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The study of Caspian Sea salt water intrusion to aquifer of Ghaemshahr-Joybar plain

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ABSTRACT— The Ghaemshahr plain based on geological, hydro geological, hydrological and regional conditions, humans' factors and nearness to Caspian Sea is faced with salt water intrusion. These studies show that, contrary to routine discharge, continual drought and unsuitable watering methods have caused a decreasing trend of accessibility level and salt water intrusion into the aquifer. During geological periods Caspian Sea had multiple transgression and regressions, so some water of this sea remains in the sediments. This has formed a connate water aquifer in different parts of the plain. The water of such aquifers, due to reduced water pressure and possibly through ion exchange in the middle of the plain, has entered to freshwater aquifers and caused salinization of aquifers. It is necessary to control the amount of water elicitation and the irrigation depending on the cultivation. Selecting the appropriate method for artificial feeding in the vicinity of altitudes by considering the status of the water table in the discharging area is necessary because this aquifer is currently in a critical condition and with this trend, in not so distant future, it will be destroyed due to population growth, the increase in the land under cultivation and continuous droughts.
KEYWORDS: hydro geochemistry, saline-fresh water, drought, interface, pH-Eh diagram

Introduction

A Coastal Aquifer is one of the most important water reserves in the world. In many countries, such as Iran, close dependence on utilization of these aquifers is observed. Indiscriminate use of these types of aquifers and also the intrusion of saline water are considered to be potential problems for coastal aquifers. Groundwater aquifers in the coastal areas of the seas and saline lakes always face the risk of progression and invasion of salt water. With development exploitation, progression and intrusion of salt water into the land increases and gradually contaminates freshwater aquifers. Excessive exploitation of groundwater resources causes a drop in the water table, accelerates the water intrusion and therefore causes complete destruction ion freshwater aquifers. In most cases, compensation for damage is not an easy task and requires a long time and heavy costs. Therefore, care must be exercised when using groundwater, especially in the coastal zone. An examination of the problem of the salt water intrusion must be conducted and this must consider the amount and the method of the exploitation, so that appropriate decision for careful management can be applied. Mainly in coastal areas, there is a flow of underground water from land to the sea. When the amount of these flows is greater, penetration of sea water will be less. Naturally there is equilibrium between the fresh water of coastal aquifers and saline water. Aquifers' fresh water and salt water can be considered as two immiscible fluids and consequently applies a level of separation between them. This surface is defined as a separation level or interphase. This level is not linear but it is an area which is called the dispersion region. This area changes over the years for reasons such as: seasonal changes in the water table, tides, excessive harvest and climatic conditions and issues that are not known yet. Salt water intrusion can usually be observed using different tools and methods. These methods include: drilling exploratory wells and observation of the water table; evaluation and continuous chemical analysis of groundwater resources; measuring movement of tides and comparison with changes in the level of separation between saltwater and freshwater; geophysical techniques; geological evaluations and isotopic studies. There are a lot of aquifers in Caspian Sea but the problem of salt water intrusion can be seen in all of them. Geological, hydrogeological, geophysical and hydro geochemical studies have been conducted in the Caspian aquifers and these have proven the penetration of sea water and existence of some saltwater zones caused by repeated retreats and advances of Caspian Sea. A dramatic increase in exploitation in some areas has caused the loss of balance between salt and fresh water and intrusion of salt water into wells. The Caspian Sea has unique characteristics, which give it a special place among seas and oceans. Height of this sea is about 27 meters below high sea level, its salinity is between 9.26 to 12.67 gr/L, and its specific weight is around 1024.69 kg/m^3 which is much lower than the average of seas and oceans (Hem 1985, Ministry of Agriculture 2007). Average chemical changes of Caspian Sea are presented in table 1.

