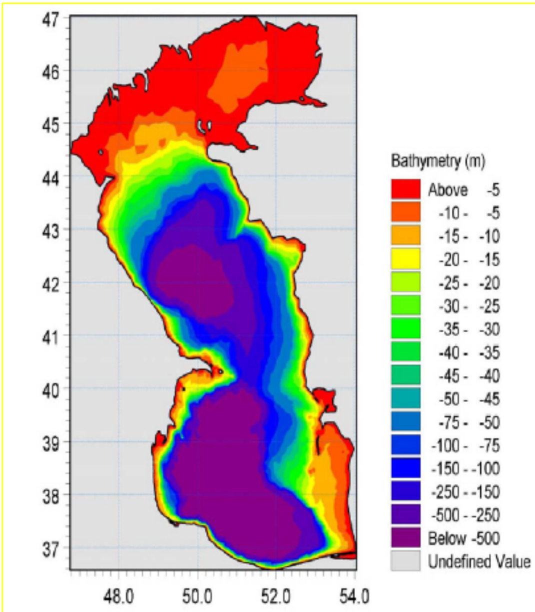

Figure 2.7. Bathymetry of the Caspian Sea (Kosarev, 2005). Shallow water basin is in the north and deep water basins are in the middle and southern parts of the Caspian Sea.

2.4.3 Mean sea level and current

Starting from 1978, a rapid sea level rise began; in 1995, the level reached a mark of – 26.7 m. This rise was also caused by the changes in the water balance, whose increment corresponds well to the range of the level rise during this period. The positive resulting value of the water balance is mostly defined by the high runoff of the Volga River, whose relation to the sea level position is reliably established. By 2004, the level of the Caspian Sea fell again by 30 cm down to a mark of – 27 m below mean sea level (Kosarev, 2005). Figure 2.8 shows fluctuations of mean sea level for the Caspian Sea.

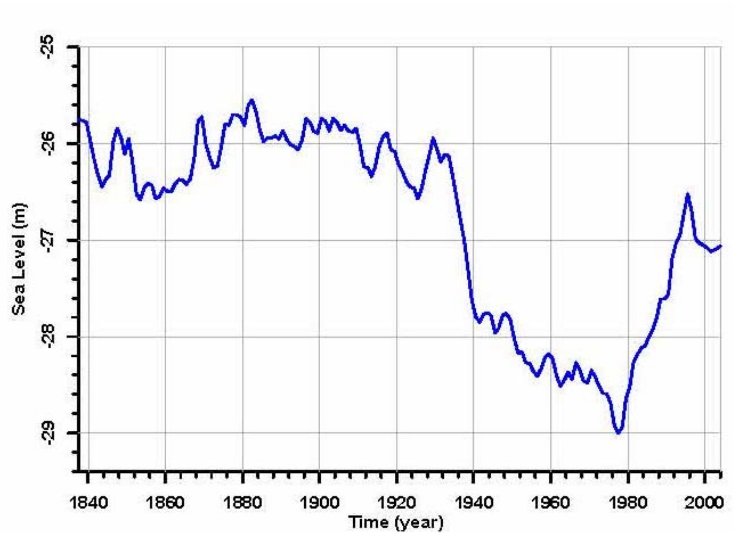

Figure 2.8. Variations of the Caspian Sea level measured by sea level of Caspian, gauges (1837–2004) (Kosarev, 2005).

Regime of current in different parts of the Caspian Sea is different (Figure 2.9). The current speed in the middle and southern parts of the Caspian Sea reaches about 0.20 m s^{-1}. In comparison, the current speed in depper layers is not high reltive to the current in surface layers. Below 100 m depth, current is very weak and the speeds reach 0.05 m s^{-1}. In the extreme conditions (storms in autumn and winter seasons) current speeds at the surface layer reach 1 m s^{-1} in the Caspian Sea, (Tuzhilkin and Kosarev, 2005).

