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RESEARCH PAPER

Spatio-Temporal Variation of an Aquifer Salinity in a Semi-Arid Area, Case Study of Sarvestan Plain, Iran

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ABSTRACT

The aim of this study is to determine the amount of quantitative and qualitative changes in groundwater in the Sarvestan plain in south of Fars province, which is one of the critical plains in Iran in terms of water resources. In this research, zoning maps of electrical conductivity of water in GIS were prepared and various hydrochemical diagrams were illustrated. Different quality parameters of water resources were compared according to the statistical data collected and the experiments performed at the beginning of the 8-year period of the research. Chemical analysis of water samples shows that the groundwater type of most of the studied wells at the beginning of the period (2013) has changed from Ca-Cl and Mg-Cl types to Na-Cl type at the end of the time period (2020). Determining the trend of chemical changes shows that the diversity of water samples in terms of anions and cations in water with increasing salinity at the end of the period is less than the variety of samples at the beginning of the period. According to the results of chemical experiments, evaporation, crystallization, and weathering of rocks are the factors that control the composition of groundwater in the study area. This study shows increasing the salinity of groundwater due to decreasing precipitation and high water use for agricultural application, also the type of geological formations, especially the presence of salt domes at groundwater inlets to the plain on the east side of the study area.

keywords: Electrical conductivity; Groundwater Salinity; Water Quality; Sarvestan Plain

INTRODUCTION

Due to drought, groundwater resources are depleted. Drought has devastating effects on agriculture, energy and industry, drinking water supply and freshwater ecosystem (Nasrabadi and Abbasi Maedeh, 2014; Stagge et al., 2015). Restriction of surface water resources and over-exploitation of aquifers as well as the entry of pollutants through agricultural, urban and industrial activities cause irreparable damage to groundwater (Asghari et al., 2010; Nasrabadi et al., 2018).

In recent years, rapid population growth has led to an increase in consumption per capita in various sectors, including agriculture and industry, and a growing gap has emerged between water demand and water supply (Doell et al., 2014). Due to population growth and water pollution, access to safe drinking water in developing countries has become a global challenge (Reda et al., 2016). Due to the special climatic situation of Iran, and the shortage of rainfall

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and its inappropriate temporal and spatial distribution, groundwater resources in Iran as a key source provides 65% of the country's water needs (Rahmati et al., 2016).

Most groundwater sources of freshwater are located near natural saline groundwater, seawater and lakes or saline effluents, and if more than of aquifer recharge is harvested, saline water will intrude to freshwater (Suma et al., 2015).

Various studies in the United States and parts of Europe, including Germany, the United Kingdom, Norway, Bulgaria, Slovenia, Austria, China and Oman have examined the impact of catchment characteristics and drought indicators on groundwater resources (Li et al., 2015; Van et al., 2015; Reda et al., 2016; Yu et al., 2017; Abulibdeh et al., 2021). In a study to evaluate the quality of groundwater in the Congra region of Himachal Pradesh, India, the results showed that most water quality variables are beyond the limits set by international and regional standards (Dev et al., 2019). The use of geochemistry in studying the relationship between different water sources, especially in coastal areas, has been done in many researches (Tillman et al., 2014; Gopinath et al., 2015; Gopinath et al., 2015; Annapoorna et al., 2015; Ayers et al., 2016).

Water quality characteristics are one of the components that need to be considered in planning related to water resources management, as well as assessing the health of the watershed, and making managerial changes in it (Khadam et al., 2006). Gargij and Asghari Moghaddam studied the hydraulic relationship between Azarshahr plain and Urmia lake using inverse hydrochemical modeling and their results showed that the main reason for groundwater salinity in this area could be related to evaporation at the end of the plain (Docheshmeh et al., 2016). Fayazi et al. have studied the hydrochemical evolution and salinity of Maharlu lake, the results indicate changes in water type during the study period (Fayazi et al., 2007).

Transgression and intrusion of saline seawater into groundwater of coastal aquifers occurs in the face of natural or man-made factors that are discussed in exploitation management (Shi et al., 2018). The general state of saline water is the predominance of chlorine and sodium, and the excess of chlorine over alkaline elements (Bear et al., 2010).

