ASSESSMENT OF IRRIGATION GROUNDWATER IN ALGHURAYFAH MUNICIPALITY, LIBYA

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Abstract

To understanding the hydrochemical characteristics and the suitability for irrigation purposes of the groundwater, fifteen samples from different sites in the municipality of Alghurayfah, Libya were collected and analyzed.

Irrigation water quality indices were used to evaluate water quality based on the total dissolved solids (TDS), electrical conductivity (EC), sodium absorption ratio (SAR), Kelly's index (KI), sodium percentage (Na%), residual sodium carbonate (RSC) and permeability index (PI). Furthermore, graphical representation diagrams were prepared such as USSL, Gibbs, Doneen and Wilcox.

The results indicated that the majority of the groundwater samples in the study area were suitable for irrigation. According to Gibbs classification, the majority of groundwater samples fall under rock weathering dominance. The USSLS chart indicates that the water is of low salinity and sodium, and it is of an excellent grade. Besides, Wilcox and Doneen diagrams show that the samples are safe for irrigation usage.

Keywords: Groundwater; Quality indices; Irrigation water; Diagrams; Ghurifa municipality.

Introduction

In the countries which surface water is rare, groundwater is their main source for agricultural and industrial activities. Therefore, in arid and semi-arid agricultural regions, the assessment of groundwater quality and its sustainable use is of paramount importance (Kumar et al., 2006; Delgado *et al*., 2010; Khudair *et al*, 2022; El Osta *et al*, 2022; Eid *et al*, 2023).

Generally, shallow aquifers are of calcium-bicarbonate type and calcium-magnesium-bicarbonate type while the deeper aquifers are mostly of calcium-magnesium-bicarbonate type, of calcium-magnesium-sodium-bicarbonate type and of sodium-calcium-bicarbonate type (Houéménou *et al.*, 2020; Gad *et al.*, 2020).

Geochemical studies of groundwater provide better understanding of the possible quality changes. The suitability of groundwater for domestic and irrigation purposes is determined by its geochemistry (Bezborodov *et al.*, 2010; Ghazaryan *et al*., 2016; Wang *et al*., 2022). Many studies have shown that the evaluation of groundwater quality is needed to protect and properly manage agricultural lands (Mitra *et al*., 2007; Zhang *et al*. 2011; Li *et al*, 2012; Nagaraju *et al*, 2017; Asante-Annor *et al*., 2018; Kumar *et al*. 2019).

The major water ions are used to classify groundwater based on the basic element compounds of cations and anions of dissolved salts in water. This study is to evaluate groundwater quality status by using water quality indices namely, salinity index; EC and TDS, SAR, KI, Na%, PS, PI, RSC, and USSLS, Wilcox, Doneen and Gibbs diagrams.

Materials and Methods

The study area is in the southwestern side of Libya in the municipality of Alghurayfah, which is located between the following latitudes and Longitude:

Table (1): Location of the Study Area.

Well	Latitudes	Longitude	Town
W1	26°31'37.25"N	12°58'26.80"E	Qwirat-القعيرات
W2	26°31'24.88"N	12°58'39.19"E	Qwirat-القعيرات
W3	26°31'5.28"N	13° 0'17.59"E	Alghurayfah- الغريفة
W4	26°31'20.08"N	13° 0'38.47"E	Alghurayfah- الغريفة
W5	26°31'34.80"N	13° 1'3.81"E	Alghurayfah- الغريفة
W6	26°31'33.94"N	13° 2'41.47"E	Germa - جرمة
W7	26°32'20.88"N	13° 3'50.84"E	Germa - جرمة
W8	26°31'30.73"N	13° 4'40.92"E	Germa - جرمة
W9	26°32'23.59"N	13° 5'60.00"E	Twash - توش
W10	26°33'9.61"N	13° 6'41.56"E	Burik - ابريك
W11	26°33'41.42"N	13° 7'32.57"E	Fakhfakha - الفخفاخة
W12	26°33'34.32"N	13° 9'8.26"E	Tweewa - تويوة
W13	26°33'15.93"N	13°10'18.58"E	Tweewa - تويوة
W14	26°33'25.67"N	13°11'13.29"E	Khariq- الخرائق
W15	26°33'2.55"N	13°12'49.09"E	Garagra - قراقرة

Fifteen ground water samples were collected from the study area. These samples were collected from bore wells in pre-cleaned polyethylene bottles. The samples have been collected after 5 minutes of run-off water drawn from the wells.

