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RESEARCH ARTICLE

APPLICATION OF TRADITIONAL METHOD AND WATER QUALITY INDEX TO ASSESS SUITABILITY OF GROUNDWATER QUALITY FOR DRINKING AND IRRIGATION PURPOSES IN SOUTH-WESTERN REGION OF LIBYA

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ABSTRACT

Groundwater quality of the arid and semi-arid regions needs great attention because it is the main water exporter for household and irrigation purposes. In this study, the traditional method and the water quality index were applied to evaluate the suitability of groundwater quality for drinking and irrigation purposes in south-western part of Libya. To achieve this, twenty groundwater samples were collected from different places representing the area understudy and the necessary physic-chemical analyzes were carried out to examine the suitability of groundwater for drinking purposes. Eleven parameters (pH, electrical conductivity, total dissolved solids, total hardness, calcium, magnesium, sodium, potassium, chloride, bicarbonate and sulphate) have been applied for calculating the WQI for drinking testes. The obtained values for water quality parameters were compared with World Health Organization (WHO) guideline values (traditional method). Also, seven parameters were selected for irrigation testes for calculating the WQI such as: EC, SSP, SAR, MAR, PI, KR and PS were used in traditional method. The results revealed that the groundwaters of most samples were fit for drinking purposes according to WHO (traditional method). However, the calculated DWQI for drinking propose showed that 35% of water samples are considered of excellent category, 20% good category, 15% poor category and 20% very poor category. On the other hand, two samples (only 10%) are of unsuitable categories. For irrigation purposes, most of studied samples were suitable for irrigation purposes (traditional method). The computed IWQI showed that 15% of water samples were in excellent category and 85% were in good category. The graphical interpretation of water quality was made according to Gibbs plots, Piper diagram, Chadha's scheme, USSL diagrams, Wilcox diagram and Doneen diagram.

KEYWORDS

Drinking water quality index (DWQI), Irrigation water quality index (IWQI), water quality parameters

1. INTRODUCTION

Groundwater is the main source for drinking, irrigation and other purposes, especially in arid and semi-arid areas. Therefore, water quality is a key factor for using this water for sustainable development [1]. More than half of the world's population depends on the groundwater for their daily life [2]. According to the statistics of the Food and Agriculture Organization [3], more than 50% of the world uses groundwater in irrigation and more than 60 % of the world's food is produced by groundwater.

Groundwater quality is of great importance because it has impact on human health, environmental and aquatic life and sustained economic growth. In fact, without good water quality, sustainable development and sound management are meaningless [4-6]. The groundwater quality is usually characterized by different physical and chemical properties. Its change varies widely due to the seasonal fluctuation of rain, various types of contamination and depletion of groundwater, etc. Monitoring of groundwater quality is necessary to manage groundwater pollution, as well as to reduce pollution factors [7, 8].

WQI is a technique for detecting water quality. It is also an effective tool for assessing spatial and temporal changes in groundwater quality and delivering information for decision makers [9]. The aim of this indicator is to convert multifaceted water quality data into simple information that can be understood and used by the public [10]. In recent years, the Water Quality Index (WQI) has been successfully used to groundwater quality assessment by integrating complex data and generating a degree describing the state of water quality to understand water quality issues [11].

Assessment of groundwater quality index with respect to different uses has been carried out by several researchers around the world and can be found in recent numerous publications such as: [12-29].

The main objective of this study is to using the traditional method and the water quality index (WQI) to assess the suitability of groundwater quality in the study area to drinking and irrigation.

2. LOCATION OF STUDY AREA

The area under investigation is located on the north-western area of Libya (Wadi Al-Hayaa). It lies between latitudes 26° 30′ and 28° 30′ N and longitudes 12° 15′ and 14° 30′ E (Figure 1). The area is characterized by the rural environment and the main activity of the people is agriculture. Water in this area is generally obtained from drilling wells that are used for different purposes.

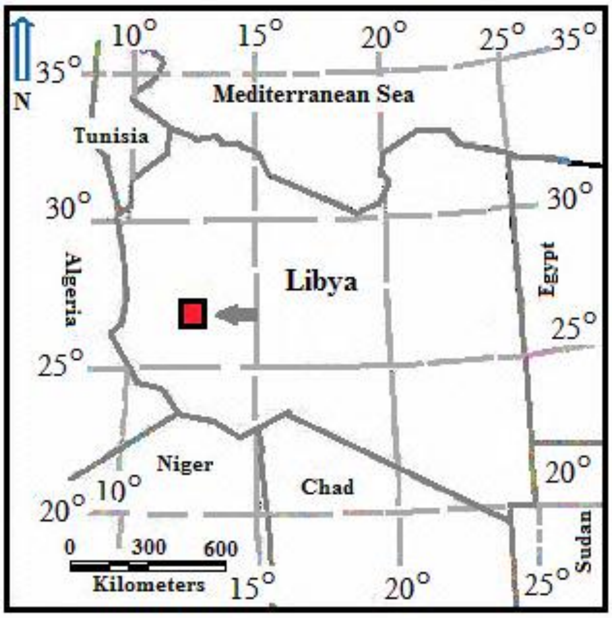


Figure 1: Location map of the study area

2.1 Study Area Climate

The Libyan climate is the Mediterranean climatic zone and it is characterized by hot and dry summer with cold and rainy winter. The mean annual temperature is 23.4 °C. The average maximum temperature was 30.9 in summer and the average minimum temperature was 15.9 °C in winter. The rainfall is mostly in winter season around an average of 8.0 mm/y (last twenty years) and the relative humidity is 31.6 %, while the average of annual evaporation is 1525 mm/y.

2.2 Water Resources

Libya is an arid country, the sources of water resources are surface water, groundwater and desalinated water. The surface water contributes only 3% of the current water resources used. The groundwater represents 95% of water resource in Libya [30].

3. OBJECTS AND METHODS

3.1 Water sampling

Groundwater samples were randomly collected from different locations (20 well) using standard sampling procedures as will be shown and analyzed for different drinking and agricultural parameters. Dry, clean and sterilized plastic bottles were used to get fresh aquifer water for sampling. Before collection the bottles were well rinsed. Labelling was done properly indicating date and location of sampling. Transportation to the laboratory followed standard methods and preservation (4^{O}C) of the water sample.

3.2 Analytical methods

The labeled samples were analyzed with various physicochemical parameters. The pH and electrical conductivity (EC) were measured within few hours after sampling by using Elico pH meter and conductivity meter due to the sensitivity of groundwater to environmental changes. The TDS was measured using TDS meter. The soluble ions (Ca, Mg, Na, K, HCO_3, SO_4, and Cl) were analyzed using the standard methods suggested by the American Public Health Association [31]. Total Hardness (TH) as $CaCO_3$, Calcium and Magnesium were analyzed titrimetrically, using standard EDTA. Sodium and potassium concentrations were determined by flame photometer. Chloride concentration was measured by silver nitrate titration. Carbonate and bicarbonate concentrations were measured by acid-base titration. Sulphate concentrations were measured using a spectrophotometer.

3.3 Drinking water quality

3.3.1 The traditional method

The suitability of groundwater for drinking was assessed by comparing the obtained results for different parameters with those values of the World Health Organization [32] for drinking water guideline. Also, Gibb's diagram and hydrogeochemical facies (Piper trilinear and Chadha's diagram) was used to assess the suitability of groundwater for drinking.

