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Geochemical Processes and Assessment of Water Quality for Irrigation of Al-Shagaya Field-C, Kuwait

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***Abstract*— *Al-Shagaya Field-C is located southwest of Kuwait City, where the brackish groundwater is produced from the Dammam aquifer. The main objectives are to recognize the major geochemical processes operating in the aquifer and controlling its quality; in addition, to evaluate the groundwater quality criteria for drinking and irrigation. The investigation was carried out by estimating pH, EC, TDS, TH, SAR, %Na, RSC, RSBC, potential salinity, magnesium ratio, chloro-alkaline index, Kelly's ratio, Permeability index, and salinity hazard respectively. The TDS ranges between 2474 and 3232 mg/l, with an average value of 2753mg/l and the water is exceeding very hard. Groundwater shows Ca-Cl and Ca-Mg-Cl genetic water types. Results revealed that the groundwater is oversaturated with respect to dolomite and calcite and under-saturated with respect to gypsum and anhydrite. The main geochemical processes controlling groundwater chemistry in the study area are due to dissolution/ precipitation process along the path flow. The major ions composition in groundwater of the study area indicated that the water is not suitable for drinking. However, the irrigation parameters revealed that the groundwater is suitable for irrigation purposes.*
***Keywords*— Dammam aquifer, saturation index, Gibb's ratio, hydro chemical facies & GIS.**

I. INTRODUCTION

Kuwait covers an area of 18,000 km^2 and lies in the north-eastern corner of the Arabian Peninsula and occupies the north-western part of the Arabian Gulf as shown in Fig (1A).The climate is extremely hot and dry in summer and mild to cold in winter . The rainfall is scarce with an annual average precipitation of 115 mm. The average evaporation is equal 17 mm/ day .The location of Kuwait within the arid gives groundwater great importance. The brackish groundwater in Kuwait is used in agriculture, gardening and domestic purposes. Moreover, it is blend with the fresh water produced by desalination plants to make potable drinking water. The groundwater is abstracted from two main aquifers, the Kuwait Group aquifer, which is leaky to water-table aquifer, and the Dammam aquifer is confined to semi-confined aquifer. Al-shagaya area is located in the southwest of Kuwait and was put in use in early 1970's .This area includes five water well fields. Fields A, B, C, D, and E supply Kuwait city with brackish groundwater produced mainly from Dammam aquifer at a peak rate of 60 MIGD, with an expected quality of 4,000 mg/l of TDS, from a total of 115 production wells distributed over the five water-well fields. The salinity of the Dammam aquifer increases from southwest to north-northeast ranging from 2,500 to, 8,000 mg/l .The major hydro chemical water types are $CaSO_4$, Na_2SO_4 and NaCl [1] . Field-C is the area under investigation, where Figs. 1B and 1C show the location and the distribution of the water wells. Al-Shagaya Field-C is located approximately 64 km to the south-west of Kuwait City, with 32 wells produced groundwater from the Dammam aquifer.

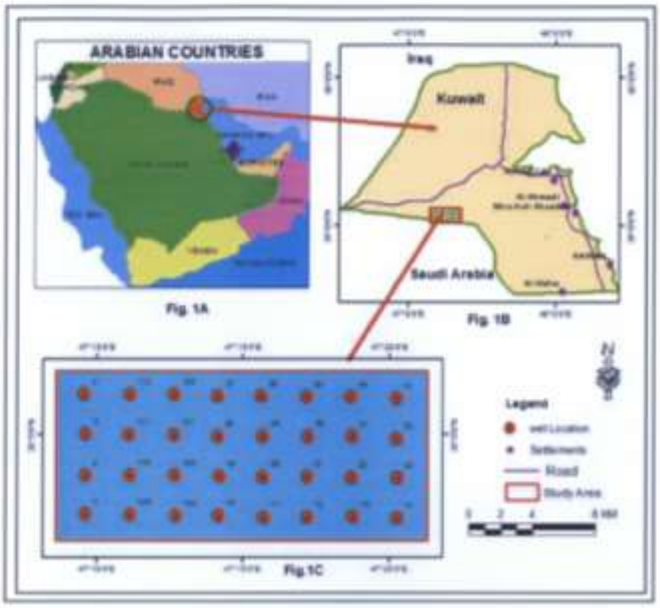

Fig. 1A: Location map of Kuwait.
Fig. 1B: Location map of the study area.
Fig. 1C: Location map of the water wells.

The objectives of this investigation are to identify the water chemical types and hydro chemical processes operating within the main aquifer, in addition to the determination of degree of saturation of groundwater with

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respect to some minerals. Moreover, the suitability of groundwater for drinking and irrigation purposes will be carried out.

Several studies were conducted to date addressing water quality criteria for irrigation. In the research paper published by [2] six soil samples were collected during pre and post monsoon season from Coring mangrove region of East Godavari estuaries for physicochemical of pH, EC, TDS, TH, Cl^- , SO_4^{2-}, NO_3^-, PO_4^{3-}, Na^+, K^+, Ca^{2+}, and Mg^{2+}, and irrigation parameters such % Na, SAR, RSC, KR, and MH, were determined. The results showed that the pH ranges from 7.2 – 7.8 and 7.0 – 7.5 and indicate slight alkaline nature of the soils. Total hardness ranges from 400 – 1550 mg/l pre and post monsoon indicating the hardness of soils. The Magnesium Hazard (MH) ranges from 61.93 – 93.4 pre and post monsoon, exceeding the permissible limit of irrigation standards. Higher Magnesium level in soil causes Magnesium Hazard, so that the soil fertility will be depleted and affects the crop yields. According to [3] Salinity and Sodicity have been reported among the major problems of irrigated agriculture across the world. The methods that are commonly used as indices of salinity or sodicity in the soils include electrical conductivity, Sodium Adsorption Ratio (SAR) and Exchangeable Sodium Percentage. Also, [4] found that the effect of high SAR can be poor soil tith, and soils become sticky when wet resulting in reduced water infiltration. Aza –Gnandji et. al. [5] found that high salinity levels tend to affect soil structure and crop productivity. And chloride is an essential plant micronutrient, but, it's toxic to some crops at higher concentration. Sodium is important to some plant growth, and at high concentrations, it is toxic to many plants. The high salinity of water of C_4-S_2 class permits occasional use and then only under favorable soil and plants of high salt tolerance should be grown. Dastorani et. al. [6] reported that the groundwater resources can be available to help support development, and the limited recharge of groundwater resources is dependent on the amount duration and intensity of rainfall as well as soil properties. According to a study conducted by [7] on the groundwater quality in Abdalli area in Kuwait, it reveals that most of the groundwater samples fall within class C_3-S_4 in Wilcox salinity hazard diagram, which means poor water quality for irrigation and it can be used in well – drained soil. Moreover, with reference to [8], based on Kelly's ratio, water is classified for irrigation. Kelly's ratio of more than 1 indicates excess level of Na^+ in water. Therefore, water with Kelly's ratio of less than 1 is suitable for irrigation, while those with ratio more than 3 are unsuitable for irrigation. In addition, the authors [9] pointed out that the higher level of TDS confirms the unsuitability of water for drinking and irrigation purposes. And the presence of magnesium in water would adversely affect the soil quality rendering it unsuitable for cultivation. If MH is less than 50 the water is safe and suitable for irrigation. However, Narany et al. [10] reported that bicarbonate hazard is usually represented in term of RSC, which shows the tendency for calcium and magnesium to participation as the soil become concentrated. Therefore, the relative proportion of sodium in the water is increased in the form of sodium bicarbonate. According to [11] when electrical conductivity values exceeded the permissible of limits 4000 µ mhos/cm, the water is considered of salinity nature, and is not suitable for irrigation purposes .

