Original Research Article

Assessment of groundwater quality for drinking and agriculture purposes in Al-Jouf Region, Saudi Arabia

ABSTRACT

Saudi Arabia (KSA) depends mainly on groundwater for drinking and irrigation purposes. This study was therefore aimed to identify groundwater quality in Al-Jouf Region, KSA using water quality index (DWQI)and irrigation water quality index (IWQI) for drinking and irrigation purposes. In addition, investigating the hydro-chemical processes that control the groundwater chemistry. 150 groundwater wells at depth ranging from 300-500 m were collected for chemical analysis. The values of chemical constituent are compared with the KSA and WHO standards for drinking and irrigation water. The obtained results revealed that the concentrations of ions were within the standards of KSA for drinking water and (WHO). Based on DWQI for drinking water, 23.8 % of the wells are within poor water category (III), while 9.9 % are very poor water within (IV) group, whereas 45.6 % is good water of group (II), and 20.53 % is excellent water within category (I). For irrigation purposes, the schematic diagram of salinity revealed that 60% of the groundwater is in C2-S1, C3-S1, 25% in C3-S2, and 25% in C4-S3. The Piper diagram showed that cations are decreasing as follow Na+>Ca2+>Mg2+, while the anions are decreasing as follow Cl− > HCO_3− > $SO_4$2−>$CO_3$2-. SAR values ranged from 0.68 to 15.43; while KR ranged between 0.32 and 4.02. The estimation of IWQI of all wells revealed that water is moderate type in which its value ranging between 22-27. It appears that the groundwater wells of this area are better water for irrigation and drinking purposes according to indices.

Keywords: Al-Jouf, groundwater, water quality index, salinity hazard, irrigation water quality index.

1. INTRODUCTION

In many countries, groundwater is considered as a primary source of drinking water, and sometimes also the irrigation purposes, particularly in some arid or semiarid areas. It is approved that groundwater supports about two-thirds of the world's population by supplying freshwater for drinking and other domestic requirements [1].

Saudi Arabia is in arid and hyper arid regions, suffers from water scarcity and limited water resources [2]. Exploitation of ground water led to serious shortage of water and the deterioration of ground water at a reduction of agricultural land in different regions of Saudi Arabia [3]. In the rural area of Saudi Arabia such as Al-Jouf region rely mainly on ground water for drinking and agricultural activities. Al-Jouf area is considered one of the new agricultural regions in Saudi Arabia with very high potential in agricultural development. During the last three decades the region witnessed a huge agricultural project from most of agricultural companies. This stress on agricultural water demand is the main cause of water resources deterioration around Saudi Arabia [2]. In Al-Jouf area, groundwater is currently limiting factor for intensifying the agricultural activities. The irrigation water quality may affect crop production and soil chemical and physical properties [3]. Thus, there is lack of knowledge on irrigation water quality of this area which is very important to make necessary management decisions in crop production. In irrigation waters, salinity, sodicity, and ion toxicity are very important issues. Sodicity or the presence of too much sodium, causes the soil structure to deteriorate [4]. Various factors such as rock-water interaction, lithology, usage of fertilizers and pesticides for agricultural purposes, and climatic conditions largely influence the quality of groundwater [5].

The drinking water quality index (DWQI) and irrigation water quality index (IWQI) are functions to access water quality and help to take the right decision for the policy makers in reassure the public and farmers on their water quality [6,7]. The aim of both indices is to provide a simplified approach for evaluating drinking and irrigation water by merging all or some measures or evaluated parameters into single value [8,9]. Numerous studies were conducted using DWQI and IWQI with different methods of calculation of the index and the weight values for each parameter [10,11]. On DWQI, [12] reported that DWQI of ground water in Riyadh region, Saudi Arabia ranged from 34-513 with an average value of 282. In Iran, [13] used DWQI to evaluate groundwater quality and their result proved that water is of good quality. [14] reported same results in El-Khairat, Tunisia.

In India, DWQI was used to identify the ground water quality in Palakhal District in Kerala [15]. Evaluation of irrigation water quality index (IWQI) has been proposed by many researchers [16-18]. The proposed procedure is mainly an index method that utilizes five hazard groups, salinity, infiltration, specific ion toxicity, trace elements and miscellaneous impacts as described by [19]. Based on this technique, results indicated that ground water quality in the western Anatolia, Turkey are fairly good and aquifers are mostly suitable for irrigation. [17] applied the same procedure in south-central Bangladesh. They reported that groundwater using (IWQI) is moderate to suitable for irrigation.

Apart from its high potential in terms of quantity on the Earth, groundwater resources are generally less vulnerable to pollution than surface water resources due to the first purification in the soil column through filtration, anaerobic decomposition, and ion exchange [20]. There was no research carried out in this area regarding evaluation of ground water using irrigation water index. Hence, this study aimed to investigate the quality of the groundwater for both drinking and agricultural purposes using DWQI and IWQI indices.

2. MATERIAL AND METHODS

2.1 Study Area

In this study, samples were taken from agricultural areas in Al-Jouf region, north of Saudi Arabia. In the north of the Kingdom Fig. (1), has an area of 100,212 square kilometers, and a population of 508,475 and the city of Sakaka is the administrative headquarters for the region, which includes three governorates which is a governorate Al-Qurayyat, Dumat Al-Jandal Governorate, Tabarjal Governorate.

Al-Jouf was considered one of the most fertile soils in the Kingdom, and the region is famous for its olive trees cultivation. Al-Jouf area produces approximately 67% of the domestic production of olive oil in the Kingdom. Also, the cultivation of palm trees, as the region is about 150 thousand tons of old dates additionally, fruits, vegetables, wheat, and barley are also common in this area [21]. The climate in this area is dry, hot in summer and cold in winter Rainfall varies greatly among seasons which has an annual average of 50-60 mm. The soils this area consist of sandy plains of different canals and sandy plains of marshes Rumaila with the presence of sedimentary plains topped by sandy layers, a sedimentary joint and a lower slope valley, coastal plains, and wet coastal sand, and there are rocky plains in some places [22].

