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Analytical Groundwater Quality Assessment for Drinking and Agriculture Purposes in Al-Jouf Region, Kingdom of Saudi Arabia

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Authors' contributions

This work was carried out in collaboration among all authors. Author ANAS, is the first author as graduate student, his contribution was in execution the research work, collecting data, analyzing data, writing first draft of the manuscript and presenting the work in its form in terms of tables and figures. Author KDAO is co-advisor and work closely with first author on collecting data and interpretation of it. Author AMAO is the advisor of the graduate student his contribution was in design the work, analyzing data, interpretation of the data and final version of the manuscript All authors read and approved the final manuscript.

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ABSTRACT

Kingdom of Saudi Arabia (KSA) primarily relies depends mainly on groundwater for drinking and irrigation purposes. The study was therefore aimed to identify groundwater quality in Al-Jouf Region, KSA using water quality index (DWQI). In addition, investigating the hydro-chemical characteristics that control the groundwater quality. Groundwater samples were collected from 150 groundwater wells at a 300-500 m depth and subjected for chemical analysis. The values of chemical constituents were compared with the KSA and World Health Organization (WHO) standards for drinking and irrigation purposes. The results indicated that, the concentrations of ions were within the ranges of KSA for drinking water and WHO. Based on DWQI data, for drinking water about 23.9% of the wells were within poor water category (III), while 9.91% was very poor water within (IV) group, 45.6% is good water of group (II) and 20.5% is excellent water within category (I). Regarding the evaluation of water quality, the estimated DWQI values for the 150 well

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waters in Al-Jouf, region ranged from 40.7 to 319. About 23.9% of 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. The result shows that the groundwater possess moderate to high salinity hazards with low to medium sodium hazards. The piper diagram showed that cations were decreasing as follow: Na^{+}>Ca_2^{+}>Mg_2^{+}, while the anions were decreasing as follow Cl^{-} > HCO_3^{-} > SO_4^{2-}>CO_3^{2}-. The SAR values varied from 0.68 to 15.43; while Kelly’s ratio (KR) ranged between 0.32 to 4.02. The calculated IWQI values of all wells revealed that water was moderate type in which its value was between 22 to -27.

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

1. INTRODUCTION

Across many countries, groundwater quality is considered as important source for drinking water and irrigation activities, particularly, in the semi-arid and arid regions. Resultantly, it is estimated that groundwater is the main source for drinking [1]. Kingdom of Saudi Arabia (KSA) is in arid regions, suffers from limited water resources [2]. Exploitation of groundwater led to serious shortage of water and the deterioration of groundwater led to reduction of agricultural land in different regions of KSA [3]. In the rural area of Saudi Arabia such as Al-Jouf region is rural area in KSA, rely mainly on groundwater for drinking and agricultural activities. Al-Jouf area is considered one of the new agricultural regions in KSA with very high potential in agricultural development recently. 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 [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 information on irrigation water quality in Al-Jouf area to make necessary management decisions in crop production. Salinity and sodicity, and ion toxicity of the water are very important issues. Sodicity or the presence of too much Na^{+}, which causes the poor soil structure [4]. Various factors such as rock-water interaction, lithology, usage of fertilizers and pesticides for agricultural purposes, and climatic conditions largely influence the water quality [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 reassuring the public and farmers on their water quality [6,7]. The aim of both DWQI and IWQI parameters is to provide a simplified approach for evaluating drinking and irrigation water purposes [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, Al-Othman [12] reported that DWQI of ground water in Riyadh region, KSA ranged from 34 to 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. Similar results were reported in El-Khairat, Tunisia [14] and in Palakhal District in Kerala, India [15-18]. The proposed index utilizes five hazard groups namely salinity toxicity, infiltration rate, specific ion and heavy metals toxicity [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. This study aimed to investigate the groundwater quality assessment for drinking and agriculture purposes in Al-Jouf Region, KSA.

2. MATERIAL AND METHODS

2.1 Study Area Description

Water samples were collected from different agricultural sites in Al-Jouf aera, north of KSA (Fig. 1). Al-Jouf region has an area of 100,212 km^2, population of 508,475 and the city of Sakaka is the administrative headquarters for the region, which includes three governorates of Al-Qurayyat, Dumat Al-Jandal and Tabarjal.

Al-Jouf aera was considered one of the most fertile soils in the KSA, and its famous for olive tree cultivation. Al-Jouf area produces approximately 67% of the domestic production of olive oil in the Kingdom. Also, the cultivation of palm tree, is about 150 thousand tons of old dates additionally, fruits, vegetables and wheat [20]. Rainfall varies greatly among seasons which has an annual average of 50-60 mm. The soils in this area consist of sandy plains of different canals and sandy plains of marshes with the presence of sedimentary plains topped by sandy layers, a sedimentary joint and a lower slope valley, coastal plains, wet coastal sand, and there are rocky plains in some places [21].

