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HYDROCHEMICAL FACIES DESCRIPTION TO ASSESS THE WATER QUALITY OF HABBANIYA LAKE, IRAQ

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ABSTRACT

The present study depicts the hydrochemical processes controlling the variance in the hydrochemical facies for sixteen samples obtained from Habbaniya Lake. The water samples were analyzed for the major ions (cations and anions) data in mg/l, total dissolved solids in mg/l, pH unitless, electrical conductivity in µS/cm, and temperature in °C. Piper trilinear (three-line) diagram indicate the overall of samples belongs to class 1 (Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}), category I (SO_4^{2-} - Cl^- and Ca^{2+} - Mg^{2+}) and permanent total hardness (calcium chloride type). The contribution of cations in the Habbaniya lake was almost the same percentage (no dominant cation), while the SO_4^{2-} is the dominant ion of the surface water in the Habbaniya lake. The analytical values showed that overall the samples were freshwater and low enrichment salts within the permissible limits of the World Health Organization standards. Irrigation parameters and water quality index were calculated for samples to assess water for agricultural and drinking uses for the inhabitants of the study area. The basic exchange is the exchange of Na^+ and K^+ ions in water with Mg^{2+} and Ca^{2+} ions in materials which is exposed to weathering.

Keywords: Hydrochemical facies; Piper diagram; Irrigation; Habbaniya Lake

INTRODUCTION

A long time ago, surface water has been used for industrial, agricultural, and domestic purposes all over the world. As a natural water resource, surface water is an essential supply for drinking water in surrounding urban and rural environments. Environmental problems arise as a result of wasting water and not treating wastewater, and this indicates a low environmental feeling for society, (Awadh, 2018). Recently, water consumption has increased rapidly with the increase in water demand for developing industry and building energy, abundant agriculture, keeping pace with urbanization, improving livelihood, and constructing a livable environment. Our daily life requires more attention in evaluating water and its suitability for different expediency purposes. Special investigations to understand the hydrochemical properties of surface waters and their evolution not only help protect the waters as a valuable resource and its use but also give an insight into changes in the water's environment (Lawrence et al. 2000 and Edmunds et al. 2006). The abundance of surface water is affected by climate change and thus affects the quality of water and the possibility of using it for various purposes, (Al-Kubaisi and Al-Kubaisi 2018). Increased drainage is more effective in winter and spring depending on precipitation values, (Jirjees et al., 2020). The decrease in water flow leads to an increase in water salinity, which affects crop production and future droughts (Awadh and Al-Kilabi, 2016). The Habbaniya lake is a natural resource of water that the inhabitants of the region depend on for different uses, and it is one of the largest bodies of water in Iraq. Geologically, the formations will affect the chemistry of the water, so it is necessary to know the formations surrounding by the Habbaniya lake. The area around the lake was characterized by the existence of different formations belonging to Miocene to Recent periods. Euphrates, Nfayil, Fatha, and Anjana formations are belonging to the Early, Middle, and Late Miocene respectively, as well as Quaternary sediments (Jassim and Goff, 2006). Different graphical and its representations can be plotting the concentrations of major cations and anions to understood variation in hydrochemical facies and chemical nature of the Habbaniya lake water. Hence, this study was done through an attempt to demonstrate variance in the hydrochemical facies by using Piper trilinear diagram. Further, the waters of Habbaniya lake are evaluated for various purposes.

STUDY AREA

Habbaniya lake is located about 11 kilometers southeast of Ramadi city. Its fed by surface water from the Euphrates and has two water outlets: the first is the Majara canal, through which the lake's water drains towards Razzazah lake. The second is the Theban canal, which returns water to the Euphrates. The lake is bounded by the following coordinates: latitudes 33˚10′37.7″–33˚22′20.8″ and longitudes 43˚19′40.6″– 43˚36′34.4″. The area of this lake is approximately 365 km^2 with elevation ranges from 43 to 45 m above sea level (Fig.1). The Habbaniya lake is part of the Western plateau or Western desert that is characterized by the predominant of an arid desert climate with a clear variation in climatic conditions during the months of the year. The total annual rainfall was 119 mm and the highest temperatures were in July 43.31 ºC, while the lowest temperatures were in January as they reached 14.20 ºC. Therefore, the nature of the prevailing climate was also reflected in the nature and quantity of rainfall, as well as the winds that have a great influence on tourism, agricultural activities and population stability.