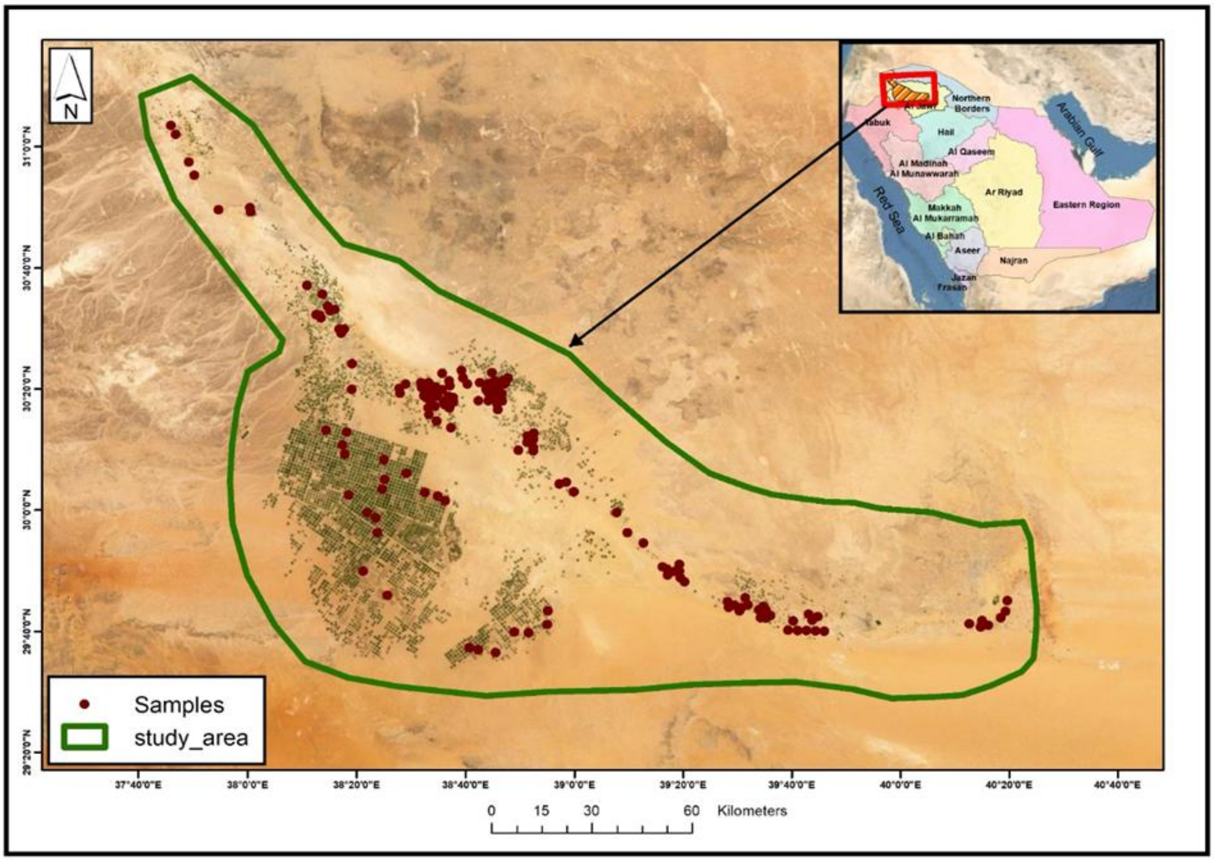

Fig. 1. Location of the study area and sampling

2.2 Chemical Analysis

Groundwater samples were collected from 150 different wells located in the Al-Jouf region to capture the spatial variations in groundwater quality. All samples of these wells were stored and later were analyzed for EC, pH, Ca_2^+, Mg_2^+, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, and B. The EC (Electrical conductivity) was measured by using an EC meter in units of dS/m at 25 °C (Test kit Model 1500_20 Cole and Parmer).

The water reaction (pH) was determined using a pH meter (pH meter—CG 817). While the soluble Ca_2^+ and Mg_2^+ were determined by versenate titration method (EDTA). Whereas the soluble Na^+ and K^+ concentrations were measured using flame photometer (Corning 400) [34-14].. The HCO_3^- concentration was determined by titration with sulfuric acid (H_2SO_4), whereas the Cl^- concentration was determined by titration with silver nitrate ($AgNO_3$) [23]. The sulfate (SO_4^{-2}) concentration was determined by the turbidity method [24]and the nitrate

(NO_3^-) concentration was determined by the phenoldisulfonic acid method [25]. The B was measured using azomethine-H method [26].

2.3 Accuracy of collected data Ion balance errors

The correctness of the chemical analysis was verified by calculating ion balance errors; furthermore, standard solutions and blanks were commonly run to check for possible errors in the analytical procedures. The level of error in the data was calculated using the following formula (1) [27]:

$$\text{Error of ion balance} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100 \qquad \textbf{(1)}$$

An error of up to ±10 % is tolerable, while every water sample with a calculated error outside this range should be measured again. Approximately 95 % of the measured water samples were within this range. This means that the resultant data quality is sufficient for chemical modeling and/or for drawing simple conclusions about water quality, between 0.2 and 10.7.

2.4 Calculation of water quality index

The DWQI calculations include three successive steps [6,14,28,29] as indicated below:
The first step is “assigning weight”: each of the 12 parameters has been assigned a weight (wi) according to its relative importance in the overall quality of drinking water as shown in Table 1. The most significant parameters have a weight of 5 and the least significant have a weight of 1 In this study, the maximum weight of 5 has been assigned to nitrate, due to its major importance in water quality assessment [30], the less harmful parameters i.e., calcium, magnesium, and sodium have been given a weight of 2.

Table 1. Relative weight for parameters [30]

Chemical parameters	Weights (wi)	Relative weight (Wi)
pH	3	0.0938
TDS (mg L^{-1})	5	0.1563
Calcium (mg L^{-1})	2	0.0625
Magnesium (mg L^{-1})	2	0. 0625
Sodium (mg L^{-1})	2	0. 0625
Potassium (mg L^{-1})	3	0.0938
Bicarbonate (mg L^{-1})	3	0.0938
Chloride (mg L^{-1})	3	0.0938
Sulfate (mg L^{-1})	3	0.0938
Nitrate (mg L^{-1})	3	0.0938
Boron (mg L^{-1})	3	0.0938
Total	32	1

The second step is the “relative weight calculation”: the relative weight (Wi) is computed from the following equation (2):

$$Wi = \frac{wi}{\sum_{i=1}^{n} wi} \qquad \textbf{(2)}$$

Where *Wi* is the relative weight, *wi* is the weight of each parameter and n is the number of parameters. The calculated relative weight (*Wi*) values of each parameter are given in Table 1.

Table 2. Parameters WHO standards

Parameters	Unit	Standards
pH		6.5–8.5
Hardness	mg/L	500
TDS		600
Calcium		75
Magnesium		50
Sodium		200
Potassium		12
Bicarbonate		120
Chloride		250
Sulfate		250
Nitrate		10
Boron		0.5

The third step is “quality rating scale calculation”: the quality rating scale (qi) for each parameter is calculated by dividing the parameter concentration in each water sample by its respective standard (WHO2011) (Table 2) multiplied by 100 as shown below in equation (3):

$$\mathrm{qi} = \frac{\mathrm{Ci}}{\mathrm{Si}} \times 100 \quad \textbf{(3)}$$

where qi is the quality rating, Ci is the concentration of each chemical parameter in each water sample in milligrams per liter, except pH, and Si is the WHO (2011) standard for each chemical parameter. Finally, the Wi and qi is used to calculate the SIi for each chemical parameter, and then the WQI is calculated from the following equations (4) and (5):

$$\mathrm{SL}i = \mathrm{Wi} \times \mathrm{qi} \quad \textbf{(4)}$$

$$\mathrm{WQI} = \sum_{i=1}^{n} \mathrm{SL}i \qquad \textbf{(5)}$$

where SIi is the sub index of each parameter; qi is the rating based on concentration of each parameter and n is the number of parameters. The computed WQI values are classified into five categories, as shown in Table 3.

Table 4. Irrigation water quality criteria classification [33]

Table 3. Water quality classification based on WQI

WQI Range	**Class**	**Type of water**
<50	I	Excellent water
50–100.1	II	Good water
100–200.1	III	Poor water
200–300.1	IV	Very poor water
>300	V	Water unsuitable for drinking

2.5 Hydro-chemical characterization

The hydro chemical characterization of the untreated groundwater samples was evaluated by means of major ions, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, and SO_4^{2-}. The chemical analysis data of the water samples were plotted on the Piper, Schoeller, and Durov diagrams using Geochemistry Software Aq.QA, version AQC10664 for the identification of water types. The [31]and US salinity laboratory [32] diagrams were also presented in this study. In addition, salinity hazard, sodium adsorption ratio (SAR), total hardness (as $CaCO_3$), and Kelly's ratio (KR) were calculated to investigate the groundwater suitability for irrigation.

2.6 Irrigation water quality index (IWQI)

IWQI is calculated through the following equations from (6) to (11) as proposed by [9,16]; Table (4-8).

$$\text{IWQ Index} = \sum_{i=1}^{5} Gi \qquad \textbf{(6)}$$

where is an incremental index and G representing the contribution of each one of the five hazard categories that are important to assess the quality of an irrigation water resource. The first category is the salinity hazard that is represented by the EC value of the water and is formulated as:

$$G_1 = w_1 r_1 \qquad (7)$$

where w is the weight value of this hazard group and r is the rating value of the parameter as given in Table 5.

Table 4 represents the groundwater quality criteria according to [19]. It includes various potential irrigation problems (effect of salinity on crop water availability, permeability, and specific ion toxicity) and their degrees of restriction on use.