3.3.2 Drinking water quality index (DWQI)

The water quality index (WQI) was calculated using eleven important parameters (pH, TDS, EC, TH, Ca, Mg, Na, K, Cl, SO_4 and HCO_3). Water Quality Index was calculated using the following formula:

DWQI= $(\sum_{i=1}^{n} qiWi/\sum_{i=1}^{n} Wi)$

Where: Wi= weight of the parameter; Wi= K/ Si; Where K is proportionality constant =1; Si: is standard value of the ith quality parameter;
n is the total number of water quality parameters;
qi: is the quality rating for the ith water quality parameter,

Where:

$$qi = \{(Va - Vi)/(Si - Vi)x100\}$$

Where Va= the value of the ith water quality parameter determinate in laboratory
Vi = ideal value of the ith water quality parameter obtained from standard values (WHO, 2011), Vi for pH = 7 and for the other parameter the Vi value is 0 [33].
For pH: q_i = (Va – 7)/ (S_i - 7) ×100.

A quality rating scale (qi) for other parameters is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines of WHO and then multiplied by 100:

$$qi = \left(\frac{Ci}{Si}\right)x100$$

Where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in mg/l, and Si is the WHO drinking water standard for each chemical parameter (mg/l) according to the guidelines of WHO.

3.4 Irrigation water quality

3.4.1 The traditional method

The electrical conductivity (EC) and sodium soluble percentage (SSP), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), permeability index (PI), Kelly's ratio (KR), and potential salinity (PS) were used to assess the suitability of the groundwater quality for irrigation as follows.

Sodium percentage (SSP)

$$Na\% = \{(Na^+ + K^+)/(Ca^{2+} + Mg^{2+} + Na^+ + K^+)\}\,x100$$

Sodium Adsorption Ratio (SAR):

$$SAR = Na^+/\sqrt{(Ca^{2+} + Mg^{2+})/2}$$

Permeability index (PI)

$$PI = \{(Na^+ + \sqrt{HCO_3^-})/(Ca^{2+} + Mg^{2+} + Na^+)\}\,x100$$

Kelly's ratio (KR)

$$KR = Na^+/(Ca^{2+} + Mg^{2+})$$

Magnesium adsorption ratio (MAR)

$$MAR = \{Mg^{2+}/(Ca^{2+} + Mg^{2+})\}\,x100$$

Potential Salinity (PS)

$$PS = Cl^- + 0.5\,SO_4^{2-}$$

All the above calculated by meq/l (epm)

3.4.2 Irrigation Water quality index (IWQI) method

The IWQI provides a comprehensive picture of the quality of groundwater for irrigation uses. To calculate the IWQI in the present study, 7 parameters namely, salinity (EC), soluble sodium percentage (SSP), sodium adsorption ratio (SAR), magnesium adsorption ratio (MAR), permeability index (PI), Kelly's ratio (KR), and potential salinity (PS) have been considered. There are three steps for calculate IWQI. In the first step each of the parameters has been assigned a weight (Wi) according to its relative importance in the overall quality of water for irrigation purpose, maximum weight of 5 has been assigned to SAR and SSP due to its major importance in water quality assessment and it is directly related to sodium hazard. EC is considered as second important parameter for irrigation and is assigned a weight of 4 as it suggests salinity hazard. PI, KR and PS are signified as third important parameters and assigned a weight of 3 as it predicts the accumulation of salts and sodium in soil as calcium and magnesium carbonate. Finally, MAR are signified as fourth important parameters and assigned a weight of 2 as it suggests magnesium hazard. In the second step, the relative weight (W_i) is estimated from the following formula:

$$W_i = Wi / \sum_{i=1}^{n} Wi$$

Where W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameters. Relative weight (W_i) of individual parameters is determined. For SAR it is calculated as W_{SAR} = 5/ (5+ 5+4 +3+3+3+2), ie., 0.2; W_{SSP} = 0.2, W_{EC}= 0.16, $W_{PI,KR,PS}$ = 0.12 and W_{MAR} = 0.08. The third step is a quality rating (q_i) for each parameter is determined by the following equation:

$$Q_i = (C_i/S_i)\times 100$$

Where,
Q_i = the quality rating of individual parameter.
C_i = the concentration of individual parameter obtained from the laboratory analysis.
S_i = the standard concentration value for irrigation quality of the individual parameter

In this study the standard values of individual parameters have been taken from mean values of doubtful category of classification of water for irrigation (Table 8). For carrying out the calculation of IWQI in this study, determined subindex (SI) of individual parameter of each water sample which has been calculated from the following equation:

$$SI_i = W_i \times Q_i$$

Where:
Qi = Quality rating
Wi = Relative weight
In this study the subindex of parameters are SI_{SAR}, SI_{SSP}, SI_{EC}, SI_{PI}, SI_{KR}, SI_{PS} and SI_{MAR}.
Finally, Irrigation Water quality index (IWQI) of each water sample is determined as:

$$IWQI_i = \sum (SI_{SAR})_i + (SI_{SSP})_i + (SI_{EC})_i + (SI_{PI})_i + (SI_{KR})_i + (SI_{PS})_i + (SI_{MAR})_i.$$

4. RESULTS AND DISCUSSION

For a sustainable study of groundwater, it is important to assess the quality of groundwater for different purposes. In the present study, an attempt was made to evaluate the quality of groundwater through the drinking water quality index (DWQI), irrigation water quality index (IWQI) and traditional method in hard rock aquifer system and sustainable water use in Wadi Al Hayaa, south-western Libya.

4.1 Groundwater quality for drinking

4.1.1 The traditional method

The results of the various samples were compared with the World Health Organization limits for drinking standard and the results revealed the following (Table 1 and 2)

Table 1: Physico-chemical characteristics and their Drinking Water Quality Index (DWQI) of groundwater samples in the study area

Well No.	pH	EC	TDS	TH	Soluble cations				Soluble anions			DWQI
					Ca^{+2}	Mg^{+2}	Na^{+}	K^{+}	CO_3^{2-} $+HCO_3^{-}$	Cl^{-}	SO_4^{2-}	
		(µS cm^{-1})	mg/l									
1	6.7	2580	1651.2	1129.04	96.0	216.1	42.1	23.0	4.9	113.6	1113.6	83.34
2	7.1	170	108.8	62.2	17.0	4.8	7.8	4.7	21.4	32.7	21.6	24.39
3	7.1	160	102.4	52.21	13.0	4.8	8.1	9.8	45.8	18.8	11.0	36.93
4	6.9	640	409.6	121.28	28.4	12.2	75.4	31.2	24.4	117.9	202.1	79.46
5	7.1	2490	1593.6	1073.72	95.4	203.0	41.6	24.2	6.1	286.1	764.6	121.94
6	7.3	2050	1312.0	834.46	33.0	182.8	80.0	13.7	4.3	329.4	558.2	105.17
7	6.8	500	320	114.28	25.2	12.5	45.3	26.1	4.9	54.3	183.8	53.51
8	7.3	1780	1139.2	732.19	13.6	169.7	58.2	10.9	3.7	454.4	202.1	91.76
9	7.1	210	134.4	50.62	9.0	6.8	27.6	7.0	27.5	42.6	26.4	30.33
10	7.3	1070	684.8	250.99	40.4	36.5	100.5	20.7	3.1	129.9	302.9	95.81
11	7.1	150	96.0	42.72	9.0	4.9	11.9	5.5	21.4	36.2	8.2	25.71
12	6.8	210	134.4	44.76	11.2	4.1	19.6	9.8	3.1	30.2	61.4	7.82
13	6.8	1060	678.4	228.15	71.2	12.2	130.2	17.6	4.9	110.8	350.4	38.1
14	6.9	150	96.0	26.90	8.4	1.4	26.2	6.6	3.7	23.4	46.1	8.85
15	7.1	600	384.0	119.26	26.8	12.7	76.4	27.3	24.4	101.5	155.0	61.52
16	7.1	550	352.0	123.27	28.8	12.5	57.5	17.6	3.7	81.7	173.8	61.44
17	6.7	250	160.0	56.61	11.2	6.9	26.9	17.6	3.1	18.5	103.2	19.76
18	6.7	380	234.2	107.28	22.0	12.7	36.6	10.5	4.9	46.9	127.2	3.23
19	6.9	220	140.8	66.51	12.0	8.9	24.8	3.5	4.3	30.2	70.1	2.71
20	6.8	240	153.6	35.70	8.8	5.4	25.1	15.6	3.7	26.6	79.2	22.89
Min.	6.7	150	96	26.9	8.4	1.4	7.8	3.5	3.1	18.5	8.2	2.71
Max.	7.3	2580	1651.2	1129.04	96	216.1	130.2	31.2	45.8	454.4	1113.6	121.94
Aver.	6.98	773	494.27	263.61	29.0	46.5	46.1	15.1	11.2	104.3	228.1	48.73
SD	0.2	806.8	516.6	361.04	27.2	75.9	32.6	16.5	11.9	118.2	283.4	36.8