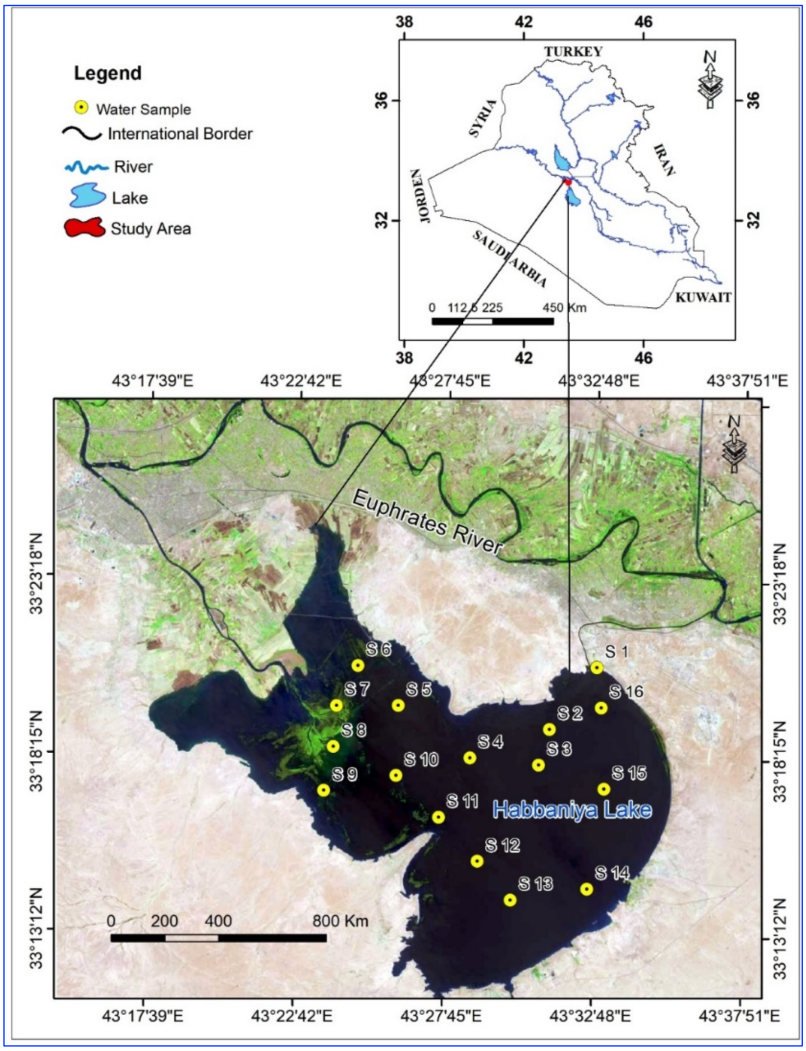

Fig. 1. Location of the Habbaniya lake and sampling location of 16 stations

MATERIALS AND METHODS

Sixteen water samples were collected from an area spread over the Habbaniya lake. Polyethylene bottles were used to collect these samples during October 2019 for hydrochemical analyses. Sampling was carried out at a depth of 30 cm and considering cleaning the bottles and obtaining a representative sample from the lake. To avoid changes in the chemistry of water samples before the analyzes, in-situ (in the field) measurements of total dissolved solids (TDS) in mg/l, pH unitless, electrical conductivity (EC) in µS/cm, and temperature in °C were calculated using manual devices (portable digital meters). Using standard methods and analytical methods that are recommended (APHA, 2005), the samples were preserved in the field and then transferred to the laboratory of the Anbar Water Directorate for analysis of the major ions. The charge balance error (CBE) was used to verify the accuracy of the results for the major ions data, which were calculated according to the following Eq. 1.

$$CBE\% = \left|\frac{\sum \text{cations (meq/l)} - \sum \text{anions (meq/l)}}{\sum \text{cations (meq/l)} + \sum \text{anions (meq/l)}}\right| x\ 100 \qquad (1)$$

CBE was calculated for all chemical ions data and all results were within permissible limits (less than 5%) (Hounslow, 1995). The RockWare-16 software was used to plot a piper diagram, while the RockWare Aq•QA program was used to calculate irrigation and drinking parameters. In addition to using the MS Excel spreadsheet and IBM SPSS statistics were applied to create the Box-plot analytical results (Table 1). Irrigation parameters (TDS, EC, Sodium Absorption Ratio (SAR), Sodium percentage (%Na), Residual Sodium Carbonate (RSC), Kelly Index (KI), and Permeability Index (PI)) were calculated for sixteen samples distributed in the Habbaniya lake to assess their potential for agricultural use, while the water quality index was applied to it to assess their potential for human use based on World Health Organization (WHO) standards (WHO, 2011).

RESULTS AND DISCUSSIONS

The Physico-chemical results for water samples of the Habbaniya lake are shown in Table 1 and also as box-plot in Fig. 2. In the Habbaniya lake, the average contribution of cations in the Habbaniya lake was Ca^{2+} (17%), Mg^{2+} (17%), and Na^{+} + K^{+} (18%), and anions contribution is Cl^{-} (20%), SO_4^{2-} (24%) and HCO_3^{-} (4%) (Fig. 3). These results indicated that cations have almost the same percentage (no dominant cation), while the SO_4^{2-} is the dominant ion of the surface water in the Habbaniya lake. None of the samples showed the cations (calcium, magnesium, sodium, and potassium) and anions (chloride, sulfate, and bicarbonate) concentrations exceed the permissible limits of 150, 100, 200, 10, 350, 400, and 200 mg/l, respectively (IQS, 2009 and WHO, 2011).

Table 1. Analytical results of surface water samples of the Habbaniya lake

Physico-chemical parameters	Units	Mean	Max.	Min.
pH	Unitless	8.18	8.50	7.64
T	(°C)	29.38	30.50	28.30
EC	(µS/cm)	853.19	1037.72	603.86
TDS	(mg/l)	650.50	811.73	455.22
TH	(mg/l)	341.58	403.31	276.64
Turb.	(NTU)	1.85	4.14	1.30
Salinity	(‰)	0.53	0.64	0.37
Ca^{2+}	(mg/l)	69.60	85.50	55.00
Mg^{2+}	(mg/l)	41.45	51.95	30.17
Na^{+}	(mg/l)	79.81	112.00	47.00
K^{+}	(mg/l)	6.60	8.60	3.80
Cl^{-}	(mg/l)	145.71	185.00	97.00
SO_4^{2-}	(mg/l)	237.99	304.92	158.00
HCO_3^{-}	(mg/l)	53.68	77.92	34.09
NO_3^{-}	(mg/l)	4.20	6.20	2.30