Potential irrigation problem		Unit	Degree of restriction on use		
			None	**Slight to moderate**	**Severe**
Salinity (affects the crop water availability)	EC	μS/cm	<700	700–3,000	>3000
	TDS	mg/l	<450	450– 2,000	>2000
Permeability (affects the infiltration rate into soil)	SAR=0–3	and EC=	>700	700–200	<200
	SAR=3–6		>1200	1,200–300	<300
	SAR=6–12		>1900	1,900–500	<500
	SAR=12–20		>2900	2,900–1,300	<1300
	SAR=20–40		>5000	5,000–2,900	<2900
Specific ion toxicity (effects sensitive crops)	Sodium*	SAR	<3	3.0–9.0	>9
	Chloride*	mg/l	<140	140–350	>350
	Boron	mg/l	<0.7	0.7–3.0	>3
Miscellaneous effects (effects susceptible crops)	Nitrate–nitrogen	mg/l	<5	5–30	>30
	Bicarbonate	mg/l	<90	90–500	>500
	pH	–	Normal range 6.5–8.4		

*Surface irrigation.

Classification for IWQI parameters is presented in Table 5, The table reflects five hazards categories that are important to assess the quality of an irrigation water resource. These includes salinity, infiltration and permeability, specific ion toxicity, and trace element toxicity as well as miscellaneous effects to sensitive crops. Every hazard was given a weight to rank its suitability for agricultural uses.

Table 5 Classification for IWQI parameters

Hazard	Weight Parameter	Parameter	Range	Rating	Suitability
Salinity hazard	5	Electrical conductivity (µS/cm)	EC < 700	3	High
			700 ≤ EC ≤ 3,000	2	Medium
			EC > 3,000	1	Low
Infiltration and permeability hazard	4	See Table 4 for details			
Specific ion toxicity	3	Sodium adsorption ratio (-)	SAR < 3.0	3	High
			3.0 ≤ SAR ≤ 9.0	2	Medium
			SAR > 9.0	1	Low
		Boron (mg/l)	B < 0.7	3	High
			0.7 ≤ B ≤ 3.0	2	Medium
			B > 3.0	1	Low
		Chloride (mg/l)	CI < 140	3	High
			140 ≤ CI ≤ 350	2	Medium
			CI > 350	1	Low
Trace element toxicity	2	See Table V for details			
Miscellaneous effects to sensitive cops	1	Nitrate Nitrogen (mg/l)	NO3–N < 5.0	3	High
			5.0 ≤ NO3–N ≤ 30.0	2	Medium
			NO3–N > 30.0	1	Low
		Bicarbonate (mg/l)	HCO3 < 90	3	High
			90 ≤ HCO3 ≤ 500	2	Medium
			HCO3 > 500	1	Low
		pH	7.0 ≤ pH ≤ 8.0	3	High
			6.5 ≤ pH < 7.0 and 8.0 < pH ≤ 8.5	2	Medium
			pH < 6.5 or pH > 8.5	1	Low

Table 6 described the second category regarding the infiltration and permeability hazard which was represented by EC-SAR combination and is formulated as:

$$G_2 = w_2 r_2$$ **(8)**

where w is the weight value of this hazard group and r is the rating value of the parameter as given in Table 6. Infiltration and permeability are very much affected by SAR and EC levels.

Table 6. Classification for infiltration and permeability hazard

	SAR					**Rating**	**Suitability**
	<3	**3–6**	**6–12**	**12–20**	**>20**		
EC	>700	>1200	>1900	>2900	>5000	3	High
	700-200	1200-300	1900-500	2900-1300	5000-2900	2	Medium
	<200	<300	<500	<1300	<2900	1	Low

Table 7 below explained the third category which the specific ion toxicity is involved SAR, chloride and boron ions in the water and is formulated as a weighted average of the three ions:

$$G_3 = \frac{w_3}{3}\sum_{j=1}^{3} r_j \qquad \textbf{(9)}$$

where j is an incremental index, w is the weight value of this group as given in Table 5 and r is the rating value of each parameter as given in Table 6. The fourth category is the trace element toxicity that is represented by the elements given in Table 7 and is formulated as a weighted average of all the ions available for analysis:

$$G_4 = \frac{w_4}{N}\sum_{k=1}^{N} r_k \qquad \textbf{(10)}$$

where k is an incremental index, N is the total number of trace element available for the analysis, w is the weight value of this group and r is the rating value of each parameter as given in Table 7.

Several heavy metal such as (Arsenic, Cadmium, Cobalt, Copper, Iron, Lead, Manganese, Molybdenum, and Zinc were classified and rated in table 7 to show the suitability levels of the toxicity.

Table 7. Classification for trace element toxicity

Factor	**Range**	**Rating**	**Suitability**
Arsenic (mg/l)	As < 0.1	3	High
	0.1 ≤ As ≤ 2.0	2	Medium
	As > 2.0	1	Low
Cadmium (mg/l)	Cd < 0.01	3	High
	0.01 ≤ Cd ≤ 0.05	2	Medium
	Cd > 0.05	1	Low

Cobalt (mg/l)	$\mathrm{Co} < 0.05$	3	High
	$0.05 \le \mathrm{Co} \le 5.0$	2	Medium
	$\mathrm{Co} > 5.0$	1	Low
Copper (mg/l)	$\mathrm{Cu} < 0.2$	3	High
	$0.2 \le \mathrm{Cu} \le 5.0$	2	Medium
	$\mathrm{Cu} > 5.0$	1	Low
Iron (mg/l)	$\mathrm{Fe} < 5.0$	3	High
	$5.0 \le \mathrm{Fe} \le 20.0$	2	Medium
	$\mathrm{Fe} > 20.0$	1	Low
Lead (mg/l)	$\mathrm{Pb} < 5.0$	3	High
	$5.0 \le \mathrm{Pb} \le 10.0$	2	Medium
	$\mathrm{Pb} > 10.0$	1	Low
Manganese (mg/l)	$\mathrm{Mn} < 0.2$	3	High
	$0.2 \le \mathrm{Mn} \le 10.0$	2	Medium
	$\mathrm{Mn} > 10.0$	1	Low
Molybdenum (mg/l)	$\mathrm{Mo} < 0.01$	3	High
	$0.01 \le \mathrm{Mo} \le 0.05$	2	Medium
	$\mathrm{Mo} > 0.05$	1	Low
Zinc (mg/l)	$\mathrm{Zn} < 2$	3	High
	$2 \le \mathrm{Zn} \le 10$	2	Medium
	$\mathrm{Zn} > 10.0$	1	Low

Table 8 represents the suitability of the irrigation water based on the irrigation water quality index (IWQI). When the IWQ index is <22, the suitability of this water is low, while the index ranging from 22-37 is moderate. Whereas, when the IWQI exceeds 37, irrigation water will be classified as high suitable.

Table 8. Irrigation water quality (IWQI) index

IWQ index	Suitability of water for irrigation

< 22	Low
22–37	Medium
> 37	High

The fifth and the final category is the miscellaneous effects to sensitive crops that is represented by nitrate–nitrogen and bicarbonate ions and the pH of the water, and is formulated as a weighted average:

$$G_5 = \frac{w_5}{3} \sum_{m=1}^{3} r_m \qquad \textbf{(11)}$$

where m is an incremental index, w is the weight value of this group and r is the rating value of each parameter as given in Table 5 above.
Sodium adsorption ratio SAR was calculated through the below equation (12):

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca} + \mathrm{Mg}}{2}}} \qquad (\mathbf{12})$$

The effect of sodium on water quality for irrigation usage was measured using the below Kelly's ratio (KR).

$$\mathrm{KR} = \frac{\mathrm{Na}}{\mathrm{Ca} + \mathrm{Mg}} \qquad (\mathbf{13})$$

Residual sodium carbonate (RSC) was calculated as indicated in equation 14 below;

$$\mathrm{RSC} = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \qquad \mathbf{(14)}$$

Magnesium hazard (MH) was computed through the following equation:

$$\mathrm{MH} = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100 \qquad \mathbf{(15)}$$

Sodium percent was calculated as follow:

$$\%\mathrm{Na} = \frac{Na^+}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100 \qquad \mathbf{(16)}$$

Soluble sodium percentage (SSP) was expressed below in equation 17:

$$\mathrm{SSP} = \frac{Na^+}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \qquad \mathbf{(17)}$$

Total hardness (TH) was computed via the following equation:

$$\mathrm{TH} = Ca^{2+} + Mg^{2+} \times 50 \qquad \mathbf{(18)}$$

Permeability index (PI) was also calculated as follow:

$$\mathrm{PI} = \frac{Na^+ + \sqrt{HCO_3^-}}{(Ca^{2+} + Mg^{2+} + Na^+} \times 100 \qquad \mathbf{(19)}$$

3. Statistical Analysis

The data was analyzed using the statistical package for social sciences (IBM SPSS Statistics 21 Core System, IBM Corporation 2012). descriptive statistics such as (maximum, minimum, mean, standard deviation, variance, standard error, median, skewness) was applied. Spearman's correlation matrix (assuming p<0.01) was also used to measures the closeness of the relationship between chosen variables.