Table 1 Average concentration of dissolved elements in seawater (Hem 1985, Ministry of Agriculture 2007)

Chemical Parameter(gr/L)	EC (µS/cm)	TDS	$SO4^{-2}$	Cl^{-}	$HCO3^{-}$	K^{+}	Na^{+}	Mg^{+2}	Ca^{+2}
Mean of Sea, Ocean	55	35	2.7	19	0.142	0.309	10.5	1.35	0.41
Mean of Caspian Sea	20	12.6	3.6	6.5	1	0.08	3.1	1.1	0.45

As can be seen in the table, the amount of sodium and chloride in Seas and oceans is usually much higher than in the Caspian Sea, thus water composition is similar to a freshwater lake. In this study, we tried to determine all the factors that play a role in salinity and location, time and common depth. In this context one of the most important factors is the interaction between groundwater and geological formations and the entrance of salty water and it's mixing with fresh water of coastal aquifers. In the same connection, with drawing of maps, hydro geological sections, hydro geochemical and geophysical diagrams like Gibbs and modified Piper, combination charts, ion exchange, dispersion map and penetration of salt water are investigated and analyzed. The objectives of this research are:

The reactions of geological formations with Ghaem Shahr groundwater and their impacts in increasing salinity.

The detection of saltwater intrusion into freshwater of aquifers through geophysical and chemical techniques.

Determining the infected area in terms of location and its changes over recent years by using map and sections.

Precedence studies

In order to supply drinking water to Tehran, quantitative and qualitative studies of the catchment area of Babol and Haraz were conducted (Alexander Gibb 1976). Another investigation was done regarding the qualitative and quantitative characteristics of the Sari aquifer where effective factors on low quality of ground water, penetration of different wastewater, brackish water, a seawater mixture and evaporation of groundwater had been detected. Based on geological and hydrogeological studies of Caspian coastal aquifers, the existence of some saltwater zones resulting from retreats of the Caspian Sea has been proven (Kaboli 2003). The groundwater flow and geochemical investigation of drinking water wells in Sari has been modelled (Mostafavi 2010). The quality of Babol – Amol aquifer has been modelled using a GIS package (Sanjavy 2011). salt water intrusion into the aquifers of northern Albania, based on observations of chloride concentration in five wells and geochemical studies (Hoxhaj 2005).studying salt water intrusion in west of Sinai Desert used 60 vertical electrical sondes (Khalil 2006). This studied spatial and temporal changes of ions by using maps, and proved salt water intrusion using combination charts and salt water intrusion problems and conservation activities in southeast of Georgia (U.S.A.). They realized that sea salt water intrusion in coastal aquifers of Georgia was due to: increase in electrical conductivity and some ions such as sodium and chloride, and a linear relationship between chlorine and sodium with main ions (Gibbson, Randall 2006).

The Study Area

The Ghaem Shahr plain is located on the northern slope of the Alborz Mountains and in the north-eastern part of the Caspian Sea (Mazandaran province). It is strongly influenced by the hydro-climatic and geological conditions that result from its bordering the Caspian Sea. This area is geographically located in 52˚ 35′ to 53˚ 23′ longitude and 35˚ 44′ to 36˚ 47′ latitude. The total area is about 3348.1 Km^2. The location of the study area is shown in Figure 1.

