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Groundwater quality for agricultural use in Zacoalco de Torres and Autlan de Navarro, Mexico

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Abstract: In Mexico, one of the main sources for agricultural irrigation is groundwater, which irrigates approximately 2 million hectares, accounting for 75% of the country's rural and urban water volume. These water resources are affected by industrial waste and residual pollutants, as well as the leaching of chemical substances from agricultural soils. In order to evaluate the physical and chemical characteristics of groundwater, this study was conducted in Zacoalco de Torres and Autl á n de Navarro. Sampling was conducted during the dry and rainy seasons in 2017. The sampling locations were deep wells and water wheels. A total of 48 samples were obtained from two sites. In each sample, pH value, anion and cation, electrical conductivity (EC), residual sodium carbonate (CSR), sodium adsorption ratio (SAR) and hydrogeochemical classification were analyzed. The underground water of Zacoalco is mostly chlorinated-magnesic and in Autlán it is bicarbonate-magnesic with medium and low concentrations, so it is recommended for irrigation. With respect to salinity, Zacoalco has 40% high salinity water in dry conditions and 66% medium salinity water in rains; Autlan has 75% high salinity water in dry and 75% medium salinity water in rainfall, so its use shows moderate restrictions.

Key words: residual sodium carbonate; sodium adsorption ratio; hydrogeochemistry; anions; cations

1 Introduction

Mexico presents contrasts and shortages with respect to water, both in quality and quantity. Availability and quantity are important to satisfy social needs, since it is a necessary condition to make social, economic and environmental development viable (Mancilla-Villa[1], 2012) . The problem of degradation, due to anthropogenic effects, with regard to the quality and quantity of surface and groundwater resources, is of great concern. Until a few years ago, it was little investigated and was considered to be not very susceptible to pollution. Currently it is known that its contamination is caused by national and even global exploitation policies, filtration of water containing pollutants from industrial waste or washing of substances in agricultural soil (Cardona et al., 1992).

The National Water Commission considers that the insufficiency of groundwater in some areas is due to population growth and its indiscriminate application for different uses, which leads to a continuous supply of groundwater, causing overexploitation and a decrease in the natural quality of the water resource (CONAGUA, 2008). In Mexico in 2001 alone, the number of overexploited aquifers ranged between 100 and 106 wells annually. As of December 2013, 106 overexploited aquifers were reported. 55.2% of groundwater was extracted and the extraction exceeded 10% of its natural recharge (CONAGUA, 2014). Can-Chulim et al. (2014) mentioned that the development of agricultural activity depended on extraction, regardless of its adaptability of its use, and to its concentration of specific ions. Mancilla-Villa et al. (2014) mentioned that the development of agricultural activities depends on extraction, regardless of its adaptability to use or the concentration of specific ions. For groundwater quality, the content of salts and other specific ions is of great importance, since it allows its classification into fresh, slightly brackish, brackish and saline waters; in summary, the optimum state or quality of the water is related to the different concentrations in the chemical and mineralogical aspect.

In terms of irrigation water resources, poor quality is due to the addition of salt (salinization) to the soil, the infiltration of contaminated water into the soil, and the toxicity caused by heavy metals and ions. This can have physiological effects on plants, leading to low crop yields (Mancilla Villa, January 2012). Physical conditions and soil type, mineralogy, crops to be established and their nutritional requirements must be taken into account to understand the needs of different seedlings or restrict crop planting and production, so as to avoid soil pollution (García, 2012).

Water quality is defined by the specific use of water resources. In this sense, the importance of groundwater for agricultural irrigation lies in the concentration of CO_3^{2-}, HCO_3^-, Cl^-, SO_4^{2-}, Ca_2^+, Mg^{2+}, Na^+, K^+, and with less relevance in some studies adhere to the determination of N, P and B + (Massone and Martínez, 2008; Mancilla-Villa, 2012; Martinez and Osterrieth, 2013). Characterizing the ionic content of groundwater to be used for agricultural irrigation provides the necessary information to infer the possible problems, both in crops and agricultural soils, since some crops are more susceptible to physiological damage due to the content of ions and salts present in the water resource. In addition to damaging crops, it generates soil salinization, resulting in economic losses for producers (Doneen, 1975; Can-Chulim et al., 2014; Mancilla-Villa et al., 2014). In the state of Jalisco, there are 59 aquifers, of which 33 are with low availability and 26 are over exploited, with a deficit in the order of 343.69 cubic hectometers. Coupled with this problem of overexploitation and deficit, studies on the quality of groundwater for agricultural irrigation are very few (Ramos-Olmos et al., 2003 ; CONAGUA, 2015). In this sense, the main objective of this study was to evaluate the quality of groundwater used for agricultural irrigation in order to generate knowledge regarding the use of the analyzed water.

