INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 12, No. 1, p. 52-62, 2018
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

The quality groundwater for irrigation in Fetzara basin, northeast Algeria

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Article published on January 20, 2018

Key words: Irrigation, Groundwater, Sodium percentage, Permeability index, Kelly's index

Abstract

The Fetzara basin occupying an area of about 515 km² is a part of the alluvial deposits of the Annaba plain. The main source of irrigation water in Fetzara basin is groundwater, hence its quality needs to be controlled; otherwise it can damage soil and reduce crop production. The aim of this study was to review hydro chemical processes that control the groundwater chemistry and to determine the suitability of groundwater for irrigation. Hydro chemical analysis has been carried out based on concentrations of Ca^{++}, Mg^{++}, Na^+, K^+, Cl^-, SO_4^{--}, CO_3^{--} and HCO_3^-. Different irrigation quality parameters viz, salinity, Sodium Adsorption Ratio (SAR), sodium percentage (Na%), Residual Sodium Carbonate (RSC), Magnesium Hazards (MH), Kelly's index (KI) and Permeability Index (PI) are calculated for the evaluation of groundwater quality for irrigation purposes. The evaluation of SAR (2.127-9.021) and EC (1240-6390 µS/cm) resulted in classification category 'C3S1 and C4S1', indicating high salinity and low sodium water which can be used for irrigation in most soils and crops with little to medium danger of development of exchangeable sodium and salinity. However, samples with doubtful Na% (56%), unsuitable KI and MH (88%, 64% respectively), and high salinity hazard (60%) values restrict the suitability of the groundwater for agricultural purposes, and plants with good salt tolerance should be selected for such ground waters.

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Introduction

Groundwater forms one of the primary resources for development activities. In recent times, there has been tremendous demand for fresh water due to population growth and intensive agricultural activities. Irrigation water quality has a significant role in crop production and has a profound impact on physical and chemical soil properties (Mohsen, 2009). Water quality, soil types, and cropping practices play an important role for a suitable irrigation practices. Excessive amounts of dissolved ions in irrigation water affect plants and agricultural soil physically and chemically, thus reducing productivity. The physical effect of these ions is to lower the osmotic pressure in the plant structural cells, thus preventing water from reaching the branches and leaves. The chemical effects disrupt plant metabolism. Water quality problems in irrigation include indices for salinity, chlorinity, sodocity (Mills, 2003). Assessment of groundwater quality requires determination of ion concentrations which decide the suitability for drinking, domestic, agricultural and industrial uses (Kshetrimayum and Bajpai, 2012). In the present study, the evaluation of the water quality of the Fetzara basin (NE Algeria) suitability for agricultural purposes has been attempted.

Materials and methods

Study area

The study area is located in the northeastern part of Algeria, bounded on the north by the Edough Massif, on the west by the valley of the wadi Kébir, on the south by the mountains of Ain Berda and on the east by the sandy cord of El-kantara. It covers approximately 26.000 h (Fig. 1).