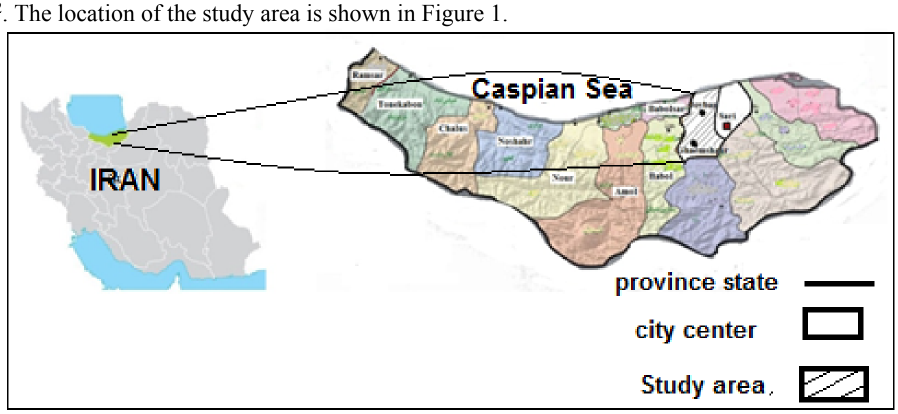

Figure 1 Location of studying area

Material and Methods

This research was performed based on data from chemical analysis from 22 wells (Figure 3). These data were collected and tested in 1999 and 2014 for comparison and qualitative trend (Table 2). Analysis of water samples consisted of measuring the concentrations of cations and anions and parameters such as EC, TDS and pH. For analysis of elements, the American Public Health of Association (APHA 1995) was used. Sodium and potassium concentrations are calculated using flame photometer; Calcium, magnesium, bicarbonate and chloride by volumetric method; sulfate by Spectrophotometer; electrical conductivity and total dissolved solids with a conductivity meter, pH with a pH meter and other parameters by chemical relationships. The procedure of this research consists of: data collection, Ministry of Energy reports, Regional Water Authority, articles, theses and maps related to research and evaluation and the analysis of geochemical data of aquifers, drawing maps and charts using Excel and Surfer software. The interpretation of the results and the overall status of water in the aquifer are based on the relationship of water in the aquifer sediments and seawater constituents. In each analysis values of cations and anions should be equal. Differences in value can result from experimental error or lack of elements and other substances in water, but should not be more then %6 (Moghimi 2006). On this basis, the analysis error percentage of the Ghaemshahr Plain, in all cases, was less than the mentioned amount (Table 2, Figure 2). As can be seen in Figure 2, there is a high correlation among anions and cations in the 22 samples. Considering the ionic balance in the water samples, evaluation of water type and its mixture was done using the combination charts and diagrams of Gibbs and modified Piper.

Table 2 Statistical Characteristics of resources chemical analysis in the area

Ions(meq/L) Parameters(2014)	**$SO4^{-2}$**	**Cl^{-}**	**$HCO3^{-}$**	**K^{+}**	**Na^{+}**	**Mg^{+2}**	**Ca^{+2}**	**pH**	**TDS**	**EC**
Max	2.5	42.1	16	0.14	38.1	11.4	16.9	7.6	4275	6680
Min	0.9	0.8	3.8	0.08	0.9	2.2	3.4	6.9	543	798
Mean	2.5	6.67	8.45	0.1	6.3	4.56	6.75	7.3	1157	1801
S.D.	1.94	8.81	2.9	0.01	8	1.97	2.88	0.24	801	1259
Ions(meq/L) Parameters(1999)	**$SO4^{-2}$**	**Cl^{-}**	**$HCO3^{-}$**	**K^{+}**	**Na^{+}**	**Mg^{+2}**	**Ca^{+2}**	**pH**	**TDS**	**EC**
Max	12.4	15.5	16.2	0.25	19.5	8.9	11.5	8.1	2368	2700
Min	1.4	0.9	4.1	0.05	0.9	2.4	3.4	7.5	475	720
Mean	4.7	6	8.6	0.12	8.27	4.7	6.3	7.7	1263	1981
S.D.	3.08	4.7	3.3	0.05	6.2	1.8	1.98	0.2	553	863