2 Materials and methods

2.1 Description of the study area

According to the State Water Commission of the State of Jalisco (CEA, 2015), the municipality of Zacoalco de Torres Jalisco is located in the southeast of the state, in the geographical coordinates 20° 01' 30" to 20° 21' 05" N and 103° 30' 30" to 103° 41' 25" W, with average altitude of 1,354 m. It has a warm semi-arid climate with average annual precipitation of 828 mm and an average annual temperature of 20.2 °C (Fig. 1). The municipality of Autlán de Navarro is located in the southwest of the state between the extreme coordinates 19° 34' 30" to 19° 53' 45" N, and 104° 07' 00" to 104° 27' 35" W. Its influence climate is semi-dry and semi-hot with average precipitation of 719.9 mm, average annual temperature of 23.5 °C, with average altitude of 900 m (H. Ayuntamiento de Autlán de Navarro, 2016[2]). The study area is made up of mainly feozems, regosols and cambisols soils, with smaller proportions of vertisols, luvisols and lithosols present. The origin of these soils is due to the presence of extrusive igneous rock, alluvial soils, rhyolite limestone rock, andesite and basalt among others (CONAGUA, 2018). In the study, 24 water wells are analyzed, of which 12 are located in the municipality of Zacoalco de Torres and the remaining are distributed over the municipality of Autlán de Navarro.

The selected wells in the municipality of Zacoalco de Torres are located in an area where alfalfa, sugarcane, avocado, blackberry, blueberry, fig and lemon are grown. In the municipality of Autlán de Navarro, the wells are mostly distributed over the valley where agricultural activities such as sugar cane, vegetables, radishes and corn, among others, are developed.

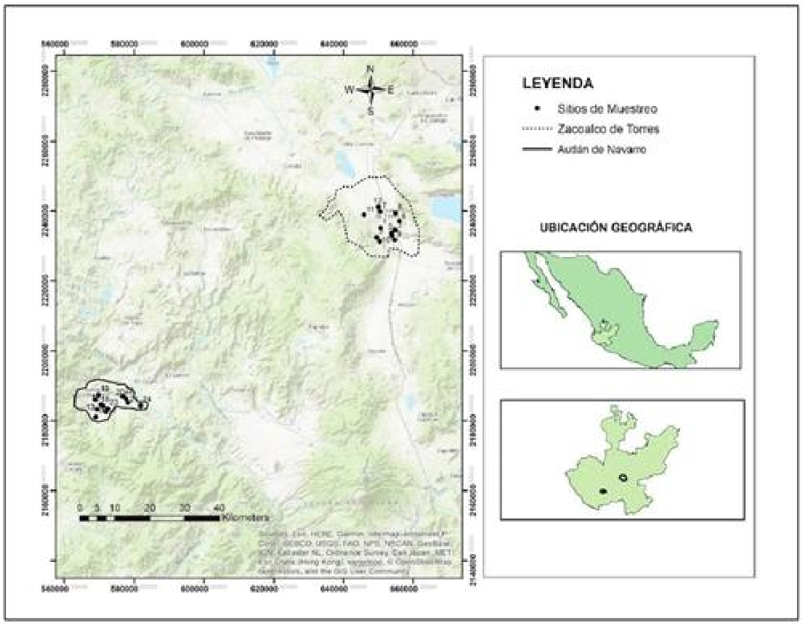

Fig. 1. Geographic location of sampling sites in Navarro Autonomous Region of Halysco Autonomous Region and Tacoalco de Torres Municipality City, Mexico

2.2 Water sampling and analysis methods

In this study, 24 collection sites were selected for each season, with 12 sites established in Zacoalco de Torres city and 12 sites established in Autlán de Navarro city in Jalisco. These sites were located and chosen for being groundwater wells and Ferris wheel. The information of these sites was obtained from the underground utilization layer registered in the public water rights registry in the KMZ format. Through the Water Geographic Information System (SIGA) obtained from Conagua (2015), all sites were geographically referenced through GPS (Fig. 1).