In recent years, the use of GIS has been used to plan, design and solve problems. In a study in India, the vulnerability of groundwater in West Bengal was investigated using GIS and the results showed that fifty percent of the study area has a high vulnerability to industrial and urban pollutants (Shahid et al., 2000). Jamshidzadeh et al. (2011) examined the reasons for the decrease in groundwater level of Kashan. The results indicate that the accumulation of villages and water overharvesting for agricultural use causes a decrease in groundwater level. In Iran, various researchers have succeeded in using GIS techniques to assess the potential of groundwater (e.g. Zabihi et al., 2016). Janbaz et al. (2020) studied land subsidence due to changes in groundwater level in Qazvin province. The results showed that the average annual subsidence in the Qazvin aquifer was 39.9 mm from 2013 to 2017.

Iran is an arid and semi-arid country where two thirds of its land is classified as desert land and with an average annual rainfall of about 250 mm per year, is one of the driest countries in the world (Moradi et al., 2016).

In this study, Sarvestan plain located in the south of Fars province as one of the critical plains in Iran in terms of water resources is selected. It is necessary to conduct oriented studies of groundwater resources monitoring in this plain for quantitative and qualitative management of water resources. The main goals of this study are i) to evaluate the concentration of major anions and cations (salinity) in Sarvestan aquifer and ii) to determine the spatial-temporal variation of concentrations within the recent decade.

MATERIALS and METHODS

Sarvestan plain with an estimated surface area of 1650 km^2 forms the eastern part of Maharlu lake catchment. Sarvestan city is one of the cities of Fars province which is located on the northeastern side of this plain. This city is located in latitude 29 degrees and longitude 53 degrees. Fig. 1 shows the location of the study area and sampling points.