SD Standard deviation

Table 2: Maximum permissible limits of groundwater for drinking purposes by WHO (2011)

Water quality parameter	Desirable limit	Maximum Permissible limit	Number of sample desirable	%	Number of samples unfit	%
pH	6.5	8.5	20	100	--	--
EC (µS/cm)	500	1500	16	80	4	20
TDS (mg/l)	500	1500	18	90	2	10
TH (mg/l	100	500	16	80	4	20
Cl^- (mg/l)	200	600	20	100	--	--
SO_4^{2-} (mg/l)	200	400	17	85	3	15
HCO_3^- (mg/l)	--	240	20	100	--	--
Ca^{2+} (mg/l)	75	200	20	100	--	--
Mg^{2+}(mg/l)	50	150	16	80	4	20
Na^+(mg/l)	--	200	20	100	--	--
K^+(mg/l)	--	12	8	40	12	60

4.1.1.1 pH

pH is criterion for water acidity and one of the most important indicators of the quality of water. pH of the groundwater samples is in the range (6.7 to 7.3) with an average value of 6.98 and standard deviation of 0.20. The desirable limit of pH is 6.5 and the maximum permissible is 8.5. Therefore, the investigated groundwater samples fall within the permissible limits given by WHO (2011).

4.1.1.2 Electrical conductivity (EC)

Electrical conductivity (EC) is one of the most important criteria for water salinity. The electrical conductivity (EC) value of the samples varies from 150 to 2580 μScm^{-1} at 25 ^{0}C with an average value of 773 μScm^{-1} and standard deviation of 806.81μScm^{-1}. According to the results, 80% of the groundwater samples fall within the permissible limits of WHO (500 - 1500 μScm^{-1}), only four samples (20%), have values higher than these limits.

4.1.1.3 Total dissolved solids (TDS)

The values of TDS ranged from 96 to1651.2 mg/l, with an average value of 494.27 mg/l and standard deviation of 516.6 mg/l. Total dissolved solids (TDS) are desirable and maximum limit are 500, 1500 mg/l. According to WHO (2011), only 2 samples exceeded the permissible limit while, 90% of water samples in the suitable range for drinking.

4.1.1.4 Total hardness (TH)

High calcium and magnesium in the water increase water hardness and the interaction of magnesium with bicarbonate lead to the presence of insoluble salts of calcium and magnesium [34]. The total hardness (TH) was in the range of 26.90 - 1129.04 mg/l with an average 263.61 mg/l and standard deviation of 361.04 mg/l. The results revealed that 80% of groundwater samples values are within the permissible limit of 500 mg/l[32]. Only, four samples (20%) are exceed the permissible limit of WHO.

4.1.1.5 Soluble cations

1. Calcium and magnesium (Ca and Mg)

Calcium in the study area ranged between 8.4 and 96.0 mg/l with an average value of 29.0 mg/l and standard deviation of 27.2 mg/l. Mg^{2+} concentration varied from 1.4 to 216.1 mg/l with a mean value of 46.5 mg/l and standard deviation of 75.9 mg/l. According to WHO, the permissible limit of Mg^{2+} concentration of drinking water is specified 50-150 mg/l (WHO), only four samples were exceeding these limits. Magnesium concentration was usually less than calcium with ratios of 1:1.5 to 1.6 Mg: Ca ratio, except only in four cases of wells number 1, 5, 6 and 8 in which magnesium dominated calcium by ratio of 2.25:1 Mg: Ca in sample 1 and 5, and ratio of 6:1 and 12:1 Mg: Ca in samples 6 and 8 respectively. These four samples possess the highest value of EC_w. However, these four groundwater wells are the only wells which are not suitable for drinking (>150 mg Mg/l). While, 100% of the groundwater samples are suitable concerning Ca^{2+} concentration (75 - 200 mg/l) and considered suitable for drinking [32]. Excess of magnesium increases the hardness of water. Therefore, the same four wells (1, 5, 6 and 8) of high Mg^{2+} were not suitable because of their hardness. Calcium is the third cation in terms of its abundance in groundwater samples.

2. Sodium and potassium (Na and K)

The sodium concentration in the groundwater of the study area varies between 7.8 to 130.2 mg/l with a mean value of 46.1 mg/l and standard deviation of 32.6 mg/l. The results illustrated that sodium was the dominant cation in the groundwater. Sodium concentration was two to three folds that of calcium, except wells number 1, 2, 3 and 5 in which calcium was as double as sodium. Also, sodium was higher than magnesium. None of the 20 samples showed sodium concentration above permissible limit of 200 mg/l. The concentration of K^+ ranges between 3.51 and 31.2 mg/l with an average of 15.1 mg/l and standard deviation of 16.5 mg/l. The maximum permissible potassium concentration in the drinking water is 12 mg/l and it was found that 12 samples were above the permissible limit of WHO. High potassium concentration was associated with high sodium. Only in five samples (wells 4, 7, 15, 17, and 20) potassium concentration was higher than calcium. The calculated average of four cations did not reveal the actual case of cations concentration. In the twenty wells only four wells (1, 5, 6 and 8) had high EC_w and affected the mean values.

4.1.1.6 Soluble anions

Soluble anions are characterized by the predominance of sulphate followed by chloride and then bicarbonates in most case.

1. Sulphate (SO4)

Sulphate varied between 8.2 and 1113.6 mg/l with an average of 228.1 mg/l and standard deviation of 283.4. Sulphate concentration in the study area was in the permissible limit of 200-400 mg/l (85%), only three samples (15%) have excesses sulphate than the permissible limit of WHO. The major origin of sulphate is the dissolution of gypsum deposits and anthropogenic activities.

2. Chloride (Cl)

Chloride presented in groundwater samples ranges from 18.5 to 329.4 mg/l with an average of 104.3 mg/l and standard deviation of 118.2 mg/l. Soluble chloride in the groundwater was found within the permissible limit of 600 mg/l as per the WHO standards.