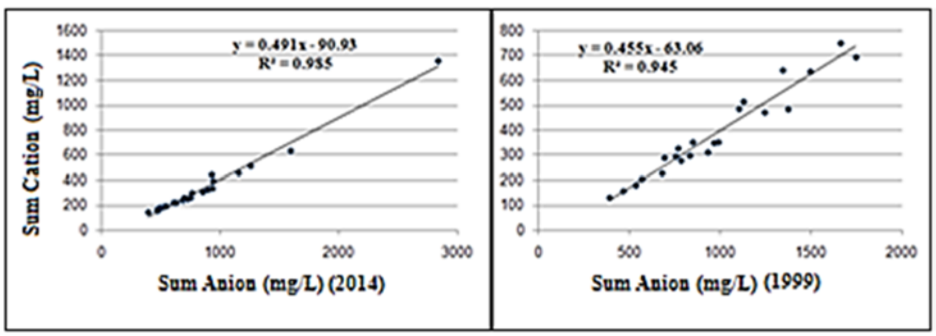

Figure 2 Relationships and correlations between the total anions than cations

Geology, Hydrogeology and Geophysics of the Study Area

Geology is the most important factor when assessing the quantity and quality of water resources. So far as the catchment area of the Ghaemshahr Plain is concerned, there are different formations from the early Carboniferous era and outcrops from the Quaternary period. One-third of the formations belong to Shemshak (sandstone, quartz, rocks, clay shales and coal). This formation has qualitative and quantitative relationships with the aquifers. However, because of its solubility, the maximum impact on groundwater quality is related to Elika carbonate formations (Triassic), mostly of limestone, calcareous shale and dolomite, Delichay Formation (which is formed of calcareous marls and marly limestone), Lar Formation and subsequently Tiz Kouh formation (Cretaceous) including limestone dolomite and limestone with volcanic rocks. Sediments at the boundary between mountains and the plain consist of hard clays, marl, sand, gravel layers and a thin layer of volcanic ash. Above this layer, investigations have found lake sediments containing sand and mud which are not hard (New Caspian Formation) and evidence of volcanic activity covered by discontinuous sediments that cause the main aquifer to have relatively good permeability. In order to evaluate the alluvial deposits, exploratory wells and geophysical logs were used. The map in figure 4 shows the results summarily presented in table 3. One of the objectives of geophysical studies in coastal areas is to determine the range of saline water and separation of saline water with a freshwater boundary. In coastal areas the amount apparent resistivity is affected by the chemical quality of groundwater resources. So, apparent resistivity maps will help to identify areas that are vulnerable to invasion by saline water. By combining geophysical studies, exploratory wells logs, hydro geochemistry and geology, intrusion of salt water can be seen in the study area. Accordingly, much of depth between 140 to 170 m via 10 ohm-meter curve is separable (Figure 3, section

B-B’). The horizontal expansion in the range of Babolsar 19 km and the more eastern parts of the river basin Ghaemshahr Talar and the Siyah River, which is the discharge section, this influence is much greater (the salinity increases from West to East). Considering to section B-B 'in Figure 4 can be seen, from south to north, middle, reduced salinity seawater near Babolsar influence is also visible in the surface layers. Though zone of saltwater intrusion from west to east of in coastal regions to inland increases (Sedaghat 1975).

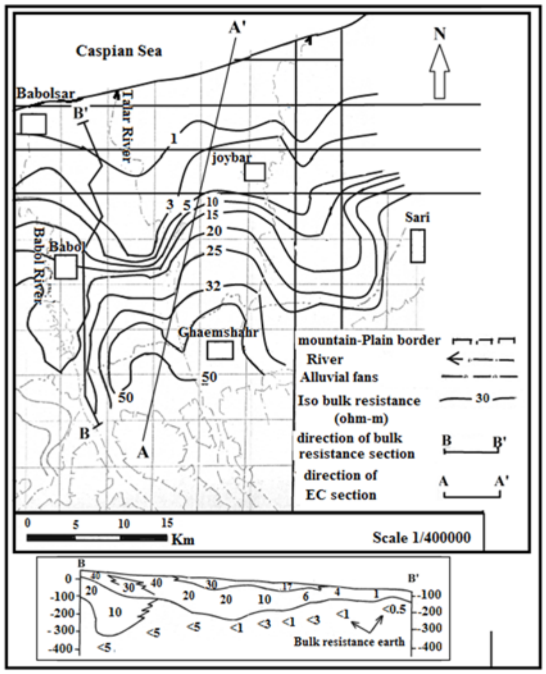

Figure 3 Map of apparent resistivity geophysical methods

Table 3 Characteristics of Ghaemshar-Joybar water resource and alluvial deposits using geophysical methods

Apparent Specific resistivity	Characteristics of sediments
Less than 10	Including middle and drain parts. Fine-grained sediments and high mineral content. To a depth of 100 to 150 meters without fresh water. The water is brackish and saline
10 to 20	The end of the alluvial fan. Medium grained sediments and freshwater resources. Its thickness is about 150 m
More than 20	The foothills and alluvial fan. With sediment thickness more than 200 meters. It is the best area for exploitation of water resources.