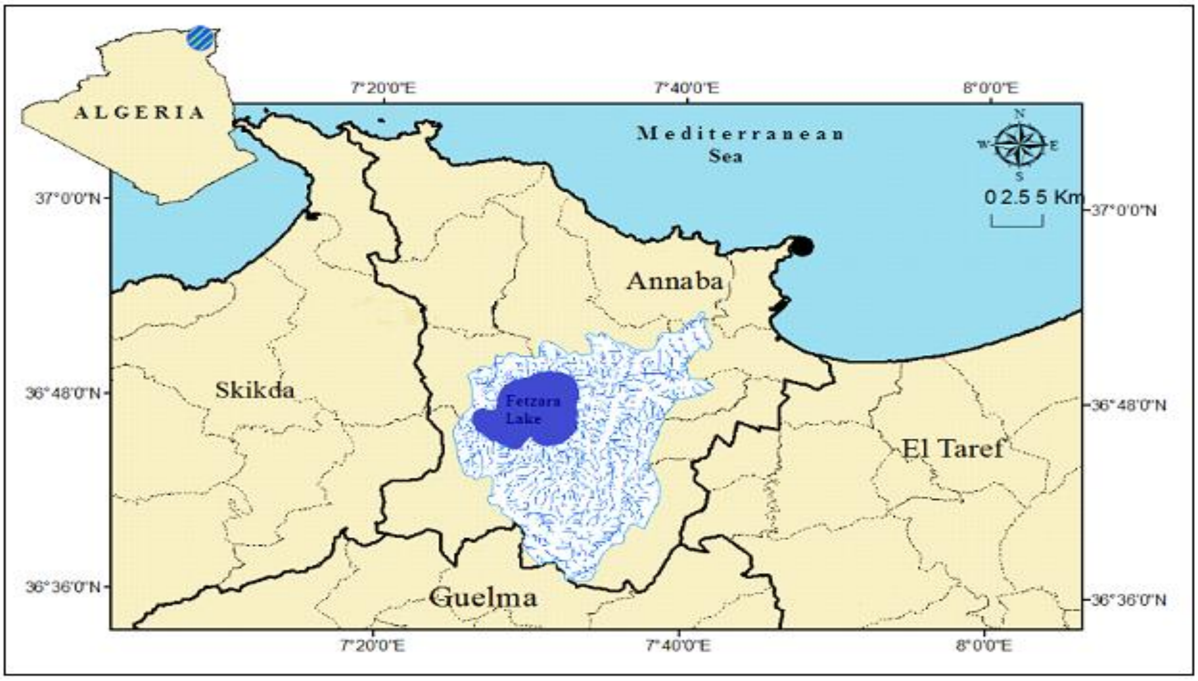

Fig. 1. Location of the study area in Algerian Northeast.

The climate is of the Mediterranean type: moderate and characterized by a one soft wet season and a hot and dry summer. The average temperature is 11°C in winter and 25°C in summer, though summer high temperature can reach 40°C. Annual precipitation in the area ranges from 600 to 700 mm, and the average humidity is 68% to 75%.

Annual total evaporation rises to 1.376 mm, and monthly evaporation is higher than monthly pluviometry during October and March.

Waters of the lake are collected from oueds three main things which are: Zied, El-Hout and Melah. The oued Zied (on 1008 m) is situated in the Northeast of the lake with a pond of 19 Km^2.

The oued El-Hout (795 m) is considered as being the biggest stream in the Southeast, its paying pond is of 81km². The oued Melah is situated on the West of the lake Fetzara and its paying pond is 47 km².

The main sources of the region constitute in gneisses, but they are little important. They are rare in the mica-schists and their level is in contact of underlying crystalline limestones.

In the regions of the Eocene, the wills constitute a permeable basis giving rise to groundwaters pouring at the level of clays.

The masses of fallen rocks of the wills and diverse alluviums also give levels of water.The geological formations of the studied zone contain:

Recent alluviums of the Quaternary constituted by silt, sand, gravel and travertine which occupy the alluvial plain.

Table 1. Irrigation quality parameters results in groundwater samples in the Fetzara basin.

Sample no.	RSC	Na%	SAR	KI	MH	PI	EC (µS/cm)
1	-0.44	73.914	8.093	2.779	48.113	85.040	2420
2	-4.08	69.729	8.900	2.270	63.542	76.974	3770
3	-1.04	75.032	9.021	2.961	58.621	83.857	2670
4	-0.36	71.911	7.297	2.529	45.192	84.941	2340
5	3.16	71.081	5.752	2.331	46.053	91.152	1380
6	1.00	49.001	3.255	0.858	35.556	65.941	2000
7	2.76	63.479	3.733	1.313	66.337	82.973	1500
8	2.96	68.722	4.740	1.710	62.500	85.834	1510
9	5.12	71.532	6.228	2.180	84.314	90.889	1930
10	2.68	59.615	5.711	1.453	44.041	74.537	2260
11	-0.52	60.061	5.728	1.497	53.552	72.895	3150
12	-5.4	53.513	5.930	1.145	59.701	61.907	6390
13	-1.68	62.767	6.570	1.676	68.750	73.285	3840
14	0.00	58.545	6.277	1.390	68.235	69.607	3690
15	-0.32	62.727	6.072	1.656	81.548	76.073	3060
16	1.8	57.381	4.836	1.331	70.303	75.011	2320
17	-10.00	50.580	4.746	1.012	44.727	54.812	3880
18	0.72	65.301	5.154	1.849	63.918	82.531	1610
19	0.40	34.577	2.127	0.490	74.894	52.830	1520
20	4.84	53.029	3.704	1.110	48.201	77.893	1610
21	1.52	68.855	4.964	2.068	36.111	91.140	1240
22	0.00	44.860	4.055	0.807	83.492	57.847	3070
23	-0.24	52.569	3.677	1.095	78.014	69.604	1450
24	2.96	52.057	4.424	1.018	86.864	68.628	2660
25	3.76	76.164	8.958	3.151	33.663	91.228	2700

Outcrops of flysch of wills of Numidie (quartzeux and reddish), alternating with beds of clay training the reliefs of the massifs of the northwest and the South of the zone, dated of the upper Eocene associated to outcrops of marl with pyritic ammonites of the lower Cretaceous as well as the limestone of Trias. Eruptive and metamorphic rocks (crystalline and granitelike schists) of sorted out, training the massifs of the North of the zone.Some outcrops of limestone and marl limestone phosphated by the lower and average Eocene.