II. GEOLOGY OF KUWAIT

2.1 Topography

The topography of Kuwait is generally flat, broken by occasional low hills and shallow depressions. Elevations range from sea level in the east to nearly 300 m in the southwestern corner of the country. The Jal Az-Zor escarpment form one of the main topographic features in Kuwait [12]. The major depression, Wadi Al-Batin is a valley along the western border with 8 to 11 Km and relief of 70 m. The coast lies along the east of the country and sabkha has developed along the coast. In the northeastern part of the country a few barchans dunes up to 25 m are found [13, 14].

2.2 Stratigraphy

The stratigraphical column of Kuwait was mainly influenced by the stable shelf condition of the Arabian plate, causing the deposition of shallow water sediments and evaporates. The surface of Kuwait is formed by sedimentary rocks and sediments ranging from Middle Eocene to Recent. The Dammam Formation represents the oldest exposed sedimentary rocks. The Recent deposits of fine-grained beach sands cover southern coast of Kuwait and the Neutral Zone.

Kuwait Group consists of the Dibdibba, Lower Fars, and Ghar Formations in descending order. Dibdibba Formation includes all rocks between the overlaying Holocene deposits. It consists of fluviated sequence of cross-bedded sands and gravel with subordinate intercalations or lenticular bodies of sandy clays, sandstone, conglomerate and siltstone. Lower Fars Formation consists of sands, Quartz, loosely consolidated gravels, clay and marl. The Ghar Formation consists mainly of marine to terrestrial coarse and unconsolidated sand, silt and gravel.

Hasa Group consists of three formations in descending order; Dammam, Rus and Radhuma Formations. Dammam Formation is considered the largest and the most potential productive aquifer of brackish groundwater in Kuwait. Its thickness ranges between 150 and 275 m increases towards the northeast. Dammam Formation consists mainly of dolomitic limestone and limestone inter-bedded with shale at the base of the formation, forms the relatively impermeable lower boundary over most of the region. Rus Formation is composed of hard, dense, massive anhydrite and unfossiliferous limestone. Radhuma Formation consists mostly of anhydrite, dolomitic and marly limestone with few fossiliferous horizons [15].

2.3 Hydrology and Aquifer System

The most significant aquifer in Kuwait is the Tertiary-Quaternary system. These are the upper clastic sediments of the Kuwait Group aquifer, and the Dammam aquifer which are separated by a confining layer of cherts and/or clay [16]. Under natural hydrological conditions, the flow through the Kuwait aquifer is in SW-NE direction, from the main recharge area in Saudi Arabia to the main discharge area in the Arabian Gulf and Shaat Al-Arab. Generally, part of the natural recharge of the Kuwait Group aquifer gains by leakage from the Dammam aquifer, and also comes from infiltration through the wadies and depressions, as well as the lateral flow coming from Saudi Arabia [17]. The effect of leakage between the two main aquifers may give rise to the similarities of groundwater chemistries.

2.4 Objectives of the Study

The main objectives are to study the geochemistry of the study area in order to recognize the prevailing and the major geochemical processes that control the quality of the groundwater. Moreover, the suitability of groundwater for drinking and irrigation were evaluated by determining physiochemical and irrigation parameters.

III. METHODOLOGY

In this study, the chemical analyses of the major cations and anions such as Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^-, SO_4^{2-}, and Cl^- expressed in mg/l were converted to equivalent per million (e.p.m), (which is equivalent to mq/l) and %e.p.m [18]. Ion balance equation was applied to validate the accuracy of the chemical analyses where ±5% is acceptable [19]. Also, the reaction error of all groundwater samples was less than the accepted limit of ±10% [20] as in Table1 1.

To achieve these objectives a speciation model has been used to determine the degree of saturation of groundwater with respect to some minerals using WATEQ4F program [21]. Along with the application of the Gibb's ratio to assess the functional sources of dissolved chemical constituents and to recognize the main processes governing the groundwater chemistry of the study area. Hydrochemical facies interpretation is used to determine flow pattern and origin of chemical histories of groundwater by plotting of the major cations and anions on the Piper diagram [22]. The assessment of groundwater for irrigation purposes based on different irrigation indices is carried out includes SAR, RSC, %Na, residual sodium bicarbonate (RSBC), Permeability Index (P.I) Potential Salinity (P.S)), Salinity hazard, magnesium ratio (MgR), Kelly's ratio (KR), and chloro-alkaline index (CAI-1). Wilcox diagram (1955), and Doneen permeability index [23, 24] also have been utilized for classification of groundwater for irrigation. The spatial distribution of TDS, TH, RSC, SAR, gypsum and calcite parameters, were illustrated using ArcGIS10 software.

3.1 Mechanisms of Controlling Groundwater Chemistry

It is important to study the relationship between the water chemistry and the aquifer lithology. Gibb's [25] suggested a diagram that represents the ratio of dominant anions and cations plotted against the value of TDS. These ratios can be divided into two formula, the first ratio is for the cations $[(Na^+ + K^+) / (Na^+ + K^+ + Ca^{2+})]$, and the second ratio is for the anions, $Cl^- / (Cl^- + HCO_3^-)$ as a function of TDS. This diagram is widely used to evaluate the functional sources of dissolved constituents such as precipitation-dominance, rock-dominance, and evaporation-dominance. The chemical analyses of the study area are plotted in the Gibb's diagram as shown in Fig. 2, and showed that the predominant samples fall into the category of rock-water interaction field and few samples are located in evaporation-dominance field , which revealed that the chemical weathering of rock-forming minerals are influencing the groundwater quality by dissolution of rock through which there is circulation, while the data in the evaporation-dominance field indicate that the increasing ions of Na^+ and Cl^- are in relation with the increasing of the TDS.