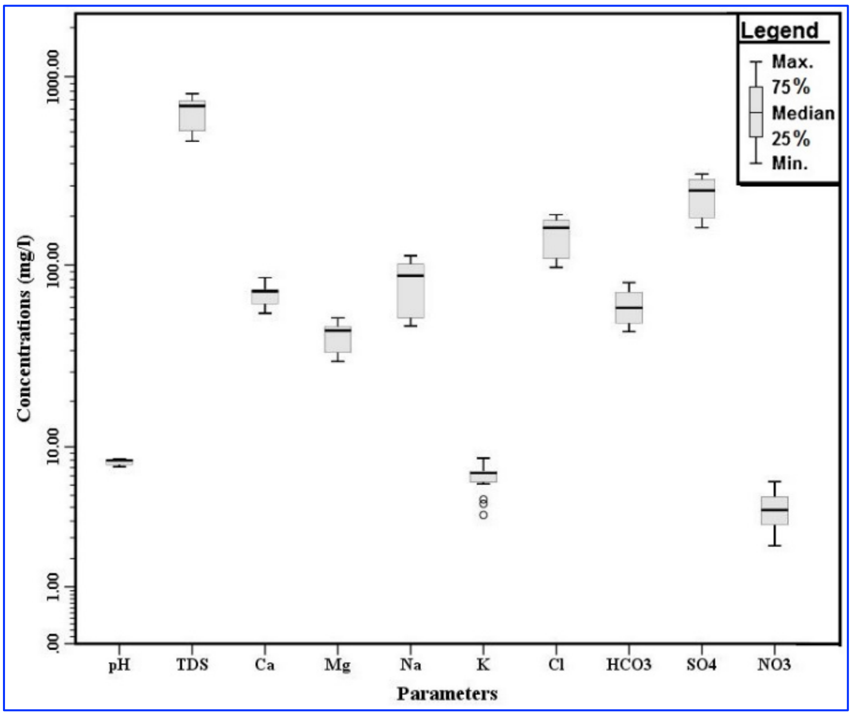

Fig. 2. Box-plot for the chemical compositions in the Habbaniya lake

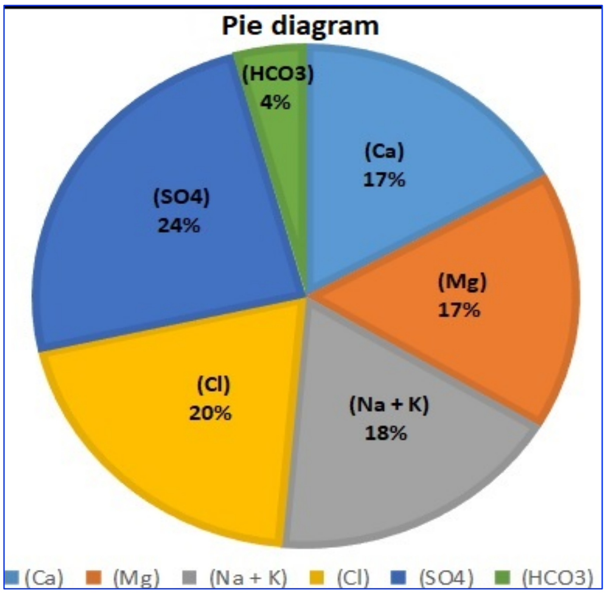

Fig. 3. The Pie diagram displays the average ionic constituents in Habbaniya lake

The minimum and maximum values of pH were 7.64 and 8.50 respectively, with an average of 8.18 indicating slightly alkaline water samples and these values do not exceed the permissible limits (6.5–8.5) (IQS, 2009 and WHO, 2011). High Electrical conductivity (EC) refers to the enrichment of salts to substances dissolved in water, which is a measure of the ability to conduct an electrical current. The average EC was 853.19 µS/cm, with a minimum and maximum of 603.86 µS/cm and 1037.72 µS/cm respectively. According to EC values, the water can be classified into three types: Type I, if the EC < 1500 µS/cm (the enrichments of substances dissolved in water are low); type II, if the EC between 1500 and 3000 μS/cm (the enrichments of substances dissolved in water are medium); and type III, if the EC >3000 μS/cm (the enrichments of substances dissolved in water are high); (Subba Rao et al. 2012). Accordingly, all the surface water samples are from the first class (type I) (the enrichment is low in salts) in the Habbaniya lake.

TDS ranged from 455.22 to 811.73 mg/l with an average of 650.50 mg/l (Fig. 4). According to TDS values, the water can be classified into four type: Type I, if the TDS <1000 mg/l (freshwater); type II, if the TDS between 1000 mg/l and 10,000 mg/l (brackish water); type III, if the TDS between 10,000 mg/l and 100,000 mg/l (saline water); and type IV, if the TDS >100,000 mg/l (brine water) (USSL, 1954), therefore, all samples are freshwater. The samples showed EC and TDS values do not exceed the permissible limits (1500 μS/cm and 1000 mg/l) of (IQS, 2009 and WHO, 2011).

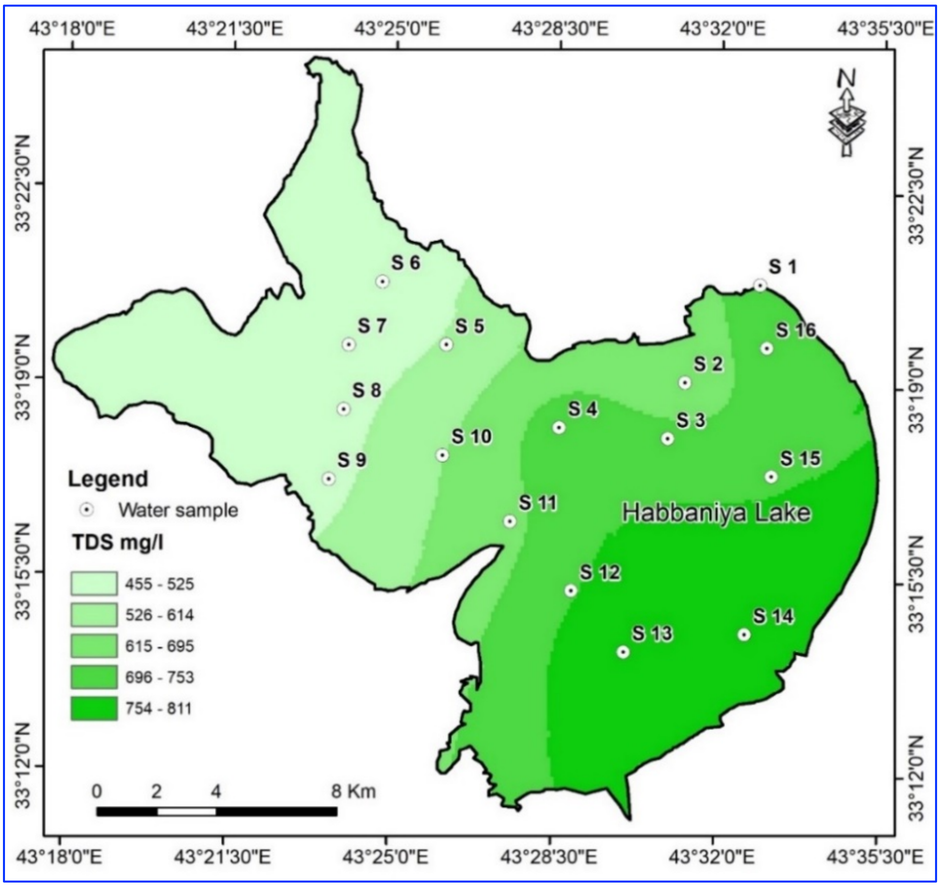

Fig. 4. Map of the TDS of the Habbaniya lake

The average salinity was 0.53‰, (varied from 0.37‰ to 0.64‰), while the mean temperature of surface water was 29.38°C (varied from 28.30°C to 30.50°C). The average TH was 341.58 mg/l, with a minimum and maximum value of 276.64 mg/l and 403.31 mg/l respectively, within the permissible limits of 500 mg/l (IQS, 2009 and WHO, 2011).