Waters sampling and laboratory analysis

The water samples have been collected (May-2017) from 25 wells scattered all over the study area and sterilized plastic bottles were used to get fresh aquifer water for sampling. The collected samples were carefully sealed with proper labeling which preserved in a refrigerator at a temperature of about 4° C until analysis.

In situ field measurements were for parameters like temperature, pH, electrical conductivity (EC) immediately after sampling using portable conductivity and pH meter. The sum of cations (Na^+, K^+, Ca^{++}, Mg^{++}) and anions (Cl^-, HCO_3^-, CO_3^{--}, SO_4^{--}). Calcium and magnesium were determined by EDTA titration method. Sodium and potassium quantity were determined using a flame photometer, sulfate was determined by turbid metric method using visible spectrophotometer. Bicarbonate and carbonate were determined by titrating against standard H_2SO_4 solution using methyl orange concentrate. Chloride was analyzed by standard $AgNO_3^-$ titration using potassium chromate as the indicator.

Hydrochemistry of major ions

The composition of the dominant ions was displayed graphically using Piper and Durov diagrams using aqqa software version 1.5. On Piper diagram the relative concentrations of the major ions were plotted on cation and anion triangles, and then the locations were projected to a point on a quadrilateral representing both cation and anions to give a specific groundwater type. The Durov diagram is an alternative to the Piper diagram. The Durov diagram (Durov 1948) plots the major ions as percentages of mill equivalents in two base triangles. The main purpose of the Durov diagram (Durov 1948) is to show clustering of data points to indicate samples that have similar compositions. Chemical facies that determine the water type are calculated by first converting the concentration (meq/l) of the major cations (Na^+, K^+, Ca^{++}, Mg^{++}) and anions (CI^-, SO_4^{--}, HCO_3^-) to percentages (Guler *et al.* 2002).

Irrigation water quality

The quality of water used for irrigation is vital for crop yield, maintenance of soil productivity and protection of the environment. Based on the hydrochemicals analyses, irrigation quality parameters like sodium absorption ratio (SAR), sodium percentage (%Na), residual sodium carbonate (RSC), and permeability index (PI), magnesium hazards (MH) were calculated. US Salinity Hazard (Richards) and percent sodium vs. EC Diagrams were constructed using the aqqa 1.5 software to delineate irrigation quality parameters in the study area.

The SAR was computed using Eq. (1), where the ion concentrations were expressed in meq/l. The %Na+ was computed with respect to relative proportions of major cations present in water, where the concentrations of ions are expressed in meq/l, using Eq. (2):

$$\text{Sodium Adsorption Ratio, SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad (1)$$

$$Na^+\% = \left(\frac{Na^+ + K^+}{Ca^{++} + Mg^{++} + K^+ + Na^+}\right) \times 100 \quad (2)$$

The United States Salinity Laboratory Staff diagram, where SAR is plotted against EC (Richards, 1954) and the Wilcox's diagram, wherein the EC is plotted against $\%Na^+$ (Wilcox, 1955) were used for the classification of groundwater for irrigation purposes. Residual sodium carbonate (RSC) was calculated to assess the suitability of groundwater with respect to high bicarbonate and carbonate content using Eq. (3), where all constituents are in meq/l.

$$RSC = (CO_3^{--} + HCO_3^-) - (Ca^{++} + Mg^{++}) \quad (3)$$

Soil permeability is affected by long term use of water rich in Na^+, Ca^{++}, Mg^{++}, and HCO_3^-. The permeability index (PI) was calculated using equation 4 (where all concentrations are in meq/l) to assess influence of irrigation water on physical properties of soil.

$$PI = \frac{(Na^+\sqrt{HCO_3^-}) \times 100}{Ca^{++} + Mg^{++} + Na^+} \quad (4)$$

Based on Kelly's index (KI) waters are classified for irrigation. Sodium measured against calcium and magnesium was considered by Kelly (1940) and Paliwal (1967) to calculate this parameter.

A Kelly's index of more than one indicates an excess level of sodium in waters. Kelly's ratio was computed to assess suitability of water for irrigation purposes by using Eq. (5) (where all concentrations are in meq/l):

$$\text{Kelly's Index (KI)} = \frac{Na^+}{Ca^{++} + Mg^{++}} \quad (5)$$

Paliwal (1972) introduced an important ratio called index of magnesium hazard. Magnesium hazard value of more than 50% would adversely affect the crop yield as the soils become more alkaline.

