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

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Abstract: Ghaemshahr plain based on geological, hydro geological, hydrological and regional conditions, human’s factors and nearness to Caspian Sea faces with salt water intrusion. This plain is located at the northwest of Iran in Mazandaran province and near Caspian Sea. In this, study graphs and maps are produced by using geophysical, geological and chemical analysis information based on salt water intrusion. These studies show that, contrary to routine discharge, continually drought and unsuitable watering methods caused a decreasing trend of accessibility level and salt water intrusion into aquifer during past 40 years. On the other hand, during geological periods Caspian Sea had multiple developments and regressions, so some water of this sea is remained into Absheron Formation sediments and covered by New Caspian formation above sediments and formed fossil saline aquifer in different parts of the Plain. Fresh water aquifers due to reduced water pressure and possibly through ion exchange in middle of the plain entered to freshwater aquifers and caused salinization of aquifers. It is necessary to control the amount of water elicitation and the way of irrigation depending on the cultivation should be set. Selecting the appropriate method for artificial feeding in vicinity of altitudes by considering the status of water table in discharging area is necessary because this aquifer is currently in critical condition and with this trend in not so distant future will be destroyed thoroughly due to population growth, the increase in land under cultivation and continuous droughts.

Key-Words: Caspian Sea, Ghaemshahr plain, salt water intrusion, Gibbs-piper diagrams

1 Introduction
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. Due to indiscriminate use of these types of aquifers in many countries and also intrusion of saline water are considered to be potential problem in coastal aquifers. Groundwater aquifers in seas coastal areas and saline lakes always face the risk of progression and invasion of salt water. With development of exploitation, progression and intrusion of salt water into the land would increase and gradually will contaminate freshwater aquifers. Excessive exploitation of groundwater resources while causes a drop in the water table, salt water intrusion would be faster and thereby causing complete destruction in freshwater aquifers. In most cases, compensation for damages is not an easy task and requires long time and costs. Therefore, must be careful in using groundwater, especially in the coastal zone and examined the problem of saltwater intrusion and about the amount and method of exploitation appropriate decisions and careful management must be conducted. Mainly in coastal areas, there is a flow of underground water from land to the sea. With greater amount of these flows, penetration of sea water will be less. Naturally there is equilibrium between fresh water of coastal aquifer and saline water. Aquifers fresh water and salt water can be considered as two immiscible fluids and consequently imagine a level of separation between them. This surface defined as separation level or interphase. This level is not linear but it is an area which is called dispersion region. This area is changing over the years for various 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 with different tools and methods. These methods include: drilling exploratory wells and observation of water table, evaluation and continuous chemical analysis of groundwater resources, measuring movement of tides and comparison with changes in level of separation between saltwater and freshwater, geophysical techniques, geological evaluations and isotopic studies. There are a lot of aquifers in Caspian Sea that problem of salt water intrusion can be seen in all of them. Studies of geology, hydrogeology, geophysical and hydrogeochemical in aquifers of Caspian have been conducted and besides the penetration of seawater and existence of some saltwater zones which caused by repeated retreats and advances of Caspian Sea has been proven. Dramatic increase in exploitation considering depth of wells in some areas causes the loss of balance between salt and fresh water and intrusion of salt water into the wells. Considering characteristics of the Caspian Sea, it has special place among seas and oceans. Because height of this sea is about 27 meters below high sea level, salinity between 9.2 to 12.6gr/lit, specific weight around 1024.7 kg/m³ which is much lower than the average of open sea and oceans. Average chemical changes of Caspian Sea are presented in Table 1

Table 1 Average concentration of dissolved elements in seawater [different resource]

<table>
<thead>
<tr>
<th>chemical parameter</th>
<th>EC (mS/cm)</th>
<th>TDS</th>
<th>SO₄²⁻</th>
<th>Cl⁻</th>
<th>HCO₃⁻</th>
<th>K⁺</th>
<th>Na⁺</th>
<th>Mg²⁺</th>
<th>Ca²⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean of Sea, Ocean</td>
<td>20</td>
<td>12.6</td>
<td>5.6</td>
<td>6.5</td>
<td>1</td>
<td>0.98</td>
<td>5.1</td>
<td>1.1</td>
<td>0.45</td>
</tr>
<tr>
<td>mean of Caspian Sea</td>
<td>55</td>
<td>35</td>
<td>2.7</td>
<td>10</td>
<td>0.142</td>
<td>0.589</td>
<td>10.5</td>
<td>1.35</td>
<td>0.41</td>
</tr>
</tbody>
</table>

As can be seen in the table, the amount of sodium and chloride in Seas and oceans is much higher than Caspian Sea, thus water composition is similar to freshwater lake. In this study, we tried to determine all 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 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:

1) Geological formations reactions with Ghaemshahr groundwater and their impacts in increasing salinity.
2) Detection of saltwater intrusion into freshwater of aquifers through geophysical and chemical techniques.
3) Determine the infected area in terms of location and its changes over recent years by using map and sections.