3. Bicarbonate (CO3 and HCO3)

The concentration of HCO_3^- is ranges from 3.1 to 45.8 mg/l with an average of 11.2 mg/l and standard deviation of 11.9 mg/l. The bicarbonate (HCO_3^-) and carbonates (CO_3^{2-}) in water are responsible of alkalinity. The highest desirable limit of total bicarbonate of WHO (2011) is 240 mg/l. All sampled groundwater was within the permissible limit.

4.1.1.7 Mechanism Controlling Ground Water Quality

Gibb's diagram is used to determine the source of dissolved ions in water. The Gibbs ratio Na / (Na+Ca) for cations (mg/l) and Cl / (Cl+HCO_3) for anions (mg/l) of water samples are plotted separately against the respective TDS. Gibb's diagram is useful in knowing the suitability of water for drinking and irrigation and sources of pollution of this water. It is suggested that chemical interaction between rock forming minerals of aquifer and the groundwater is the main mechanism in contributing ions and the major source of the dissolved ions in the groundwater of the study area (Figure 2).

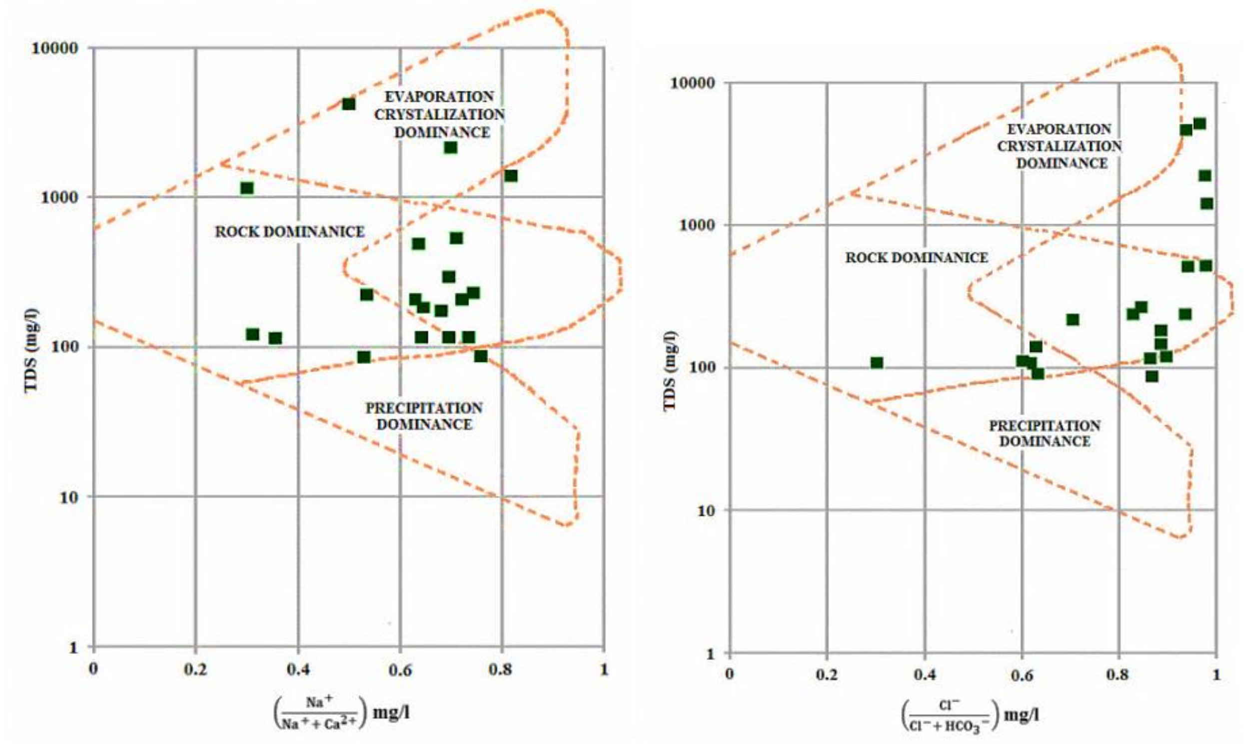


Figure 2: Mechanisms governing groundwater chemistry according to Gibbs diagram

4.1.1.8 Hydrochemical Facies

The representation of major groundwater dissolved major cations and major anions in graphic helps greatly to understand their hydro-chemical development as well as their distribution. Piper's trilinear diagram and Chad's plot were used to assess variability in the hydrochemical faces.

1. Piper trilinear diagram

Piper's scheme is used to identify the major ions of groundwater samples and to assess the geochemical structure of groundwater and detecting changes in groundwater chemistry across an area or over time (Figure 3). Piper diagrams are drawn by plotting the proportions of the major cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} by epm) on one triangular diagram, the proportions of the major anions (CO_3^{--} + HCO_3^{-}, Cl^{-} and SO_4^{2-} by epm) on another, and combining the information from the two triangles on a quadrilateral (diamond). Therefore, the piper's scheme illustrates the potability of drinking water and the domination of cation or anion ions in water. According to data in Table 3 and Figure 4 alkaline earth type of water (Ca^{2+} + Mg^{2+}) equal the alkalies (Na^{+} + K^{+}) whereas strong acids anion (Cl^{-} + SO_4^{2-}) exceeds the weak acids anion (HCO_3^{-} + CO_3^{2-}) which shows the chemical properties that are dominated by alkaline earths, alkalies and strong acids. Half of the samples (50%) fall in the Ca-Mg-Cl-SO_4 field and the rest (50%) fall in the Na-K-Cl-SO_4 field. It is also observed that some of the groundwater samples (20 %) fall in the mixed zone. On other hand, 30 % of groundwater samples fall in zone 6 (permanent hardness). Remaining samples (50 %) in zone 7 show secondary salinity where the samples are concentrated in the Na-Cl type indicating the saline nature in the groundwater. None of the samples fall under zone 5 (magnesium bicarbonate type) and zone 8 (sodium bicarbonate type). So, it is clear that the water samples fall under the Na-K-Cl-SO_4 (Saline type) and Ca-Mg-Cl-SO_4 (sulfate type).