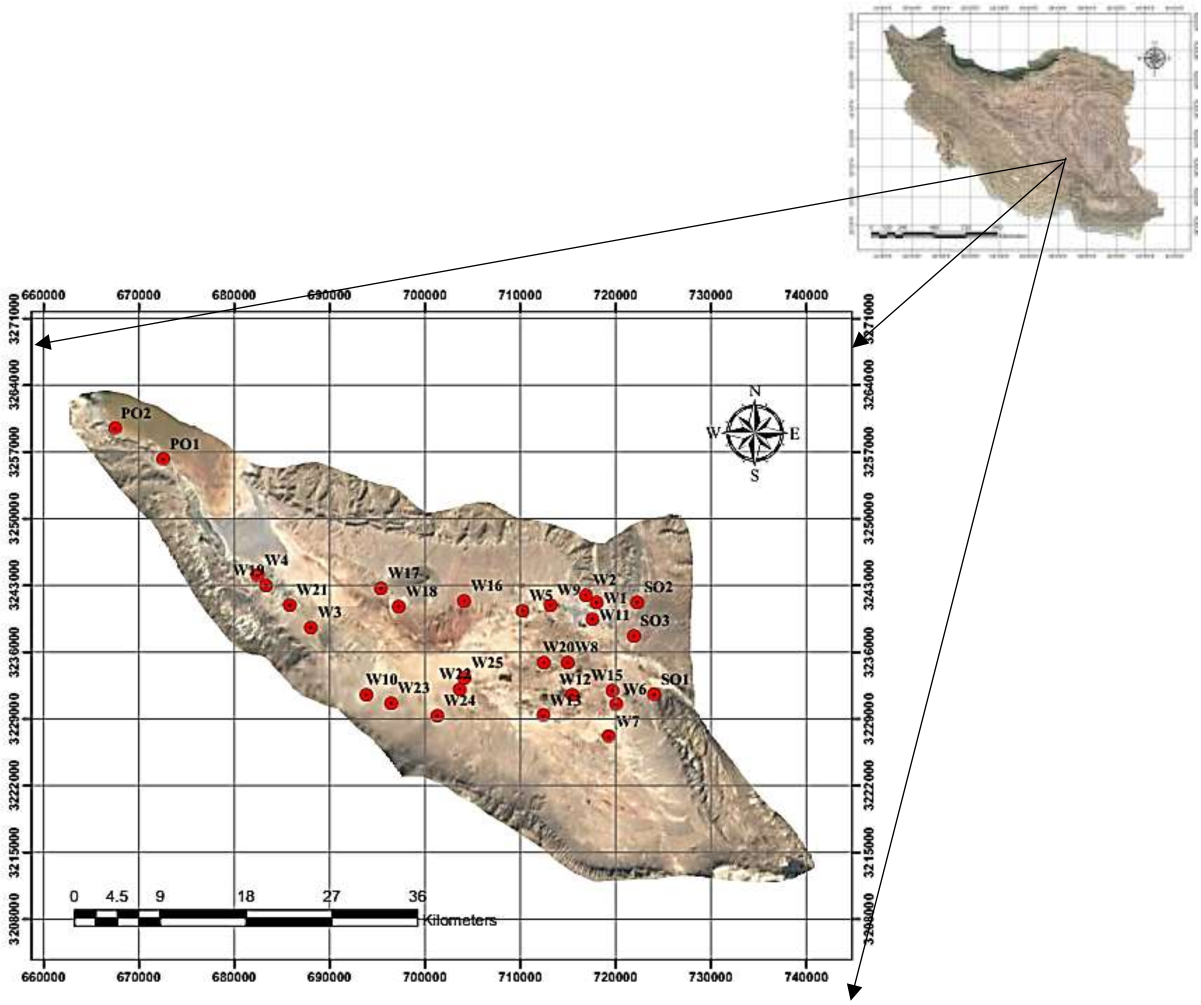

Fig. 1. Location of the study area and sampling points

Sarvestan watershed does not have a permanent river and several waterways bring runoff from snow and rain to the plain. The required meteorological statistics are prepared from the statistics available in the study unit of Fars Regional Water Company and are analyzed as follows. Sarvestan study area has a special situation in terms of geology. Sarvestan's large fault in the east of the plain has caused major changes in the location of formations and also the outcrop of two salt domes in the northeast and southeast of the plain and the highlands of the eastern part of the plain. The Sarvestan study area is such that a part of Maharlu lake is also included.

The alluvium of the plain forms an alluvial groundwater aquifer. The alluvium is coarse-grained in the range of highlands and alluvial fans, and their grains are reduced to the center of the plain and are fine-grained at the edge of Maharlu lake. Groundwater resources of the study area include calcareous springs in the highlands around the basin and alluvial springs in the Sarvestan plain.

In order to study how the groundwater level of Sarvestan changes, 29 observation wells have been drilled in the plain area and the groundwater level in these wells is measured. In this study, in addition to sampling and sending water samples to the laboratory and determining the concentrations of main anions and cations in water, in order to investigate the trend of annual changes over a period of 8 years, the quality statistics in water resources of the regional water company database was used.

Assessment of the plain water quality was done by collecting 30 samples including 23 agricultural alluvial wells and 2 deep calcareous drinking water wells, as well as sampling from 3 springs and 2 lake samples.

It is noteworthy that wells in this study are marked with W, springs with SO and water samples taken from the lake are marked with PO. Wells W1 and W2 have been drilled in hard calcareous formations for drinking purposes and the rest of the wells have been drilled in alluvial formations for agricultural purposes.

To investigate the changes in water quality factors during the study period, statistics related to the concentration of all anions and cations in milliequivalents per liter (meq/l) and other quality factors such as electrical conductivity (EC), total dissolved solids (TDS) and pH was prepared and diagrams of changes in these parameters were drawn over a period of 8 years. Total concentration of anions and cations (in meq/l) was calculated and cross checked to be less than 5%.

One of the most important tasks in groundwater researches is the analysis of chemical data in a way that can be visually examined. The use of graphs is a useful and fast solution to determine the origin and compare the chemical composition of groundwater (Hounslow et al., 2018).

A set of diagrams, such as piper diagrams, are designed to determine the trend of chemical changes or mixing (Annapoorna et al., 2015).

In this study, Excel, GIS and Aqqa software are used to analyze the spatial and temporal variations of interested parameters.

RESULTS and DISCUSSION

According to long-term statistics, the rainfall in the plain has decreased significantly over the years, which justifies the recent droughts. Fig. 2 shows the rainfall values in the study period. The average rainfall of Sarvestan plain during the statistical period is 226.5 mm, which is less than the long-term provincial average (295 mm) and long-term national average (250 mm).