Groundwater sampling was conducted in accordance with the guidelines of the Mexican standard NMX-AA-034-SCFI-2015 (Mexican standard, 2015), with two random directional probability based sampling conducted during the dry and rainy seasons of 2017. Samples were collected using a high-density polyethylene bottle with a capacity of 500 milliliters, as shown in Table 1.

Table 1. Method for determining chemical and physicochemical parameters in well water samples collected in Oteland de Navarro and Zaco Alco de Torres Municipality, Halysco, Mexico

Determination	Method	Reference
pH	Potential measurement	Trujillo-Piña et al., 2014.
Conductivity	Conductivity measurement using a Wheatstone bridge conductivity meter with a glass battery	Rodríguez-Pozueta, 2016; Richards, 1990.
Calcium and magnesium	The volumetric titration method uses EDTA and EricromeBlack T as indicators, and Ca+Mg and Murexide as Ca.	González-Peréz, 2016; APHA, 1995.
Sodium and potassium	For flame measurement, use IL automatic flame photometer 643, L=589 nm, and calibrate with 145 mmolc L^{-1} (Na) and 5 mmolc L^{-1} (K) Standard solution.	BVSDE, 2016; APHA, 1995.

Carbonatos	The volumetric method using sulfuric acid and phenolphthalein titration as indicators.	Severiche Sierra et al., 2013; APHA,1995.
Bicarbonate	Volumetric method with sulfuric acid and Methyl orange titration as indicators.	APHA,1995.
Chloride	Silver and 5% Potassium chromate are used as indicators.	2016; APHA, 1995.
Sulfate	Perkin-Elmer 35 spectrophotometer, L=420 nm.	Ucroz-Peréz, 2014; APHA, 1995.

2.3 Quality parameters

Hydrogeochemical classification and cation-anion balance. Hydrogeochemical studies are used to determine the origin of the chemical composition of water and the relationship between water and the chemical constitution of rocks. The most commonly used graphical method is the triangular diagram of Piper and Durov (Can-Chulim et al., 2014). Chemical composition is understood as the set of substances (generally inorganic) incorporated into the water by natural processes, the chemical composition of natural groundwater is defined from the analysis of properly collected samples, and is quantified by means of the concentration of each constituent analyzed (Freeze and Cherry, 1979). The following are considered as majority or fundamental constituents: Anions: (HCO_3^- +CO_4^-), Cl^-, SO_4^{2-}, NO_3^- and Cations: Ca^{2+}, Mg^{2+}, Na^+, K^+, NH_4^+ (García-Hidalgo, 2015).

Electrical conductivity. The total concentration of soluble salts, for diagnostic and classification purposes, can be expressed in terms of electrical conductivity. And, according to Richards (1990), soluble salts are divided into four: low salinity water (C1: < 250 mS cm $^{-1}$), medium salinity water (C2: 250-750 mS cm $^{-1}$), high salinity water (C3: 750-2250 mS cm $^{-1}$) and very high salinity water (C4: > 2250 mS cm $^{-1}$) (Pérez-León, 2011; Can-Chulim et al., 2014). Salinity is assessed using electrical conductivity indices, and effective salinity and potential salinity indices are sometimes used (Pérez-León, 2011). Electrical conductivity is one of the most frequently used indices to analyze the risk of salinization, based on the characteristics of conducting current when dissolved ions are present (Mancilla-Villa, 2012). Regarding hydrogen potential (pH), according to Steiner (1968), water can be classified as strongly acidic < 5, moderately acidic 5.1-6.5, neutral 6.6-7.3, medium alkaline 7.4 to 8.5 and strongly alkaline > 8.5. To use the water resource in agricultural irrigation, values ranging from 5.5 to 6.5 are recommended since most of the ions will be available to the plant (Silva-García et al., 2006 ; Ortiz-Vega et al., 2019).