2 Precedence studies

In order to supply drinking water of Tehran, studies in terms of quantitative and qualitative in catchment area of Babol and Haraz have been conducted [2]. Another investigation has done in case of qualitative and quantitative characteristics of Sari aquifer which effective factors on low quality of ground water, penetration of different wastewater, brackish water and seawater mixture and evaporation of ground water has been detected [10]. Modelling of groundwater flow and geochemical investigation of drinking water wells in Sari [15], monitoring quality of Babol – Amol aquifer by using GIS package [16], Sea salt water intrusion zone is determined among empty spaces of sediments that cause a substantial decrease in resistance. Based on conducted geological and hydro geological studies of Caspian coastal aquifers, existence of some saltwater zones resulting from retreats of Caspian Sea has been proven [11]. Hoxhaj in 2005 could prove salt water intrusion into the aquifers of northern Albania based on observations of chloride concentration in five wells and geochemical studies. Khalil to study salt water intrusion in west of Sinai Desert used 60 vertical electrical sondes. Gibson and Randall in 2006 presented an article entitled salt water intrusion problem and conservation activities in southeast of Georgia, first studied spatial and temporal changes of ions by using maps, and could prove salt water intrusion by combination charts. So they realized that sea salt water intrusion in coastal aquifers of Georgia is due to: increase in electrical conductivity and some ions such as sodium and chloride, also linear relationship between chlorine and sodium with main ions.

3 Studying area

Ghaemshahr located on the northern slopes of Alborz Mountains and plain in the north-eastern
Mazandaran province (NE of Iran). According to the Hydro climatic and geological conditions and bordering with Caspian Sea, is strongly influenced by this situation in terms of quality. This area geographically located in 52° 35’ to 53° 23’ longitude and 35° 44’ to 36° 47’ latitude. Vastness of watershed is about 3348.1Km² and studying area is 935.5 Km². Location of studying area is shown in Fig. 1.

4 Material and Methods

This research was performed based on data of chemical analysis from 22 wells (Fig. 2). These data were collected and tested in 2000 and 2012 for comparison and qualitative trend (Table 2). Analysis of water samples consisted of measuring concentrations of cations and anions and parameters such as EC, TDS and pH. For analysis of elements, Society of Public health of America [1] was used. Sodium and potassium concentrations are calculated by flame photometer, Calcium, magnesium, bicarbonate and chloride by volumetric method, sulphate by Spectrophotometer, electrical conductivity and total dissolved solids by conductivity meter and other parameters by chemical relationships. Procedures of these researches consist of: data collection, Ministry of Energy reports, Regional Water Authority, articles, theses and maps related to research and evaluation and analysis of geochemical data of aquifers and drawing maps and charts by using Excel, Surfer and GIS software’s. Basis of results interpretation and overall status of water in the aquifer is based on relationship of water in the aquifer sediments and seawater constituents. In each analysis values of cations and anions should be equal. Their inequality can be result from experimental error or lack of elements and other substances in water [14]. On this basis, analysis error percentage of Ghaem Shahr plain in all cases was less than the mentioned amount (Table 2, Fig. 2). As it can be seen in Fig. 2, there is a high correlation among anions and cations of 22 samples. Considering the ionic balance in the water samples, evaluation of water type and its mixture has been done by using combination charts and diagrams of Gibbs [4] and modified Piper [16].

Table 2 Statistical Characteristics of resources chemical analysis in the area

<table>
<thead>
<tr>
<th>Element</th>
<th>Min</th>
<th>Max</th>
<th>Mean</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO4²⁻</td>
<td>2.2</td>
<td>2.6</td>
<td>2.4</td>
<td>0.26</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>4.6</td>
<td>4.8</td>
<td>4.7</td>
<td>0.22</td>
</tr>
<tr>
<td>Na⁺</td>
<td>12.4</td>
<td>12.5</td>
<td>12.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>1.4</td>
<td>1.6</td>
<td>1.5</td>
<td>0.16</td>
</tr>
<tr>
<td>Ca²⁺</td>
<td>0.8</td>
<td>1.0</td>
<td>0.9</td>
<td>0.08</td>
</tr>
</tbody>
</table>

4.1 Geology, Hydrogeology and Geophysics of studying area

Catchment of Ghaemshahr in terms of geology which is the most effective factor on water resources (quality and quantity) different formations from earlier Carboniferous to Quaternary has outcrops according to Fig 3.