4. RESULTS AND DISCUSSION

4.1 Water quality assessment for drinking purpose

The statistical analysis of the groundwater was applied to identify the chemical parameters that are needed for water quality evaluation for both drinking and irrigation purposes (Table 9a and 9b). It was noticed that, mean, median and maximum for most parameters of groundwater of Al-Jour region are within acceptable rates of the standard guide proposed by WHO and Saudi standards [2,7]. [21] used CWQI method to evaluate the water quality. Besides that, the following parameters, salinity index, salinity, SAR, Na%, and residual sodium carbonate (RSC) alkali damage index were also to evaluate the groundwater quality of groundwater.

Table 9a. Descriptive Statistics of Al-Jouf Groundwater chemical composition (n = 150)

	pH	EC dS^{-1}	Ca^{2+} mg L^{-1}	Mg^{2+} mg L^{-1}	Na^{+} mg L^{-1}	K^{+} mg L^{-1}	Cl^{+} mg L^{-1}	HCO_3^{-} mg L^{-1}	CO_3^{-2} mg L^{-1}	SO_4^{-2} mg L^{-1}	B mg L^{-1}	NO_3^{-}
Maximum	7.92	6.7	76.9	238.8	91.3	18.8	2100	1220	0	400.52	1.51	4.5875
Minimum	7.2	0.28	8	0	14.9	1.3	28	0	0	30.58	0	0.0875
Mean	7.5351	1.6703	28.438	22.685	42.787	6.6193	433.61	257.89	0	102.98	0.339	1.7642
SD	0.1632	1.4224	14.958	26.375	18.057	4.2569	423.15	194.89	0	93.711	0.3958	0.8477
Variance	0.0266	2.0232	223.73	695.65	326.06	18.121	179053	37980	0	8781.7	0.1567	0.7186
SE	0.0133	0.1161	1.2213	2.1535	1.4744	0.3476	34.55	15.912	0	7.6515	0.0323	0.0692
Median	7.55	1.265	24.35	15.24	38.75	4.75	280	183	0	56.67	0.183	1.7125
Skew	-0.0442	1.4533	1.0469	4.5855	0.6208	0.6577	1.5439	1.7502	0	1.5801	2.0476	0.5175

Table 9b. Descriptive Statistics of Al-Jouf Groundwater chemical composition (n = 150)

	SAR	KR	RSC	MH	IWQI	DWQI	Na %	TH	SSP%	PI%
Maximum	15.439	4.0174	3.5	0.75	36.973	319.14	75.53	1650	0.814001	0.995973
Minimum	0.6892	0.3214	-24	0	25.421	40.771	22.34	85	0.304792	0.339279
Mean	4.2382	1.0765	-3.5583	0.2827	32.678	96.99	46.71	382.63	0.508586	0.674354
SD	3.0389	0.6101	4.8094	0.1696	3.5621	56.146	-	-	-	-
Variance	9.2347	0.3722	23.13	0.0288	12.688	3152.3	-	-	-	-
SE	0.2481	0.0498	0.3927	0.0138	0.2908	4.5843	-	-	-	-
Median	3.6748	1.0038	-2.05	0.2673	33.196	75.804	-	-	-	-
Skew	1.0851	1.8751	-1.9843	0.2752	0.5832	1.6192	-	-	-	-

4. 2 Evaluation water quality for drinking purposes

Regarding the evaluation of water quality, the computed DWQI values for the 150 well waters in Al-Jouf, region ranged from 40.7 to 319.1 (Fig. 2), 23.8% of studied wells were considered poor water "class (III)", 9.9% were very poor water "class (IV)", 45.6% were good water for drinking or "class (II), and 20.53% were excellent water (Fig. 2). The reasons for the high DWQI values obtained for this study area in some wells have high values of TDS (total dissolved solids), Mg^{2-}, Ca^{2-}, HCO_3^-, Cl^-, and NO_3^-. The degree of a linear association between the water quality parameters and WQI has been measured by the simple correlation coefficient (r) (Tables 10). Correlation analysis measures the closeness of the relationship between chosen variables; if the correlation coefficient is nearer to +1 or −1, the linear relationship between the two variables is perfected [1,2,25]. It was observed that the total dissolved solid (TDS) variations are mainly controlled by sulfate (r=0.91), chloride (r= 0.91) and total hardness (r= 0.98) concentrations. The calculated WQI showed also highly significant interrelation between its values and TDS (r=0.96), HCO_3^- (r=0.76), Cl^- (r=0.93), SO_4^{-2} (r=0.85), and total hardness (r=0.94) (Table 10).
According to [57], TDS showed strong positive correlation with Mg^{2+} (0.94), Cl^- (0.95), SO_4^{-2} (0.89) Ca^{2+} (0.77), Na^+ (0.73) and moderate correlation with NO_3^- (0.67) which showed that these ions are largely sourced from chemical fertilizers used in agriculture. Very high correlation coefficients between these values were also reported by [19,53,35,24]. Likely, most of wells in studied area were considered for drinking purposes, and all of them may be used in irrigation.
The suitability of water quality for various proposals such as drinking, or irrigation can be categorized based on chemistry parameters and indexes. Water balance in terms of quality and utilization using the result of individual parameters can be useful in decision-making by managers and administrative organizations [18].

Table 10. Correlation coefficient matrix of water quality parameters and WQI (n=150)

Parameters	**pH**	**TDS**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**HCO_3^{-}**	**Cl^{-}**	**SO_4^{-2}**	**NO_3^{-}**	**B**	**Total Hardness**	**WQI**
pH	1	-0.1628	-0.186	0.1096	-0.078	0.0293	-0.0247	-0.1906	-0.1658	-0.1145	-0.1466	-0.1849	-0.1323
TDS		1	-0.1603	0.3175	0.3815	-0.6234	0.6697	0.9685	0.9088	0.185	0.4932	0.9588	0.9658
Ca^{2+}			1	-0.1351	0.6407	0.5133	-0.343	-0.0988	-0.2443	-0.0502	-0.2313	-0.1016	-0.1567
Mg^{2+}				1	0.0117	-0.207	0.2374	0.2856	0.2865	0.1303	0.262	0.4446	0.3737
Na^{+}					1	0.256	0.0642	0.4212	0.315	-0.0096	0.1662	0.3153	0.3916
K^{+}						1	-0.5328	-0.6009	-0.5493	-0.1476	-0.3252	-0.6573	-0.5611
HCO_3^{-}							1	0.5942	0.5579	0.1379	0.2604	0.6501	0.7607
Cl^{-}								1	0.8618	0.1703	0.475	0.9479	0.9363
SO_4^{-2}									1	0.1417	0.4932	0.8552	0.8563
NO_3^{-}										1	-0.0086	0.1888	0.2125
B											1	0.4762	0.4667
Total Hardness												1	0.9401
WQI													1