The sodium adsorption ratio (RAS). The sodium concentrations in the water resource are classified using the RAS with respect to the ionic concentrations (EC), using the diagram proposed by Richards (1990). This classification is based on the effects of the sodium ion absorbed by the soil on its physical conditions; this relationship infers the effect of the sodium in the irrigation water, which will become part of the soil. Based on the sodium content, irrigation water can be classified into four classes: low sodium water (S1), medium sodium water (S2), high sodium water (S3) and very high sodium water (S4) (Can-Chulim et al., 2008 ; Pérez-León, 2011). The RAS is calculated using the following equation, with its original values not considering variations in calcium and magnesium concentrations:

$$RAS = \frac{[Na^{+}]}{\sqrt{\frac{[Ca^{2+} + Mg^{2+}]}{2}}}$$

Where:

Na^+, Ca^{2+} and Mg^{2+} refer to the concentrations of the soluble cations expressed in mEq L $^{-1}$.

Residual sodium carbonate (RSC). Authors such as Richards (1990) recommend that, when assessing water quality, the concentration of bicarbonates should be considered in relation to the concentration of Ca and Mg. Since in water with high concentrations of bicarbonate ions, as the soil solution becomes more concentrated, calcium and magnesium tend to be precipitated as carbonate (Can Chulim et al, (Can-Chulim et al., 2014). Eaton (1950) uses the term residual sodium carbonate (RSC) when referring to such a reaction. This rate is calculated with the following formula, where all ionic constituents are expressed in mEq L^{-1}.

Residual sodium carbonate (RSC) = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}).

Water with a value less than 1.25 is classified as high-quality water for agricultural purposes, 1.25 to 2.5 is classified as conditional water, and 2.5 is classified as not recommended water (Richards, 1990). When the difference is negative, there is no problem, and the RSC value can be inferred to be equal to zero. When this value is positive, it indicates that calcium and magnesium will precipitate as carbonates, with only sodium salts present in the solution (Can-Chulim et al., 2014).

Statistical analysis. Using the SPSS V 25.0 program, perform a mean variance test (ANOVA) to compare the determination results of analysis parameters between two sampling seasons.

3 Results and discussion

Hydrogeochemical classification. The ion distribution allows us to observe more clearly the dominant position of ions in groundwater samples at each sampling point in Zacoalco de Torres and Aután de Navarro during the dry season (Fig. 2) and rainy season (Fig. 3) in 2017. In addition, due to a concentration difference of less than 2%, the electrolyte balance between anions and cations is correct. In the ion composition, with respect to the anions the chloride ion (Cl^-) predominated, while in the cations the magnesium ion (Mg^{2+}) predominated. It was observed that in the first samples of each municipality the concentrations of cations and anions are low, while in the following samples the concentrations are high and varied, without exceeding 30 $mmol_c$ L^{-1}. The ion that presents the highest concentration is magnesium, only significant differences are found between the sampling seasons for Cl^- ($F = 30.59$; $P = 0.01$) and SO_4^{2-} ($F = 16.73$; $P = 0.02$).

Fig 2. Cation and anion distribution of groundwater from Zacoalco de Torres and Autlan de Navarro in the dry season, Jalisco, Mexico

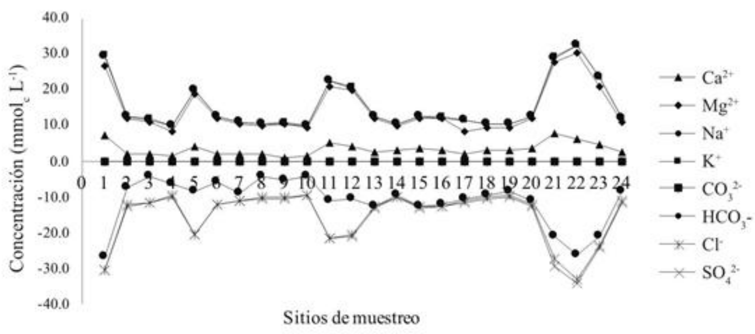

Fig. 3. Cation and anion distribution of groundwater from Zacoalco de Torres and Autlan de Navarro in the rainy season, Jalisco, Mexico

On the other hand, during the rainy season, for Zacoalco and Autlán, the highest concentration of cations is magnesium, followed by calcium, sodium, and potassium.