Geochemical mechanisms of controlling Ghaemshahr groundwater aquifer

During the weathering and water flow in the geological formations, ions separated from minerals and dissolved in groundwater. Calculation of main ions and their relationship with each other to understand, the conclusions and chemical impact rocks on the groundwater chemistry is very important (Hounslow 1995). In order to analyze of hydro geochemical data and determine the effective factors in Ghaemshar plain have been used different methods up in this way to influence the evolutionary process hydro geochemistry position of saline water intrusion (sea water and fossil aquifer) is identified in the study area. Hydro-climatic conditions (such as precipitation and evaporation) and irregular withdrawals of water resources, geology and followed by the reaction between water and rocks ions relative variability of the factors that control mechanisms are groundwater geochemistry.

Evaluation of this data and combined charts demonstrate that in the study area from 1999 to 2014 the total ions and substances in groundwater at the end of the Plains almost doubled. This increase can be explained by the following factors:

Evaporation: In the study area about 48% of land is under rice cultivation. Due to the high amount of water consumption, exploitation has increased rapidly. This issue not only causes a drop in the water table but also increases the concentration of ions in groundwater.

Precipitation: According to statistics for 15 years (1999-2014) average precipitation in the plains was 734 mm and in the heights 560 mm. Consequently, the decrease in precipitation, directly reduced the feed rate from highlands and plains which caused the water table to drop. It also affected the reaction between rock and water. These cases alter the concentration of trace elements in groundwater.

Geological Formations: Altitudes in the selected area are composed of calcareous, marly and dolomitic formations. The plain was formed by alluvial fans that were themselves made up of granular and permeable sediments. This debris included calcareous, marly and dolomitic particles, and the calcic bicarbonate water type reduced moving from west to east. In the middle of the plain, water type is mostly bicarbonate sodic that resulted from ion exchange between groundwater and clay rocks. At the end of the middle section (eastern region), the type of water is sodium chloride. As demonstrated in Figure 3, in this section anomalies occurred through geophysical procedures. The reason for that is water that remained on Abesheron deposits after the regression of the Caspian Sea in different geological periods. This water was covered by deposits from the Caspian Sea then formed new connate water aquifers. Saline water easily replaced fresh water because of uncontrolled exploitation. In part the discharge was due to proximity to the sea. A substantial amount of sea water penetrated into the aquifer due to a drop in the water table and this caused the aquifer to become saline. In the early and middle sections changes in the values of ions in groundwater cannot be seen over 15 years, but approaching the sea the values of sodium, chloride, EC and TDS dramatically increase (double). This increment represents an intrusion of salt water into the freshwater aquifer. There are various methods for the detection of salt and salt water intrusion in coastal aquifers, the most important ones include:

Combined charts: These charts are useful tools in determining the salt, mixture and source of water (Mazor 1991). These graphs can be used in analysis of geological correlation, hydro climate and intrusion of salt water and other factors affecting the ground water control mechanism. These diagrams are used to identify and compare the groundwater Hydro geochemistry of the selected area from 1999 to 2014. The relationship between EC and TDS is linear (the ratio of this relationship is approximately 0.64). It is quite obvious that values of these parameters increased due to the intrusion of saline water into the aquifer (Fig 4). The high correlation between EC and TDS as well as Cl, TDS and Na + K (Fig 5) indicates the presence of sodium chloride in the groundwater of the study area. The high correlation indicates the mixture of two types of saline water and fresh groundwater which caused the dissolution of halite. Considering the sustainability of chloride and a lack of participation in chemical reactions combined charts have been prepared, relating to sodium and potassium, and TDS (Fig 5).