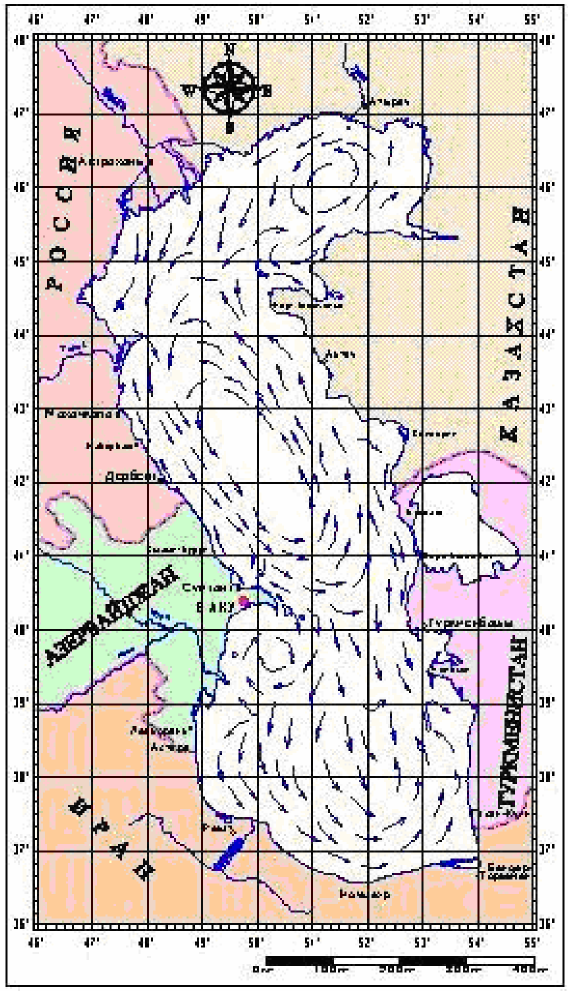

Figure 2.9. A general pattern of the current at the surface in the Caspian Sea (Tuzhilkin and Kosarev, 2005).

2.4.4 Climate

According to meridional extension of the Caspian Sea, there are several climate zones over the sea. In the winter, the weather in the north and middle parts of the sea is under effect of continental polar climate and Siberian anticyclone while in the southern part, penetration of southern cyclones is detected (Kosarev, 2005). The climate in the southern coasts of the Caspian Sea is subtropical and characterized by warm summers and mild winters. The air temperature is maximum in July-August and minimum in January-February. 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 (Rodionov, 1994; Kosarev and Yablonskaya, 1994; Kosarev, 2005). Mean temperature in the study area and near the Anzali Lagoon was reported about 16 ^{o}C, which varies from 4.5 ^{o}C in February to 27.5 ^{o}C in August (Asadullayeva and Alekperov, 2007). The atmospheric precipitation over the various areas of the sea is difference. Values from 100 mm per year near to the eastern coasts of the sea to 1700 mm per year in the southwester part was reported (Kosarev, 2005). In the south region of the Caspian Sea, the mean annual wind speed is 3–4 ms^{-1}, and the repetition rate of weak winds here reaches 90%. In the southern part of the sea, the number of days with storms (wind speed more than 15 ms^{-1}) is not more than 20–30 day year^{-1} (Kosarev, 2005). Figure 2.10 shows the seasonal mean temperature over the Caspian region in the period 1982-2000. Figure 2.11 indicated mean monthly rainfall in the southern coastal waters of the Caspian Sea (Anzali Port) during the year 2008.