The classification of waters that develop different types of salinization are numbered as 1. chlorhydric 2. sulfate-chlorhydric 3. chlorhydric-sulfate 4. sulfate 5. sulfate-sodium. Therefore, salinity is related to the content and dominance of most ions in solution (Mancilla Villa, January 2012; Herrera Apablaza et al., 2018). In this case, the composition of groundwater from Zacoalco and Autlán is classified as magnesic-chlorhydric. (Mancilla-Villa et al., 2017) conducted a study in surface waters in the Ayuquila-Tuxcacuesco-Armería river, in which they found that the concentrations of cations and anions were relatively low since it did not exceed 30 mmol c L -1; however, the predominant cation was magnesium and anion sulfates, followed by bicarbonates and chlorides. In addition, they mentioned that most of the samples that presented high ionic concentrations corresponded to wells and ferris wheel. They attributed these concentrations to waters that were in contact with volcanic materials, since they had low ionic concentration and therefore low solubility. Magnesium is attributed to ferromagnesian minerals made up of basalts, including pyroxenes (Al, Mg, Fe, Mn, Cr, Sc, Ti) $(Si, Al)_2O_6$), which are removed by water, causing the presence of magnesium in solution.

Conductivity, dissolved total solids, and pH values. Table 2 shows the EC (µs cm^{-1}) and dissolved total solids (STD) classifications of groundwater in Zacoalco de Torres and Autlán de Navarro for two sampling periods.

Table 2. Classification of groundwater according to electrical conductivity (EC) and total dissolved solids (TDS) of Zacoalco and Autlan de Navarro, Jalisco, Mexico

Classification	EC at 25 °C	Salt concentrations	Location			
			Zacoalco		Autlán	
	µmhos cm^{-1}	g L^{-1}	Number of samples			
			S	LL	S	LL
C1: Low salinity water	0 - 250	< 0.2	3	0	0	0
C2: Medium salinity water	250 - 750	0.2-0.5	4	8	3	9
C3: High salinity water	750 - 2250	0.5 – 1.5	5	4	9	3
C4: Very high salinity water	> 2250	1.5 – 3.0	0	0	0	0

S=Dry season; LL=rainy season.

Table 2 shows that most of the groundwater in both Zacoalco and Autlán is classified as high salinity water, with a variation between 0.5-1.5 g L^{-1} of salts in the water and an E.C. of between 750 to 2250 µmhos cm -1, which means a high risk of soil salinization, as well as restricting the establishment of sensitive crops; therefore, it will be necessary to opt for crops tolerant to the salts that make up the groundwater. No significant differences in E.C. values were found between sampling seasons (F = 0.17; P = 0.60). Pérez-Díaz (2018[3]) mentions that salts in water are originated from weathering processes of minerals and rocks. They are found within the composition of the earth's crust, then become part of aqueous solutions, and are subsequently transported as irrigation water producing soil salinization. It also mentions that chlorides, nitrates, sulfates and carbonates of alkaline earth ions are the salts that are most easily formed as a result of weathering. Based on the above, the salinity of the groundwater in the municipalities is attributed to the predominant ionic composition, originated by weathering processes of the rocks as mineral deposits in abundance in the subsoil of the municipalities, as well as leaching by agricultural products in the aquifers. As for pH, an average value of 7.7 is found in the waters, which classifies them as slightly alkaline. And significant differences are found between the two sampling seasons (F = 27.2; P = 0.01).

Sodium adsorption ratio. As a result of the two samplings in 2017, in the dry season according to the SAR, 100% of the water classification corresponded to S1 (low sodium water). While, for the rainy season in Zacoalco and Autlan, one sample was classified as medium sodium water. It was explained that the relation of ionic compositions, presented important concentrations of magnesium and calcium in comparison to those of sodium. Therefore, groundwater from both municipalities can be used in almost all soils without the risk of an increase in sodium exchange levels. It is possible that the low concentrations of sodium in the groundwater of the municipalities are directly related to the composition of the subsoil, i.e., there are no abundant mineral deposits of this compound. Osicka and Giménez (2004), in contrast to the above, mentioned that groundwater and surface rivers in the lowlands had higher sodium levels, while in the highlands they showed relatively low contents and attributed this to the abundance of mineral deposits or areas with salt leakage pollution. In the two samples, the classification of groundwater according to the RAS corresponded to S1, while in the rainy season two samples were S2; that is, most of them corresponded to waters low in sodium. Fig. 4a and b show the classification of irrigation water according to sodium content and electrical conductivity in the two sampling periods. Both figures show that the risk of sodification decreases as the EC of the water increases.