2.2 Chemical Analysis

Groundwater samples were collected from different 150 different wells located in Al-Jouf aera to estimate groundwater quality. The samples were analyzed for electrical conductivity (EC), pH, cations, anions and B. The EC was measured at 25°C by using EC- meter in and pH was determined using a pH meter (pH meter—CG 817). While the Ca_2^+ and Mg_2^+ was determined by titration method; whereas the Na^+ and K^+ concentration was measured using flame photometer (Corning 400) [22,14]. The HCO_3^- and SO_4^{-2} concentration was determined by titration methos [23], while NO_3^- concentration was determined by the phenoldisulfonic acid method [24] and B was measured using azomethine-H method [25].

2.3 Accuracy of Collected Data Ion Balance Errors

The ion balance errors were used to check accuracy in the analytical procedures using the following formula (1) as described by American Public Health Association [26]:

$$\text{Ion balance} = \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \times 100 \qquad (1)$$

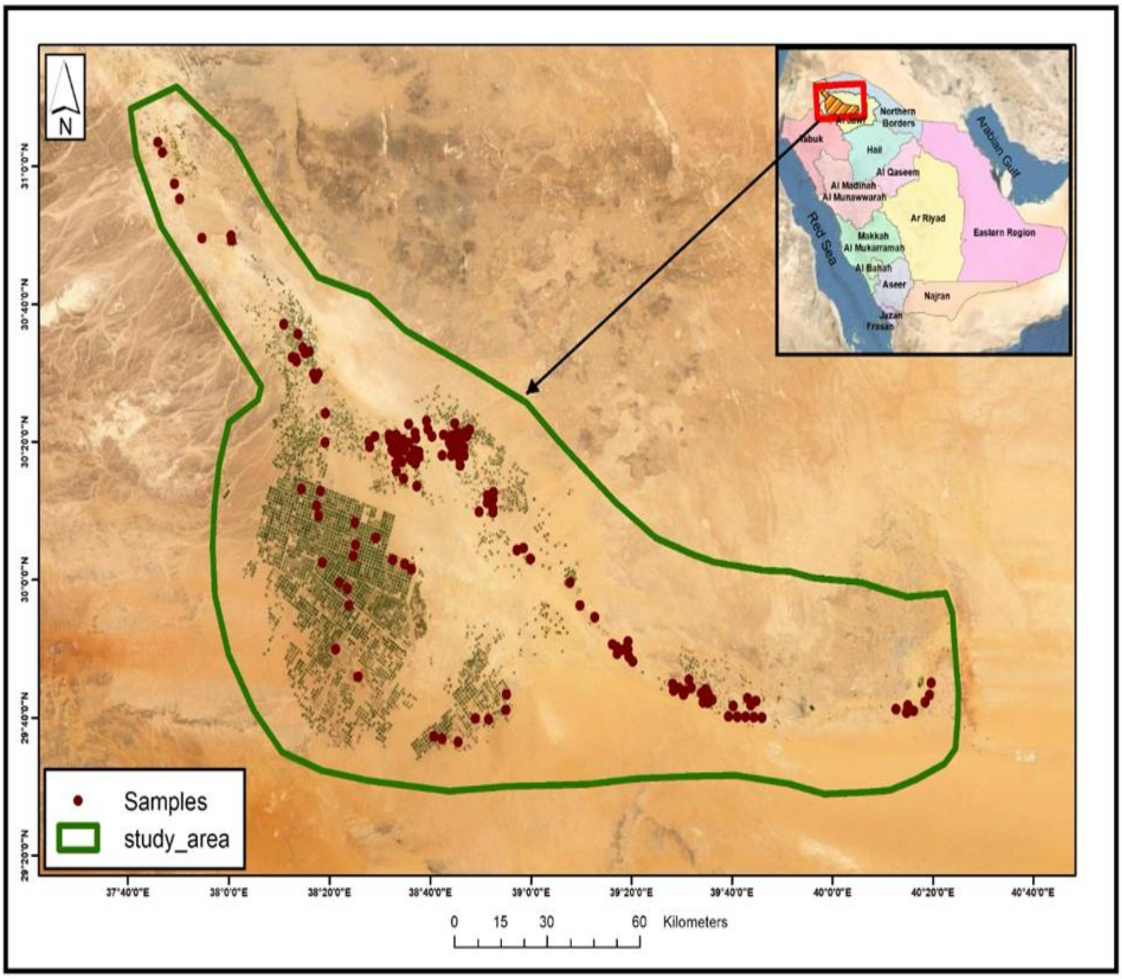

Fig. 1. Location of the study area and sampling

2.4 Water Quality Index Calculation

The DWQI calculations include three successive steps were used [6,14,27,28] as indicated below:

DWQI calculations, 12 parameters have been used including weight (wi) as shown in (Table 1). The most important parameters have a weight of (5) and the lower scale (1). The results indicated that, the maximum weight of (5) has been assigned for NO_3^-, due to its major importance in water quality assessment [29], the minimum weight (2) has been used for Ca_2^+, Mg_2^+, and Na^+.