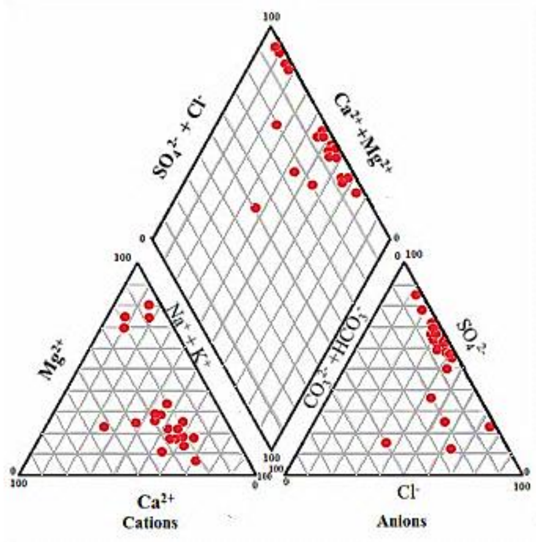
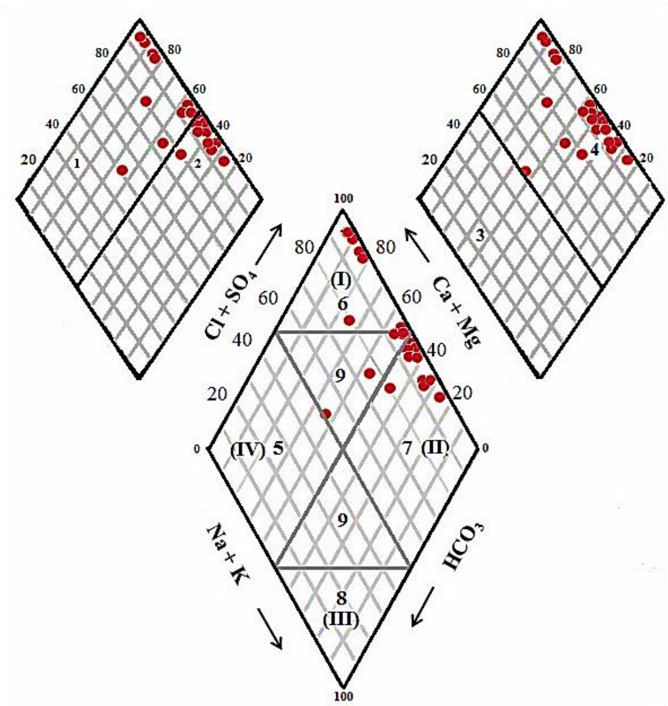


Figure 3: Piper diagram for the groundwater of the study area

Table 3: Classification of groundwater samples based on Piper trilinear diagram

Class Groundwater types /characteristics of corresponding subdivisions of diamond-shaped fields	Samples in the category	
	No. of samples	%
(I) Ca^{2+}- Mg^{2+}- Cl^{-} - SO_4^{2-}	10	50
(II) Na^{+}- K^{+}- Cl^{-} - SO_4^{2-}	10	50
(III) Na^{+}- K^{+}- HCO_3^{-}	--	--
(IV) Ca^{2+}- Mg^{2+}- HCO_3^{-}	--	--
1. Alkaline earth (Ca + Mg) exceed alkalies (Na + K)	10	50
2. Alkalies exceeds alkaline earths	10	50
3. Weak acids (CO_3 + HCO_3) exceed strong acids (SO_4 + Cl)	--	--
4. Strong acids exceeds weak acids	20	100
5. HCO_3-CO_3 and Ca-Mg (temporary hardness); magnesium bicarbonate type (carbonate hardness exceeds 50 %)	--	--
6. SO_4-Cl and Ca-Mg (permanent hardness); calcium chloride type (non-carbonate hardness exceeds 50 %)	6	30
7. SO_4-Cl and Na-K (saline); sodium chloride type (non-carbonate alkali exceeds 50 %)	10	50
8. HCO_3-CO_3 and Na-K (alkali carbonate); sodium bicarbonate type (carbonate alkali exceeds 50 %)	--	--
9. Mixing zone (no one cation–anion exceed 50 %)	4	20



LEGEND
Hydrochemical Facies
(I) Ca^{2+}-Mg^{2+}-Cl-SO_4^{2-}
(II) Na^{+}-K^{+}-C $^{-}$-SO_4^{2-}
(III) Na^{+}-K^{+}-HCO_3^{-}
(IV) Ca^{2+}-Mg^{2+}-HCO_3^{-}
Water Type
1. (Ca+Mg) > (Na+K)
2. (Na+K) > (Ca+Mg)
3. (CO_3 +HCO_3) > (SO_4 + Cl)
4. (SO_4 + Cl) > (CO_3 +HCO_3)
5. HCO_3 -CO_3 and Ca-Mg (Temporary hardness)
6. SO_4-Cl and Ca-Mg (permanent hardness)
7. SO_4-Cl and Na-K (Saline)
8. HCO_3-CO_3 and Na-K (Alkali carbonate)
9. Mixing zone

Figure 4: Hydrochemical facies on Piper's trilinear diagram appear alongside dominant anions, cations and classification water samples

2. Chadha's plot

Chadha Hydrochemical diagram is used to identify the various hydrochemical processes. In the present study, 50% of the samples fall in field 2 (Ca-Mg-Cl) types of reverse ion-exchange waters. The remaining of the samples (50 %) falls in field 3 (Na-Cl) suggesting that the water shows typical seawater mixing (Figure 5). The results obtained from Chadha's plot are considered compatible with those obtained from piper diagram. Eventually, the results obtained from Piper's and Chadha's diagrams revealed that the strong acidic anions (Cl^{-}, SO_4^{2-}) are dominant over the weak acidic anions (CO_3^{2-}, HCO_3^{-}) and the hydrochemical facies are Na-K-Cl-SO_4 and Ca-Mg-Cl-SO_4 type.

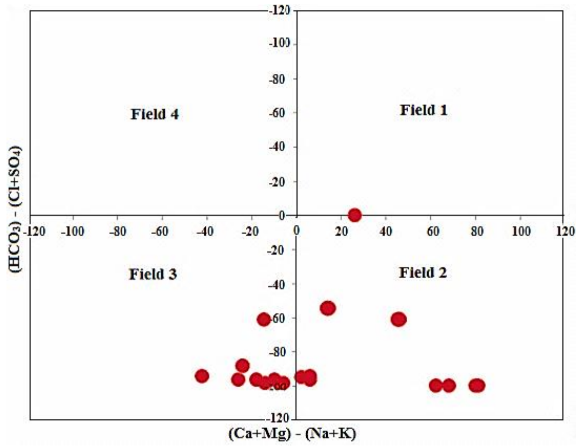


Figure 5: Chad's Scheme to assess major geochemical processes in the study area

4.2 Drinking water quality index (DWQI)

The Drinking Water Quality Index (DWQI) for 20 ground water samples ranges from 2.71 to 121.94 with an average of 48.73 and standard deviation of 36.83. The calculated DWQI classified the groundwater into excellent to unsuitable quality based on the data in Table 4. The DWQI method appears to be more realistic for assessing water quality at sampling stations. The high value of DWQI of these wells has been found to be mainly from the higher values of EC, TDS, hardness, sulphate and potassium. Accordingly, 35% of wells water falls in the excellent water quality and 20% falls in the good water quality. On the other hand, about 15 % of water samples are falling in poor quality while 20 % are in very poor range. Two samples only (10%) are unfit for drinking purpose (Tables 1, 4 and Figure 6).

Table 4: Water quality classification based on WQI limits for drinking proposes

WQI value	Water quality	No. of water samples	% of water samples
0-25	Excellent water quality	7	35
25-50	Good water quality	4	20
50-75	Poor water quality	3	15
75-100	Very poor water quality	4	20
> 100	Unfit for drinking	2	10

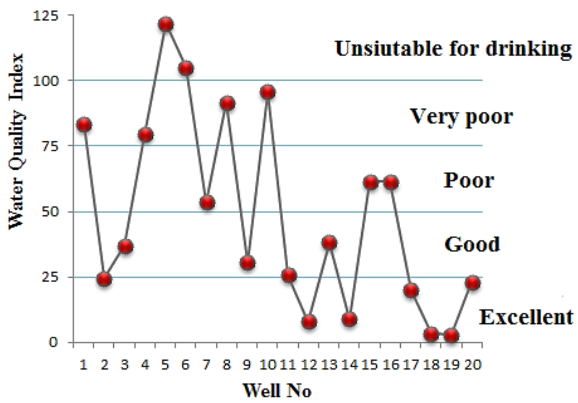


Figure 6: Water quality index (WQI) values for drinking water samples

4.3 Statistical analysis

The degree of linear correlation between any two—water quality parameters and with DWQI measured by a simple correlation coefficient (r) is showed in Table 5. DWQI showed highly significant interrelated with the values of EC (r = 0. 834**), TDS (r = 0.835**), TH (r = 0.774**), Ca^{2+} (r =0.617**), Mg^{2+} (r = 0.760**), Cl^- (r = 0.781**) SO_4^{2-}(r 0.690**) and significant interrelated with the values of pH (r = 0.546*), Na^+ (r = 0.525*), K^+ (r = 0.528*). The highest r value between DWQI and other parameters and ions indicate that the DWQI value affected by these ions and parameters. The correlation coefficients of the pH of the groundwater and that of the Cl^- are highest positively correlation (r = 0.568**).