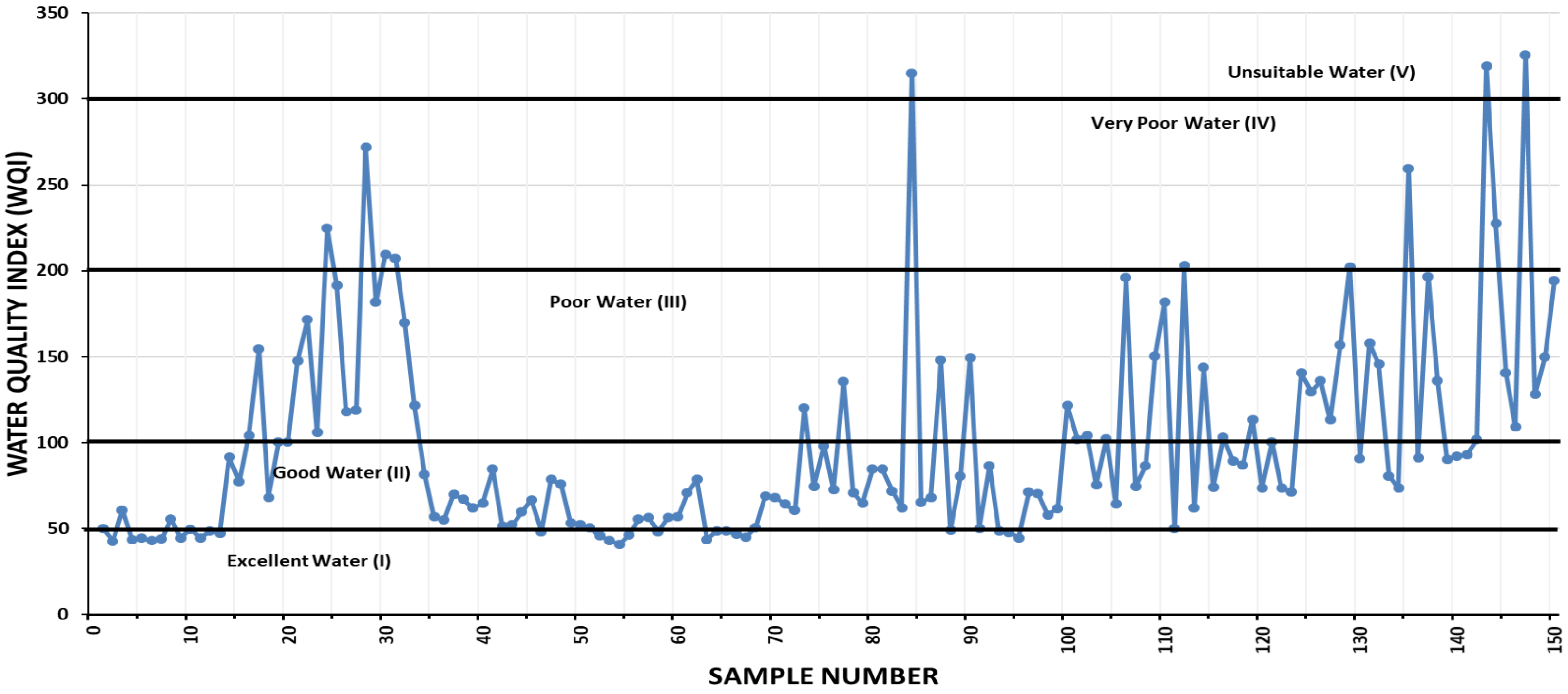

Fig. 2. Drinking water quality index (DWQI) for 150 wells in Al-Jouf region, Saudi Arabia.

4.3 Evaluation of water quality for irrigation purposes

The major ions chemistry of groundwater samples of Al-Jouf were statistically analyzed and the results summarized by minimum, maximum, mean as shown in (Table 9a, 9b). Suitability of the groundwater for irrigation purpose was discussed based on the following basic criteria:

(i) The cations: the concentrations of Ca^{++}, Mg^{++}, Na^{+}, and K^{+} ions ranged between 8 and 76.9, 0 and 238.8, 14.9 and 91.3, 1.3 and 18.8 mgL-1 with a mean value of 28.4, 22.6, 42.7, 6.6, mgL^{-1}, respectively (Table 9). The maximum permissible limit of these ions in irrigation water is 75, 50, 200, and 12 ppm, respectively [40-42]. On the basis of these permissible limits only, most of the wells water are considered suitable for irrigation usage with respect to Ca++, Mg++, Na+, respectively.

(ii) The anions: the concentrations of HCO_3^{-}, Cl^{-}, SO_4–, and NO_3^{-} ions lie in between: 0 - 1220; and 28 – 2100; and 30.5 - 400.52; and 0.08 - 4.5875 mgL-1, respectively with a mean value of 257.89, 433.6, 102.98, and 1.76 mgL^{-1}, respectively (Table 9). The maximum permissible limit of HCO_3^{-}, Cl^{-}, SO_4–, and NO_3^{-} in irrigation water is 120, 250, 250, and 30 ppm [19-40-41-43]. According to the standards, most of the wells are suitable for irrigation usage with respect to HCO_3^{-}, Cl^{-}, SO_4–, and NO_3^{-}.

(iii) pH; the pH is a term used universally to express the intensity of the acid or alkaline condition of a water. Table 9 showed that the pH values of the water samples ranged between 7.2 and 7.92 with a mean value of 7.53. These mean that all studied water samples were within safe limit with respect to pH [19].

(iv) Salinity hazard: determination of salinity hazard is very important in irrigation water as high salt content renders the soil saline. This also affects the salt intake capacity of the plants through the roots. EC is a measure of water capacity to convey electric current. It represents the amount of TDS. Thus, in the present study, the salinity hazard was evaluated by TDS, their amounts varied from 179.2 to 4288 mg L^{-1} with an average value of 1024 mg L^{-1}. Salinity is between excellent and doubtful based on the classification of TDS suggested by Ayers and Westcot [19]. The suitability of wells is summarized in Table (11).

(v) Sodium hazard: the excessive sodium content in water sample reduces the permeability, and hence, the available water for the plant is reduced. Sodium replacing adsorbed calcium and magnesium is a hazard, as it causes damage to the soil structure resulting in compact and impervious soil [33]. Excess absorption of sodium can cause sodium toxicity in sensitive plants, causing marginal leaf burn on older foliage and possibly defoliation. The water containing excessive amount of sodium may immobilize other nutrient ions particularly calcium, magnesium, and potassium, which can result in deficiencies of these elements in plants [34].

(vi) Excess amounts Na^{+}, Ca_2+, $Mg_2^{+}$and HCO_3^{-} in the irrigation water affect soil permeability through widespread irrigation water use [35].

(vii) One of the most important criteria in determining sodium hazard is Sodium Adsorption Ratio (SAR) [36].

(viii) The SAR values of the groundwater samples varied between 0.6892 and 15.439 with an average value of 4.275 (Table 9). About 85 % of the SAR values of the water samples were less than 10 and are classified as excellent for irrigation [32] as presented in (Table 11). In addition, spatial distribution of SAR in the region were measured and

Table 11. Classification of water samples within the study area for irrigation based on %Na, SAR, MH, KR RSC, TDS

Parameters	Range	Water class	References
TDS	<450	Best	
	450-2000	Moderate	
	>2000	Hazard	[5,16,24,34]
SAR	0–10	Excellent	
	10–18	Good	

presented in Fig. (3) as the values increasing in North part of the region which might create a sodium hazard with
intensive agricultural activities. This area should be monitored closely to prevent any accumulation of Na and cause further sodium hazard.