Second the relative weight (Wi) is calculated as equation (2):

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

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

Third is the quality index (qi) for each parameter as:

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

where qi is the quality index, Ci is the concentration of each chemical parameter mg/L, except for pH, and Si is the WHO standard value, Wi and qi is used to calculate the SIi for each chemical parameter as shown in equations (4) and (5):

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

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

SIi = the sub parameter; qi = the concentration and n = the parameter number. The calculated WQI values are presented in (Table 3).

Table 1. Parameters Relative weight

Chemical parameter	Weights (wi)	Relative weight (Wi)
pH	3	0.0938
TDS (mg/L))	5	0.1563
Ca_2^+ ((mg/L))	2	0.0625
Mg_2^+ (mg/L))	2	0. 0625
Na^+ (mg L^{-1})	2	0. 0625
K^+ (mg/L)	3	0.0938
HCO_3^- (mg/L)	3	0.0938
Cl^- (mg/L)	3	0.0938
SO_4^{2-} (mg/L)	3	0.0938
NO_3^- (mg/L)	3	0.0938
B (mg/L)	3	0.0938
Total	32	1.0000

Table 2. Parameters standards for WHO

Parameters	Standards
pH	6.50 –8.50
Hardness	500
TDS (mg/L)	600
*Ca_2^+	75
Mg_2^+	50
Na^+	200
K+	12
HCO_3^-	120
Cl^-	250
SO_4^{2-}	250
NO_3^-	10
B	0.50

** (mg/L)*

Table 3. Water quality classification according to WQI

WQI Range	Index	Type of water
<50.5	I	Suitable
50.5–100.1	II	Good
100.1–200.1	III	Poor
200.1–300.1	IV	Very poor
>300.1	V	unsuitable

2.5 Hydro Chemical Characterization

The hydro chemical characterization of the untreated groundwater samples was evaluated using Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, Cl^-, and SO_4^{2-} concentrations. The piper, Schoeller, and Durov diagrams were drown using Geochemistry Software Aq.QA, version AQC10664, in addition US salinity laboratory [30] diagrams were also used. The following data, salinity hazard, sodium adsorption ratio (SAR), total hardness (as $CaCO_3$), and Kelly's ratio (KR) were calculated to assessment of the groundwater for irrigation purposes.

2.6 Irrigation Water Quality Index (IWQI)

The IWQI is calculated using equations from (6) to (11) as proposed by [9,16].

$$\text{IWQ Index} = \sum_{i=1}^{5} Gi \tag{6}$$

where is an incremental index and G the contribution of the 5 hazard groups. The first category is the salinity hazard of water is estimated using:

$$G_1 = w_1 r_1 \tag{7}$$

w = the weight value of this hazard group and r = the parameter index value of the as are shown in (Table 5).

Table (4) represents the groundwater quality according to Ayers [19]. It includes various potential irrigation problems such as salinity on crop water availability, permeability and specific ion toxicity.

Table (5) described the infiltration and permeability hazard which was represented by EC and SAR combination as:

$$G_2 = w_2 r_2 \tag{8}$$

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. Classification of Irrigation water

Potential irrigation problem		Unit	Degree of restriction use		
			None	**Slight to moderate**	**Severe**
Salinity	EC	µS/cm	<750	750–3,000	>3000
	TDS	mg/L	<450	450–2,000	>2000
Permeability	SAR=0–3	and EC=	>750	750–200	<200
	SAR=3–6		>1300	1,300–300	<300
	SAR=6–12		>1800	1,800–500	<500
	SAR=12–20		>2900	2,900–1,300	<1300
	SAR=20–40		>5000	5,000–2,900	<2900
Specific ion toxicity	*Na+	SAR	<3	3.00–9.00	>9
	Cl-	mg/L	<140	140–350	>350
	B	mg/L	<0.7	0.70–3.00	>3

Surface irrigation.

Table 5. Infiltration and permeability hazard index

	SAR-range					Rating	Suitability
	<2-3	3–6	6–12	12–20	>20		
EC-range	>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 (6) shows the specific ion toxicity involved SAR, Cl^- and B concentration ions in the water as calculated using:

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

Where j= is an incremental index, w = is the weight value and r= is the index value.

The heavy metals toxicity which calculated as:

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

Where k = is an incremental index, N = is the total number of heavy metals, w = is the weight value of this group and r = is the rating value of each parameter as given in (Table 6).

Table (7) shows the suitability of the irrigation water based on (IWQI). When the IWQ index is <22, the suitability of this water is low, while the index ranging from 22-37 is moderate and when the IWQI exceeds 37, irrigation water will be classified as high suitable.