Water samples were analyzed to find out electrical conductivity (EC), total dissolved solids (TDS), cations such as calcium (Ca^{++}), magnesium (Mg^{++}), sodium (Na^{+}) and

potassium (K^+); and anions as Chloride (Cl^-), bicarbonate (HCO_3^-), Sulfate (SO_4^{--}) and nitrate (NO_3^-). The groundwater chemical composition was measured to determine the concentrations of sodium ions (Na^+), potassium ions (K^+), the water samples contents of these cations is measured using flame photometer. The total hardness calcium ions (Ca^{++}), and magnesium ions (Mg^{++}) was determined by EDTA titrimetric method. Chloride ions (Cl^-) were determined by silver nitrate titration. Carbonate ions (CO_3^{--}) and bicarbonate ions (HCO_3^-) were determined by sulfuric acid. Sulfate ions (SO_4^{--}) and nitrate ions (NO_3^-) contents were determined using Spectro-photometer.

Salinity refers to the amount of total dissolved solids (TDS) in water and it is frequently measured by electrical conductivity (EC). Waters with higher TDS concentrations will be relatively conductive. TDS is measured in parts per million or mg/L and EC is measured in micro-Siemens per centimeter (μS/cm). The general formula adopted to calculate the TDS (Kelly, 1946) is:

$$\boldsymbol{TDS\left(\frac{mg}{L}\right) = 0.64 \cdot EC} \ldots\ldots\ldots\ldots (1)$$

The statistical parameters and the major ion-concentrations are tabulated in Table (2).

Table (2): Groundwater Chemical Analyses.

Well	pH	TDS	$Ca2^+$	Na^+	Mg^{2+}	K^+	$HCO3^-$	$NO3^-$	Cl^-	SO_4^{-2}
1	8.75	164.37	5.50	31.66	7.80	7.18	2.40	0.02	50.05	5.33
2	8.60	156.76	4.80	30.00	7.68	7.18	2.40	0.02	55.06	5.83
3	7.20	73.49	27.20	1.67	31.20	7.81	0.80	2.42	50.05	15.16
4	7.10	80.77	9.60	1.67	2.88	6.53	1.08	0.13	60.06	9.33
5	6.60	73.75	16.80	30.00	18.24	7.18	0.80	2.22	65.07	10.16
6	6.60	66.97	8.00	5.00	13.92	7.18	0.84	0.42	60.06	5.25
7	6.80	86.86	16.80	11.67	9.60	7.18	1.12	0.13	65.07	8.83
8	6.60	93.51	14.40	10.00	0.96	7.18	7.36	0.25	60.06	11.16
9	6.90	83.82	6.40	16.67	4.80	5.88	7.08	0.76	65.06	5.66
10	6.70	81.60	8.80	8.33	10.08	7.84	0.80	0.68	50.05	7.16
11	6.70	108.80	12.00	13.33	12.00	8.49	0.60	0.25	70.07	7.00
12	6.80	65.66	11.20	8.33	3.84	6.53	0.84	0.28	55.06	6.83
13	6.80	63.74	5.60	6.67	16.32	7.18	0.64	0.26	50.05	8.33
14	6.90	64.88	5.60	8.33	8.64	7.18	0.88	0.13	55.06	6.66
15	6.70	63.25	4.00	5.00	13.44	7.84	0.80	0.53	55.06	7.75

Results and Discussions

To determine water quality indices namely, sodium absorption ratio (SAR), Kelly index (KI), sodium percentage (Na%), potential salinity (PS), permeability index (PI),

residual sodium carbonate (RSC) and standard diagrams of Wilcox, Gibbs, Doneen and U.S. salinity diagram, mathematical computations on the basis of water quality parameters major cations and anions were used; see Table (3) below.

Table (3): Groundwater Quality Indices for Irrigation Purposes.

	EC	SAR	KR	Na%	PS	PI	R1	R2	∑con	TH	RSC
W1	256.83	1.97	1.41	61.57	1.30	69.39	0.85	0.97	4.10	3.55	-1.01
W2	244.94	1.98	1.50	63.06	1.43	71.47	0.86	0.98	4.07	3.19	-0.91
W3	114.83	0.05	0.02	6.49	1.10	9.22	0.17	0.99	5.98	13.92	-3.94
W4	126.20	0.12	0.10	25.07	1.50	38.99	0.33	0.99	2.86	2.17	-0.73
W5	115.23	1.21	0.56	38.88	1.62	41.87	0.64	0.99	5.92	8.25	-2.35
W6	104.64	0.25	0.14	20.61	1.58	26.64	0.50	0.99	3.77	5.69	-1.56
W7	135.72	0.56	0.31	29.80	1.65	35.64	0.45	0.99	4.36	5.33	-1.65
W8	146.11	0.69	0.55	43.68	1.46	68.22	0.46	0.93	3.47	2.12	-0.92
W9	130.97	1.21	1.01	55.06	1.72	76.50	0.73	0.94	3.67	2.42	-0.83
W10	127.50	0.45	0.29	30.73	1.26	36.98	0.56	0.99	3.42	4.50	-1.28
W11	170.00	0.65	0.37	33.43	1.83	37.60	0.57	1.00	4.52	5.55	-1.60
W12	102.59	0.55	0.41	37.70	1.41	46.05	0.49	0.99	3.12	2.69	-0.89
W13	99.59	0.32	0.18	22.60	1.24	27.48	0.63	0.99	3.70	6.21	-1.63
W14	101.38	0.51	0.37	35.53	1.41	43.35	0.66	0.99	3.24	3.61	-1.00
W15	98.83	0.27	0.17	24.25	1.39	30.89	0.68	0.99	3.46	5.03	-1.32