Hydrochemical Facies

To understand the hydrochemical evolution, distribution, and grouping of major ions in the waters of the Habbaniya lake, a graphical representation was used. In this study, variability in the hydrochemical facies was assessed by constructing a Piper diagram as a graphical trilinear representation. Illustrated by Piper diagram (Piper, 1944) it's 16 samples belong to class 1 (Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}) and category I (SO_4^{2-} - Cl^- and Ca^{2+} - Mg^{2+}), permanent hardness (calcium chloride type) for the waters of the Habbaniya lake (Fig. 5) and (Table 2).

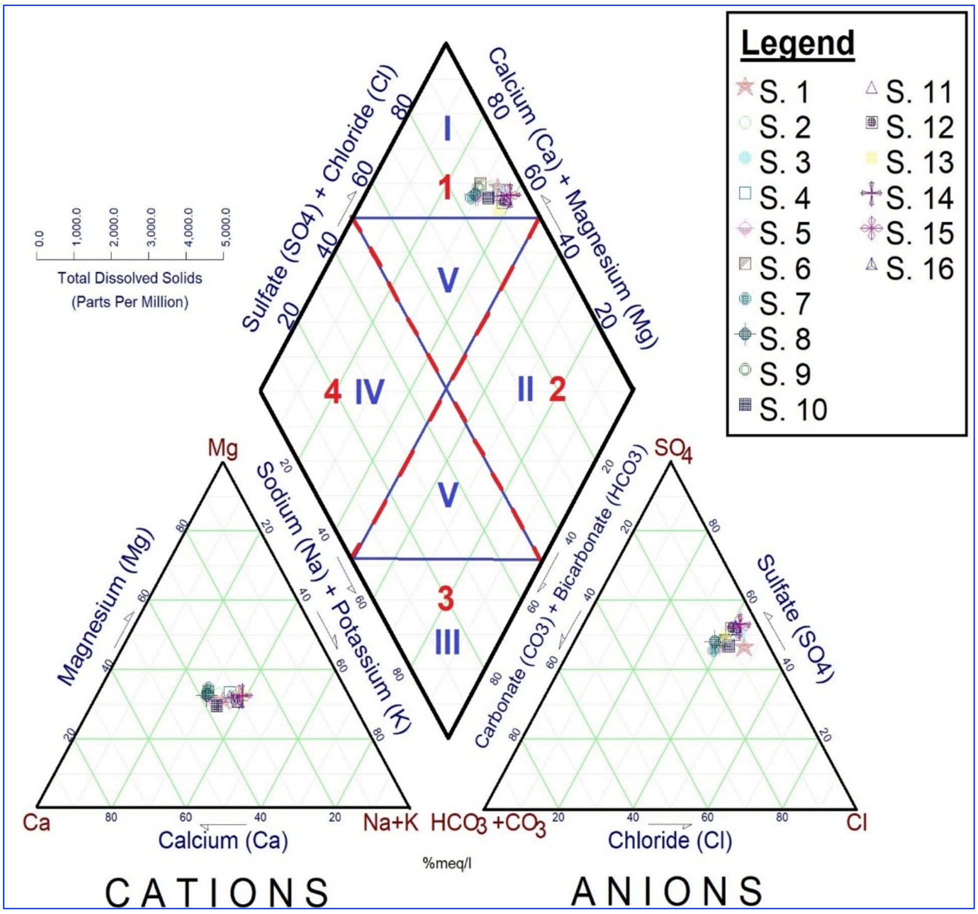

Fig. 5. Piper's diagram of the Habbaniya lake

Table 2. Classification of surface water samples according to Piper trilinear diagram

Hydrochemical facies	Class	Water type	Category
Ca^{2+} - Mg^{2+} - Cl^- - SO_4^{2-}	1	SO_4^{2-} - Cl^- and Ca^{2+} - Mg^{2+} (Permanent hardness); (non-carbonate hardness exceeds 50 %) calcium chloride type.	I
Na^+ - K^+ - Cl^- - SO_4^{2-}	2	SO_4^{2-} - Cl^- and Na^+ - K^+ (Saline); (non-carbonate alkali exceeds 50 %) sodium chloride type.	II
Na^+ - K^+ - HCO_3^-	3	HCO_3^- - CO_3^{2-} and Na^+ - K^+ (Alkali carbonate); (carbonate alkali exceeds 50 %) sodium bicarbonate type.	III
Ca^{2+} - Mg^{2+} - HCO_3^-	4	HCO_3^- - CO_3^{2-} and Ca^{2+} - Mg^{2+} (Temporary hardness); (carbonate hardness exceeds 50 %) magnesium bicarbonate type.	IV
		Mixing zone (no one anion – cation exceed 50 %)	V

Irrigational Water Quality Indices

The growth of crops and their productivity is affected by numerous water quality parameters, and the mineralization of water and its effect on soil and plants is an indicator of the suitability of surface water for irrigation. Numerous studies confirm the importance of irrigation water quality parameters such as EC, TDS, Ca^{2+}, Na^{+}, Mg^{2+}, SO_4^{2-}, Cl^{-}, HCO_3^{-}, Na%, SAR, PI and RSC (Raghunath, 1987; Ravikumar et al. 2011; Ravikumar and Somashekar, 2013). In this study, many parameters were used such as TDS, EC, Sodium Absorption Ratio (SAR), Sodium percentage (%Na), Residual Sodium Carbonate (RSC), Kelly Index (KI), and Permeability Index (PI).Sixteen samples of the Habbaniya lake are suitable for irrigation in general based on TDS (ranged from 455.22 to 811.73 mg/l), EC (ranged from 603.86 µS/cm to 1037.72 µS/cm), SAR (ranged from 1.23 to 2.43), percent sodium (ranged from 28.62 to 38.73), RSC (ranged from -7.46 to -4.47), KI (ranged from 0.36 to 0.61), and PI (ranged from 38.49 to 47.19) (Fig. 6). Thus, the sixteen samples of the Habbaniya lake belong to a freshwater class of TDS (Freeze and Cherry, 1979), good to a permissible class of EC (Richards, 1954), no problem of SAR (Bouwer, 1978), good of Na% (Wilcox, 1955), safe for irrigation of RSC (Eaton, 1950), suitable for irrigation of KI (Kelly, 1951), suitable for irrigation of PI (Doneen, 1964) (Fig. 6).