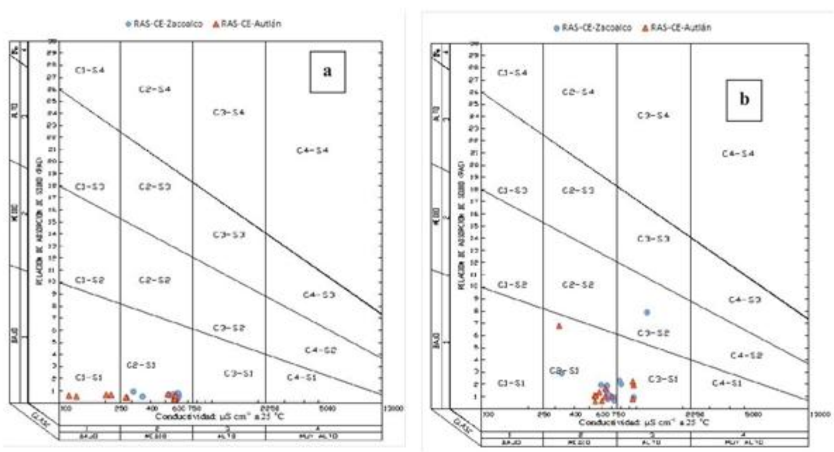

Fig. 4 (a) and (b). Irrigation groundwater classification map for two sampling periods in Zacoalco de Torres and Autl á n de Navarro, Jalisco, Mexico

In general, the groundwater of the municipalities presented low sodium levels in the two periods sampled, being considered suitable for irrigation with little probability of reaching high sodium levels in the soils. In terms of salinity, most of the waters were classified as C2, medium salinity, meaning that the groundwater in the municipalities could be used for irrigation when there was constant soil irrigation and there were crops that were moderately tolerant to salts. For those sites that were concentrated in the C1 classification, these were low salinity waters, so they could be used for most crops and soil types, with minimal risk of salinization. With respect to the samples that were classified in C3, these were highly saline waters not suitable for irrigation, so it was necessary to take into account plants that were tolerant to high salinity (Richards, 1990; Can-Chulim et al., 2011 ; Mancilla-Villa, 2012[1]), such as tomato, wheat, sorghum, alfalfa and barley (Can-Chulim et al., 2011). Can-Chulim et al. (2011) conducted a study on groundwater in the Eastern Basin of Mexico, finding in most of the samples the classification C2-S1 (waters of medium salinity, low in sodium), followed by C1-S1 (waters of low salinity, low in sodium) and C3-S1 (highly saline waters, medium in sodium) and mentioned that the use of waters of high salinity and medium sodium should be conditioned and should not be used in soils where drainage was poor, but could be used with plant species tolerant to salinity.

Residual sodium carbonate. Fig. 5a and b, shows the classification of Zacoalco and Autlan groundwater based on residual sodium carbonate (RSC) expressed in mmol $_c$ L $^{-1}$, for both sampling seasons.