Table.1: Chemical analysis results of the Al-Shagaya Field - C, (mg/l)

Well No.	EC µmohs/cm	TDS	T.Hard	Na^+	K^+	Ca^{2+}	Mg^{2+}	Cl^-	SO_4^-	HCO_3^-
C-1	3340	2644	1308	360	12.0	338	113	476	1247	126
C-2	3460	2736	1332	365	11.5	323	128	517	1262	131
C-3	3680	2883	1379	335	10.5	330	135	535	1218	126
C-4	3700	2864	1370	470	12.0	338	128	489	1363	145

C-10	3330	2662	1355	345	12.0	345	120	439	1276	136
C-11	3720	2933	1379	355	12.0	330	135	520	1247	148
C-12	3850	3121	1460	375	12.0	338	150	535	1276	149
C-13	3430	2773	1411	305	11.5	330	143	442	1218	140
C-14	3450	2773	1411	295	11.0	330	143	451	1247	140
C-19	3410	2694	1478	345	11.5	345	150	348	1247	134
C-20	3310	2690	1209	345	12.0	323	98	467	1276	133
C-21	3430	2921	1466	345	12.3	347	146	556	1276	176
C-22	3390	2684	1478	340	12.0	345	150	429	1247	134
C-23	3430	2686	1449	345	11.5	345	143	455	1218	129
C-28	3360	2664	1337	325	12.0	338	120	439	1247	130
C-29	3340	2648	1375	340	12.0	353	120	458	1276	131
C-30	3500	2756	1288	395	13.0	330	113	467	1276	148
C-31	3360	2646	1375	330	12.5	353	120	448	1276	138
C-32	4060	3232	1549	460	16.5	398	135	505	1595	154
C-37	3510	2734	1262	395	12.0	308	120	467	1276	153
C-38	3330	2660	1370	325	12.0	338	128	420	1276	141
C-39	3370	2690	1387	330	12.0	345	128	439	1276	140
C-40	3360	2672	1355	335	12.0	345	120	429	1334	144
C-41	3880	3042	1370	445	15.0	338	128	542	1450	158
C-105	3410	2694	1478	346	11.5	345	150	438	1247	134
C-106	3380	2672	1478	340	12.0	345	150	439	1247	138
C-107	3390	2694	1370	340	12.0	338	128	429	1276	141
C-108	3370	2708	1375	335	12.0	353	120	412	1363	148
C-109	3310	2646	1346	340	12.0	353	113	458	1247	125
C-110	3320	2474	1189	350	12.0	315	98	467	1247	126
C-111	3400	2712	1339	350	12.0	323	143	467	1334	142
C-112	3360	2680	1332	330	12.0	232	128	429	1334	142
Min.	**3310**	**2474**	**1189**	**295**	**10.5**	**232**	**98**	**348**	**1218**	**125**
Max.	**4060**	**3232**	**1549**	**470**	**16.5**	**398**	**150**	**556**	**1595**	**176**
Ave.	**3467**	**2753**	**1377**	**354**	**12.13**	**336.16**	**129.50**	**462.87**	**1287.34**	**140**

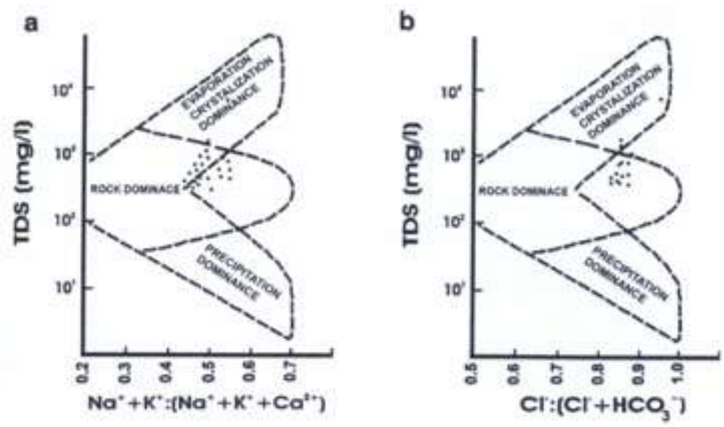

Fig.2: Gibb's diagram for controlling factor of groundwater quality in the study area

3.2 Hydrochemical Facies

Hydrochemical facies interpretation using Piper trilinear diagram is a useful tool for determining the flow pattern and origin of chemical histories of groundwater. The Piper trilinear diagram is presented in Fig.3. Two principal hydrochemical water types have been delineated. These are Ca-Cl and Ca-Mg-Cl water types respectively. The majority of the groundwater samples of the study area fall in Ca-Cl water type which suggesting an end–product water. A few of the samples show Ca-Mg-Cl water type, indicat that alkaline earth (Ca^{2+} + Mg^{2+}) exceeds the alkaline ($Na^+ + K^+$) and strong acid (Cl^- and SO_4^{2-}) exceeds the weak acid (HCO^-_3 and CO_3^{2-}).

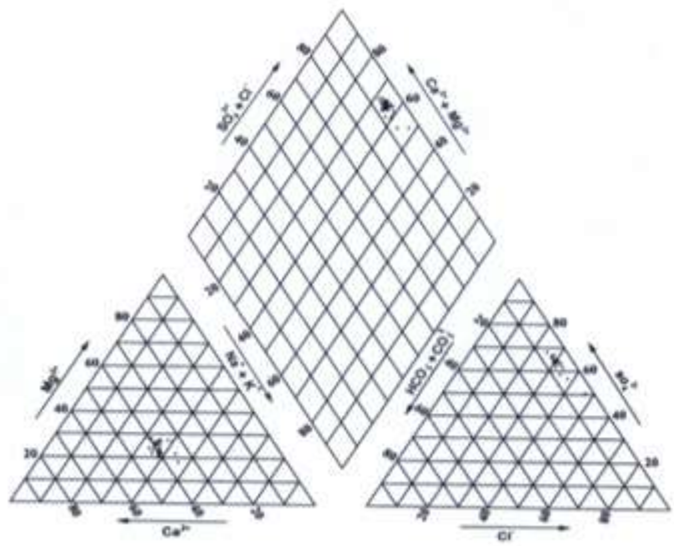

Fig.3: Piper trilinear diagram for the groundwater samples of the study area

3.3 Geochemical Modeling

Geochemical models are tools used to calculate chemical reaction in groundwater system such as dissolution and precipitation of solids, ion exchange, and sorption by clay minerals [26]. In this study, the speciation model has been applied to the groundwater samples of Al-Shagaya Field-C to determine the saturation index (SI) of minerals. The SI for a given mineral measures the degree of saturation of that mineral with respect to the surrounding system. The degree of saturation index is defined as follow [27]:

$$SI = \log \frac{K_{iap}}{K_{sp}}$$

Where "iap" is the ion activity product of the dissociated chemical species in solution, and "K_{sp}" is the solubility product of the mineral. Where SI is <0, it indicates that the groundwater is under-saturated with respect to that particular mineral. When SI > 0, it means that the groundwater is being saturated with respect to the mineral and incapable of dissolving more of the mineral. The over-saturation can also be produced by incongruent dissolution, common ion effect.