Also, a strong positive correlation and highly significant was found between EC and TH, Mg^{2+}, $SO_4^{2-}Ca^{2+}$, Cl^- and K^+ with r values of 0.982**, 0.959**, 0.921**, 0.809**, 0.779**and 0.484*, respectively. Since, it was observed that the TDS or ECw were controlled by total hardness (r = 0.982**), magnesium (r = 0.959**), Sulphate (r = 0.921**), chloride (r = 0.779**) and potassium (r = 0.484*).

Total hardness shows highly correlation with Mg^{2+}, SO_4^{2-}, Ca^{2+}, Cl^- and K^+ with r values of 0.990**, 0.908**, 0.761**, 0.754** and 0.452*, respectively. The contents of Ca^{2+}, SO_4^{2-}, Mg^{2+} and Na^+ are positively correlated with correlation coefficients of 0.906**, 0.661**, and 0.455*, respectively. The good correlation between calcium and sulphate suggests that a part of the SO_4^{2-} and Ca^{2+} may also be derived by the weathering of calcium sulfate mineral ($CaSO_4$). A close correlation was noted between magnesium and sulphate, chloride and potassium (r = 0.853**, 0.795**and 0.481*, respectively) suggests also, that a part of the SO_4^{2-} and Ca^{2+} may be derived by the weathering of magnesium sulfate mineral ($MgSO_4$). The relationship between $K^+$and Cl^- and between Cl^- and SO_4^{2-}concentrations is characterized by a relatively low correlation coefficient (r = 0.497* and 0.479**). It was observed that sodium was not correlated with any ions. Also, HCO3- was not correlated with other ions.

Table 5: Correlation coefficient matrix of water quality parameters and DWQI for study samples

Parameter	pH	EC	TDS	TH	Ca	Mg	Na	K	HCO_3	Cl	SO_4	DWQI
	1.00											
EC	0.238	1.00										
TDS	0.240	1.00**	1.00									
TH	0.221	0.982**	0.982**	1.00								
Ca	-0.088	0.809**	0.809**	0.761**	1.00							
Mg	0.273	0.959**	0.959**	0.990**	0.661**	1.00						
Na	0.196	0.424	0.424	0.253	0.455*	0.192	1.00					
K	0.321	0.484*	0.484**	0.452**	0.189	0.481**	0.398	1.00				
HCO_3	0.267	-0.330	-0.329	-0.296	-0.241	-0.291	- 0.272	-0.155	1.00			
Cl	0.568**	0.779**	0.779**	0.754**	0.352	0.795**	0.431	0.497*	-0.254	1.00		
SO_4	-0.40	0.921**	0.921**	0.908**	0.906**	0.853**	0.348	0.407	-0.326	0.479*	1.00	
DWQI	0.546*	0.834**	0.835**	0.774**	0.617**	0.760**	0.525*	0.528*	-0.083	0.781**	0.690**	1.00

** Correlation is significant at the 0.01 level
* Correlation is significant at the 0.05 level

Generally, to insure the suitability of groundwater for drinking purposes the obtained geochemical parameters of the groundwater of the study area were compared with the guidelines recommended by WHO (traditional method) and DWQI which indicate that most of the groundwater samples of the study area were suitable for drinking purposes. When comparing the two methods (WHO and DWQI), the results showed that no significant variation was found between them. However, the accuracy of the results obtained by the DWQI method was higher and more realistic than the results of the traditional method (WHO).

4.4 Groundwater quality for irrigation

The quality of groundwater is importance for irrigation in arid and semi-arid areas. In order to determine the suitability of groundwater in the study area for irrigation, the following was discussed (Tables 6 and 7):

Table 6: Parameters for groundwater quality indices and Irrigation Water Quality Index (IWQI)

Well No.	EC ($\mu S\ cm^{-1}$)	SSP (%)	SAR	MAR (%)	PI (%)	KR (meq/l)	PS (meq/l)	IWQI
1	2580	9.59	0.16	78.96	8.56	0.08	14.80	63.81
2	170	26.90	0.43	32.00	58.59	0.27	1.14	33.68
3	160	36.36	4.48	38.01	86.86	0.33	0.65	47.84
4	640	62.58	2.97	41.80	68.40	1.34	4.42	71.89
5	2490	10.07	0.55	78.01	9.05	0.08	16.02	64.77
6	2050	18.49	1.20	90.22	18.39	0.21	15.09	67.72
7	500	53.44	1.84	45.22	52.76	0.86	3.44	56.62
8	1780	15.94	0.93	95.41	15.99	0.17	14.91	63.42
9	210	57.50	1.68	55.88	84.27	1.17	1.47	65.17
10	1070	49.20	2.75	60.08	48.71	0.86	6.81	67.76
11	150	43.42	0.79	47.67	80.55	0.60	1.10	50.2
12	210	55.00	1.27	37.78	61.34	0.94	1.49	52.94
13	1060	54.26	3.74	22.27	58.03	1.23	6.77	70.58
14	150	70.81	2.19	22.22	82.44	2.11	1.14	73.85
15	600	62.61	3.03	44.17	69.10	1.38	4.47	72.62
16	550	54.33	2.24	41.93	55.11	2.19	4.11	74.57
17	250	58.69	1.55	50.87	60.33	1.02	1.59	57.61
18	380	46.27	1.53	49.07	13.62	0.74	2.64	41.61
19	220	46.61	1.32	55.22	55.56	0.81	1.58	50.65
20	240	62.61	1.63	50.56	67.42	1.22	1.57	60.84
Min.	150	9.59	0.16	22.22	8.56	0.08	0.65	33.68
Max.	2580	70.81	4.48	95.41	86.86	2.19	16.02	74.57
Mean	773	44.73	1.81	51.87	52.75	0.88	5.26	60.41
SD	806.81	18.82	1.12	20.19	25.84	0.61	5.41	11.33

SD = Standard deviation

Table 7: Suitability of groundwater for irrigation based on several classifications

Quality of parameters	Range	Type of water	No. of samples	% of samples
EC_W (µS/cm)	100 - 250	Excellent	9	45
	250 - 750	Good	5	25
	750 - 2250	Doubtful	4	20
	> 2250	Unsuitable	2	10
Soluble sodium percentage (%)	0 - 20	Excellent	4	20
	20 - 40	Good	2	10
	40 - 60	Permissible	10	50
	60 - 80	Doubtful	4	20
	> 80	Unsuitable	--	--
SAR (epm)	0 -10	Excellent	20	100
	10 - 18	Good	--	--
	18 - 26	Doubtful	--	--
	> 26	Unsuitable	--	--
Permeability index (%)	< 25	Safe	5	25
	25 - 75	Moderate	11	55
	> 75	Unsafe	4	20
Kelly's Ratio (epm)	< 1	Safe	12	60
	> 1	Unsuitable	8	40
Magnesium Adsorption Ratio (%)	< 50	Suitable	11	55
	> 50	Unsuitable	9	45
Potential Salinity (epm)	< 5	Excellent to good	14	70
	5 - 10	Good to Injurious	2	10
	> 10	Injurious to Unsatisfactory	4	20

4.4.1 The traditional method

4.4.1.1 Electrical conductivity (EC)

The electrical conductivity is or TDS a good measure of how salinity hazard is to soil or [35]. The EC data showed that 45% of the groundwater was excellent, 25% of the groundwater was suitable for irrigation, and 20% was questionable in irrigation. On the other hand, only 10% of the groundwater samples were not suitable for irrigation. This indicates the filtration and solubility of salts in the surface aquifer in the studied area.