Magnesium ratio was computed to assess suitability of water for irrigation purposes by using Eq. (6) (where all concentrations are in meq/l):

$$\text{Magnesium ratio} = \frac{Mg^{++}}{Mg^{++} + Ca^{++}} \times 100 \qquad (6)$$

Results and discussion

Classification of the groundwater

As water flows through an aquifer, it assumes a characteristic chemical composition as a result of interaction with the lithologic framework.

Table 2. Classification of groundwater quality based on suitability of water for irrigation purposes.

Parameter	Range	Classification	Range (no. of samples)	%
TDS (mg/l)	<1000	Fresh	808.44-866.20 (5)	20
	1000-3000	Slightly saline	1057.08-1855.40 (20)	80
	3000-10000	Moderately saline	-	-
	10000-35000	High saline	-	-
EC (µS/cm)(Handa1969)	0-250	Low (excellent quality	-	-
	250-750	Medium (Good quality)	-	-
	751-2250	High (permissible quality	1240-2000 (10)	40
	2251-6000	Very High	1240-3880 (14)	56
	6001-10000	Extensively High	6390 (1)	4
	10001-20000	Brines weakly con.	-	-
	20001-50000	Brines moderately con.	-	-
	50001-100000	Brines highly con.	-	-
	>100000	Brines extremely high con.	-	-
Salinity hazard (µS/cm)	100-250	Excellent (C1)	-	-
	250-750	Good (C2)	-	-
	750-2250	Doubtful (C3)	1240-2000 (10)	40
	>2250	Unsuitable (C4 and C5)	2260-6390 (15)	60
SAR (Richards 1954; Todd 1959)	<10	Excellent (S1)	2.127-9.021 (25)	100
	10-18	Good (S2)	-	-
	19-26	Doubtful/Fair poor (S3)	-	-
	>26	Unsuitable (S4 and S5)	-	-
Percent Sodium (Wilcox 1955)	<20	Excellent	-	-
	20-40	Good	34.577 (1)	4
	40-60	Permissible	44.860-59.615 (10)	40
	60-80	Doubtful	60.061-76.164 (14)	56
	>80	Unsuitable	-	-
RSC	<1.25	Safe	-10-0.72 (15)	60
	1.25-2.5	Marginally suitable	1.52-1.8 (2)	8
	>2.5	Not suitable	2.68-5.12 (8)	32
PI	<25	Bad water quality	-	-
	25-75	Good water quality	54.812-74.537 (11)	44
	>75	Very good water	75.011-91.228 (14)	56
MH	<50	Suitable	33.663-48.201 (9)	36
	>50	Unsuitable	53.552-86.864 (16)	64
KI	<1	Suitable	0.490-0.858 (3)	12
	>1	Unsuitable	1.012-3.151 (22)	88

The term hydro chemical facies is used to describe the bodies of groundwater in an aquifer that differ in their chemical composition.

The facies are a function of the lithology, solution kinetics, and flow patterns of the aquifer (Ravikumar and Somashekar, 2013). Piper and Durov diagrams were used to illustrate the relative concentrations of the different ions in the individual water samples extracted from the Fetzara basin.

The chemical compositions of the groundwater samples are shown in Figs 2 and 3.

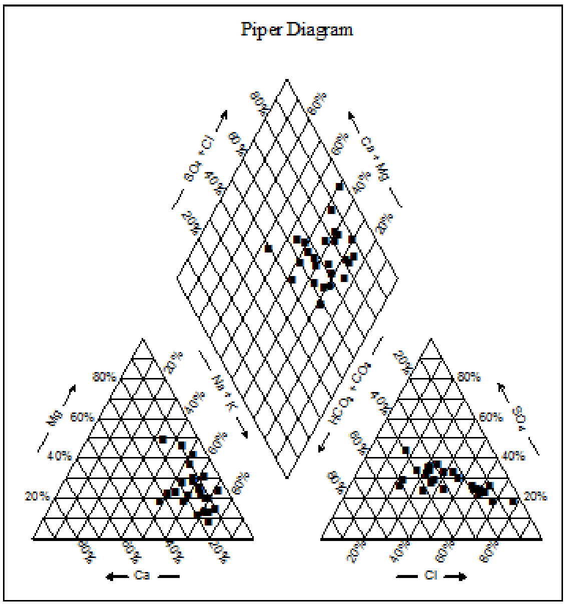

Fig. 2. Piper Trilinear diagram for classification of hydrochemical facies in the Fetzara basin, Northeastern Algeria.