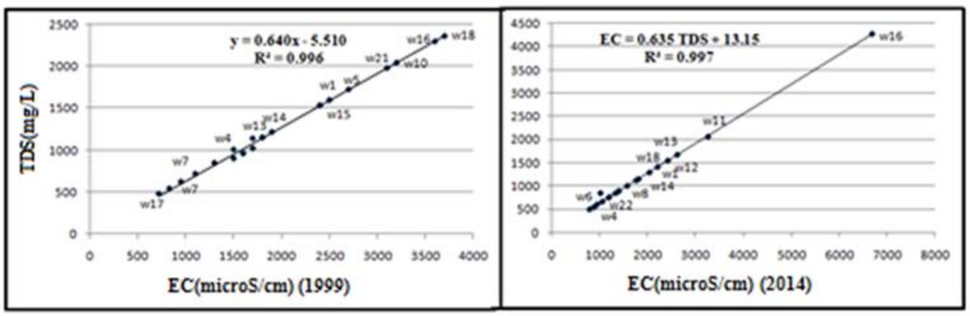

Figure 4 relationship between EC and TDS

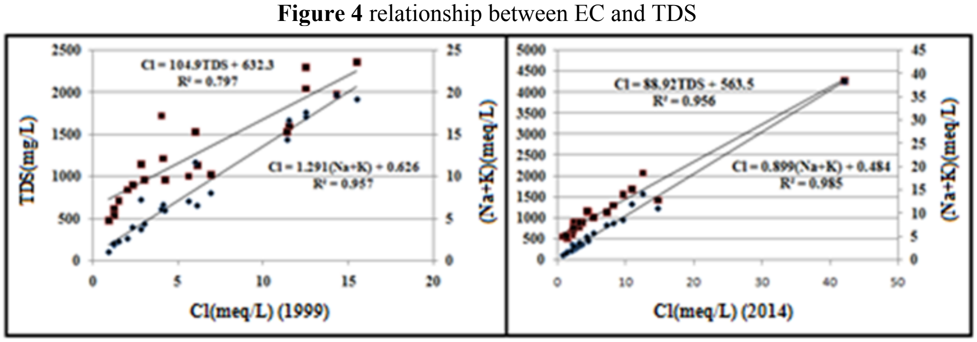

Figure 5 comparison the changes of chlorine relative to sodium, potassium and TDS

Gibbs diagram: This ratio is a useful criterion for evaluation and identification of groundwater infection by sea water or fossil water (Gibbs 1970). By using Piper modified diagrams, type and facies of groundwater in flow direction can be determined. Main ions in groundwater play a major role in the classification of water quality (Chadha 1998).The concentration of these ions is usually affected by lithology, velocity and quantity of groundwater, natural geochemical reactions, solubility of evaporative sediments and human activities (Karanth 2001). After rainfall, some water penetrates into the ground and while it is moving, considering current speed, duration of exposure, temperature and pH, with other factors, there is a chemical reaction with surrounding rocks, and thus some of the ions enter the water. To detect these reactions Gibbs diagram (Gibbs 1970) is used. This diagram is divided into three parts: At the top, is reaction of evaporation and crystallization, at the middle, rock- water reaction (range of rocks weathering) and at the bottom a range of precipitation reactions (Fig 6).

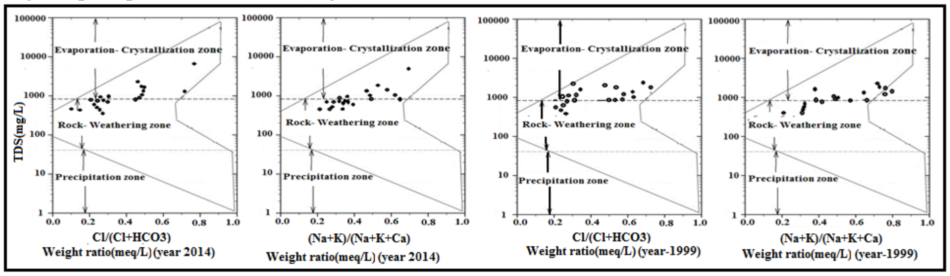

Figure 6 Gibbs diagram in study area

Ion exchange and chloro- alkaline indices: This factor is used to determine the chemical reactions that lead to ion exchange between groundwater and the surrounding aquifer. In confirmation of ion exchange between groundwater and the environment hosts that entered the groundwater, chloro- alkaline indices, which are presented by Schoeller, are used. Hydro geochemical facies, in different areas in terms of concentration of cations and anions in groundwater, can be defined and described in different groups. A modified Piper chart (Piper 1944) was used by Chadha in 1998. This presented an acceptable classification of natural waters and their geochemical behavior. In this diagram, the horizontal axis is the percentage of difference between the earthy alkalis (Ca + Mg) and metallic alkalis (Na + K) and the vertical axis is the difference between weak acid anions (CO3 + HCO3) and strong acid anions (Cl + SO4) according to Fig 7.