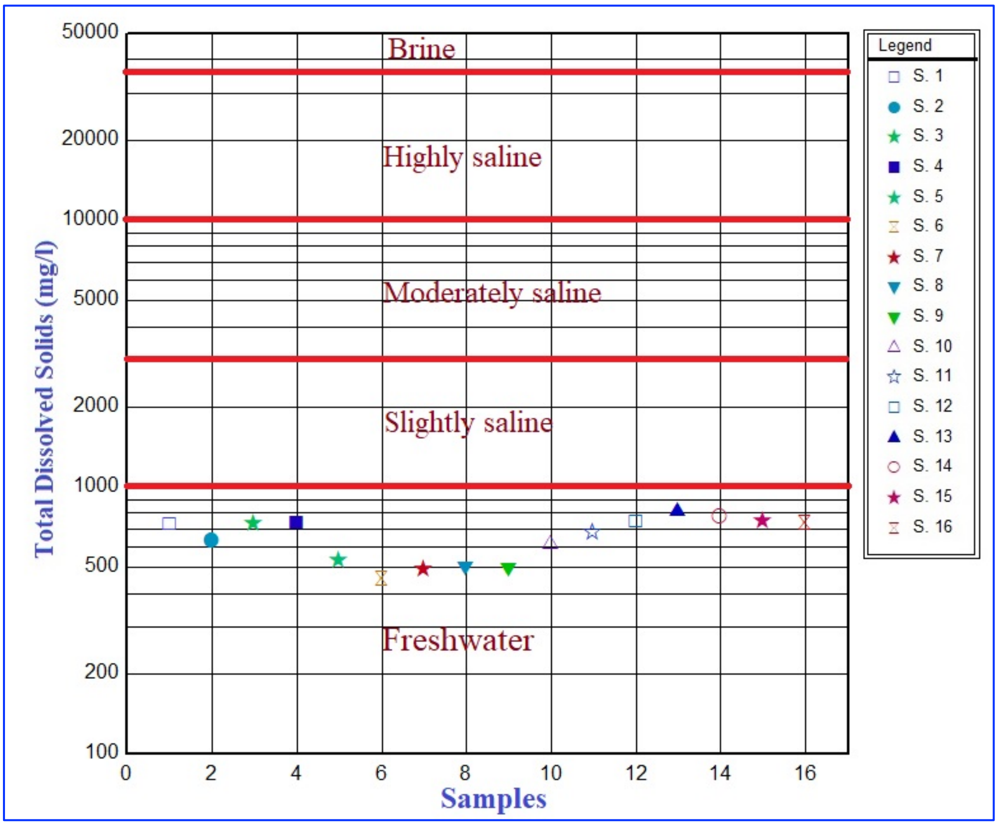

Fig. 6. a. Suitability irrigational water based on TDS (Freeze and Cherry, 1979)

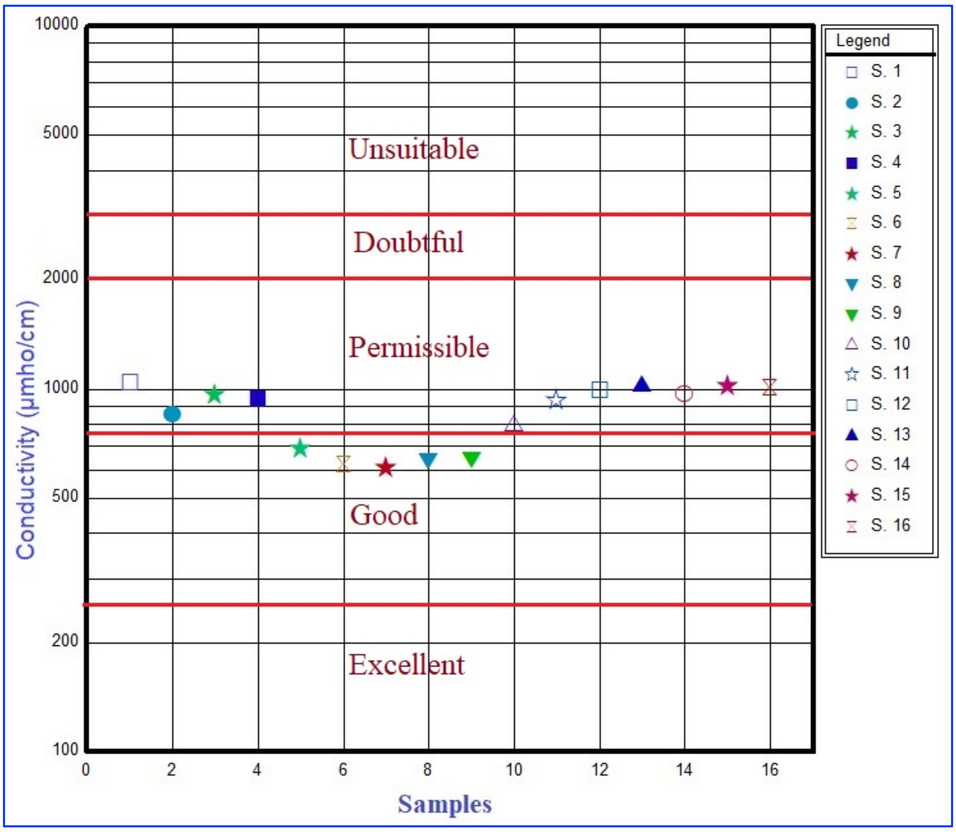

Fig. 6. b. Suitability irrigational water based on EC (Richards, 1954)