The Piper and Durov diagrams show the geochemical evolution of the groundwater. The hyrdochemical types in the study area can be classified into three major groups.

The positions of the data points in the Piper and Durov diagrams represent the Na^{+}-Cl^{-}, Na^{+}-HCO_3^{-}, Na^{+}-SO_4^{--}. The TDS concentration in the majority of the groundwater samples is >1500 mg/l, indicating that the groundwater is slightly saline or moderately saline.

Irrigation water quality

Salinity hazard

Salinity affects availability of water crops. Excess salt increases the osmotic pressure of the soil water and keeps the plant roots from absorbing water, which results in a physiological drought condition (Bhandari and Josh, 2012).

Even though the soil appears to have plenty of moisture, the plants may wilt because the roots do not absorbed enough water to compensate for the purpose of diagnosis and classification, the total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. Based on the EC, irrigation water can be classified four categories (Richards, 1954).

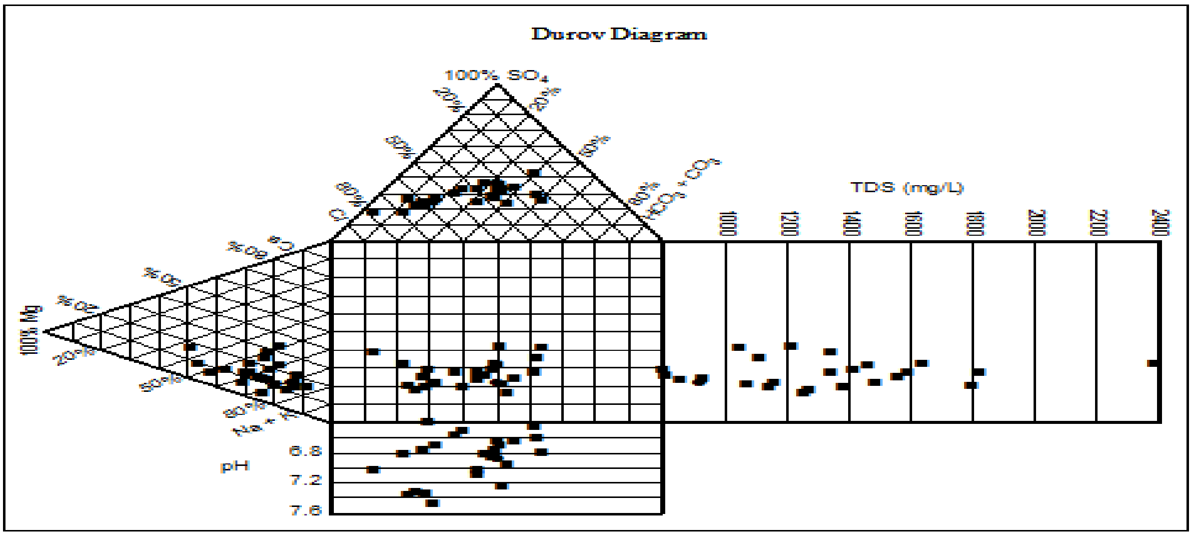

Fig. 3. Durov diagrams of groundwater samples the Fetzara basin, Northeastern Algeria.

Groundwater samples that fall in the low salinity hazard class (C1) can be used for irrigation of most crops and majority of soil. However, some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability. Groundwater samples that fall in medium salinity hazard class (C2) can be used if a moderate amount of leaching occurs.

High salinity water (C4 and C5) can be suitable for plants having good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage (Mohan *et al.* 2000). Very high salinity waters (C3, C4 and C5) cannot be used in soils with restricted drainage. Even with adequate drainage, special management for salinity control is required and crops with good salt tolerance should be selected. Based on EC values, 44% and 56% of groundwater from Fetzara basin could be classified as doubtful (C3, EC range = 100-250 µS/cm) and Unsuitable (C4, EC = 2251-6000 µS/cm) for irrigation, respectively.