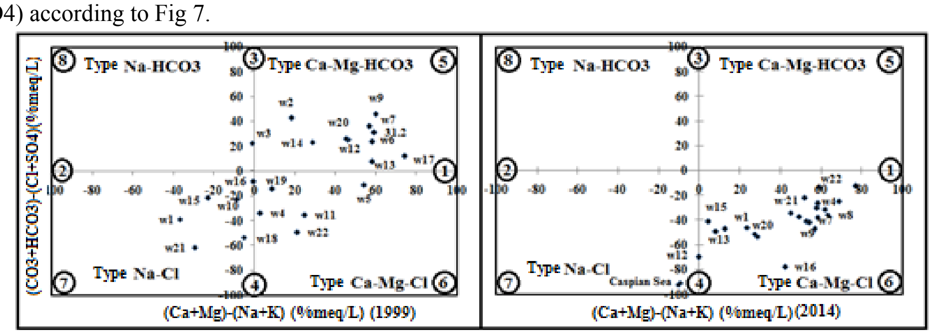

Figure 7 modified Piper charts to classify geochemical and hydro geochemical parameters

Eh/pH diagram: pH/Eh diagrams can also be used as a first approximation to characterize natural waters (Broder, Friedrich (2008) (Fig 8). However, the mentioned problems concerning the precision and uncertainties of Eh measurements must be taken into account.

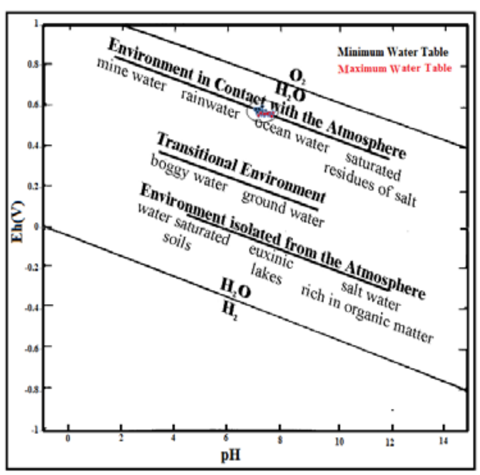

Figure 8 Classification of natural waters under various Eh/pH conditions for Ghaemshar- Joybar

Preparing sections perpendicular to the beach to determine the depth of common level of fresh – saline water: These sections indicate alterations in water quality. They are also used to determine the position of a common level between fresh and saline water. In the study area, due to the low number of exploratory wells, it was not possible to accurately estimate the depth of discontinuous sediments and common level between fresh and saline water accurately. With the help of geophysical studies it was, however, possible to find some information. According to the chemical analysis of the exploitation wells from feeding to discharge, hydro geochemical facies and type of water with the help of modified Piper diagram, the geophysical and geological information of selected area was examined and the hydro-geological and hydro geochemical sections of plain were prepared. These processes are shown in Figure 9. As it can be seen in Figure 9, salt water intrusion has continued over these years due to lack of water of rivers in the area, high evaporation, excessive exploitation and slow groundwater flow. Thus, pushing back saltwater from the sea is quite impossible and according to the section of electrical conductivity of the area, saline water has penetrated to depths of 150 to 170 meters below alluvial fan (Fig 10).