The miscellaneous effects on sensitive crops that is included NO_3^- , HCO_3^- ions and pH of the water was estimated as:

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

Table 6. Classification for heavy element toxicity

Factor	Range	Rating	Suitability
As (mg/L)	< 0.10	3	High
	0.10 ≤ 2.0	2	Medium
	> 2.0	1	Low
Cd (mg/L)	< 0.02	3	High
	0.02 ≤ 0.06	2	Medium
	> 0.06	1	Low
Co (mg/L)	< 0.05	3	High
	0.05 ≤ 5.0	2	Medium
	> 5.0	1	Low
Cu (mg/L)	< 0.20	3	High
	0.2 ≤ 5.0	2	Medium
	> 5.00	1	Low
Fe (mg/L)	< 5.00	4	High
	5.0 ≤ 20.0	3	Medium
	> 20.0	2	Low
Pb (mg/L)	< 5.1	4	High
	5.1 ≤	3	Medium
	> 10.1	2	Low
Mn (mg/L)	< 0.20	3	High
	0.2 ≤10	2	Medium
	> 10	1	Low
Mo (mg/L)	< 0.01	3	High
	0.01 ≤ 0.05	2	Medium
	> 0.05	1	Low
Zn (mg/L)	< 2.0	3	High
	2 ≤ 10	2	Medium
	> 10.0	1	Low

Table 7. Irrigation water quality index (IWQI)

IWQ index	Irrigation Suitability
< 22.5	Low
22.5–37.6	Medium
> 37.6	High

Where m = is an incremental index, w= is the weight value and r is the index value of each parameter.
SAR:

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

Kelly's ratio (KR):

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

Residual sodium carbonate (RSC) was calculated as:

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

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

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

Sodium percent was calculated as follow:

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

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

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

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

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

Permeability index (PI) was also calculated as follow:

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

2.7 Statistical Analysis

The data was analyzed using statistics 21 core system and descriptive statistics was used to estimate the relationship between the study parameters.

3. RESULTS AND DISCUSSION

3.1 Water Quality Evaluation for Drinking

Tables (8a and 8b) indicated that, salinity index, SAR, Na%, and RSC within the acceptable groundwater quality range for drinking purpose in Al-Jour region proposed by WHO and KSA [2,7]. Besides that, the following parameters.

The computed DWQI values for the 150 well in Al-Al-Jouf, region varied from 40.7 to 319.1 (Fig. 2). About 23.8% of studied wells were considered poor water "class (III)", 9.90% very poor water "class (IV)", 45.6% good water and 20.53% excellent water. The higher DWQI values for some wells have may be due to high values of salinity, cations and NO_3^-. The relationship between the water quality parameters is shown in (Table 9). The results indicated that, the TDS variations are mainly controlled by SO_4^{--} (r=0.91), Cl^- (r= 0.91) and TH (r= 0.98). 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 TH (r=0.94). in addition, TDS have strong positive correlation with Mg^{2+} (0.94), Cl^- (0.95), SO_4^{-2} (0.89) Ca^{2+} (0.77) and Na^+ (0.73) and moderate correlation with NO_3^- (0.67). The results in agreement with those reported by [19,31,32].

3.2 Evaluation of Water Quality for Irrigation Purposes

The major ions chemistry of groundwater samples of Al-Jouf were statistically analyzed and the results are shown in (Table 8a, 8b). The concentrations of Ca^{++}, Mg^{++}, Na^+, and K^+ ions ranged between 8 and 76.9, 0 and 238, 14.9 and 91, 1.30 and 18.9 mg/L with a mean value of 28.5, 22.7, 42.8, 6.7, mg/L, respectively. The maximum permissible limit of these ions in irrigation water is 80, 55, 210, and 13 mg/L, respectively [33,34]. The most of the wells water are considered suitable for irrigation usage

Table 8a. Descriptive statistics of Al-Jouf groundwater quality

	pH	**EC**	**Ca^{2+}**	**Mg^{2+}**	**Na^{+}**	**K^{+}**	**Cl^{+}**	**HCO_3^{-}**	**CO_3^{-2}**	**SO_4^{-2}**	**B**	**NO_3^{-}**
		dS^{-1}	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Maximum	7.92	6.7	76.9	238.8	91.3	18.8	2100	1220	0	400.52	1.51	4.5875
Minimum	7.20	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 8b. Descriptive statistics of Al-Jouf groundwater quality

	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	-	-	-	-

Table 9. Correlation coefficient matrix between water quality parameters and WQI

Parameters	pH	TDS	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{-2}	NO_3^-	B	TH	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
TH												1	0.9401
WQI													1