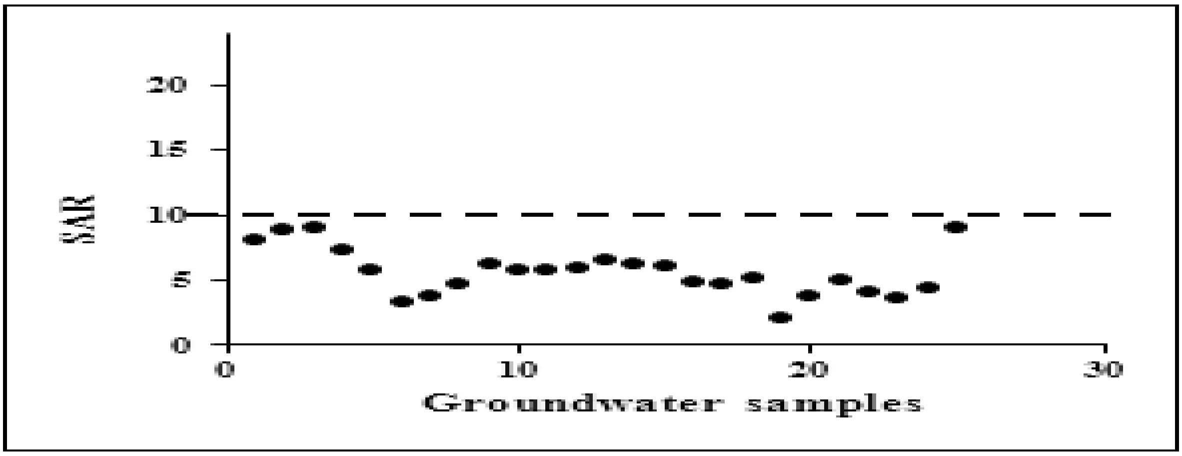

Fig. 4. Sodicity index for the groundwater samples of the study region

Sodium absorption ratio (SAR)

Excessive sodium and salinity concentrations in irrigation water result in sodium hazard, as well as salinity hazard. Sodium ion in water replacing calcium and magnesium ions in soil causes reduced permeability and soil hardens (Shaki and Adeloye, 2006). No Na^+ or alkali hazard is expressed in terms of sodium absorption ratio (Gholami and Srinkanas wamy, 2009).

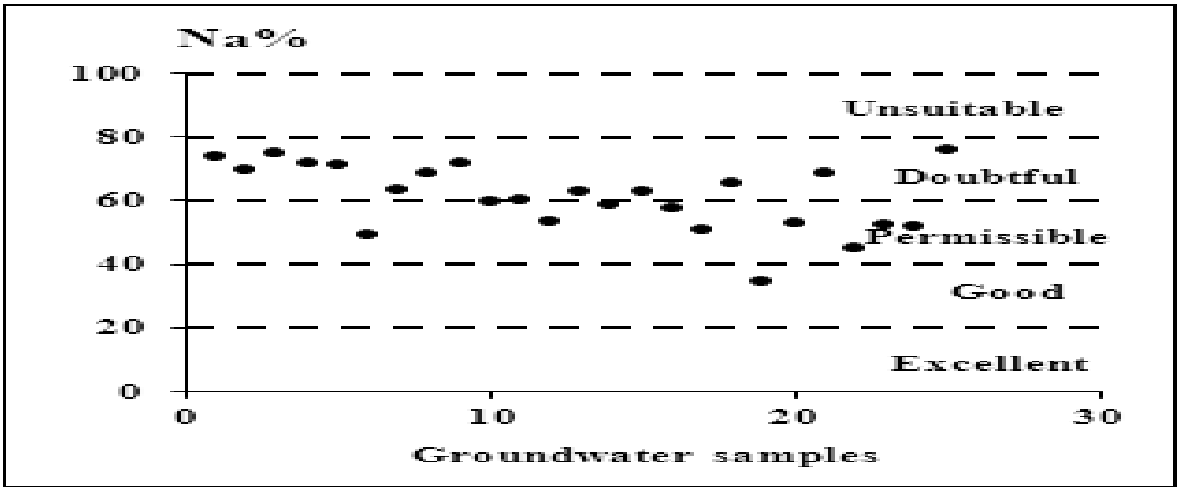

Fig. 5. Sodium percentage for the groundwater samples in the study region.

The main problem with high sodium concentration is its effect on soil permeability and water infiltration. Excessive Na^+ in water releases the undesirable effects of changing soil properties and reducing soil permeability (Kelley, 1946). The water gains a high SAR from continuous services, which leads to a breakdown in the physical structure of the soil. The sodium replaces calcium and magnesium, begins to sorbs on clay minerals and causes dispersion of soil particles (Bhandari and Hemant, 2012).

Sodicity hazard of irrigation waters is often determined by SAR which is considered as an important parameter. The SAR value of all the samples are found to be less than 10 and are classified as excellent for irrigation (Tables. 1 & 2). In order to identify the availability of waters for irrigation use, the Richards classification diagram (1954) has been used (Fig. 6).