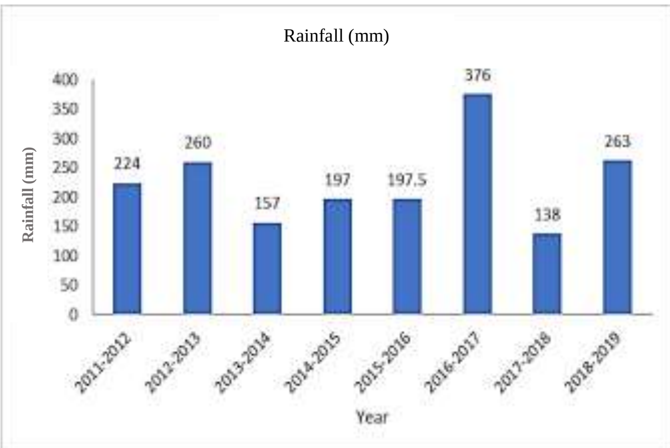

Fig. 2. Rainfall during the study period

Fig. 3 shows that in October 2013 the water level was 1472.16 meter, which if compared by the level of October 2020 (1468.25 meters), the decrease in groundwater level in the 8-year period is 3.91 meters, and the average annual loss in the last 8 years is calculated to be around 49 cm. The depth of the groundwater level in the southern and northern parts of the plain is high, and decreases towards the center and west of the plain (adjacent to Maharlu lake). Due to the shallow depth of water, it is considered as an evaporation zone.

Fig. 3. Annual average of groundwater level

In order to investigate the changes in the electrical conductivity of water, among all water sources studied in this research, 14 wells were selected with suitable dispersion, and diagrams of changes in the electrical conductivity of water were drawn in the study area from 2013-2020 which illustrated in Figs 4 and 5.

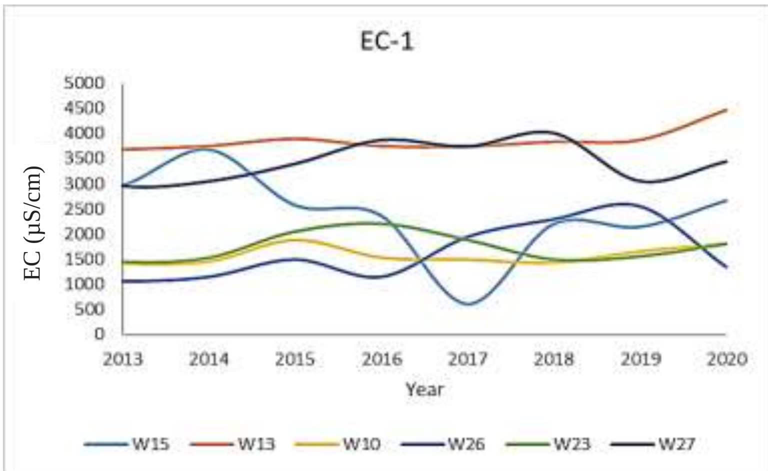

Fig. 4. Changes in the electrical conductivity of water ($617 \leq EC \leq 5590$)

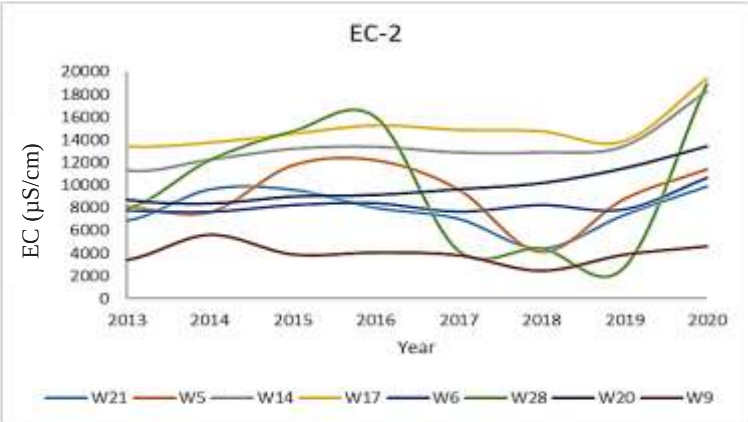

Fig. 5. Changes in the electrical conductivity of water (2748 ≤ EC ≤ 19399)

According to diagrams, the most remarkable changes in EC values of groundwater were observed in well W28 located in the western part of the study area and adjacent to Maharlu lake. The main reason for these changes is the impact of water quality and quantity of this area from the lake water level, and the progress of the lake's saline water to the adjacent aquifer in different years.