Fig.3 geological map, location of wells and average groundwater level
Considering the impacts of formations on quality of groundwater resources, according to investigations, one-third of the formation belongs to Shemshak (sandstone, quartz rocks, clay, shale and coal). This formation due to faults has qualitative and quantitative relationships with the aquifers. However, because of solubility, the most impact on groundwater quality is related to Elika carbonate Formations (Triassic), mostly limestone and calcareous shale and dolomite, Delichay Formation which is formed of calcareous marls and marly limestones, Lar Formation and subsequently Tiz Kouh Formation (Cretaceous) including: limestone dolomite, limestone with volcanic rocks. Sediments of boundary between mountains and the plain consist of: hard clays, marl, sand, gravel layers and a thin layer of volcanic ash. On this formation, lake sediments containing sand and mud which are not hard (New Caspian Formation) and volcanic activity and covered by discontinuous sediments that cause main aquifer with relatively good permeability come to exist in Ghaemshahr plain according to Fig. 3. Direction of groundwater flow in the area is from south to north and northeast. In order to evaluate the alluvial deposits, exploratory wells and geophysical logs were used. The map is shown in Fig. 4 the results presented summarily in table 3.

Table 3 Characteristics of alluvial deposits using geophysical methods

<table>
<thead>
<tr>
<th>Specific resistivity</th>
<th>Characteristics of sediments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 10</td>
<td>Including middle and drain parts. Fine-grained sediments and too much minerals. To a depth of 100 to 150 meters without fresh water. The water is brackish and saline.</td>
</tr>
<tr>
<td>10 to 20</td>
<td>The end of the alluvial fan. Medium grained sediments and freshwater resources. Its thickness is about 150 m</td>
</tr>
<tr>
<td>More than 20</td>
<td>The foothills and alluvial fan. With sediment thickness more than 200 meters. It is the best area for exploitation of water resources.</td>
</tr>
</tbody>
</table>

One of the objectives of geophysical studies in coastal areas is to determine the range of saline water and separation of saline water with 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 vulnerable to invasion of saline water. By combining geophysical studies, exploratory wells logs, hydro geochemistry and geology, intrusion of salt water can be seen in studying area.

4.2 Mechanism controlling groundwater geochemistry

Evaluation of data and combined charts demonstrate that in the study area from 2000 to 2012 all ions and substances in groundwater at discharge area of the plains almost doubled. This increase can be interpreted by following factors:

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

B) Precipitation: According to statistics of 12 years (2000-2012) Average precipitation in the plains 734 mm and in the heights 560 mm. Consequently, decrease in precipitation, directly reduce the feed rate from highlands and plains which are effective in water table drop. Also affects the reaction between rock and water. These cases are effective in altering the concentration of trace elements in groundwater.

C) Geological Formations: Altitudes of selected area composed of calcareous, marly and dolomitic formations. Plain come to exist from alluvial fans that made up of grain and permeable sediments. In input range considering calcareous, marly and dolomitic formations, calcium bicarbonate water type reduced from west to east. In middle parts, water type is mostly sodium bicarbonate that resulted from ion exchange between groundwater and clay rocks. At the end of the middle section (eastern region), type of water is sodium chloride. As demonstrated in Fig. 4, in this section anomalies approved through geophysical procedures and the reason for that is remained water from regression in Caspian Sea in different geological periods on
Absheron deposits and then this water covered by deposits of Caspian Sea and the formed connate water. Saline water would easily replace with fresh water because of uncontrolled exploitation. In part discharge due to proximity to the sea a substantial amount of sea water penetrated into the aquifer due to drop in water table and caused aquifer to become saline. In beginning and middle sections changes in values of ions in groundwater cannot be seen over 12 years, but approaching the sea values of sodium, chloride, EC and TDS dramatically increase (double). This increment represents an intrusion of salt water into freshwater aquifer. There are various methods for the detection of salt and salt water intrusion in coastal aquifers, the most important ones include:

A) Combined charts
These charts are useful tools in determining the salt, mixture and source of water. 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 groundwater Hydro geochemistry of selected area from 2000 to 2012. The relationship between EC and TDS is linear (ratio of this relationship is approximately 0.64). It is quite obvious that values of these parameters increased due to intrusion of saline water into the aquifer (Fig. 5). The high correlation between EC and TDS as well as Cl, TDS and Na + K (Fig. 6) indicates the presence of sodium chloride in groundwater of study area. The high correlation suggests mixing two different waters is salt and fresh water (Fig.5, 6). Origin of single point in Fig.5 and Fig.6 is the intrusion of sea salt water and brackish connate water aquifers. Considering sustainability of chloride and a lack of participation in chemical reactions combined charts is prepared relative to sodium and potassium, and TDS (Fig. 6).

Fig. 5 relationship between EC and TDS

B) Gibbs diagram
This ratio is a useful criterion for evaluation and identification of groundwater infection by sea water or fossil water. 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 classification of water quality. The concentrations of these ions usually affect by lithology, velocity and quantity of groundwater, natural geochemical reactions, solubility of evaporative sediments and human activities [9]. After rainfall some water penetrate into the ground and while they are moving, considering current speed, duration of exposure, temperature and pH, and other factors, chemically reacts with surrounding rocks, and thus some of the ions enter the water. To detect these reactions Gibbs diagram is used. This diagram is divided into three parts: At the top, reaction of evaporation and crystallization, at the middle, rock - water reaction (range of rocks weathering) and at the bottom range of precipitation reactions (Fig. 7).

Fig. 6 comparison the changes of chlorine relative to sodium, potassium and TDS

C) Ion exchange and chloro-alkaline indices
This factor is used in determination of 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 entered into groundwater chloro-alkaline indices which is presented by Schuler, is 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. Modified Piper chart was used by Chadha in 1998, presented acceptable classification of natural waters and their geochemical behaviour. In this diagram, in

Fig. 7 Anion and cation Gibbs diagram
horizontal axis is the percentage of difference between the earthy alkalis (Ca + Mg) and metallic alkalis (Na + K) and in vertical axis is difference between weak acid anions (CO3 + HCO3) and strong acid anions (Cl + SO4) according to Fig. 8.

![Fig. 8 modified Piper charts to classify geochemical and hydro geochemical parameters](image)

D) Preparing sections perpendicular to the beach and 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 common level between fresh and saline water. In the study area due to the low number of exploratory wells cannot estimate the depth of discontinuous sediments and common level between fresh and saline water accurately. But with the help of geophysical studies can found that information to some extent. According to the chemical analysis of the exploitation wells from feeding to discharging part, hydro geochemical facies and type of water with the help of modified Piper diagram, geophysical and geological information of selected area has been examined and hydro-geological and hydro geochemical sections of plain is prepared. These processes are shown in Fig. 9. As it can be seen in Fig. 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 of sea is quite impossible and according to the section of electrical conductivity of the area, saline water have penetrated to depths of 150 to 170 meters below alluvial fan.

![Fig. 9 Hydrogeological and Hydro geochemical maps cross section and determining the approximate range of salinity zone](image)

5 Conclusion and recommendations
Hydro geochemical evolutionary process is not observed in groundwater of studying area (bicarbonate - sulphate and Chloride combinations). Feeding area has calcium carbonate facies, middle-range has facies of sodium bicarbonate and discharge region has sodium facies. Severe reduction of the electrical resistivity (an ohm meter), high roll ratio, increment in electrical conductivity along the groundwater flow, increase 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 of fresh and saline water. Over past 40 years, salinity of the area according to uncontrolled exploitations, relative decrease in rainfall and river discharges and reduction of groundwater flow has not help to push back saline water and evaporation increases the concentration of substances in the area of discharge. Consequently with current trend in the next few years saline water of sea will thoroughly connect with fresh water and feeding section will be affected. Determining the retention time of groundwater is one of the solutions to identify fossil water and penetration of saline water to the aquifer. To determine this time, the use of 14C and 3H isotopes are required. As chloride has not influenced by chemical processes such as adsorption and ion exchange, it can be used as a tracer. Determination of qualitative and quantitative boundaries of selected wells is essential to control changes in groundwater levels and chemical Characteristics of groundwater (surface and underground) and 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 selected area, changes in irrigation methods are necessary to reduce the amount of groundwater extraction. Because of 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.

References:
[2] Alexander Gibbs Engineers Company, quantitative and qualitative studies - *Babol and
Haraz in order to supply drinking water of Tehran, 1976.