Table 2 shows the saturation indices of anhydrite, gypsum, halite, calcite and dolomite. Nearly, all groundwater samples of the study area are under saturated with respect to anhydrite, gypsum and halite and oversaturated with respect to calcite and dolomite.

Table.2: Results of thermodynamic speciation calculation of Al-Shagaya Field -C.

Well No.	Anhydrite	Gypsum	Halite	Calcite	Dolomite	P_{CO_2} Atom.
	$CaSO_4$	$CaSO_4.2H_2O$	NaCl	$CaCO_3$	$CaMg(CO_3)_2$	
C-1	-0.30	-0.33	-5.44	0.20	0.20	4.19E-03
C-2	-0.32	-0.35	-5.40	0.19	0.27	4.35E-03
C-3	-0.32	-0.36	-5.43	0.63	1.15	1.34E-03
C-4	-0.29	-0.32	-5.32	0.34	0.54	3.79E-03
C-10	-0.28	-0.32	-5.50	0.19	0.20	5.08E-03
C-11	-0.32	-0.35	-5.41	0.45	0.80	3.06E-03
C-12	-0.31	-0.35	-5.38	0.75	1.42	1.49E-03
C-13	-0.32	-0.36	-5.55	0.24	0.40	4.64E-03

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C-14	-0.31	-0.35	-5.55	0.14	0.19	5.80E-03
C-19	-0.29	-0.34	-5.60	0.24	0.39	4.42E-03
C-20	-0.30	-0.34	-5.47	0.49	0.75	2.20E-03
C-21	-0.24	-0.28	-4.94	0.11	-0.01	2.91E-03
C-22	-0.29	-0.33	-5.75	0.24	0.40	4.43E-03
C-23	-0.31	-0.34	-5.48	0.32	0.53	3.37E-03
C-28	-0.30	-0.33	-5.52	0.21	0.26	4.33E-03
C-29	-0.28	-0.31	-5.49	0.62	1.05	1.69E-03
C-30	-0.30	-0.34	-5.41	0.25	0.32	4.93E-03
C-31	-0.27	-0.31	-5.51	0.25	0.32	4.58E-03
C-32	-0.18	-0.22	-5.33	0.31	0.48	5.04E-03
C-37	-0.33	-0.37	-5.41	0.33	0.35	5.10E-03
C-38	-0.29	-0.24	-5.54	0.34	0.55	3.71E-03
C-39	-0.29	-0.32	-5.52	0.35	0.55	3.67E-03
C-40	-0.27	-0.31	-5.52	0.32	0.45	3.46E-03
C-41	-0.27	-0.31	-5.31	0.22	0.30	5.78E-03
C-105	-0.30	-0.34	-5.50	0.23	0.38	4.40E-03
C-106	-0.30	-0.34	-5.51	0.25	0.41	4.55E-03
C-107	-0.29	-0.33	-5.52	0.25	0.35	4.68E-03
C-108	-0.25	-0.29	-5.54	0.28	0.36	4.92E-03
C-109	-0.28	-0.32	-5.49	0.22	0.22	4.15E-03
C-110	-0.31	-0.35	-5.46	0.37	0.51	2.64E-03
C-111	-0.30	-0.34	-5.47	0.22	0.37	4.71E-03
C-112	-0.42	-0.45	-5.53	0.37	0.77	2.30E-03
Min.	-0.42	-0.45	-5.75	0.11	-0.01	1.34E-03
Max.	-0.18	-0.22	-4.94	0.75	1.42	5.80E-03
Ave.	-0.29	-0.33	-5.46	0.31	0.48	3.93E-03

The areal distribution map of gypsum of the study area is shown in Fig. 4 and exhibits that the medium values of gypsum are concentrated in the central part, while low values are found in the southeastern corner. In addition, high values of calcite is displays in Fig. 5 and concentrated in the central part of the study area indicating that dissolution / precipitation process of these carbonate minerals along the path flow may have influenced the chemical composition of the Al-Shagaya Field-C. The partial pressure of the carbon dioxide values (Pco_2) range between 1.34×10^{-3} atm. and 5.8×10^{-3} atm., with an average value of 3.93×10^{-3} atm. This indicates that the groundwater of the Dammam aquifer become charged with CO_2 during infiltration through the soil zones. Where, according to Appelo and Postma [28] when Pco_2 values range between $10^{-2.5}$ atm. and $10^{-6.4}$ atm., it represents a closed system. Since the Dammam aquifer is acting as a confined to semi-confined aquifer, it is more likely that the groundwater represents a deep closed environment system.

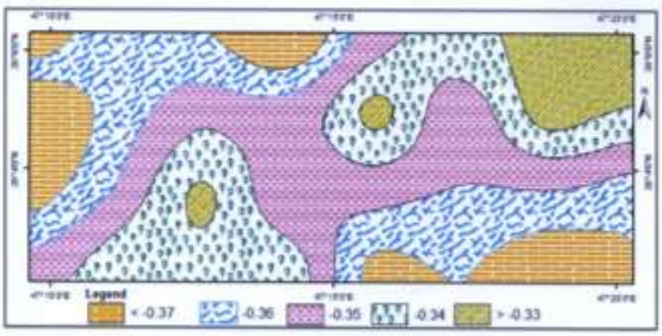

Fig.4: Spatial distribution of the saturation index of gypsum of the study area

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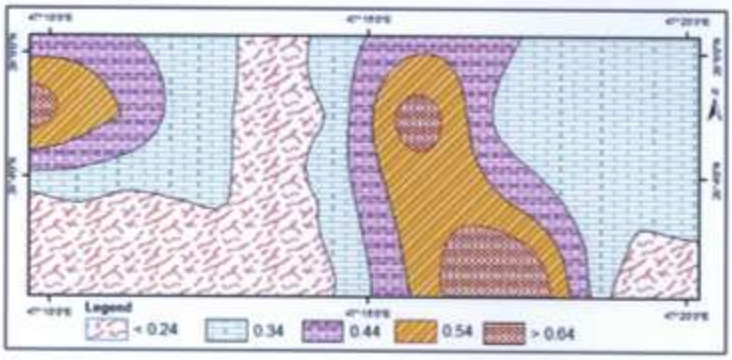