1. Sodium Absorption Ratio (SAR)

The sodium adsorption ratio (Oster, 1980) is an indicator of the relative proportion of sodium ions in a water sample to those of calcium and magnesium. SAR is used to predict the sodium hazard in water. It is formulated as Eq. (2):

$$\boldsymbol{SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}} \ldots\ldots\ldots\ldots\ldots (\mathbf{2})$$

Water having SAR values <10 is considered excellent, 10-18 is good, 18-26 is fair and above 26 is unsuitable for irrigation. use. The SAR values varied from 0.02 to 1.98 and have been classified as excellent and suitable for irrigation Table (3).

2. Kelly's Index (KI)

The concentration of Na^{+} measured against $Ca2^{+}$ and Mg^{2+} is known as Kelly's ratio, based on which irrigation water can be rated (Kelly, 1946).

$$KI = \frac{Na}{(Ca + Mg)} \ldots\ldots\ldots\ldots (3)$$

As per Kelly's ratio water is categorized into suitable, if KR < 1, marginal, when KR 1-2 and unsuitable if KR > 2. In the present study the KI values varied from 0.17 to 1.5. 80 % which indicates that the groundwater samples are suitable for irrigation according to Kelly's ratio < 1.

3. Sodium Percentage (Na%)

The sodium content in irrigation water is usually expressed in Na%. It affects soil structure by exchanging process of sodium in water for Ca^{2+} and Mg^{2+} in soil, which reduces soil permeability. To assess the suitability of water quality for irrigation, the percentage of sodium in water is calculated by the following equation (Wilcox, 1955):

$$Na\% = \frac{Na^{+} + K^{+}}{(Ca^{+} + Mg^{2+} Na^{+} + K^{+})} \cdot 100 \ldots\ldots (4)$$

Water having 0-20% Na values is considered excellent, 20-40% is good, 40-60% is permissible, 60-80% is doubtful and above 80% is unsuitable for irrigation use. The calculated values of the sodium percentage Na% in the groundwater of the study area ranged from 6.49 % to 63.06%. More than 70 % of the samples from the study area are within the good range.

4. Residual Sodium Carbonate (RSC)

The residual sodium carbonate (RSC) index of irrigation water is used to indicate the alkalinity hazard of soil. RSC levels less than 1.25 meq are considered safe. Waters with RSC of 1.25 - 2.50 meq are within the marginal range (Eaton, 1950). These waters should be used with good irrigation management techniques and soil salinity monitored by laboratory analysis. RSC can be estimated by the formula given below:

$$PS = Cl^{-} + \sqrt{(SO_4^{--})^2} \ldots\ldots\ldots\ldots (5)$$

In the present study, it was found that all the samples fall into the safe range Table (3).

5. Permeability Index (PI):

The PI in a groundwater sample measures the total concentration of Na and HCO_3 to the total cations. Doneen classified irrigation waters into three classes, Class I (>75%), Class II (25-75 %) and Class III (<25 %) using the following formula (Doneen, 1964):

$$PI = \frac{Na + K + \sqrt{HCO_3}}{(Ca + Mg + Na + K)} \cdot 100 \ldots\ldots\ldots\ldots (6)$$

The permeability index of the study area ranges from 9.22to 76.50%. The majority of the samples fall under Class II which indicates that the water is good for irrigation purposes, Table (3).

6. Potential Salinity (PS)

Doneen pointed out that the suitability of water for irrigation is not dependent on the concentrations of soluble salts. Potential salinity is defined as follows:

$$PS = Cl^{-} + \sqrt{(SO_4^{--})^2} \dots\dots\dots (7)$$

Water quality was categorized into excellent if PS < 5, good, when PS 5-10, unsuitable, if PS >10. The value of PS in all samples of the study area was < 5 and the groundwater samples have been classified as excellent and suitable for irrigation, Table (3).