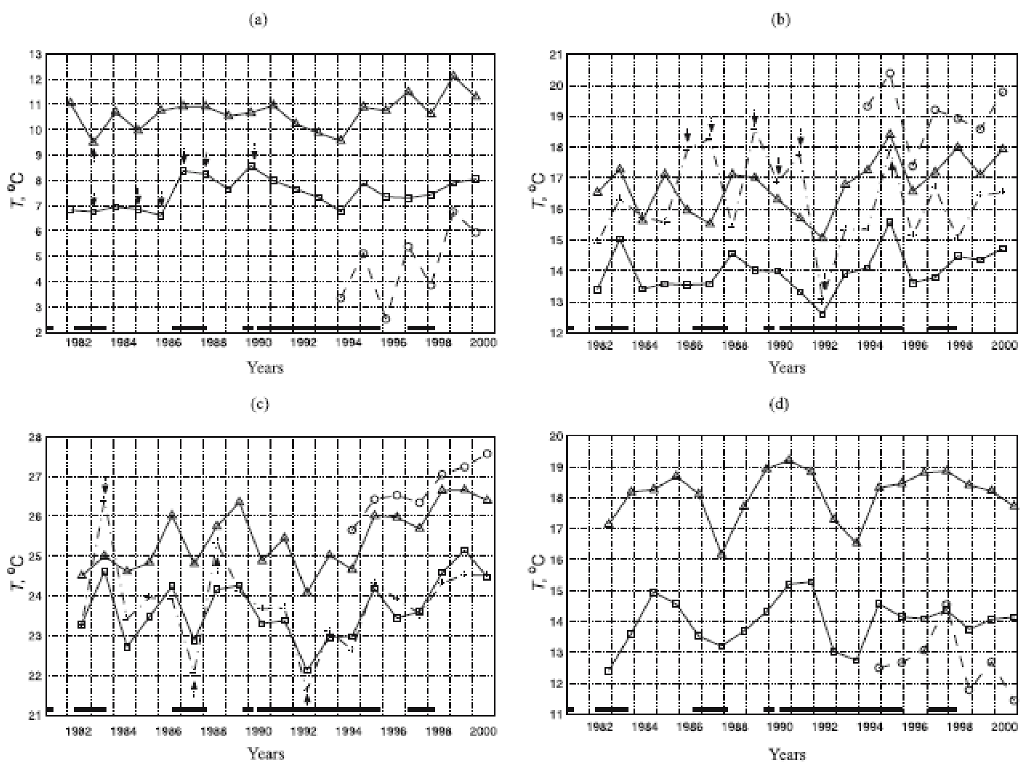

Figure 2.10. The mean temperature over the Caspian region in the period 1982-2000: a) in winter, b) in spring, c) in summer and d) in autumn. The bold solid line with triangles refers to the Southern Caspian, the thin solid line with squares refers to the Middle Caspian and the dashed-dotted line with crosses refers to the Northern Caspian (Ginzburg et al., 2005).

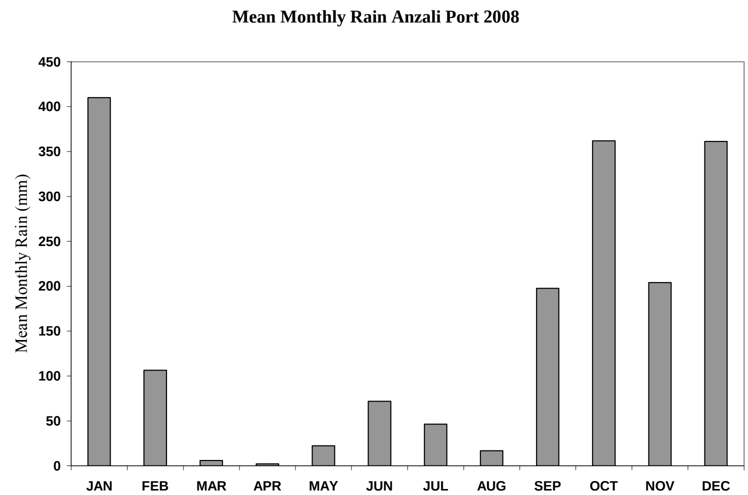

Figure 2.11. Mean monthly rainfall in the southwestern coastal waters of the Caspian Sea (Anzali Port) during the year 2008.

2.4.5 Caspian seawater temperature

In the Caspian Sea, the regime of the seawater temperature is rather abnormal between northern and southern parts of the Sea. Surface water temperature displays great seasonal variations over entire the sea. On the one hand, it is characterized by levelling of the temperature regime between mentioned parts in summer season. On the other hand, there is a considerable range in water temperature in wintertime between northern and southern basins. Northern shallow and less saline water of the sea freezes from December to March while it is not covered with ice in middle and southern areas (Dumont, 1998).