Fig.5: Spatial distribution of the saturation index of calcite of the study area

3.4 Geochemical Evolution of Groundwater

The initial composition of groundwater originates from rainfall with low concentrations of dissolved ions. During its return path to the ocean, the water composition is altered by rock weathering and evaporation causing more Ca^{2+}, Mg^{2+}, Na^{+}, SO_4^{2-}, HCO_3^{-} , Cl^{-} and SiO_2 to be added. The concentration of these ions depends on the rock mineralogy that the water encounters and its rapidity along the flow path. The abundance of the major cations in Al-Shagaya Field-C is in the order $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+}$. The sequence of the anions is in order of $SO_4^{2} > Cl^{-} > HCO_3^{-}$. Calcium and magnesium present in the groundwater are mainly due to the dissolution of limestone, dolomite, gypsum and anhydrite, the most rock forming minerals of the Dammam aquifer of the study area. Calcium ions are derived also from cation exchange process [28].The concentration of calcium ions in the study area ranges from 232 mg/l to 398 mg/l and magnesium ranges from 98 mg/l to 150 mg/l, with average values of 336 mg/l and 129 mg/l respectively. This indicates that the Ca^{2+} ion concentration in the study area is relatively higher than magnesium ion. The plot of $Ca^{2+} + Mg^{2+}$ Vs. ($HCO_3^{-} + SO_4^{2-}$) as in Fig. 6A, shows that the majority of the samples fall above the equiline indicating that the carbonate weathering is the dominant processes for supply of the calcium and magnesium ions to groundwater. The plot of (Na^{+}) Vs. (Cl^{-}) of the groundwater samples of the study area presented in Fig. 6B, shows that the Na/Cl ratio is greater than (1) which is typically indicates that the sodium was released from silicate weathering. The silicate weathering is also supported by the plot of HCO_3^{-} Vs. Na^{+} as shown in Fig. 6 C, where all the samples fall below the equiline [29], this reveals that the carbonate and the silicate weathering are the dominant processes operating in the aquifer of the study area.

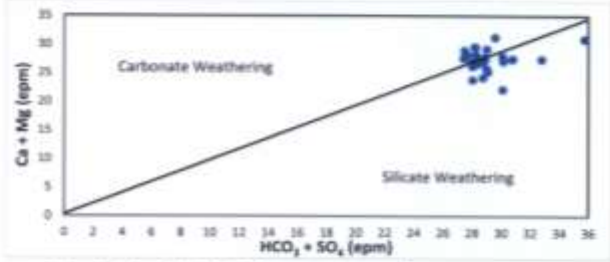

Fig. 6A: Plot of (Ca^{2+}+ Mg^{2+}) Vs (HCO_3^{-}+SO_4^{2-}) of the study area.

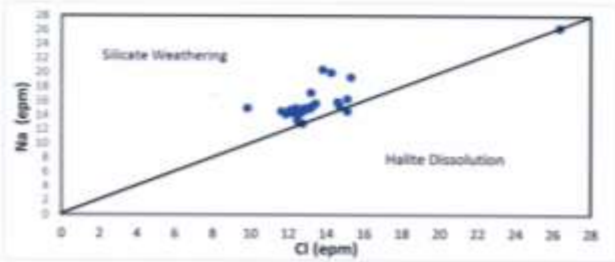

Fig. 6B: Plot of (Na^{+}) Vs (Cl^{-})) of the study area.

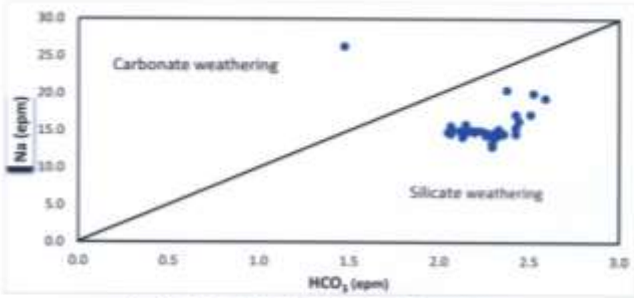

Fig. 6C: Plot of (Na^{+}) Vs (HCO_3^{-}) of the study area.

IV. DRINKING AND IRRIGATION WATER QUALITY

The assessment of the suitability of groundwater for drinking and irrigation purposes can be determined through the parameters such as pH, EC, TDS, TH, RSC, residual sodium bicarbonate (RSBC), Permeability index (P.I), Potential Salinity (P.S), SAR, salinity hazard, magnesium ratio (MgR), %Na, Kelley's ratio (KR), and chloro-alkaline index (CAI-1) as display in tables 1 and 3.

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Table.3: Irrigation water quality parameters for Al-Shagaya Field – C.