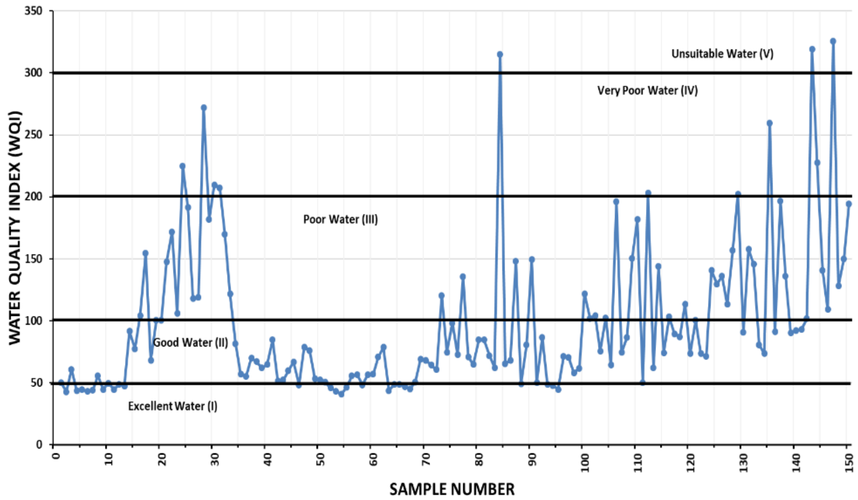

Fig. 2. Drinking water quality index (DWQI) in Al-Jouf region, KSA

with respect to Ca^{++}, Mg^{++} and Na^{+}. the concentrations of HCO_3^-, Cl^-, SO_4^{-2}, and NO_3^- ions lie in between: 0 - 1220; and 28 – 2100; and 30.5 - 403.52; and 0.08 - 4.58 mgL^{-1}, respectively with a mean value of 257.9, 432, 102.9, and 1.77 mg/L, respectively. The maximum permissible limit of HCO_3^-, Cl^-, SO_4^{-2}, and NO_3^- in irrigation water is 120, 250, 250, and 30 mg/L [19,33,35,36, 37-43]. According to the standards, most of the wells are suitable for irrigation. The pH values of the water samples varied from 7.20 to 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]. The TDS varied from 179.2 to 4288 mg/L ^{1} with an average value of 1024 mg/L. 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 10). The excessive Na^+ content in water sample reduces the permeability, and reduce the available water for the plant. The water containing excessive amount of Na^+ may immobilize other nutrient ions particularly Ca^{++} and Mg^{++}, which can result in deficiencies of these elements in plants [22]. Excess amounts Na^+, Ca^{2+}, $Mg_2^+$and HCO_3^- in the irrigation water affect soil permeability through widespread irrigation water use [32]. The SAR values of the groundwater samples varied between 0.6892 to 15.439 with an average value of 4.285 (Table 9). About 85% of the SAR values of the water samples were less than 10 and are classified as excellent for irrigation [30]. In addition, spatial distribution of SAR in the region were measured and 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. [14], was also determined the hazardous effect of sodium on water quality for irrigation usage in KR index. A Kelly's ratio of more than 1 indicates excessive Na in water. Therefore, water with a KR less than 1 is considered suitable for irrigation; on the other hand, the ratio more than 1 is unsuitable. The KR ratios in the studied water ranged between 0.3214 and 4.02 with an average value of 1.08. About 60% of the studied waters are considered suitable for irrigation [19].

The B concentrations were within permissible limits in the 92% of water samples and the remaining samples were considered slight to moderate B toxicity. The RSC value ranged between 3.50 to -24, with an average value of -3.5. About 98% of the studied waters are considered suitable for irrigation. Usually, Ca_2^+ and Mg_2^+ are in an equilibrium state in groundwater. The higher value of Ca_2^+ and Mg_2^+ in water can increase soil pH (therefore soil converting it to saline soil, resulting in decrease in the P availability). Excess concentration of Mg_2^+ in groundwater affects the soil quality by converting it into alkaline and decreases the crop yield. The excess amount of Mg_2^+ ions in waters damage the soil quality which causes low crop production. The MH in the studied water ranged between 0 to 0.75, with an average value of 0.28. About 100% of the studied waters are considered suitable for irrigation. The Na (%) in the studied water ranged between 22. 0 and 75.8, with an average value of 46.3.

The SSP in the studied water ranged between 0.81and 0.30, with an average value of 0.50 and 100 % of the studied waters are considered suitable for irrigation. The (TH) in the studied water ranged between 85 to 1650, with an average value of 382.6 and about 22 % of the studied waters are considered suitable for irrigation. The PI in the studied water ranged between 0.97 and 0.34, with an average value of 0.67 and about 100% of the studied waters are considered suitable for irrigation.

3.3 Classes of Salinity and Alkalinity Hazard

The salinity and alkalinity hazard class of studied well samples were C2–S1, C3–S1, C3–S2 and C4-S3 (Fig. 4). The result indicated that, the groundwater possesses moderate to high salinity hazards with low to medium Na hazards. The excessive amount of salts in some wells of the region can be one of the major problems in the study area. According to [1], groundwater is an essential source for crop rising and food production in this region. He 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, which cannot be used for irrigation without special circumstances.