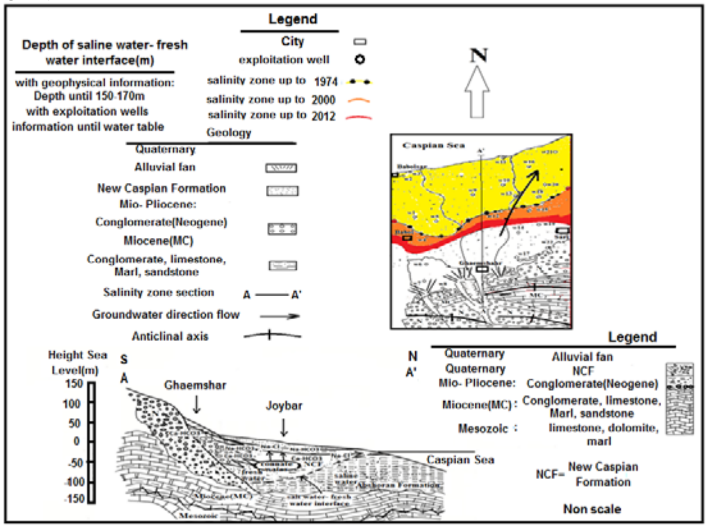

Figure 9 Hydrogeological and hydro geochemical maps and sections and determining the approximate range of salinity

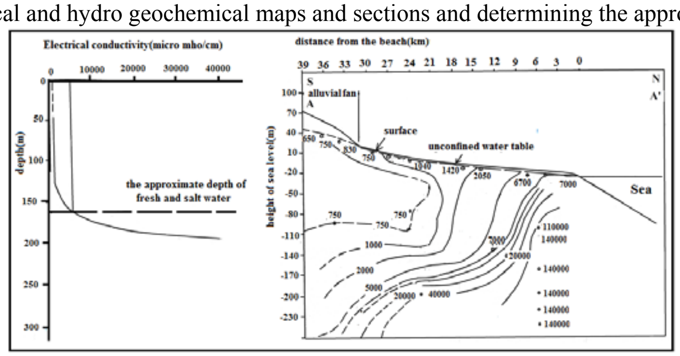

Figure 10 Vertical profile changes EC (µmhos/cm) in N-S direction (Ghaemshar- Joybar, cross A-A' in Figure 4) and determine the approximate depth of the separation of fresh and salt water

Conclusion and recommendations

No Hydro geochemical evolutionary process has been observed in the groundwater of the study area. Based on the location of Ghaemshar-Joybar (1999-2014) groundwater samples in the Gibbs diagrams, modified Piper, pH-Eh shows that most of the samples in the range of evaporation and crystallization, and few will be in the range of rock-water. The water in the range of sodium-chloride, calcium-sodium-magnesium bicarbonate and water mixture is increased. In addition, the graph line pH-Eh samples close Contact between atmospheric water and water in environment with the atmosphere and the sea. As a result the groundwater source study area of southern highlands and plains of atmospheric water penetration occurs. Then the flow of groundwater due to chemical reactions and ion exchange or reverse sediments and solutions available, type of aquifer waters constitute.The feeding area has calcic carbonate facies, the middle-range has facies of bicarbonate sodic and the discharge region has sodic facies. Severe reduction of the electrical resistivity, a high roll ratio, an increment in electrical conductivity along the groundwater flow, increased concentrations of anions and cations especially sodium and chloride in northeast and eastern parts of the plain represent the intrusion of salt water and saline fossil aquifers and thus interference by fresh and saline water. Over the past 40 years, the salinity of the area, owing to uncontrolled exploitations, relative decrease in rainfall and river discharges and reduction of groundwater flow has not helped to push back saline water and evaporation has increased the concentration of substances in the area of discharge. Consequently with the current trend, in the next few years, saline water from the sea will connect with fresh water and the feeding section will be affected. Determining the retention time of groundwater is one of the solutions to identify fossil water and the penetration of saline water to the aquifer. To determine this time, the use of ^{14}C and ^{3}H isotopes are required. As chloride is not influenced by chemical processes such as adsorption and ion exchange, it can be used as a tracer. Determining the qualitative and quantitative boundaries of selected wells is essential to control changes in groundwater levels, the chemical characteristics of groundwater (surface and underground) and to prevent the penetration of saline water. Preparing sections perpendicular to the beach shows alterations in water quality and location of fresh and saline water interface such as: drilling exploratory wells, geophysical studies and preparation of detailed hydro-geological sections. Due to excessive exploitation in the selected area, changes in irrigation methods are necessary to reduce the amount of groundwater extraction. Because of a large number of seasonal and permanent rivers in the study area, it is necessary to develop suitable methods such as artificial recharge of aquifers as soon as possible.

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