Well No.	RSC	RSBC	P.I	P.S	SAR	MgR	% Na	Kelly's ratio	CAI-1
C-1	-24.10	-14.80	40.88	26.41	4.33	35.53	37.17	0.60	-0.19
C-2	-24.50	-13.97	40.78	27.72	4.35	39.51	37.08	0.60	-0.11
C-3	-25.51	-14.40	37.99	27.77	3.92	40.28	34.36	0.53	0.02
C-4	-25.02	-14.49	45.96	27.98	5.52	38.43	42.46	0.75	-0.50
C-10	-24.86	-14.99	39.20	25.67	4.08	36.44	35.39	0.55	-0.24
C-11	-25.15	-14.04	39.52	27.65	4.16	40.28	35.65	0.56	-0.07
C-12	-26.76	-14.42	39.27	28.38	4.27	42.25	35.60	0.56	-0.10
C-13	-25.94	-14.17	35.62	25.15	3.53	41.67	31.75	0.47	-0.09
C-14	-25.94	-14.17	34.94	25.70	3.42	41.67	31.04	0.45	-0.03
C-19	-27.36	-15.02	37.00	22.80	3.90	41.75	33.46	0.51	-0.56
C-20	-22.00	-13.94	42.07	26.46	4.32	33.34	38.00	0.62	-0.16
C-21	-26.44	-14.43	37.68	28.97	3.92	40.95	33.61	0.51	0.02
C-22	-27.36	-15.02	36.69	25.08	3.85	41.75	33.12	0.50	-0.25
C-23	-26.86	-15.10	37.42	25.51	3.94	40.59	33.89	0.52	-0.19
C-28	-24.61	-14.74	38.16	25.37	3.87	36.92	34.33	0.53	-0.17
C-29	-25.34	-15.47	38.45	26.20	3.99	35.91	34.73	0.54	-0.17
C-30	-23.34	-14.04	43.64	26.46	4.79	36.08	39.70	0.67	-0.33
C-31	-25.22	-15.35	37.90	25.92	3.87	35.91	34.05	0.52	-0.16
C-32	-28.44	-17.34	42.37	30.85	5.09	35.86	38.93	0.65	-0.43
C-37	-22.73	-12.86	44.24	26.46	4.84	39.11	40.21	0.68	-0.33
C-38	-25.08	-14.56	37.70	25.13	3.82	38.43	33.79	0.52	-0.22
C-39	-25.45	-14.92	37.70	25.67	3.85	37.95	33.85	0.52	-0.18
C-40	-24.73	-14.86	38.67	25.99	3.96	36.44	34.72	0.54	-0.23
C-41	-24.81	-14.28	44.85	30.38	5.23	38.43	41.07	0.71	-0.29
C-105	-27.36	-15.02	37.06	25.34	3.92	41.75	33.52	0.51	-0.24
C-106	-27.29	-14.95	36.74	25.37	3.85	41.75	33.12	0.50	-0.22
C-107	-25.08	-14.56	38.66	25.39	4.00	38.43	34.81	0.54	-0.25
C-108	-25.06	-15.19	38.35	25.81	3.93	35.91	34.40	0.53	-0.28
C-109	-24.86	-15.57	38.90	25.90	4.03	34.54	35.21	0.55	-0.17
C-110	-21.71	-13.65	42.72	26.16	4.42	33.90	38.73	0.64	-0.18
C-111	-25.55	-13.79	38.86	27.06	4.08	42.19	35.07	0.55	-0.18
C-112	-19.78	-9.25	43.55	25.99	4.32	47.63	39.04	0.65	-0.21
Min.	-28.44	-17.34	34.94	22.80	3.42	33.34	31.04	0.45	-0.56
Max.	-19.78	-9.25	45.96	30.85	5.52	47.63	42.46	0.75	0.02
Ave.	-25.13	-14.48	39.49	26.46	4.17	38.80	35.68	0.56	-0.21

4.1 Drinking Water Quality

The suitability of groundwater in the study area is evaluated for drinking by comparing with the standard guide line values [30]. According to WHO specifications, TDS up to 500 mg/l is the highest desirable and up to 1500 mg/l is the maximum permissible level. Based on this classification, the TDS of the groundwater of the study area ranges between 2474 and 3232 mg/l with an average value of 2753 mg/l which exceed the recommended limit. The areal distribution map of the TDS is plotted in Fig. 7, and showed that the minimum values are located in the southwestern corner of the study area. However, the major cations and anions composition of the study area are all above the standard guideline of the WHO for drinking purposes. Moreover, the total hardness of the study area is varying from 1189 to 1549 mg/l as $CaCO_3$, with an average value of 1377 mg/l as shown in Table 1. The areal distribution map of TH is shown in Fig. 8, where, the lower values of TH are found in the southwestern part, which seems to be the best quality zone in the study area. The analytical result of TH indicates that the groundwater of the study area is

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exceeding very hard water type according to [31] and as shown in Table 4. Therefore, according to TDS and TH standards the groundwater is not suitable for drinking purposes.

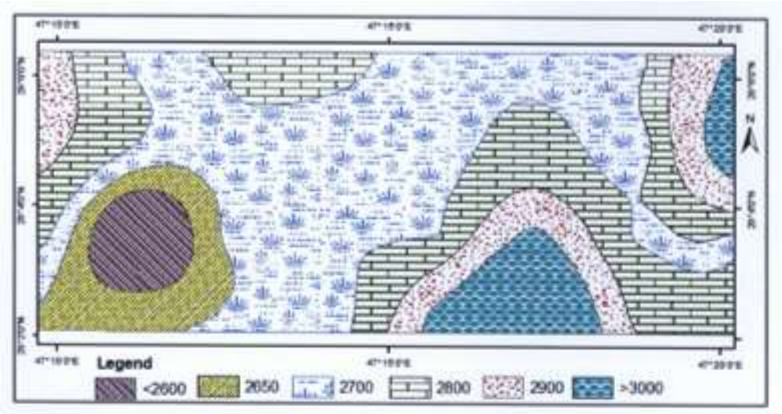

Fig.7: Spatial distribution of TDS of the study

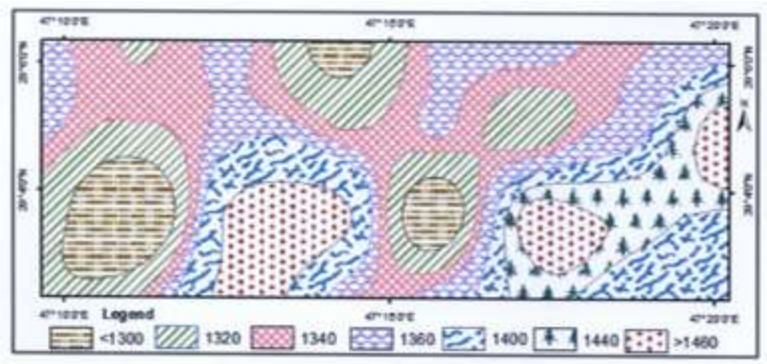

Fig.8: Spatial distribution of total hardness of the study area

Table.4: Water Classes (After Sawyer and McCarthy, 1967).

Total Hardness as $CaCO_3$ (mg/l)	Water Class
<75	soft
75-150	moderately hard
150-300	hard
>300	very hard

Water hardness causes more consumption of detergents at the time of cleaning, and some evidences indicate its role in heart disease [32]. The total hardness (TH) was determining by the following equation according to [33, 21 and 34].

$$TH = 2.5\ Ca^{2+} + 4.1\ Mg^{2+}$$

Where Ca^{2+} and Mg^{2+} concentration are expressed in mg/l as $CaCO_3$. Hardness of water is by inhabitation of soap action in water due to precipitation of Ca^{2+} and Mg^{2+} salts like carbonate, sulphates and chlorides. Hardness of water causes scaling of pots, boilers and irrigation pipes. In order to examine the degree of correlation between the different chemical parameters affecting groundwater quality of the study area, the correlation matrix was determined between the different parameters as display in Table 5. It is found that there is a good correlation between TH and Ca^{2+}, Mg^{2+}, Cl^- respectively , which indicates that the hardness of groundwater is mainly due to $CaCl_2$ and $MgCl_2$.

Table.5: Correlation matrix for different water quality parameters in the study area.