According to the meridional extension (in north-south direction) and effect of several atmospheric systems over the sea, air and water temperature vary in wide ranges. The study by Zenkovitch in 1963 indicates water temperature in the southern Caspian Sea ranges between 9-26 ^{o}C during period of winter to summer (Khoshravan, 2007). Based on results of the studies presented by Kaplin (1995) and Tuzhilkin and Kosarev (2005) during the summer season the maximum water temperature at the surface exceeds 27 ^{o}C in the southern part of the sea while it reaches its annual minimum of about 7 ^{o}C in winter (Kaplin, 1995; Tuzhilkin and Kosarev, 2005). During a field study, International Atomic Energy Agency (IAEA) conducted a research-training cruise in the Caspian Sea in September 1995. In the cruise, seawater promoters (temperature and salinity) were measured using an automatic hydrosonde available on board the ship. Based on the results, water temperature at the surface observed about 27.5 ^{o}C in the southern Caspian Sea in September (IAEA, 1996). Based on Dumont (1998) reports, the existed north-south gradient of water temperature is caused by synergism of depth and climate. The horizontal gradient of water temperature between northern and southern basins is significant in winter (about 10 ^{o}C) while it reaches 2-3 ^{o}C between northern shallow water and southern deepwater zones in summertime. The observed surface water temperature in the southern part was about 10 ^{o}C in February and 27-28 ^{o}C in August. Tuzhilkin and Kosarev (2005) reported that the major variations of water temperature are occurred in the upper layers. They reported that temperatures in the deepwater part of the Caspian Sea are well below the annual mean temperature of the seasonal mixed layer and in the southern basin, they are even below the annual minimum of the monthly surface temperatures. Because of isolation nature of the sea from other world oceans, the formation of its thermocline and circulation regime proceeds under atmospheric conditions over the sea and its vast drainage region. Tuzhilkin and Kosarev (2005) reported the water temperature at the sea surface layer of the southern Caspian as follows: in February (8-10 ^{o}C), April (12-14 ^{o}C), August (27-28 ^{o}C) and November (15-16 ^{o}C) (see Figure 2.12). In a study carried out by Zaker et al. (2007) seawater properties in the eastern part of the southern Caspian Sea were examined in 2003 (Zaker et al., 2007). Based on their measurements, the daily average temperature of the surface mixed layer (above the thermocline) in a range of 25-30 ^{o}C in summer and it decreases to 20 ^{o}C at the end of autumn. The temperature ranged between 10.5 ^{o}C at 50 m level and 7.5 ^{o}C at depth of 110 m (maximum depth of sampling station) with small variation (Zaker et al., 2007).

Nasrollahzadeh et al. (2008) performed some measurements only in the sea surface of the southern coastal waters of the Caspian Sea. Based on their observations, the surface water temperature was in ranges of 9.9 °C (winter) to 28.6 °C (summer) during years 1996-7 and 9.2 °C (winter) to 28.8 °C (summer) during year 2005. Roohi et al. (2008) in a part of their biological researches presented variations of the seawater temperature and salinity up to 100 m depth in the southern Caspian Sea. They reported the maximum water temperature about 30 °C in summer. However, there were some measurements of seawater temperature in the southern Caspian Sea about measuring seawater temperature. But the mentioned studies are not adequate for understanding variations of seawater temperature in various seasons in southwestern coastal waters of the Caspian Sea. Because they were not measured water temperature through the deep layer and were not done in selected date in four seasons.