The highest amount of EC has been measured in well W17 (19399 µS/cm) at 2020. Sodium in water has increased as a result of increased sodium leaching from the soil and its addition to groundwater.

By comparing the water type of groundwater sources whose water quality parameters were measured in 2013 and 2020, it was concluded that the water type of a large number of wells studied, including wells W6, W7, W12, W16, W17, W18, W19, W21 and W22 have been changed from different types of Ca-Cl and Mg-Cl to Na-Cl type. According to the electrical conductivity zoning maps of the plain, the value of electrical conductivity of water has increased in the entire study area. The highest values of electrical conductivity of water has increased from about 13,000 µs/cm in 2013 to about 20,000 µs/cm in year 2020.

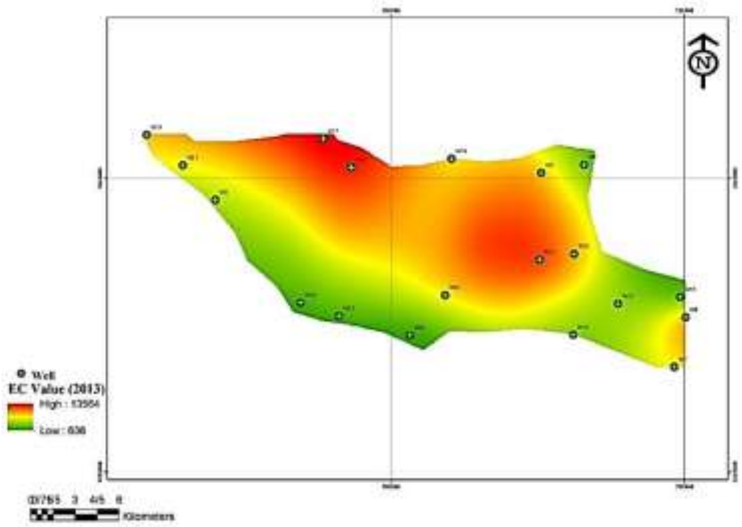

Fig. 6. Zoning map of electrical conductivity of water in 2013

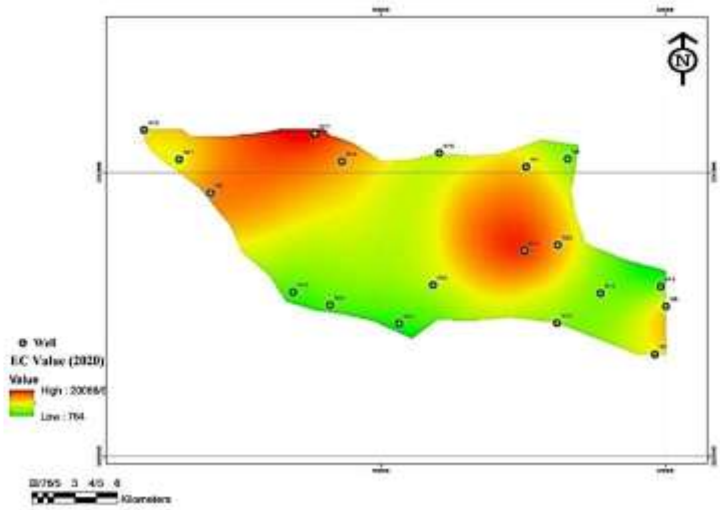

Fig. 7. Zoning map of electrical conductivity of water in 2020

In zoning maps of electrical conductivity of water, highest values of electrical conductivity of water can be seen in two areas, the first area on the eastern side of the plain and the second area on the western side. The increase in water salinity on the eastern side of the plain can be attributed to the density of exploitation wells for agricultural use and the increase in groundwater overharvesting and the location of this area downstream of the salt domes. The average decrease in groundwater level in wells in this area at the beginning and end of the research period is thirteen meters. Groundwater level has not significantly decreased in the marked area on the western side of the plain. The important influencing factors in increasing the salinity of water in this part of the study area included the replacement of groundwater harvested by agricultural wells in this area, the saline water intrusion from the lake to the aquifer and the existence of evaporative formations.