	EC	TDS	Na	K	Ca	Mg	Cl	SO_4	HCO_3	T.Hard
EC	**0.000**	0.985	0.889	0.656	0.541	0.148	0.908	0.478	-0.316	0.493
TDS	0.985	**0.000**	0.842	0.650	0.549	0.200	0.880	0.491	-0.274	0.543

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Na	0.889	0.842	**0.000**	0.726	0.507	-0.067	0.821	0.569	-0.273	0.304
K	0.656	0.650	0.726	**0.000**	0.503	-0.115	0.486	0.847	0.089	0.316
Ca	0.541	0.549	0.507	0.503	**0.000**	0.102	0.467	0.305	-0.340	0.583
Mg	0.148	0.200	-0.067	-0.115	0.102	**0.000**	- 0.052	-0.057	0.138	0.778
Cl	0.908	0.880	0.821	0.486	0.467	-0.052	**0.000**	0.242	-0.565	0.273
SO_4	0.478	0.491	0.569	0.847	0.305	-0.057	0.242	**0.000**	0.354	0.255
HCO_3	-0.316	-0.274	-0.273	0.089	-0.340	0.138	- 0.565	0.354	**0.000**	-0.129
T.Hard	0.493	0.543	0.304	0.316	0.583	0.778	0.273	0.255	-0.129	**0.000**

4.2 Irrigation Water Quality

The suitability of groundwater for irrigation is depending on the effect of mineral composition of water on the soil and plants. The effect of the salt on soils causes change in soil structure, permeability, and hence, it effects on plant growth.

4.2.1 Residual Sodium Carbonate

Residual sodium carbonate (RSC) has been calculated to determine the hazards effects of carbonate and bicarbonate on quality of water for irrigation and is expressed by the equation:

$$RSC = (HCO^{-}_{3} + CO_3^{2-}) – (Ca^{2+} + Mg^{2+})$$

Whereas, all ionic concentrations are expressed in meq/l. The classification of irrigation water according to the RSC presents in Table 6 after [35] , where water containing more than 2.5 meq/l of RSC are not suitable for irrigation, while those having < 1.25 meq/l is good for irrigation [36].

Table.6: Water classes based on RSC (after Richards, 1954).

RSC value	Water quality
<1.25	suitable
1.25-2.5	marginal
>2.5	not suitable

Eaton (1950) indicated that if waters which are used for irrigation contain excess of HCO_3^- + CO_3^{2-} than its equivalent Ca^{2+} + Mg^{2+}, there will be a residue of Na^+ + HCO_3^- when evaporation takes place and the pH of the soil increase up to 3 [37]. When total carbonate levels exceed the total amount of calcium and magnesium the water quality diminished [38]. The calculated RSC values of the groundwater samples of the study area are ranged from -28.44 to -19.78 meq/l with an average value of -25.2 meq/l. Negative RSC indicates that sodium buildup is unlikely, since sufficient calcium and magnesium are in excess of what can be precipitated as carbonates [39]. Hence, the groundwater of the study area is safe for irrigation, and the minimum values of RSC are distributed in the southeastern as well as central part of the study area as displayed in Fig. 9.

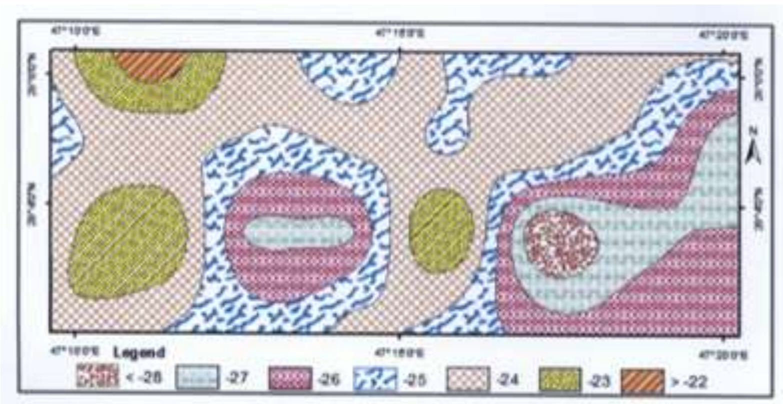

Fig.9: Spatial distribution of RSC of the study area

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4.2.2 Residual Sodium Bicarbonate (RSBC)

Residual sodium bicarbonate (RSBC) is calculated by the following formulae according to [40]:

$$RSBC = HCO_3^- - Ca^{2+}$$

It was found that the groundwater is considered satisfactory with <5 meq/l for irrigation, according to the criteria set by [40] and [41]. In the study area, the values of the RSBC ranges between -17.34 and -9.25 meq/l with an average value of -14.48 meq/l, which indicate that groundwater is good for irrigation.

4.2.3 Permeability Index (P.I)

The permeability of soil is affected by long-term use of irrigation water and is influenced by sodium, calcium, magnesium and bicarbonate contents in soil. Doneen (1964) set a criteria for assessing the suitability of water for irrigation based on permeability index (P.I), accordingly, waters can be classified as Class I, Class II and Class III. The Class I and Class II waters are categories as good for irrigation with 50-75% or more of maximum permeability. Whereas, Class III water is unsuitable with of 25% maximum permeability. Therefore, soil permeability is affected by consistent use of irrigation water which increases the presence of sodium, calcium, magnesium and bicarbonate in the soil [42].

The permeability index is used to measure the suitability of water for irrigation purpose when compared with the total ions in meq/l, it's expressed as follow:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{Ca^{2+} + Mg^{2+} + Na^+} * 100$$

In the present study, the P.I of the groundwater samples ranged from 34.94% to 45.96 % with a mean value of 39.49 %, and it's observed that all the groundwater samples fall in class II category of Doneen Chart (Fig.10). Therefore, the groundwater of the study area is good for use in irrigation.

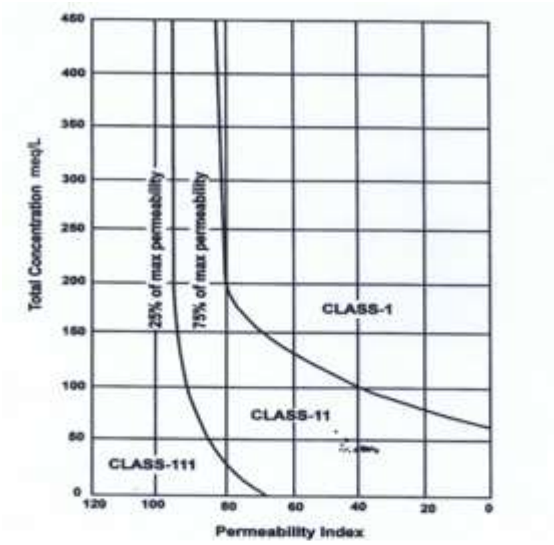

Fig.10: Showing Doneen's Chart of Permeability Index (after Doneen, 1964)

4.2.4 Potential Salinity (P.S)

Doneen, 1961 introduced an important parameter "Potential Salinity" for assessing the suitability of water for irrigation uses, which defined as chloride concentration plus half of the sulphate concentration expressed in meq/l.

$$\text{Potential Salinity} = Cl^- + ½\, SO_4^{2-}$$

On the basis of the potential salinity Doneen (1961) subdivided the irrigation water into three classes as presented in Table 7. The potential salinity of the majority of the analyzed groundwater samples of the study area ranges between 22.8 meq/l and 30.85 meq/l with an average value of 26.46 meq/l indicates high values of potential salinity. However, it is found that the classification of the groundwater of the study area for irrigation purposes fall in Class III, therefore, the groundwater should be used in case of a soil of high permeability [43].