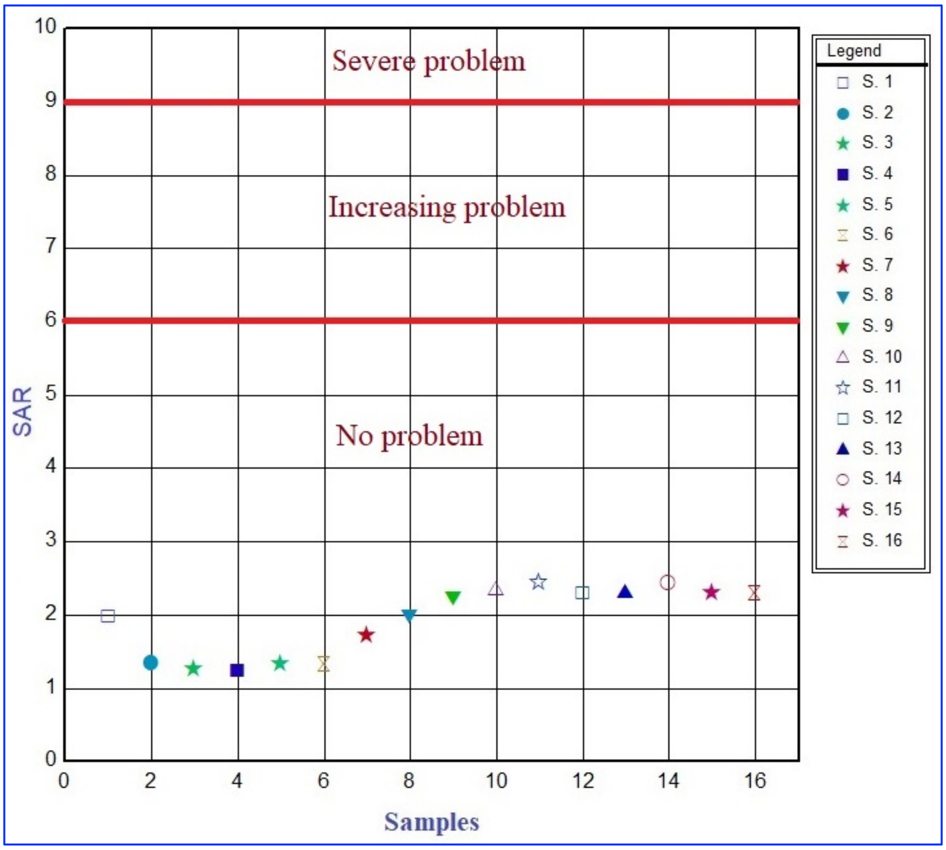

Fig. 6. c. Suitability irrigational water based on SAR (Bouwer, 1978)

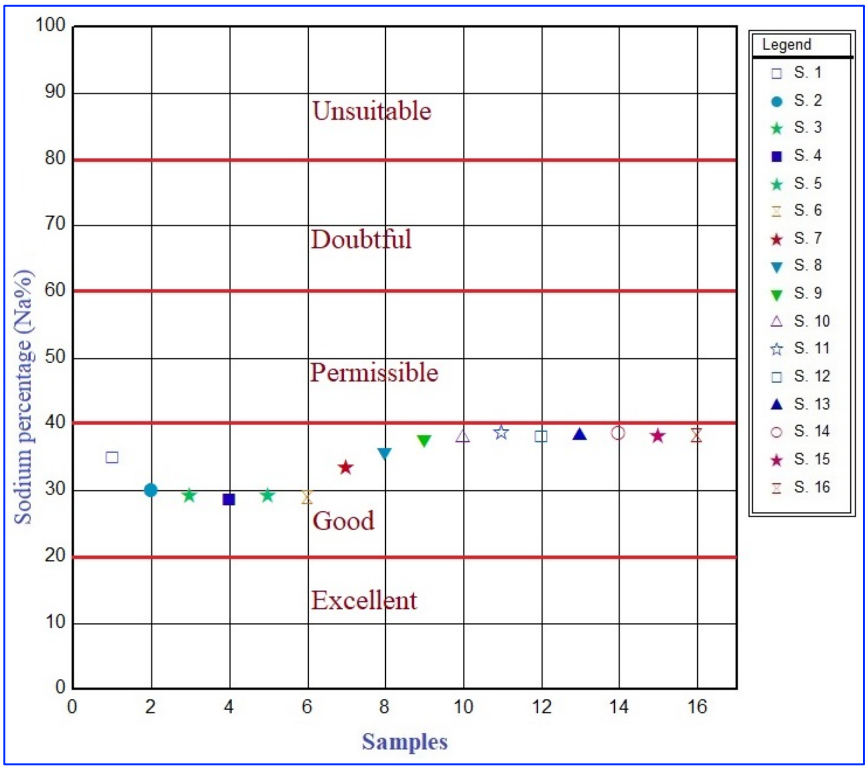

Fig. 6. d. Suitability irrigational water based on Na% (Wilcox, 1955)