	18–26	Doubtful
	>26	Unsuitable
RSC	<1.25	Good
	1.25–2.5	Doubtful
	>2.5	Unsuitable
KR	<1	Suitable
	1–2	Marginal suitable
	>2	Unsuitable
SSP	<50	Good
	>50	Unsuitable
PI	>75	Class-I
	25–75	Class-II
	<25	Class-III
MH	<50	Suitable
	>50	Harmful Unsuitable
Na%	<20	Excellent
	20–40	Good
	40–60	Permissible
	60–80	Doubtful
	>80	Unsuitable
T.H	<75	Soft
	75–150	Moderately Hard
	150–300	Hard
	>300	Very Hard

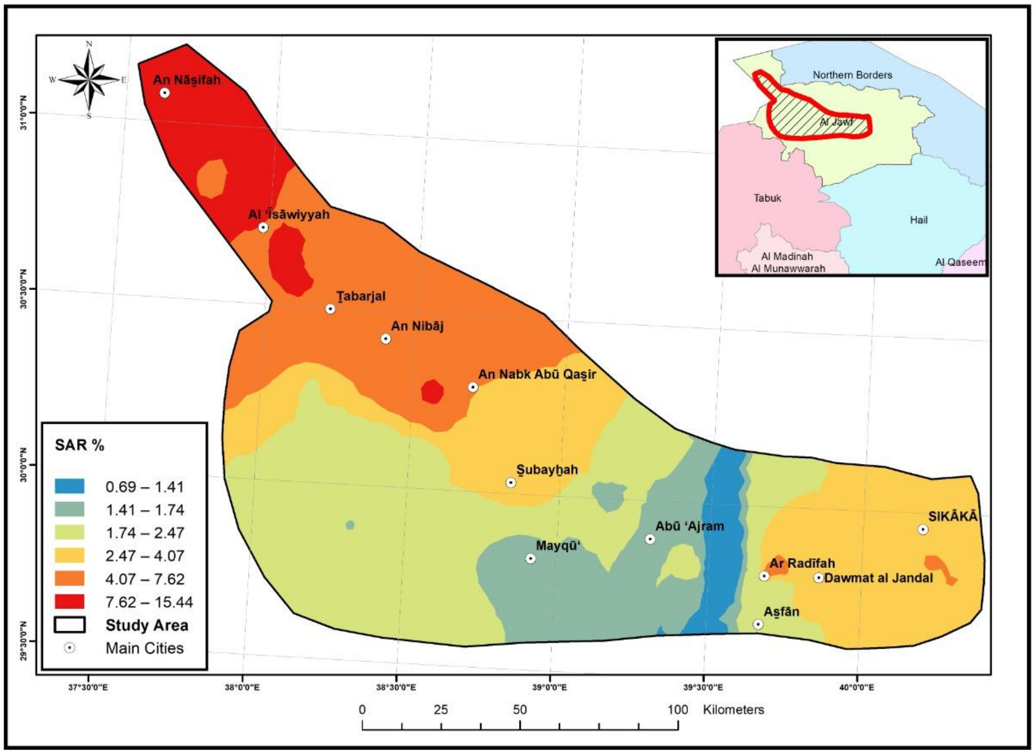

Fig. 3. Spatial distribution of SAR values in Al-Jouf area

[14], was also determined the hazardous effect of sodium on water quality for irrigation usage in terms of Kelly's ratio (KR) as discussed previously in equation (13).
where the ionic concentrations are in meq. per liter. A Kelly's ratio of more than one indicates excessive sodium in water. Therefore, water with a Kelly's ratio less than one is considered suitable for irrigation; on the other hand, the ratio more than one is unsuitable. The Kelly's ratios in the studied water ranged between 0.3214 and 4.02 with an average value of 1.08 (Table 9). About 60 % of the studied waters are considered suitable for irrigation with Kelly's ratio less than one [19].
Boron toxicity, the boron concentrations were within permissible limits in the 92% of water samples and the remaining samples were considered slight to moderate boron toxicity (Table 9) [19].

Residual sodium carbonate (RSC): RSC represent as the amount of sodium carbonate ($NaCO_3$) and sodium bicarbonate ($NaHCO_3$) present in the irrigation water.

The RSC in the studied water ranged between -24 and 3.5, with an average value of -3.5 (Table 9b). About 98 % of the studied waters are considered suitable for irrigation.

Magnesium hazard (MH): Usually, alkaline earths (Ca_2^+ and Mg_2^+) are in an equilibrium state in groundwater. Both Ca_2^+ and Mg_2^+ ions are linked with soil friability and aggregation, but both are also essential nutrients for the crop. The high value of Ca_2^+ and Mg_2^+ in water can increase soil pH (therefore soil converting it to saline Nature of the soil, resulting in decrease in the availability of phosphorous. Excess concentration of magnesium in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield. According to agriculturists, excess amount of Mg_2^+ ions in waters damage the soil quality which causes low crop production. It is calculated as indicated previously in equation 15.

The MH in the studied water ranged between 0 and 0.75, with an average value of 0.28 (Table 9b). About 100 % of the studied waters are considered suitable for irrigation.

Sodium percent (%Na): The %Na is also used in classifying water for irrigation purpose. Na^+ is important parameter and helps in categorization of any source of water for irrigation uses. It is calculated in equation 16 above. The (%Na) in the studied water ranged between 22.34and 75.53, with an average value of 46.71 (Table 9b). About 76 % of the studied waters are considered suitable for irrigation (Table 11).

Soluble sodium percentage (SSP); It is also a Na estimation parameter which was calculated using equation 17 which was mentioned previously.

The (SSP) in the studied water ranged between 0.81and 0.30, with an average value of 0.50 (Table 9b). About 100 % of the studied waters are considered suitable for irrigation (Table 11).

Total hardness (TH): Water hardness was calculated by using equation 18 above. TH is the result of existence of divalent metallic cations (Ca_2^+ and Mg_2^+)/

The (TH) in the studied water ranged between 85-1650, with an average value of 382.63 (Table 9b). About 22 % of the studied waters are considered suitable for irrigation (Table 11).

Permeability index (PI): The permeability index (PI) is an indicator to study the suitability water for irrigation purpose and it is estimated by following equation 19; The (PI) in the studied water ranged between 0.99 and 0.33, with an average value of 0.67 (Table 9b). 100 % of the studied waters are considered suitable for irrigation.

4.4 Classes of salinity and alkalinity hazard

In this study, the US Salinity Laboratory's diagram [32] is used for irrigation water quality evaluation (Fig. 4). The salinity and alkalinity hazard class of studied well samples were C2–S1, C3–S1, C3–S2 and C4-S3. The result shows that the ground waters possess moderate to high salinity hazards with low to medium sodium hazards (Fig. 5). The excessive amount of salts in some wells of the region can be one of the major problems in water used for irrigation in the study area. According to [1], groundwater is an essential source for crop rising and food production in this region. The salinity of groundwater plays a major role in crop production. They have categorized the groundwater into four types such as low salinity (EC < 250 μS/cm), medium salinity (250 to 750 μS/cm), high salinity (750 to 2250 μS/cm), and very high salinity (>2250 μS/cm).

Some of the wells, mainly in the north part of the region (figure 6), cannot be used for irrigation of most crops without special circumstances for salinity control such as leaching requirement or cropping of salt-tolerant plants [37] as the salinity can have effect on growth and development of plants in different ways, such as osmotic effects, specific ion toxicity and/or nutritional disorders.