4.4.1.2 Sodium adsorption ratio (SAR)

Sodium adsorption ratio (SAR) values range from 0.16 to 4.48 with an average of 1.81 and a standard deviation of 1.12. SAR is a measure of the alkaline / sodium of water and how dangerous it is for crops. Consequently, all the groundwater samples have excellent SAR values and acceptable for irrigation.

4.4.1.3 USSL diagram

The sodicity and EC_w hazard diagram of the US salinity scheme [36] was used. The SAR (sodicity) was plotted against the EC (salinity) and the irrigation water samples were divided into categories (Figure 7). The USSL plot indicates that 45% of the groundwater samples were in C1-S1 class (low salinity low sodium type) and 25% of the samples were in C2-S1class (medium salinity and low sodicity). This indicates that the groundwater in the study area has low to medium salinity with low sodium content and can be used for irrigation on each type of soil. About 20% of groundwater samples fall in C3-S1, indicating high salinity and low sodicity type. Only 10 % falls in the very high salinity to low sodicity category (C4-S1). This type of water can be used to irrigate tolerant crops under favorable drainage conditions without danger of exchangeable sodium.

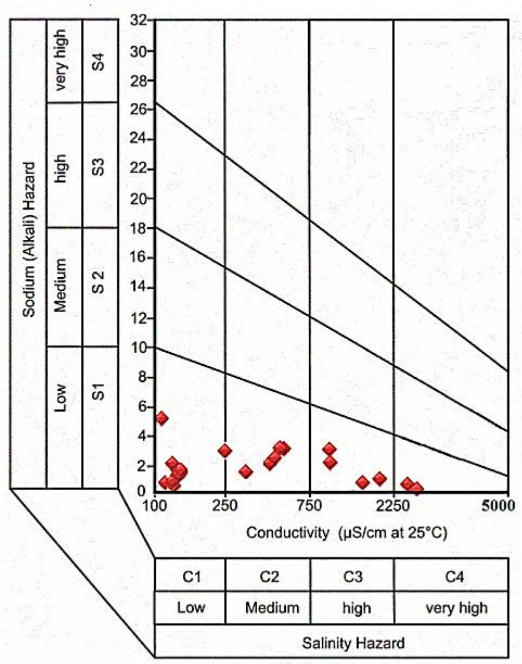


Figure 7: Evaluation of the quality of irrigation water in the study area using the USSL (1954)

4.4.1.4 Soluble sodium percentage (SSP)

The values of soluble sodium percent (SSP) range from 9.59 to 70.81% with an average value 44.73% and standard deviation of 18.82%. Sodium hazard was an important factor in irrigation water quality. The results revealed that 20% of SSP in groundwater samples fall in the excellent category, 10% fall in good and 50 % fall in permissible category. While the remaining 20% is of SSP groundwater samples fall in the doubtful water quality for irrigation.

4.4.1.5 Wilcox's Diagram

The percentage of sodium and electrical conductivity plotted on the Wilcox scheme indicates that 70% of the groundwater samples in the study area were excellent to good class, 15% was good to permissible category and 15% were in the permissible to doubtful category (Figure 8). Consequently, most of the groundwater samples were suitable for irrigation.

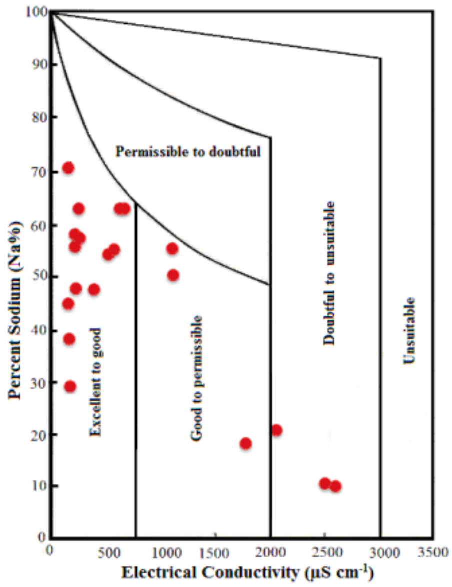


Figure 8: Classification of irrigation water quality, with respect to total salt concentration and sodium present

4.4.1.6 Kelly's Ratio (KR)

Kelly's ratio (KR) values vary between 0.08 and 2.19 meq/l with an average value of 0.88 meq/l and standard deviation of 0.61 meq/l. According to Kelley's Ratio (KR), water containing less than one is considered suitable for irrigation, while those containing more than one are considered unsuitable for irrigation. The data showed that 60% Kelley's ratio (KR) values for the groundwater of study area were less than 1 and indicate good quality water for irrigation while remaining (40%) was more than 1 which indicated unsuitable water quality for irrigation.

4.4.1.7 Permeability Index (PI)

The permeability index (PI) values in the study area vary from 8.56 to 86.86% with an average value of 52.75% and standard deviation of 25.84%. It is another indicator of the suitability of groundwater for irrigation. The results of PI of groundwater reveal that 25% of the groundwater samples fall in safe category and 55% are moderate for irrigation purpose. On other hand, 25% of the groundwater samples are unsafe for irrigation purpose.

4.4.1.8 Doneen diagram

Doneen's scheme is use to assess the quality of irrigation water and to help assess the potential impacts of groundwater from the study area on soil hydraulic properties when used in irrigation. Doneen's scheme (Figure 9) showed that 95% of the groundwater of the study area were in the first and second categories, indicating that most of the groundwater samples were suitable for irrigation, with the exception of one sample (5%) falling in the third category which is not suitable.

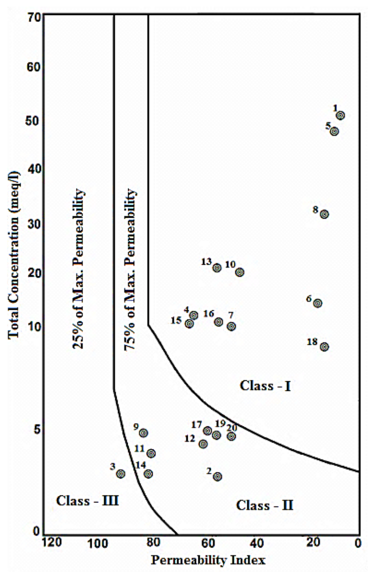


Figure 9: Doneen's diagram for classification of groundwater quality in study area

4.4.1.9 Magnesium Adsorption Ratio (MAR)

The magnesium adsorption ratio (MAR) value ranged from 22.22 to 95.41% with an average value of 51.87% and a standard deviation of 20.19%. MAR is anticipated of the risk of using high magnesium in water and the soil, resulting in poor crop production. In the study area, 55% of the collected samples showed that the MAR ratio was less than 50% (suitable for irrigation) while 45% was falls in the inappropriate category more than 50% which may have adversely affect cultivated soil and crop production.