7. Wilcox Diagram

Plottingthe data on the (Wilcox, 1955) diagram relating EC and Na% shows that all water samples fall under excellent for irrigation purposes, Figure (1).

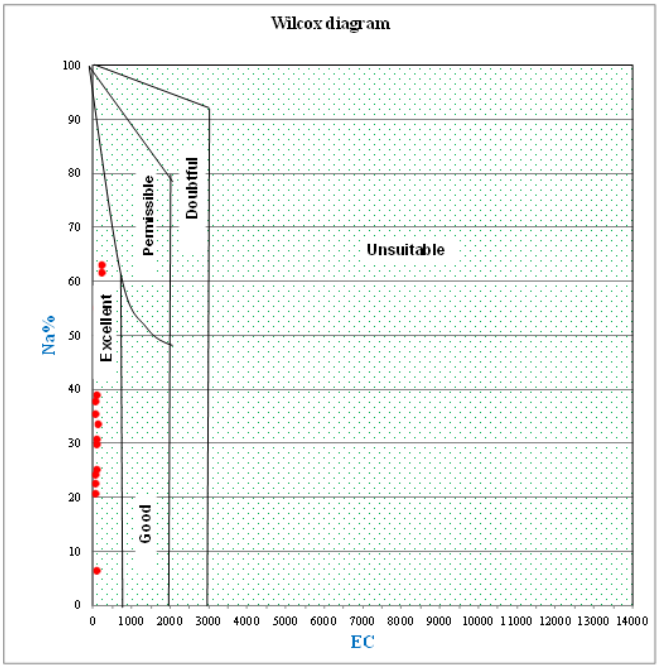


Figure (1): Wilcox Diagram Relating Na% and EC.