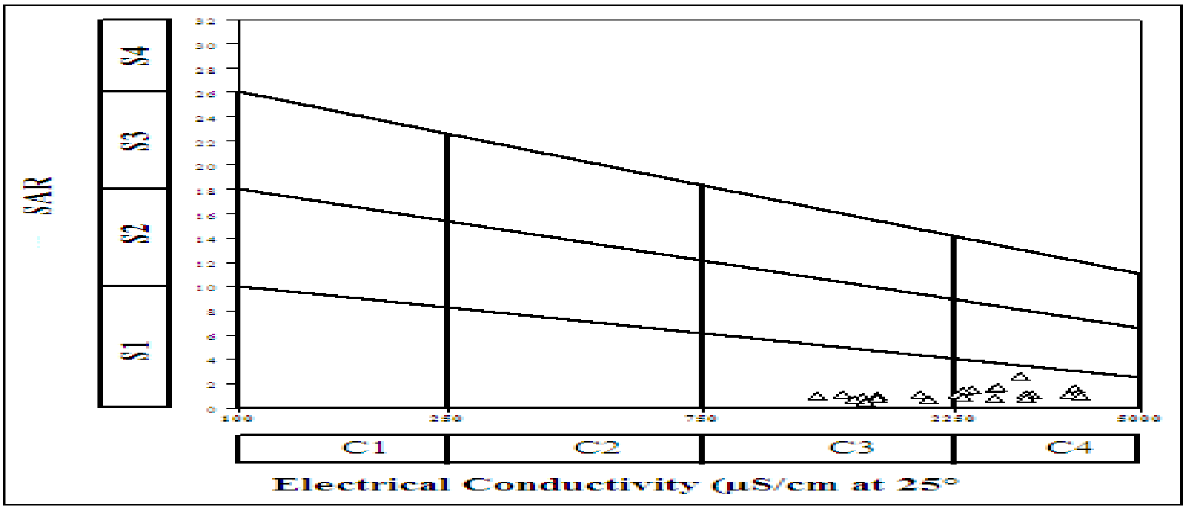

Fig. 6. US Salinity Hazard diagram (Richards, 1954).

This graph is based on the EC and SAR. According to this graph water classes in most of water samples are C3-S1 and C4-S1 are dominate water classes. Salinity in C3-S1 classes is high. Water cannot be used on soil with restricted drainage. Even with adequate drainage, special management for salinity control may be required, and plants with good salt tolerance should be selected. Sodium in this water class is low. Water can be used for irrigation on almost all soils with little danger of the development of Na^+.

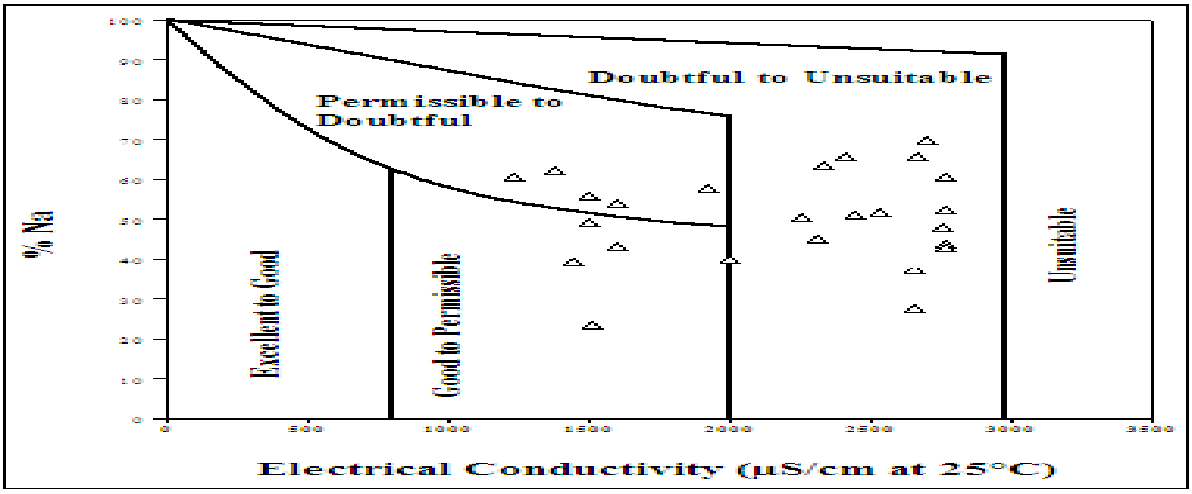

Fig. 7. Percent sodium vs. EC plot (after Wilcox, 1995).

In C4-S1 classes, salinity is very high. Water is not suitable for irrigation under ordinary conditions but may be used under very special circumstances. The soil must be permeable. Sodium in this water class is medium. Water may be present a moderate Na^+ problem in fine-textured (clay) soils. This water can be used on coarse-textured (sandy) soils.