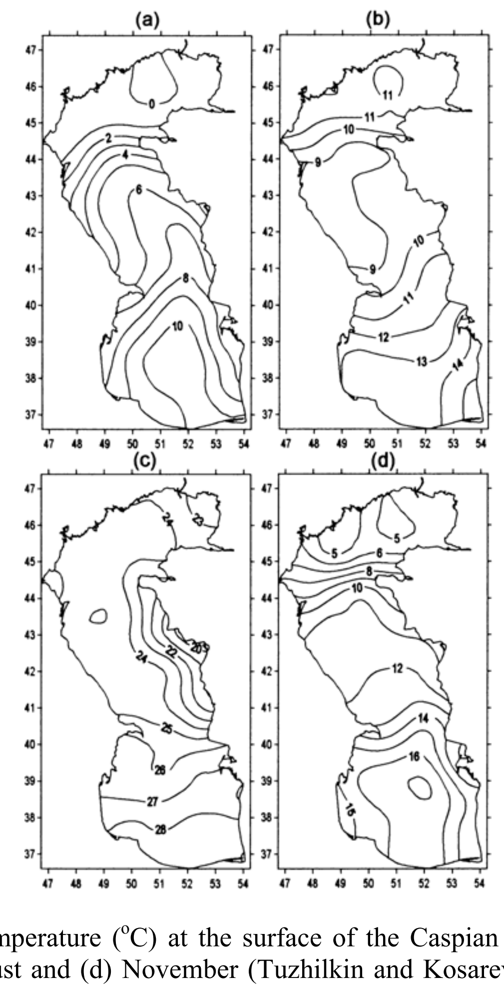

Figure 2.12. Water temperature (°C) at the surface of the Caspian Sea in (a) February (b) April (c) August and (d) November (Tuzhilkin and Kosarev, 2005). The horizontal axis, longitude (E) and vertical axis latitude (N), counter lines, sea surface temperature (°C), scale, 1:20,000,000.

2.4.6 Thermal stratification in the Caspian Sea

The seasonal thermocline influences a variety of physical, chemical and biological properties of seawater, mixing and circulation processes in the seas and oceans, in particular in the coastal area. Due to the isolation of the Caspian Sea from the other open seas and oceans, the process of formation and destruction of the thermocline and stratification in water column are controlled by the atmospheric conditions over the region and its drainage area. The mentioned factors together with heat flux and evaporation control the major seasonal variations of the thermal regime in upper layers down to 100 m depth (Tuzhilkin and Kosarev, 2005). Based on the results presented by Dumont (1998), in the Caspian Sea thermocline develops down to depths of 80 m in water column.

2.4.7 Salinity of the Caspian seawater

The major abiotic factor (nonliving components) of the Caspian Sea water is its salinity. In comparison to the World Ocean and open seas, the average value of seawater salinity in the Caspian Sea is about one-third open seawaters (Dumont, 1998).The water salinity of the Caspian Sea is not only difference from the world ocean but also the composition of salt. The relative concentrations of Ca^{2+}, Mg^{2+} and SO_4^{2-} in the Caspian seawater are more than in average world oceans waters (Table 2.1) (Peeters et al., 2000). Northern, Middle and Southern parts of the sea differ by the salinity in water. The lowest concentration of salt in observed in the north end of sea.

Table 2.1. Average major ion composition of the Caspian Sea in comparison to the major ion composition of standard sea water, based on chemistry data (Peeters et al., 2000).

Ions	Caspian Sea water		Standard sea water	
	Concentration (gkg^{-1})	Relative concentration to total mass (%)	Concentration (gkg^{-1})	Relative concentration to total mass (%)
Na^+	2.99	24.33	10.784	30.66
K^+	0.09	0.71	0.399	1.13
Mg^{2+}	0.7	5.72	1.284	3.65
Ca^{2+}	0.34	2.75	0.412	1.17
Sum cations	4.12	33.51	12.879	36.61
Anions				
Cl^-	5.18	42.22	19.353	55.02
SO^{2-}_4	2.98	24.27	2.712	7.71
Sum anions	8.16	66.49	22.065	62.73

On the beginning decades of the current century, due to enhanced freshwater discharge caused to increase in the sea level and a slight reduce in surface water salinity. The mean value of the water salinity of the Caspian Sea is lower than open seas and World Ocean (about one-third open seawaters). The seawater salinity of the Caspian Sea increases from the north to the south. The water salinity in the southern basin of the Caspian Sea ranges between 12 ppt and more than 13.5 ppt with an average of 12.8 ppt (Dumont, 1998).

Changes of the water salinity from north to south in the sea is observed, with freshwater in the shallow water of the northern basin to values of 12.5–13.5 ppt surface water salinity in the central and the southern parts. In the southern Caspian Basin, seasonal salinity variations are less than 0.2–0.4. Mean annual in water salinity of the sea in the southern deep-water zones increases from the surface to the bottom waters only by 0.1–0.3 (Zenkevitch, 1963; Kosarev and Yablonskaya, 1994).