3.4 Hydro Chemical Aspects

The piper diagram shows that the water types of Al-Jouf well waters are rich in Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-} ions (Fig. 6). The piper diagrams provided

Table 10. Classification of water samples in Al-Jouf aera for irrigation based on some characteristics

Parameters	Range	Water class	References
TDS	<450	Best	[5,16,31,22]
	450-2000	Moderate	
	>2000	Hazard	
SAR	0–15	Excellent	
	15–20	Good	
	20–27	Doubtful	
	>27	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	C-I	
	25–75	C-II	
	<25	C-III	
MH	<50	Suitable	
	>50	Harmful Unsuitable	
Na%	<25	Excellent	
	25–45	Good	
	45–65	Permissible	
	65–85	Doubtful	
	>85	Unsuitable	
T.H	<80	Soft	
	85–155	Moderately Hard	
	155–310	Hard	
	>310	Very Hard	

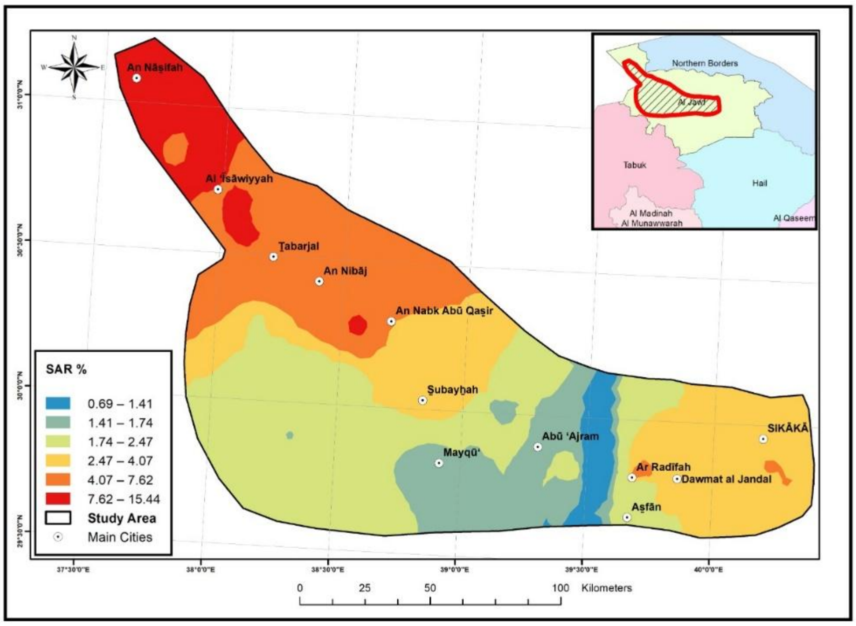

Fig. 3. Spatial distribution of SAR values in Al-Jouf area

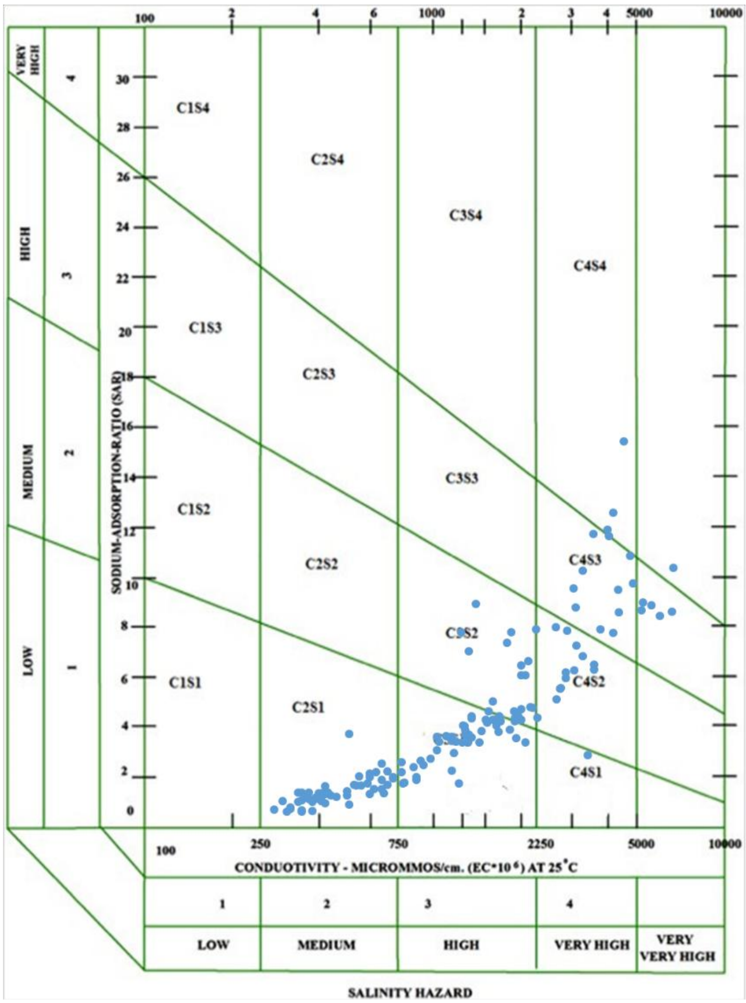

Fig. 4. Groundwater salinity classification used for irrigation

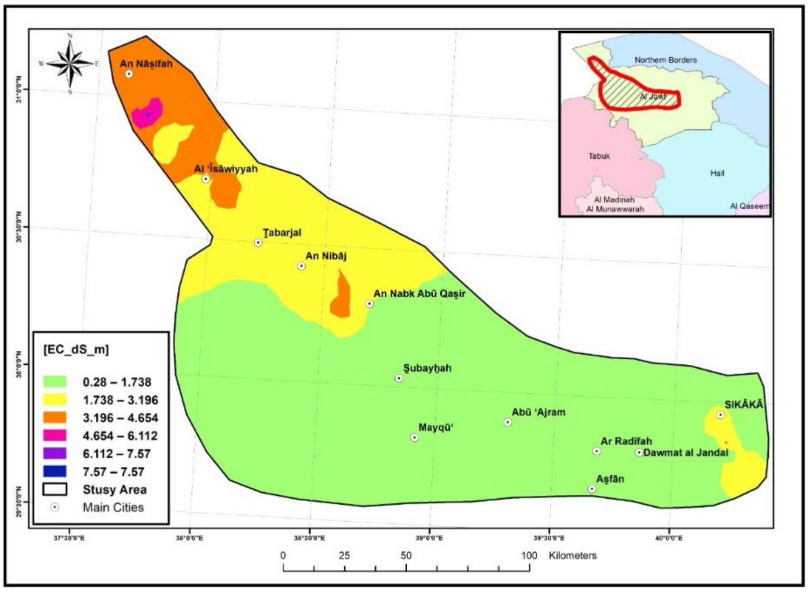

Fig. 5. Electrical conductivity spatial distribution in Al-Jouf region, Saudi Arabia