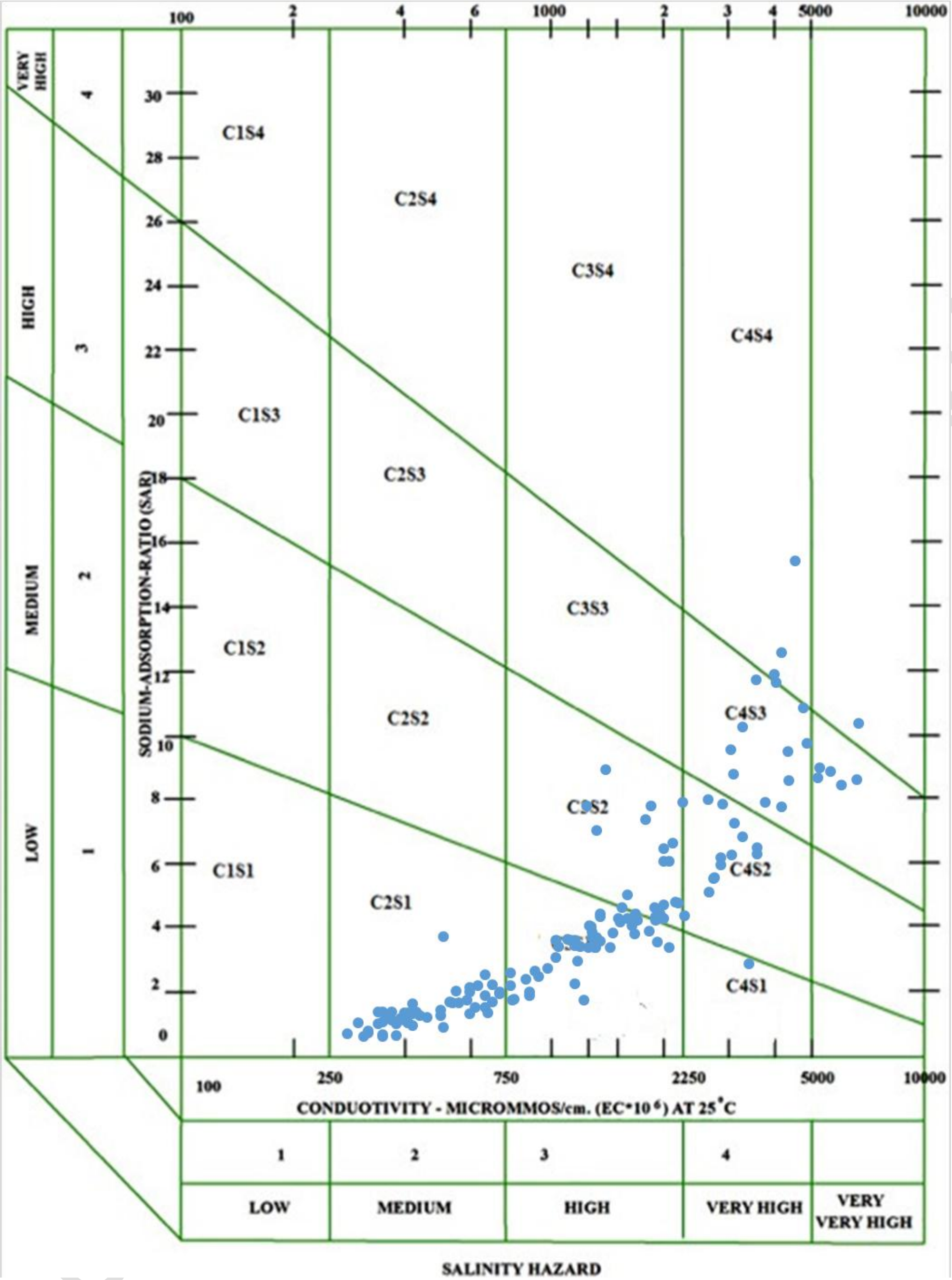

Fig. 4. Salinity classification of groundwater used irrigation

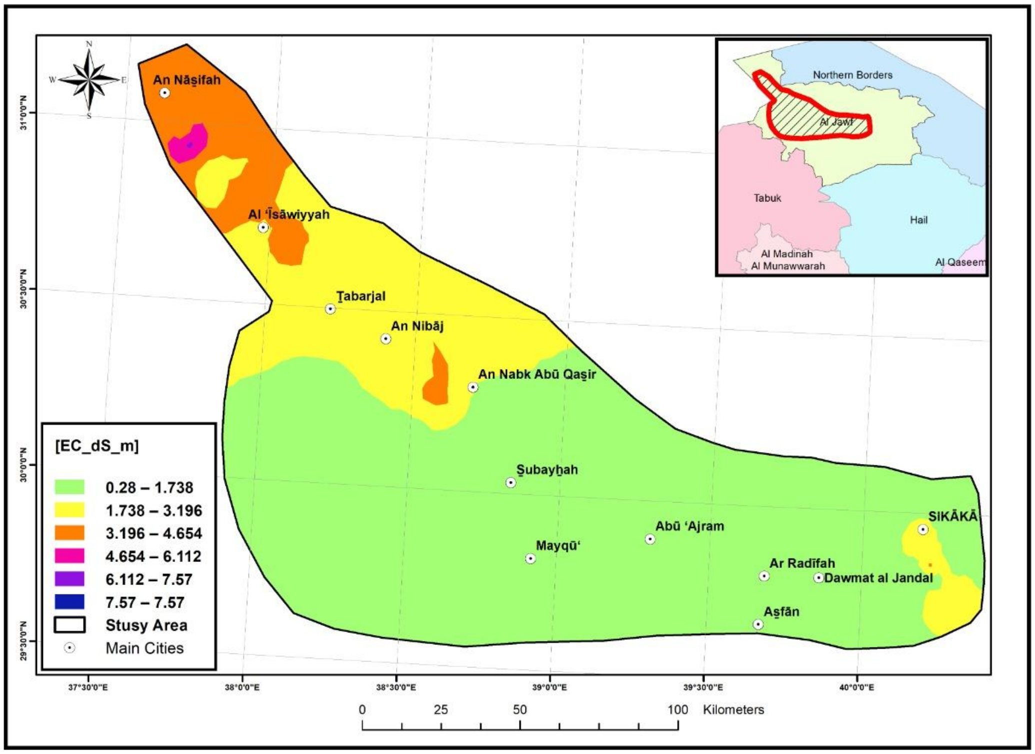

Fig. 5. Spatial distribution of Electrical conductivity (EC) in Al-Jouf region, Saudi Arabia

4.5 Hydro chemical aspects

The chemical data of the untreated groundwater samples were plotted on a Piper trilinear diagram [36] (Fig. 6). The piper diagrams provided a convenient method to classify water types collected from different groundwater resources, based on the ionic composition of different water samples [2,7] and the main water types have been identified based on the major ion concentrations. The piper diagram reveals that the water types of Al-Jouf well waters are rich in calcium- magnesium chloride-sulfate. The water type indicated that the geology in the study area mainly consist of gypsum, and anhydrite. it's obvious that predominance calcium/magnesium which is influences the tendencies towards the chloride/sulfate present. This finding is similar to [6] finding of AlHasa, Saudi Arabia well waters.

The Chemical data of well waters of Al-Jouf region are plotted in Gibbs's diagrams (Fig. 7). The distribution of sample points suggests that the chemical weathering of rock-forming minerals and evaporation are influencing the groundwater quality. Evaporation increases salinity by increasing Na+ and Cl^-) with relation to increase of TDS. The rock domain suggests that rock–water interaction is the major source of dissolved ions over the control of groundwater chemistry. The rock–water interaction process includes the chemical weathering of rocks, dissolution–precipitation of secondary carbonates and ion exchange between water and clay minerals. The evaporation greatly increases the concentrations of ions formed by chemical weathering, leading to higher salinity. The moving of groundwater sampling points in the Gibbs field towards the evaporation domain from the rock domain suggests an increase of Na^+ and Cl^- ions and consequent higher TDS due to water contamination, caused by the influences of poor sanitary conditions, agricultural fertilizers, and irrigation-return flows [7].