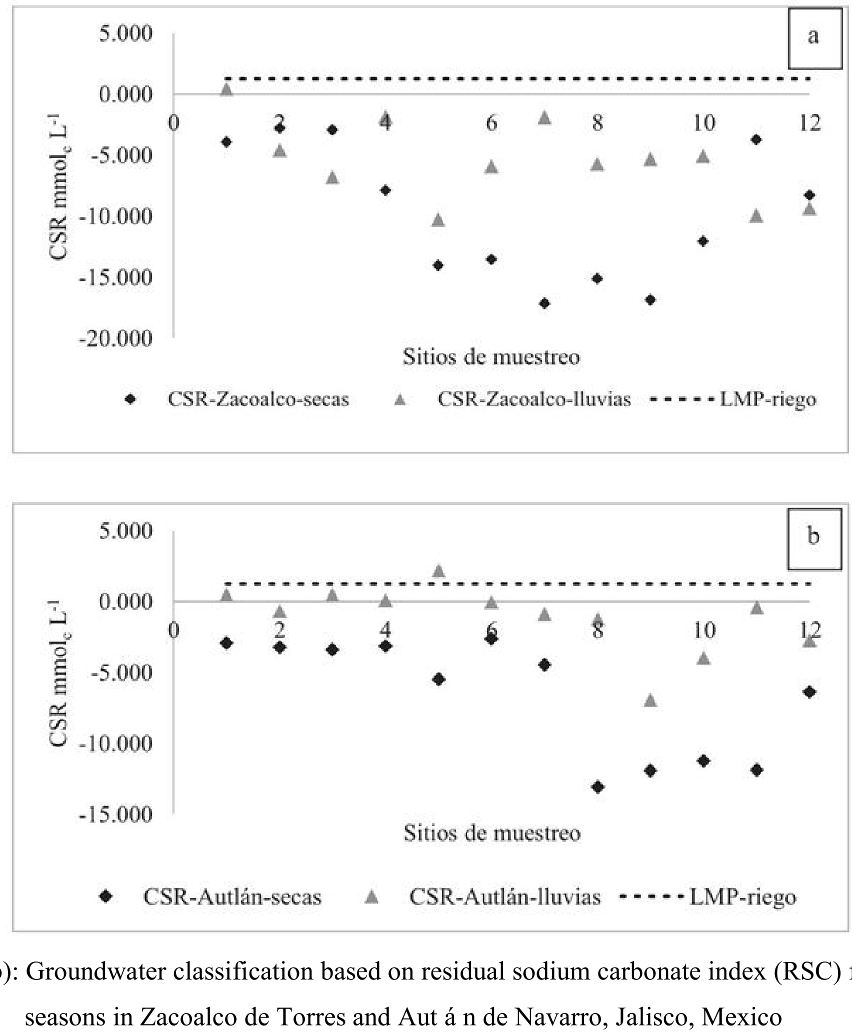

Fig. 5 (a) and (b): Groundwater classification based on residual sodium carbonate index (RSC) for two sampling seasons in Zacoalco de Torres and Aut á n de Navarro, Jalisco, Mexico

According to the residual sodium carbonate index, 100% of the samples analyzed in the established periods, present good classifications, for the groundwater of the municipality of Zacoalco de Torres and Autlán de Navarro, because they exhibited values less than 0, whoselimits did not exceed the evaluation sodicity standards mentioned by Can Chulim et al.

(2014). Therefore, it is concluded that the groundwater of the two study areas are good and suitable for agricultural irrigation, without causing sodicity hazards in the soil (Can-Chulim et al., 2011; López-García et al., 2016). Almeida and Gisbert (2006), conducted a study of irrigation water quality in a citrus orchard in Spain and found CSR values less than 0, and in which it mentioned being suitable for agricultural irrigation without causing sodicity problems in the soil. This result is consistent with the results obtained in groundwater samples from Zacoalco de Torres and Autlan de Navarro cities.

4 Conclusion

Zacoalco de Torres and Autlán de Navarro shows slight alkaline neutral water pH values in both sampling seasons, and variability in data dispersion.

The average conductivity during the dry and rainy seasons is 823 µs cm^{-1} and 680 µs cm^{-1}, respectively, indicating that the salinity of the sample is moderate. The standard deviations are 271.24 µs cm^{-1} and 191.29 µ s cm^{-1}, respectively, indicating a relatively low dispersion of the data relative to the mean.

In the ion composition of groundwater collected during the seasons of Zacoalco de Torres and Autlán de Navarro, they are classified as magnesium hydrochloric acid and bicarbonate magnesium.

In terms of EC and dissolved total solids, most of the groundwater in the two cities during the two sampling seasons is classified as high salinity water, with salinity ranging from 0.5 to 1.5g L^{-1}. Therefore, the risk of soil salinization is high, limiting the establishment of sensitive crops.

Sodium adsorption rate; In Zacoalco de Torres and Autlan de Navarro, 100% of the samples are considered low sodium during the dry season. During the rainy season, two locations are classified as water bodies with moderate sodium content, so there is no risk of an increase in sodium exchange levels in these water bodies.

For sodium adsorption rate (SAR) and EC, the majority samples from Zacoalco and Autlan during both sampling seasons are medium salinity and low sodium water (C2-S1), with a lower number of high salinity and low sodium water (C3 S1 and S2).

From the perspective of residual carbonate index, the groundwater in both study areas is good, suitable for agricultural irrigation, and will not cause sodicity hazards to the soil.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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