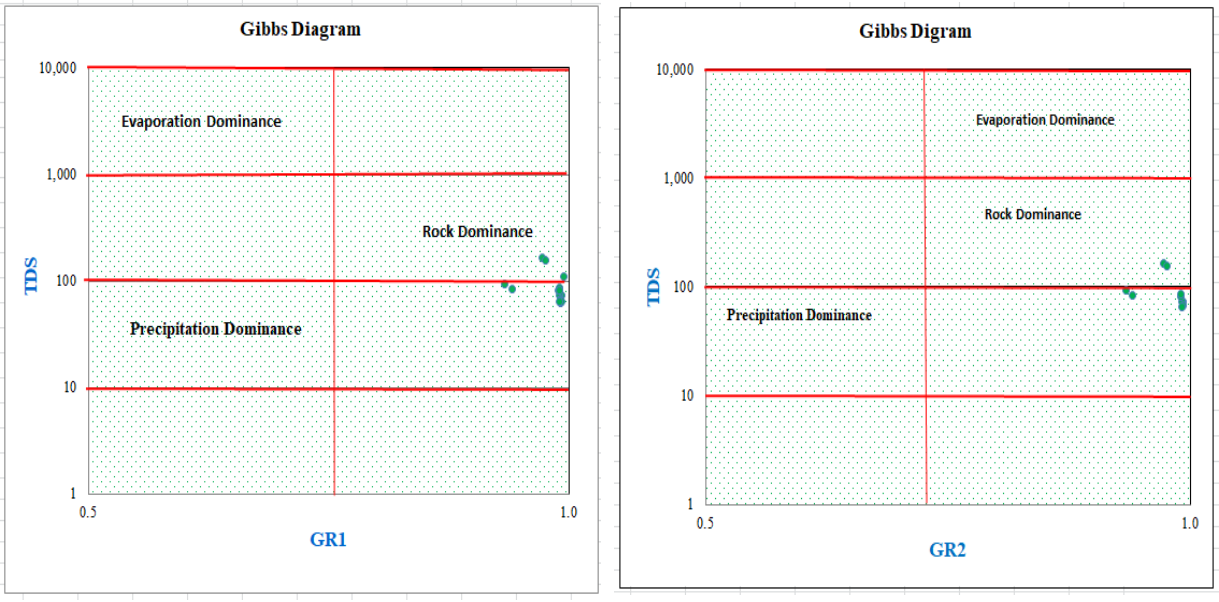
8. Gibbs Diagram

Due to the relatively high solubility and widespread occurrence of calcite, carbonate mineral dissolution often dominates the chemical evolution of natural waters, even if these minerals are present in only small amounts (Appelo and Postma, 1993). Therefore, the evolution of rain water (low TDS and usually a Na-Cl water type) to a Ca-HCO3 water type upon interaction with sediments and bedrock usually occurs relatively rapidly. The majority of fresh groundwater occurs in the middle part of the boomerang (water-rock interaction) on Gibbs diagram, but groundwater - unlike most surface waters - can span the entire range of Na / (Na + Ca) values (i.e., from < 0.1 to > 0.9) at mid-range TDS levels (Marandia and Shand, 2018). Gibbs diagram is employed to interpret the effect of hydrogeochemical processes such as precipitation, rock-water interaction mechanism and evaporation on groundwater geochemistry. The reaction between groundwater and aquifer minerals has a considerable role in groundwater quality which is useful to assume the genesis of water. Gibbs ratio is calculated by using the following equations (Gibbs, 1970):

$$\boldsymbol{GR1} = \frac{\boldsymbol{Na^+ + K^+}}{\boldsymbol{(Ca^+ + Na^+ + K^+)}} \ldots\ldots\ldots\ldots (\mathbf{7})$$

$$\boldsymbol{GR2} = \frac{\boldsymbol{Cl^-}}{\boldsymbol{(Cl^- + HCO_3^-)}} \ldots\ldots\ldots\ldots (\mathbf{8})$$

In the present study, Gibbs ratio GR1 values varied from 0.17 to 0.86 and Gibbs ratio GR2 values varied from 0.93 to 1.0 Table (3). According to Gibbs classification the majority of groundwater samples of the area on the plot TDS versus GR1 & GR2 (Figure 2a, b) fall under rock dominance. Groundwater samples of the study area on the plot Figure (2b) show similar variation with that of the cations diagram Figure (2a).



a) **TDS ver. Gibbs Ratio GR1, Cations.** **b) TDS ver. Gibbs Ratio GR2, Anions.**

Figure (2): Gibbs Diagram.

9. Doneen Diagram

Doneen (1954) proposed a categorization system for irrigation water based on PI. This takes into account the cations (Na^+, Ca^{2+}, Mg^{2+}, K^+) and HCO_3^- concentration of the soil. Doneen classified irrigation waters into three classes, Class I (>75%, excellent), Class II (25-75 %, good) and Class III (<25 %, unsuitable).

On Doneen chart Figure (3) PI was computed and plotted versus sum of all concentrations in (meq/L). All the samples fall under Class I which indicates that water is good for irrigation purposes.

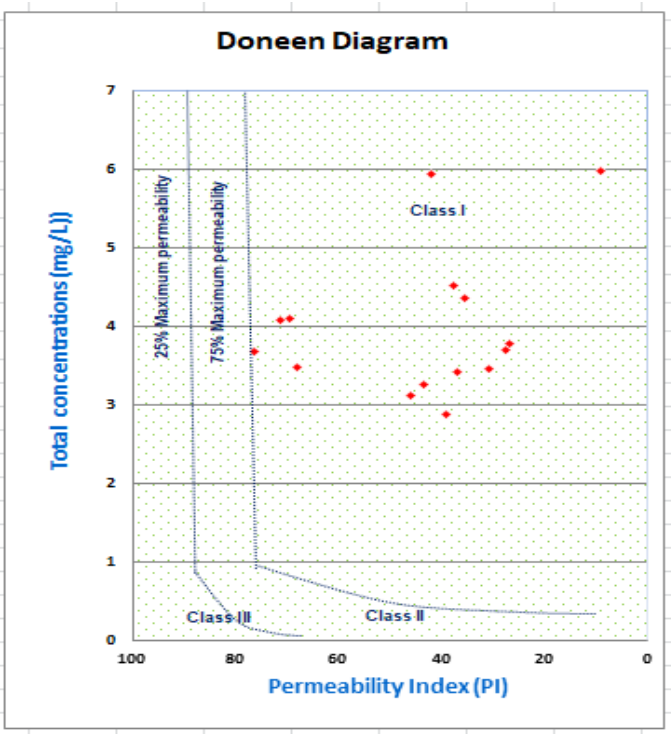


Figure (3): Doneen Classification Based on PI.

Conclusion

Finally, it could be concluded that the majority of the groundwater samples in the municipality of Alghurayfah, Libya are excellent and suitable for irrigation purposes.

The Gibbs diagram showing the hydrogeochemical characteristics is chiefly controlled by rock–water interaction process.

The Na% and the resulting Wilcox diagram also show that the groundwater is excellent category. The USSLS chart show that the samples of water are of low salinity and low sodium which ranks water as of good quality. On the Doneen chart, all samples fall under Class I and indicate that the water is good for irrigation purposes. However, the pH of the two Qwirat samples are considerably high and out of the permissible limit (8.5) which calls for more investigation.

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