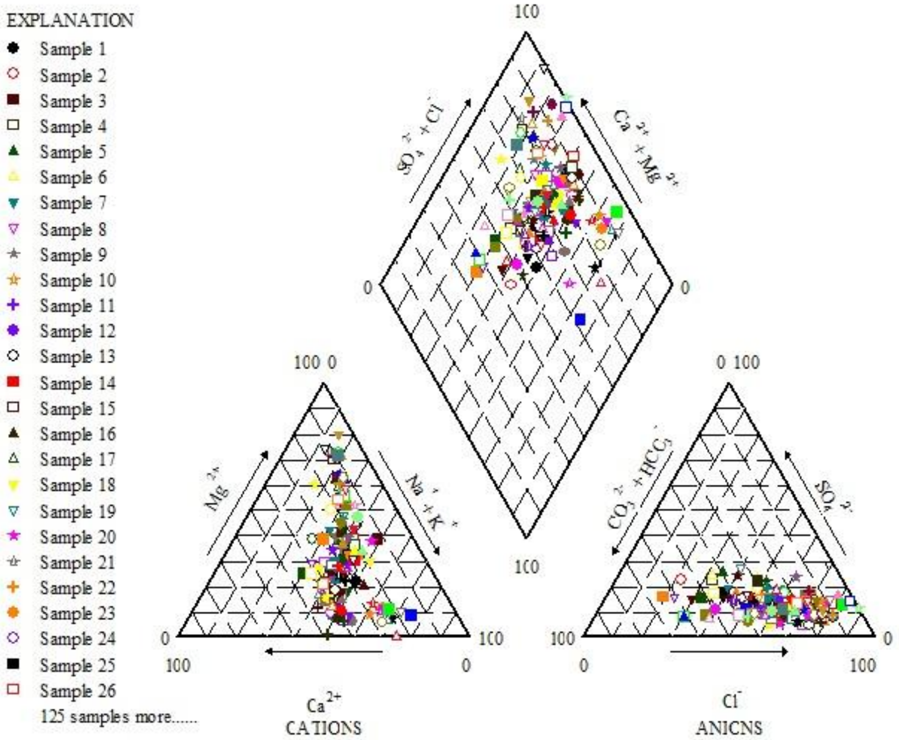

Fig. 6. Piper—tri-linear diagram of well waters of Al-Jouf region

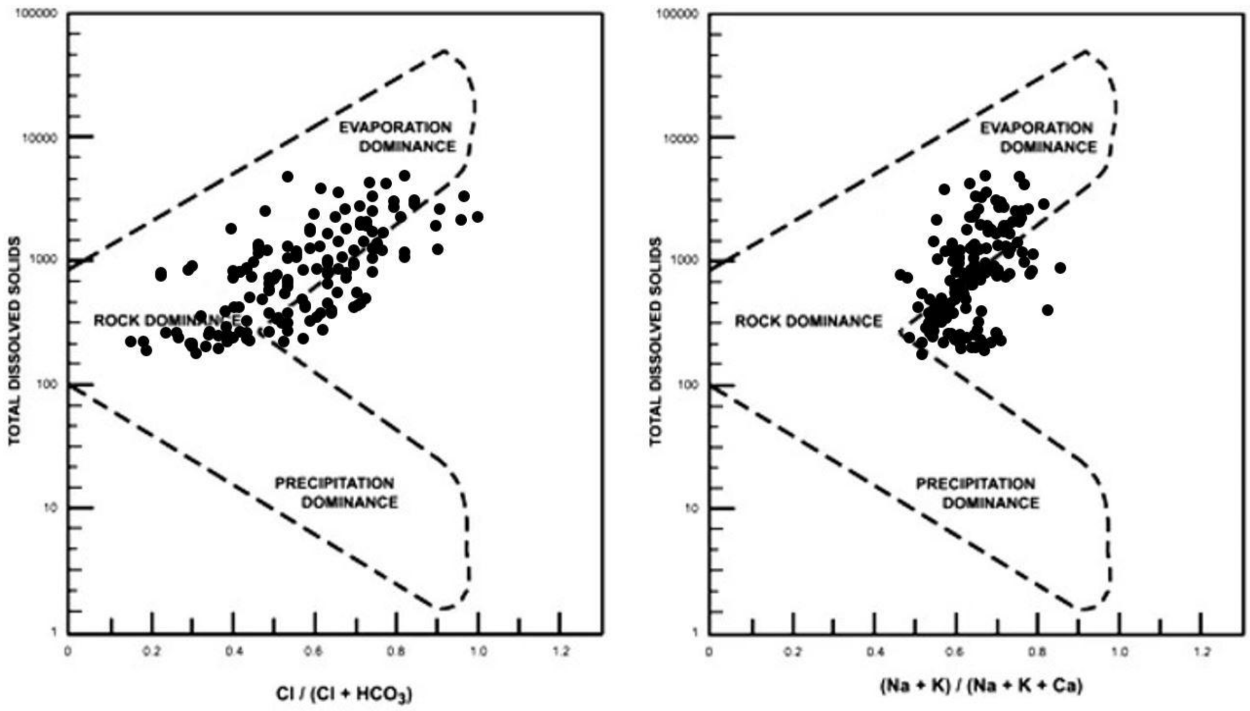

Fig. 7. Diagram depicting the mechanism controlling groundwater quality

4.6 Irrigation Water Quality Index (IWQI)

IWQI was calculated based on the proposal by Simsek, Gunduz [4] and the results presented in (Fig. 8). Accordingly, all wells water in Al-Jouf region of Saudi Arabia classified as medium in suitability and could be used for irrigation purposes. These findings agreed with those of [19] who used similar methods.

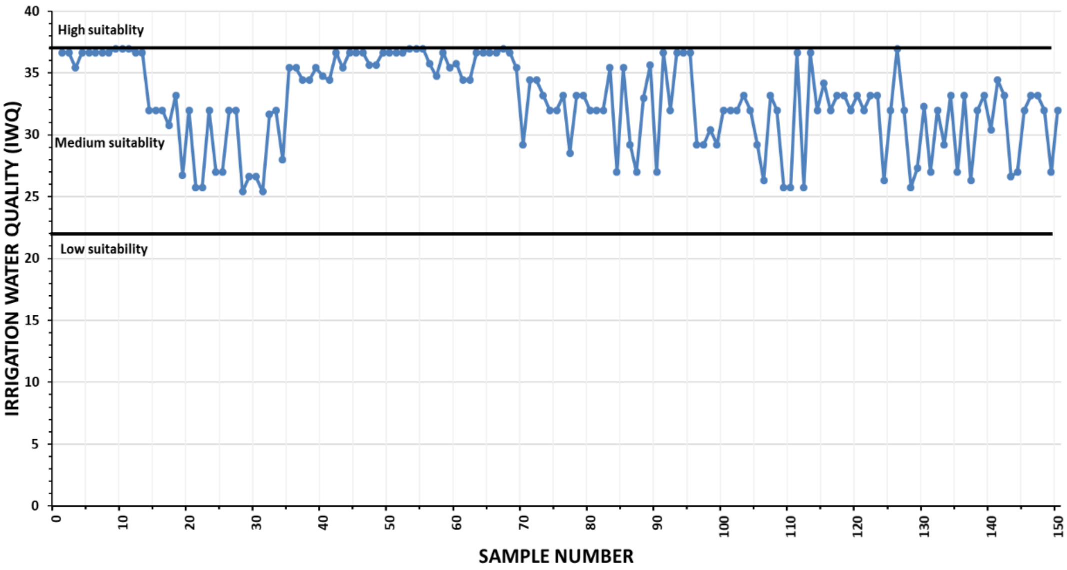

Fig. 8. Irrigation water quality index (IWQI) for 150 wells in Al-Jouf region, Saudi Arabia

CONCLUSIONS

Water quality indices have been computed to assess the suitability of groundwater for drinking and irrigation purposes in Al-Jouf, Kingdom of Saudi Arabia. 12 parameters have been considered to calculate the DWQI which includes: (pH, total dissolved solids, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, nitrate, and boron). The results indicated that 20.53% of well water considered to be excellent water, while 45.6% classified as good water. Moreover, 23.8% and 9.9 % were poor and very poor water for drinking purpose respectively. The groundwater was also evaluated for irrigation purposes. The results revealed that salinity and alkalinity hazards classes of water samples were 60% of the groundwater is in C2-S1, C3-S1, 25% in C3-S2, and 15% in C4-S3. The hydro chemical analysis showed that the analyzed water samples correspond mainly to magnesium–calcium/sulfate–chloride water types which are mainly due to the geology of the study area comprising gypsum and anhydrite. Irrigation water quality index (IWQI) was calculated for all wells water in Al-Jouf region. The result of IWQI was classified as medium in terms of suitability, thus, this could be used for irrigation purposes almost of the crops. As a result, the Al-Jouf region could contribute greatly to the sustainable agriculture if farmers use such water for irrigated agriculture in a conservative way. Effective methods should be adopted by communities of this region to protect groundwater resources, such as strengthening farmer’s awareness of water saving, improving relevant regulations, and making more reasonable planning and allocation.

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