Piper diagrams provide a convenient method to classify water types collected from different groundwater predominant facies, based on the ionic composition of different water samples (Piper et al., 1944). These diagrams are drawn and analyzed by Aqqa software (http://rockware.com, 2016). Using triangular diagrams, the cationic and anionic composition of a large number of samples can be shown on a single diagram, By comparing the diagrams drawn at different time intervals can be examined the trend of variation of water samples in terms of anions and cations can be evaluated. Piper diagrams for water resources in different years of research are shown in Fig. 8.

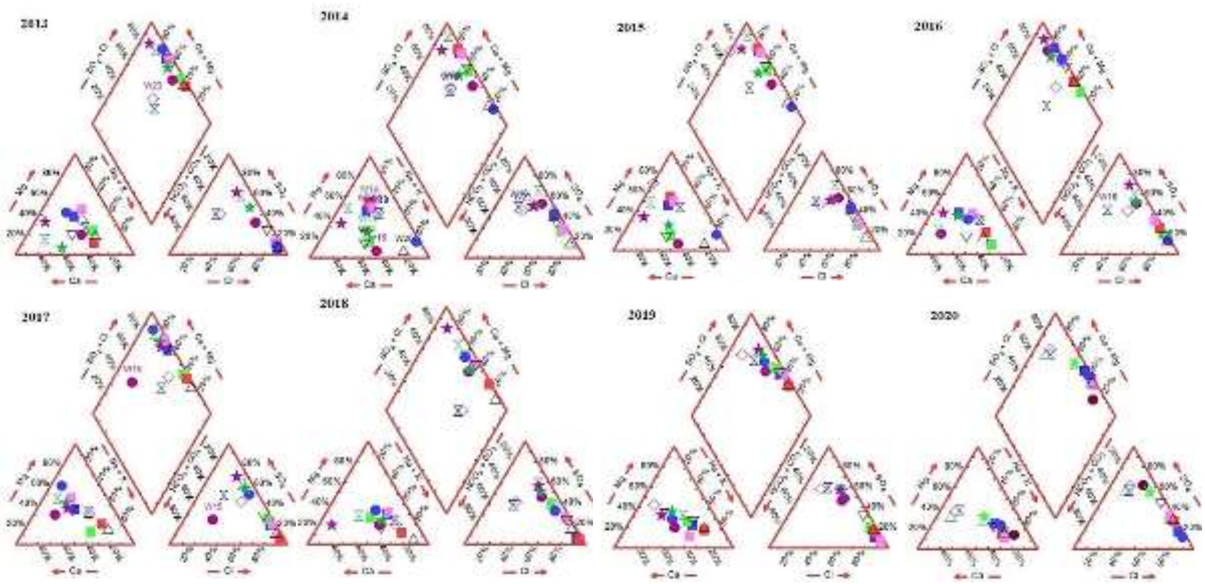

Fig. 8. Piper diagrams of the study area in different years

Considering the accumulation of samples in different parts of the diagrams, it is concluded that the diversity of water samples in 2013 in terms of distribution of cations and anions is more than that of samples in 2020. In 2020, with the increase of sodium, potassium and chloride ions affected by salinity sources (salt domes and salt water of the lake, etc.), the variety of samples in terms of distribution of cations and anions has decreased. In the analysis of diagrams for the origin of elements in groundwater, it is also worth mentioning that the location of majority of samples in the piper diagrams in comparison with the reference shapes are in the areas with shale, seawater and brine.

Gibbs diagrams, which are based on the ratio of $Na^+ + K^+/(Na^+ + Ca^{2+} + K^+)$ to TDS, are among the most widely used diagrams in the field of understanding the functional sources of dissolved chemical constituents, such as precipitation-dominance rock-dominance and evaporation-dominance (Gibbs 1970). Based on Gibbs diagrams, the factors controlling water chemistry are introduced precipitation, rock weathering, evaporation, and crystallization. Accordingly, natural water-soluble substances are either due to the reaction of rock and water, or due to the entry from the atmosphere, or due to the evaporation of water in arid and semi-arid regions (Xing et al., 2013).

In this research, Gibbs diagrams in a period of 8 years have been drawn, and illustrated in Fig. 9. These diagrams show the ratio of $Na^+ + K^+/(Na^+ + Ca^{2+} + K^+)$ versus TDS. According to these diagrams, evaporation, crystallization, and weathering of rocks control the composition of groundwater in the study area in the Sarvestan plain.