4.4.1.10 Potential Salinity (PS)

The potential salinity (PS) values of the study area vary from 0.65 to 16.02 meq/l with an average value of 5.26 meq/l and standard deviation of 5.41 meq/l. The high values of PS above the critical level of 5 meq/l where due to the higher concentration of Cl and SO4 ions in the groundwater may have negative effects on the plant and soil. Accordingly, 70% of the samples of the study area were excellent to good, 10% are good to injurious and 20% are injurious to unsatisfactory for irrigation.

4.4.2 Irrigation water quality indices (IWQI)

The computed IWQI values range from 33.68 to 74.57 with an average value of 60.41 and standard deviation of 11.33 (Table 6). Irrigation Water Quality Index (IWQI) results were presented in Table 8. The various parameters such as EC,SAR, SSP, PI, MAR, KR and PS were considered to assess the ground water quality for irrigation. The indices value summed, then classified into excellent to unfit groundwater quality. The results in Table 8 and Figure 10 revealed that 15% of IWQI of the sample fall in excellent water quality and therefore it can be used for irrigation purposes. On other hand, most of the samples (85 %) were of good water quality which can be also, used for irrigation purposes. Figure (11) illustrated the comparison between Drinking Water Quality Index (DWQI) and Irrigation Water Quality Index IWQI.

Table 8: Grads of Water Quality Index (WQI) for irrigation proposes

WQI value	Water quality	No. of water samples	% of water samples
< 50	Excellent	3	15
50-100	Good	17	85
100-200	Doubtful	--	--
200 - 300	Permissible	--	--
>300	Unsuitable	--	--

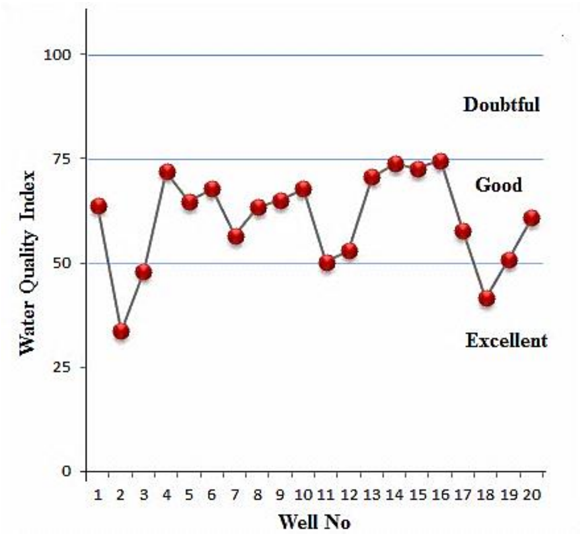


Figure10: Water quality index (WQI) values for irrigation water samples

Figure 11: The comparison between Drinking Water Quality Index (DWQI) and Irrigation Water Quality Index IWQI

4.5 Statistical analysis:

The correlation matrix of the 8 parameters analyzed (EC, SSP, SAR, MAR, PI, KR, PS and IWQI) given in Table 9 allows to distinguish high correlation coefficients, which indicate several relevant parametric relationships. The good positive correlation between EC with PS and MAR (r = 0.984** and 0.759**). Also, highly negative correlation between EC and PI, SSP and KR (r = - 0.812**, - 0.771**and - 0.533*, respectively). SSP shows highly correlation with KR, PI and SAR with r values of 0.857**, 0.737**and 0.524*, respectively. It was also observed that the negative correlation between SSP with PS and MAR (r = - 0.767** and - 0.728**). The relationship between SAR and PI values is characterized by a relatively low positive correlation coefficient (r = 0.523*) and negative correlation coefficient with MAR (r = - 0. 519*). The high correlation observed values between MAR and PS (r = 0.805**). The relationship between MAR with PI and KR is negatively (r = - 0.730** and - 0.628**). A close positive correlation noticed between the PI and KR (r = 0.559*) and negative correlation (r = - 0.818**) between the PI and PS. The correlation coefficients of the KR and that of the PS is moderately negative correlation (r = - 0.559*). There is no correlation between computed IWQI and other parameters except KR has correlation coefficients 0.509*.

Table 9: Correlation coefficient matrix of water quality parameters and IWQI for study samples

Parameter	EC	SSP	SAR	MAR	PI	KR	PS	IWQI
EC	1.00							
SSP	-0.771**	1.00						
SAR	-0.340	0.524*	1.00					
MAR	0.759**	-0.728**	-0.519*	1.00				
PI	-0.812**	0.737**	0.523*	-0.730**	1.00			
KR	-0.533*	0.857**	0.442	-0.628**	0.559*	1.00		
PS	0.984**	-0.767**	-0.339	0.805**	-0.818**	-0.523*	1.00	
IWQI	0.361	0.236	0.312	0.126	0.008	0.509*	0.376	1.00

*** Correlation is significant at the 0.01 level*
** Correlation is significant at the 0.05 level*

In general, to verify the suitability of groundwater for irrigation purpose the different parameters (traditional method) and IWQI were used for the study area, which indicated that most of the groundwater samples of the study area were suitable for irrigation purpose. The results showed that when comparing the two methods, there was a slight difference between them.

5. CONCLUSION

In the present study, interpretation of hydrochemical analysis reveals that the groundwater samples of the study area indicate that water is nature (pH around 7). The electrical conductivity values, total dissolved solids values total hardness of Wadi Al-Hayaa groundwater were found almost to be permissible limit of WHO. The order of the concentrations of the major cations and anions in the groundwater of Wadi Al-Hayaa were Na > Ca > Mg > K and SO_4 > Cl >HCO_3. In the Gibbs' diagram the cations and anions fall within the zone of the country rocks. The samples of the area fall in subfield of Na-K-Cl-SO_4 (saline type) and Ca-Mg-Cl-SO_4 (sulfate type) of hydrochemical facies according to Piper trilinear diagram and Chadha's plot. The groundwater of the study area was chemically suitable for drinking uses according to WHO (traditional method). While, DWQI revealed that 35% of the samples were excellent water quality and 20 % were good for drinking. However, 15, 20 and 10 percentages of samples were poor, very poor and unfit for drinking, respectively. Such waters are not suitable for drinking purposes under normal condition and further action for salinity control is required. The high value of DWQI at these sites has been found to be mainly due to the higher values of TDS, EC, K^+, Mg^{2+}, SO_4^{2-} and TH. When compared between the traditional and DWQI methods, it was not found much varied between them. Based on the water quality parameters analyzed like EC, SAR, SSP, MAR, PI, KR and PS (traditional method), the suitability of groundwater samples for irrigation was excellent to good in most cases, indicating low saline and sodic water. For calculating the IWQI, the results show that 15% of water sample falls in excellent categories and 85% falls in the good water category. The results also showed that when comparing between the traditional and IWQI methods little varied was found between them. Therefore, the results were concluded, that the study area groundwater quality was in general suitable for irrigation.

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