Volga and Ural Rivers and surface evaporation control fluctuation of sea water level. The former causes sea level to rise while the latter causes the sea level to fall. Values of the salinity in the northern part of the Caspian Sea are strongly influenced by freshwater discharge of Volga and Ural Rivers. Southern and northern parts of the sea are predominated by brackish water with variation in salinity between 13 to 10 ppt (Stolberg et al., 2003). In other studies, the salinity of the Caspian Sea was reported variable with average between 12.28-13 ppt (Peeters et al., 2000).

Based on IAEA measurements in the southern basin and near to the Iranian coast, the salinity ranged between 12.239 ppt at the surface and 12.863 ppt in deep water layers (IAEA, 1996). Comparison of data collected by IAEA in September 1995 with those measurements before that signifies that in August 1968–1978 the mean values of the salinity in the surface layer of the middle and southern Caspian Sea along the meridional section were higher by 0.6–1.0‰. The salinity of the bottom water layers changed only slightly and decreased by ~0.1‰ during the rise of the sea level in the deepwater basins of the sea (Ferronsky et al., 2003).

Major seasonal changes in the water salinity in the surface layer (up to 3–5 ppt) occur in the near-mouth areas of rivers and lagoons of the sea. The seasonal changes of salinity in deep-water areas of the sea are under effect of annual distribution of the evaporation intensity. Over the rest of the sea area, its multiannual variations of the salinity are not larger than 0.5 and the salinity is quasi-homogenous from the surface to the bottom. In addition, variations of the salinity in the surface were in the range of 12-13.6 ppt in the southern basin (Figure 2.13) (Tuzhilkin and Kosarev, 2005).

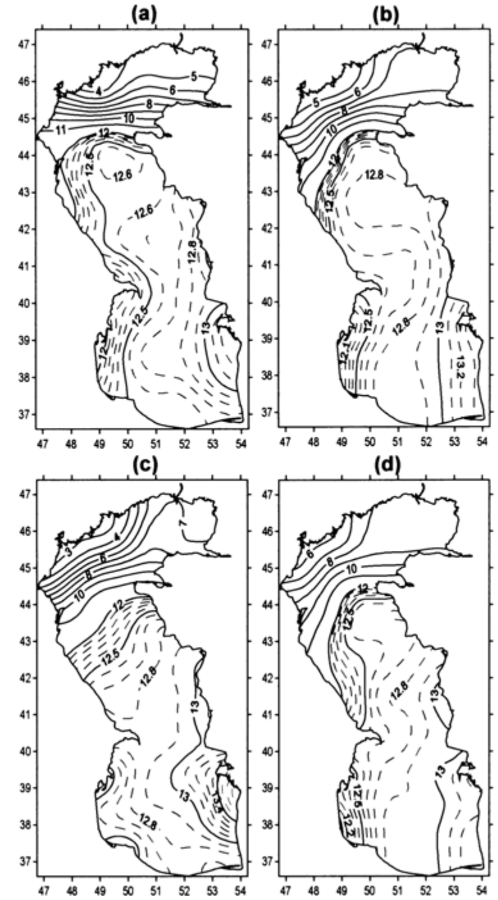

Figure 2.13. Sea surface salinity (ppt) of the Caspian Sea in (a) February (b) April (c) August and (d) November (Tuzhilkin and Kosarev, 2005). The horizontal axis, longitude (E) and vertical axis latitude (N), counter lines, sea surface salinity (ppt), scale, 1:20,000,000.

Based on Nasrollahzadeh et al. (2008) observations in the sea surface of the southern coastal waters of the Caspian Sea near to Iranian coast, the surface water salinity were in ranges of 10.85-13.18 ppt (years 1996-7) and 10.23-13.19 ppt (year 2005) (Nasrollahzadeh et al., 2008). Roohi et al. (2008) measured the average water salinity at the surface near to Iranian coastal water around 12 ppt in 2001 and 10-11 ppt in 2006. They reported a decreasing trend in average salinities of the surface waters from 2001 to 2006. Based on their collected data, the average salinity in the surface stations 11.9 ± 1.2 ppt and at 100 m depth 12.4 ± 1.6 ppt.