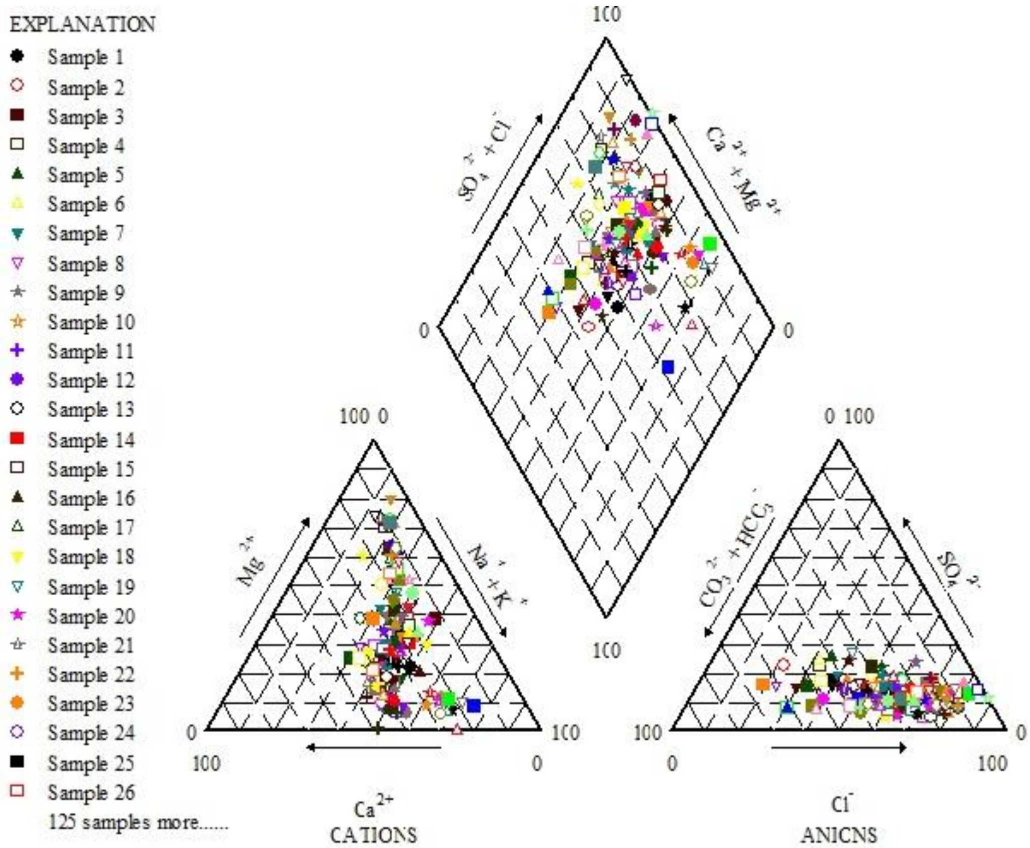

Fig. 6. Piper—tri-linear diagram of wells water in Al-Jouf region

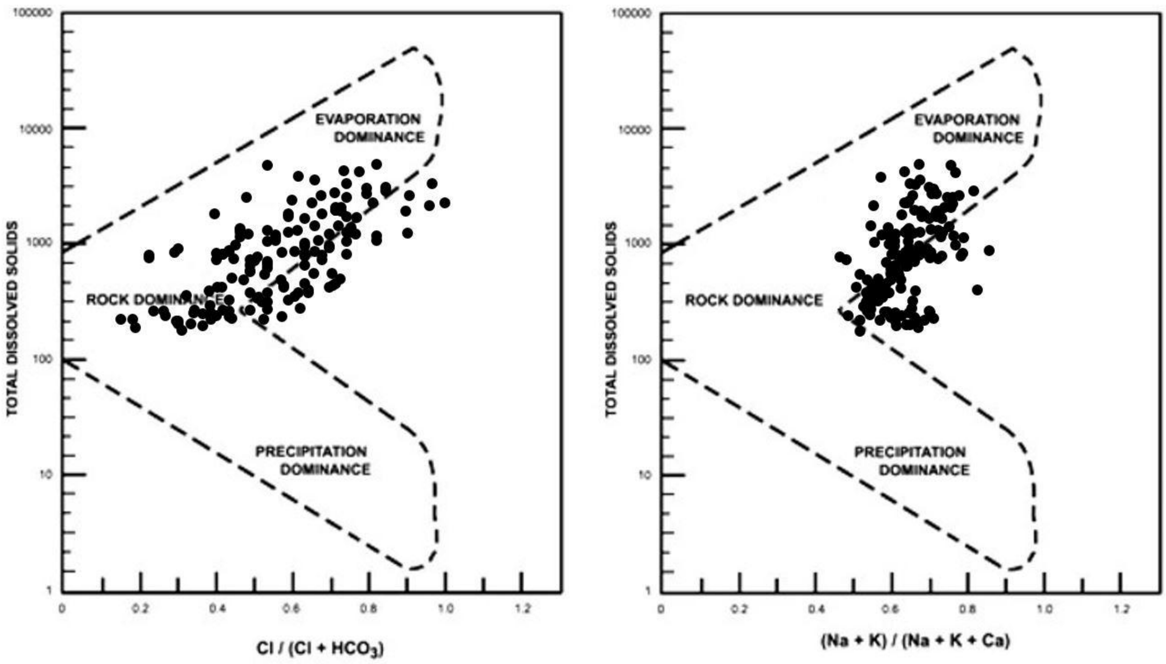

Fig. 7. Diagram showing the mechanism that control of groundwater quality

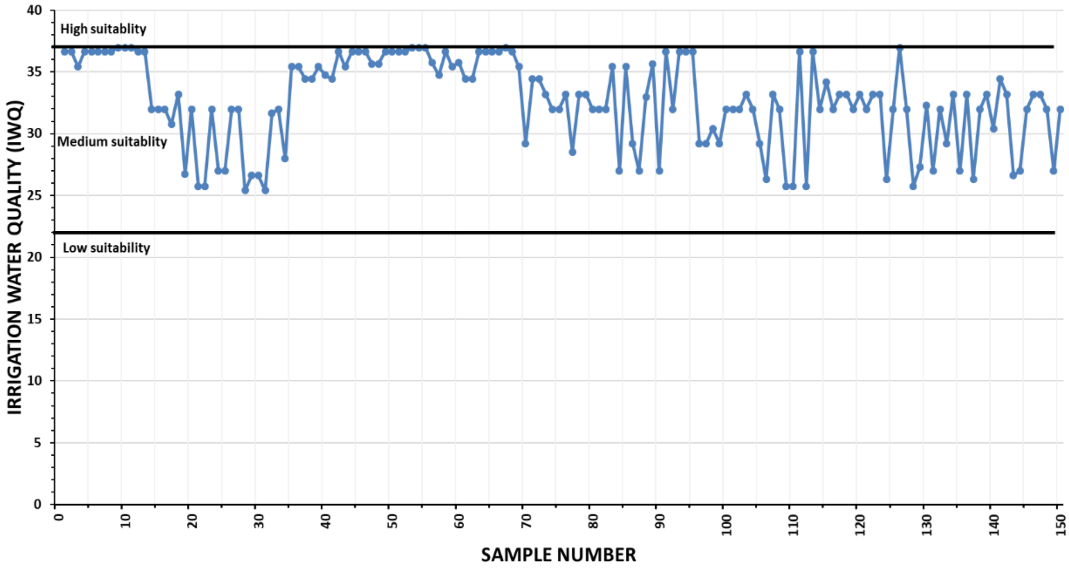

Fig. 8. Irrigation water quality index (IWQI) for 150 wells in Al-Jouf region, KSA

a convenient method to classify water types collected from different groundwater resources, based on the ionic composition of different water samples [2,7]. 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. 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 that increases the salinity [7].

3.5 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, KSA classified as medium in suitability for irrigation purposes. These findings agreed with those reported by [19].

4. CONCLUSIONS

Water quality indices have been calculated to assess the suitability of groundwater for drinking and irrigation purposes in Al-Jouf, KSA. About 12 parameters have been considered to calculate the DWQI which included: pH, TDS, cations, anions and B concentration. The results indicated that, about 20.5% of well water considered as excellent water, 45.6% classified as good water, 23.8% and 9.9% were poor and very poor water for drinking purposes, respectively. 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 Mg, Ca, SO4 and Cl- ions. The IWQI value was classified as medium in terms of suitability, thus, this could be used for irrigation purposes for all the crops. As a result, the Al-Jouf region could contribute greatly to the sustainable agriculture.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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