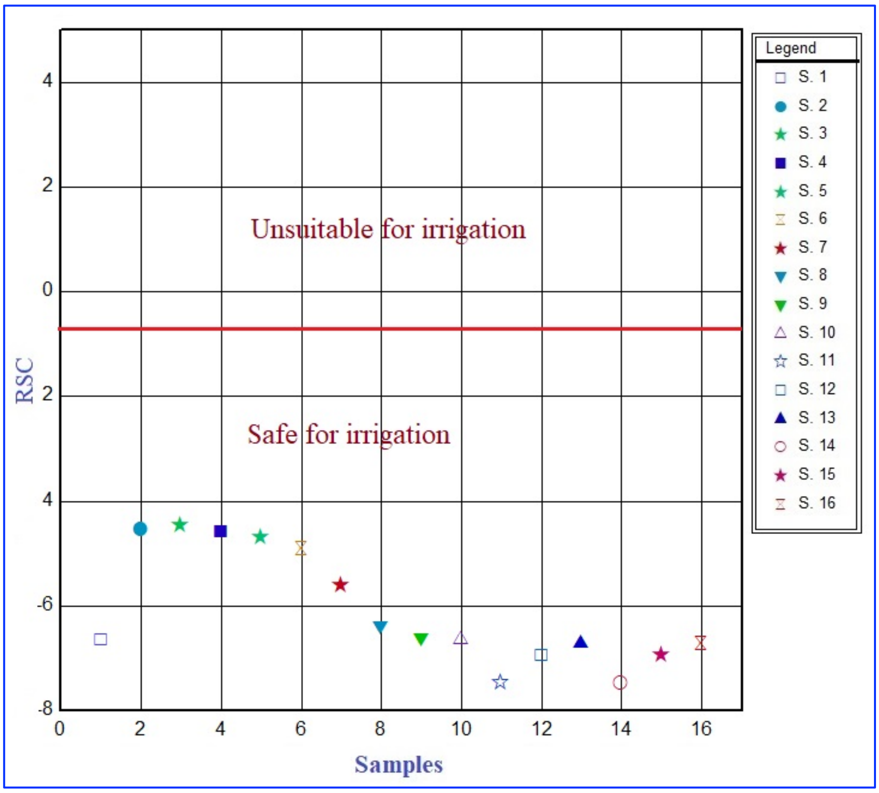

Fig. 6. e. Suitability irrigational water based on RSC (Eaton, 1950)

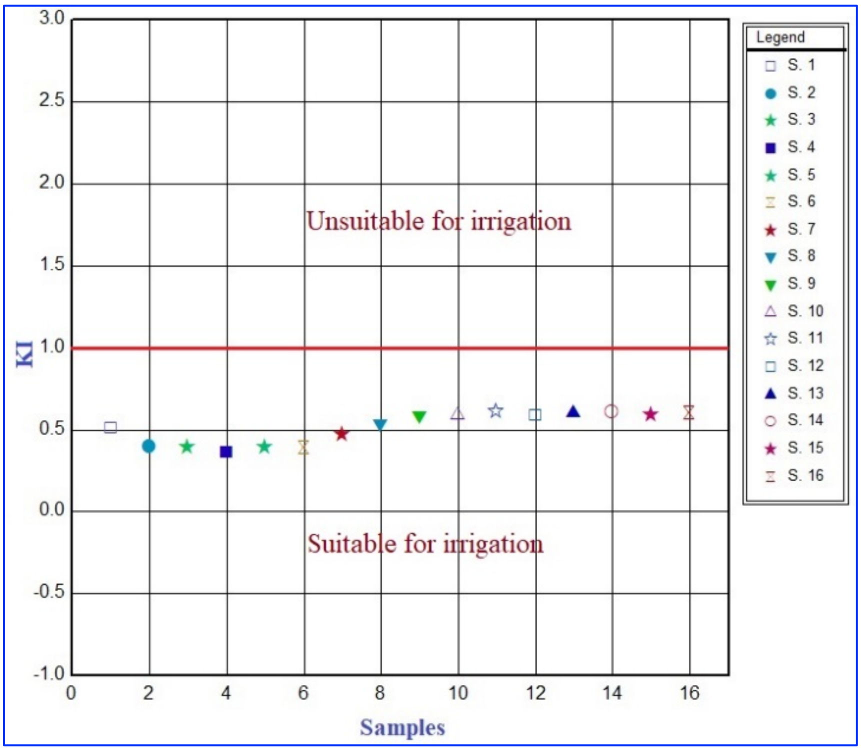

Fig. 6. f. Suitability irrigational water based on KI (Kelly, 1951)

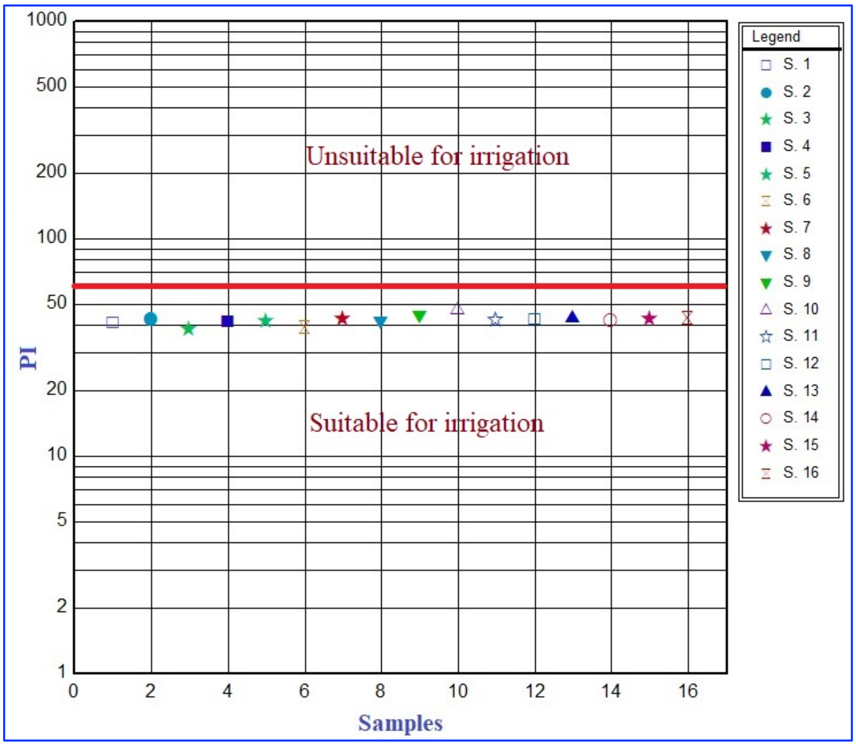

Fig. 6. g. Suitability irrigational water based on PI (Doneen, 1964)

Drinking-Water Quality Index (WQI)

The calculation of the Water Quality Index is to facilitate the judgment of water type by converting the vast amount of complex data into information that is easy and understandable. The Water Quality Index is a primary indicator of water type because it gives a general idea of potential water problems in any area. The suitability of the Habbaniya lake water for human consumption was evaluated using the WQI technique. The WQI ranges from 49.1 to 84.7, where the samples of the Habbaniya lake were good water for human drinking (87.5% of samples), while were excellent water for human drinking (12.5% of samples) (Fig. 7). This suitability for the quality of the water is mainly due to the appropriate concentrations of TDS, pH, major ions, which are responsible for improving the lake water. Fig. 8 shows the water quality indicator for the Habbaniya lake, as it appears to be in a short range of WQI.