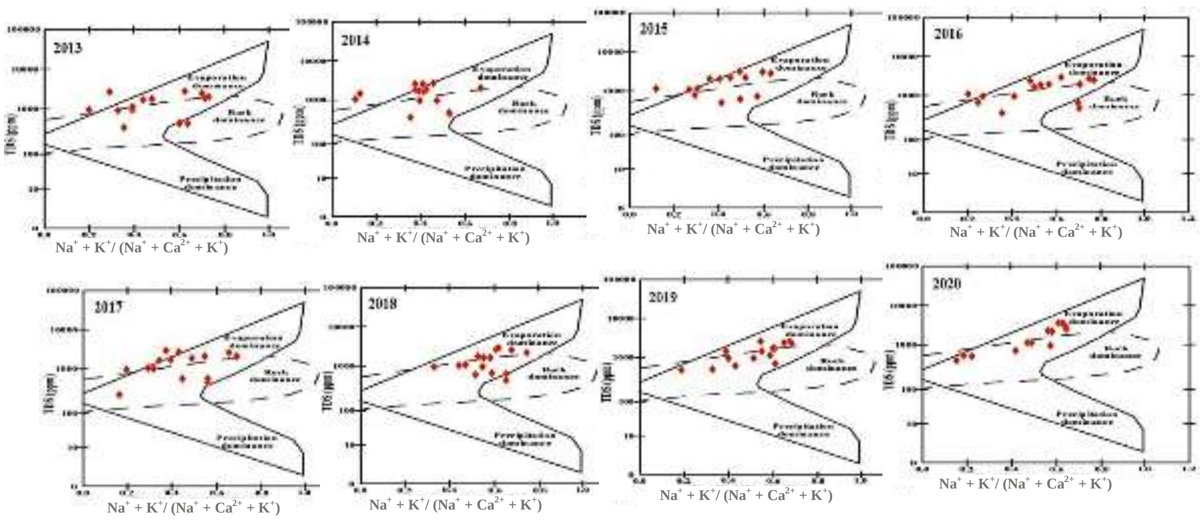

Fig. 9. Gibbs diagrams of the study area in different years

Comparison between graphs in different years of research shows that evaporative rocks control the composition of groundwater over time, and this indicates the effect of salt domes on the quality of groundwater in the Sarvestan plain. Since the weight values of Na^+ + K^+/ (Na^+ + Ca^{2+} + K^+) in a given TDS value vary in the range of low to high numbers, it can be concluded that cation exchange has taken place between sodium and calcium ions (Van et al.,2015).

CONCLUSIONS

Rainfall reduction and overharvesting of groundwater resources for agricultural use are important factors in the decline of groundwater level in Sarvestan plain in recent years, (total decrease in groundwater level up to 3.91 meters during the eight-year period of the study and average annual decline of around 49 cm).

According to the electrical conductivity zoning maps of the study area, the amount of electrical conductivity of water has increased in the entire area; the values of electrical conductivity of water has increased from around 13,000 µs/cm in 2013 to about 20,000 µs/cm in year 2020.

Chemical analysis of water samples shows that the groundwater type of most of the studied wells have changed at the beginning of the period (2013) from Ca-Cl and Mg-Cl to Na-Cl at the end of the period (2020). However, at the end of the period, only in a small area of the southern margin of the plain, the type of water is bicarbonate and sulfate, and in other parts of the study area, the predominant type of groundwater is chloride.

Determination of chemical trends using piper diagrams drawn over a period of time shows that the diversity of water samples in terms of anions and cations in water with increasing salinity at the end of the period is less than the variety of samples at the beginning of the period.

According to Gibbs diagrams, evaporation, crystallization and weathering of rocks are the factors that control groundwater composition in the study area. Over time, evaporative rocks in salt domes control groundwater composition at groundwater inlets on the northeast and southeast sides of the plain.

Overall, the results show that in addition to reducing rainfall and high evaporation due to the arid climate of the region, the presence of salt domes in the groundwater inlets to the plain, the salt water intrusion of Maharlu lake, high groundwater overharvesting and type of geology formations of the study area, as well as the release of sodium ions from the texture of clay layers at the outlet of the plain and dissolution in groundwater are the most important factors controlling the chemical quality of groundwater in the Sarvestan plain.

GRANT SUPPORT DETAILS

The present research did not receive any financial support.

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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