Sodium percentage (Na %)

Another method for determination of suitability for agricultural use in groundwater is by calculating Na^+ percentage (Wilcox, 1955), because Na^+ concentration reacts with soil to reduce its permeability (Todd, 1980). According to the Wilcox (1955) classification, which is based on Na% values (Table 1), 0% of the samples belong to the excellent category, 4% belong to the good category (1 sample), 40% belong to the permissible category (10 samples), 56% belong to the doubtful category (14 samples) and 0 % belongs to the unsuitable category (Fig. 6).

Residual sodium carbonate (RSC)

When total carbonate levels exceed the total amount of calcium and magnesium, the water quality may be diminished. When the excess carbonate (residual) concentration becomes too high, the carbonate combines with calcium and magnesium to form a solid material (scale) which settles out of the water. The relative abundance of sodium with respect to alkaline earths and the quantity of bicarbonate sand carbonate in excess of alkaline earths also influence the suitability of water for irrigation. According to the US salinity laboratory (1954), an RSC value less than (1.25 meq/l) is safe for irrigation, a value between 1.25 and 2.5 meq/l is of marginal quality and a value more than (2.5 meq/l) is unsuitable for irrigation. From the values 32% of the samples are unsuitable for irrigation purposes. Further the value of RSC is negative, indicating that there is no complete precipitation of calcium and magnesium (Tiwari and Manzoor, 1988) (Tables 1 & 2).

Permeability index (PI)

The permeability of soil is influenced by sodium, calcium, magnesium and bicarbonate contents in soil which also influences the quality of irrigation water on long term use (Srinivasamoorthy *et al*, 2013). Doneen (1964) has evolved a criterion for assessing the suitability of water for irrigation based on PI. Permeability indices were plotted with the total ionic content of the groundwater samples on a Doneen's chart (Domenico and Schwartz 1990), which represent three different classes: CI with best water type for irrigation, CII water generally acceptable and CIII waters unacceptable. The groundwater samples of the studied area fall in the classes of II and III, which implies that the groundwater is of good to very good quality for irrigation purposes (Tables 1 & 2).

Kelly's index (KI)

Based on Kelly's index (KI) waters are classified for irrigation. Sodium measured against calcium and magnesium was considered by Kelly (1940) and Paliwal (1967) to calculate this parameter. A KI value (>1) indicates an excess level of sodium in waters (Arumugam and Elangovan, 2009). Therefore, waters with a KI (<1) are suitable for irrigation, while those with greater ratio are unsuitable (Kelly, 1940). Hence, 88% the groundwater of the study area are found to be suitable for irrigation purposes (Tables 1 & 2).

Magnesium hazard (MH)

Generally, calcium and magnesium maintain a state of equilibrium in most waters. Calcium and magnesium do not behave equally in the soil system, and magnesium deteriorates soil structure particularly when waters are sodium dominated and highly saline. A high level of Mg^{++} is usually due to the presence of exchangeable Na^{+} in irrigated soils. In equilibrium, more Mg^{++} present in water will adversely affect the soil quality, rendering it alkaline, resulting in decreased and adversely affected crop yields. In the Fetzara basin, the MH values were reported to be in the range of 33.663% to 86.864% (Tables 1& 2.). Of the 25 samples, 36% of the samples showed a magnesium ratio below 50%, suggesting their suitability, while only 64% fall in the category with MH more than 50%, indicating their adverse effect on crop yield.

Conclusions

An interpretation of hydro chemical analysis for groundwater quality and evolution of hydro chemical facies in the Fetzara basin reveals that concentrations of the major ions and important physical parameters are within the permissible limits for irrigation.

SAR values range from 2.127 to 9.021 and the waters fall in C3S1 to C4S1fields on C-S diagram indicating high salinity and low sodium water which can be used for irrigation in most soils and crops with little to medium danger of development of exchangeable sodium and salinity. Percent sodium values indicate the groundwater belongs to doubtful to permissible category for irrigation.

PI values show 44% of the samples fall under class II (good) and 56% fall under class III categories (very good). Kelly's index in the present study varied from 0.490 to 3.151 and majority of samples (88%) were considered unsuitable for irrigation. In most ground water samples, MH exceeds 60%, making waters unsuitable for irrigation purpose. 40% of the samples have negative RSC values and indicate that there is no complete precipitation of calcium and magnesium. The positive value of RSC in majority of samples signifying higher concentrations of HCO_3 over alkaline earths indicates that groundwater are base exchange-softened water as there is an exchange of alkaline earths for Na^+ ions.

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