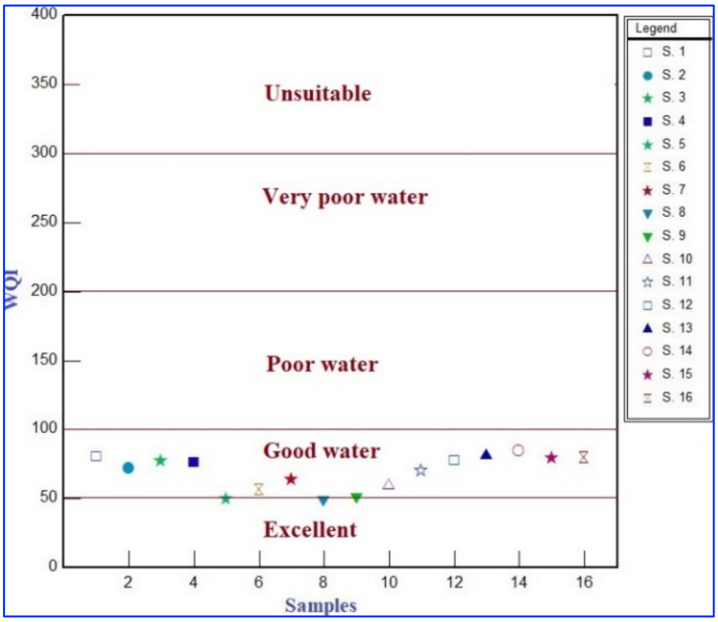

Fig. 7. Categorization of water quality according to Vasanthavigar et al., (2010)

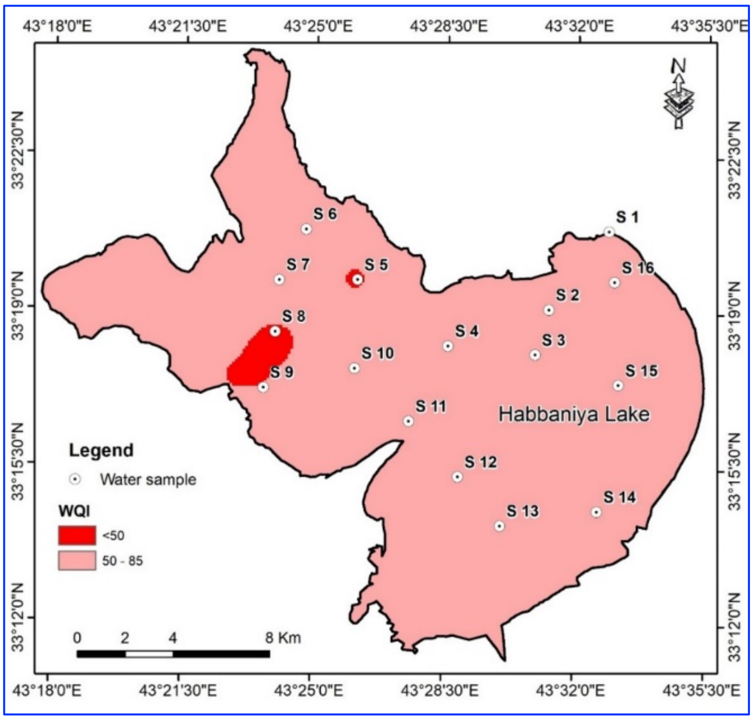

Fig. 8. Drinking water quality index (WQI) of the Habbaniya lake

Exchangeable During the Residence Time

The occurrence and distribution of ions in water depend on the geochemical reactions that control it. (Al-Kilabi, 2018). By studying the Chloro- Alkaline Index (CAI), the ion exchange between water and the host environment can be understood during residence or travel time. To explain the ion exchange between the water and the host's environment, (Schoeller, 1965) proposed the two chloro-alkaline indicators CAI 1 and CAI 2. The two chloro-alkaline indexes were confirmed by using the following equations 2 and 3.

$$\text{CAI } 1 = Cl^- - (\text{Na}^+ + K^+)\ /Cl^- \quad (2)$$

$$\text{CAI } 2 = Cl^- - (\text{Na}^+ + K^+)\ /(SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^-) \quad (3)$$

Generally, the Chloro- Alkaline Index values are negative or positive. When the values are positive, the basic exchange is the exchange of Na^+ and K^+ ions in water with Mg^{2+} or Ca^{2+} ions in materials exposed to weathering. And vice versa, when the values are negative, the basic exchange is the inverse exchange of ions. The CAI 1 values range from 1.95 meq/l to 4.41 meq/l with a mean of 3.24 meq/l while CAI 2 values range from 2.21 meq/l to 4.51 meq/l with a mean value of 3.50 meq/l. All the results of CAI are positive, thus indicating the exchange of Na^+ and K^+ ions from the water with Mg^{2+} and Ca^{2+} of the weathered material (host rocks). To understand the chemical composition of water in Habbaniya lake, the above indicator was applied, as the results indicated the basic exchange of ions between the lake water and its host materials.

CONCLUSIONS

From the study, it is concluded that water of the Habbaniya lake belongs to calcium chloride type (permanent hardness and non-carbonate hardness exceeds 50%). Its characterized by a slightly alkaline water samples, freshwater, and the low enrichment salts, within the permissible limits of the WHO standards. The average contribution of cations in the Habbaniya lake was Ca^{2+} (17%), Mg^{2+} (17%), and $Na^+ + K^+$ (18%), and anions contribution is Cl^- (20%), SO_4^{2-} (24%) and HCO_3^- (4%). Piper diagram illustrated 16 samples belong to class 1 (Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}) and category I (SO_4^{2-} - Cl^- and Ca^{2+} - Mg^{2+}), permanent hardness (calcium chloride type) for the waters of the Habbaniya lake. Overall the samples of the Habbaniya lake belong to a freshwater class of TDS, good to the permissible class of EC, no problem of SAR, good of Na%, safe for irrigation of RSC, suitable for irrigation of KI and PI. WQI of the Habbaniya lake was found to be good to excellent for human drinking. The Chloro- Alkaline Index (CAI) showed that the exchange of Na^+ and K^+ ions from the water with Mg^{2+} and Ca^{2+} of the host rocks.

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