Table.7: Classification of irrigation water based on potential salinity.

Class of water / Soil Characteristics	Class I	Class II	Class III
Soil of low Permeability	<3	3-5	>5
Soil of medium Permeability	<5	5-10	>10
Soil of high Permeability	<7	7-15	>15

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4.2.5 Sodium Adsorption Ratio (SAR)

Sodium concentration is considered an important factor to express reaction with the soil and reduction in its permeability. Therefore, sodium adsorption ratio is considered as a better measure of sodium (alkali) hazard in irrigation water as it is directly related to the adsorption of Na^+ on soil, and is an important critera for estimating the suitability of the water for irrigation. SAR can be computed as follow:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Where all ionic concentrations are expressed in meq/l. The SAR of the study area ranges between 3.42 and 5.52, with an average value of 4.17. According to the classifications of water based on SAR values [33, 35], the SAR values of all the study area are found to be <10, and are classified as being excellent for irrigation i.e S_1 category. The areal distribution map of the SAR values of the study area is presented in Fig.11, and it is exhibited that the lower values of SAR are concentrated in the southeastern and central part of the study field, which means that the groundwater of this part is suitable for irrigation.

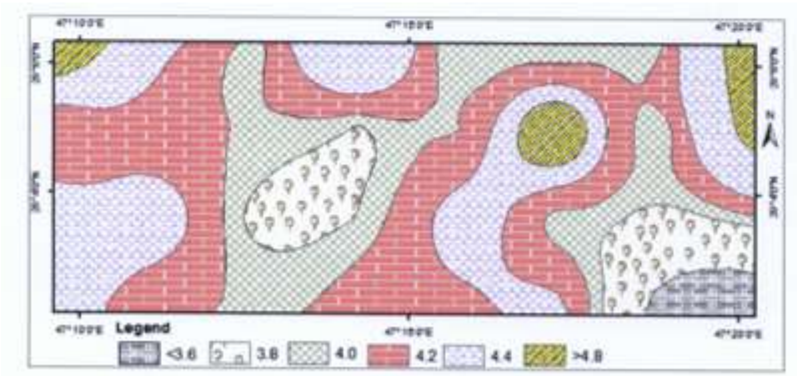

Fig.11: Spatial distribution of SAR of the study area

4.2.6 Salinity Hazard

The most important criteria regarding salinity and water availability to the plant is the total salt concentration. Since there exist a straight line correlation between electrical conductivity (EC) and total salt concentration of waters, the most expedient procedure to evaluate salinity hazard is to measure its electrical conductivity measured in (µmohs/cm) [44]. On the basis of salt concentration, US Salinity Laboratory Staff [35] divided the irrigation water into four classes as displayed in Table 8. It is found that the values of EC of the study area range from 3310 to 4060 µmohs/cm with an average value of 3467 µmohs/cm which is considered of C4 high salinity hazard class. For rating irrigation waters, the US salinity diagram was used, in which the SAR is plotted against EC as shown in Fig.12, where, all the samples of the study area fall in the category of the C_4-S_2, indicating high salinity/ medium sodium type. Therefore, the groundwater of C_4-S_2 class can be used with tolerant crops of clayey, sandy loam and loamy sand soil texture [45]. Based on these specifications, the groundwater of the study area is considered safe for irrigation.

Table.8: Salinity hazards of irrigation waters based on EC values (Richards, 1954).

EC of irrigation water (µmohs/cm)	Salinity Class	Salinity Hazards
100 – 250	C1	very low
250 – 750	C2	low
750 - 2250	C3	medium
2250 - 4000	C4	high salinity

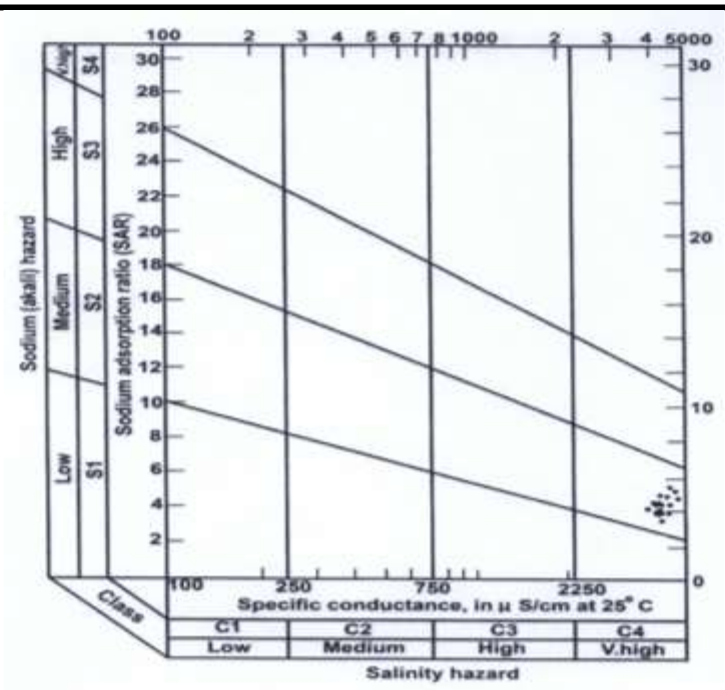

Fig.12: Showing USSL salinity hazard diagram of the study area

4.2.7 Magnesium Ratio

In most waters calcium and magnesium maintain a state of equilibrium. A ratio namely index of magnesium hazard was developed by [46]. According to this, high magnesium hazard value >50% has an adverse affect on the crop yield as the soil becomes more alkaline, and effect on the agricultural yield.

$$\text{Mg ratio} = \frac{Mg^{2+}}{(Ca^{2+}+Mg^{2+})} \times 100$$

Where all ionic concentration are expressed in meq/l.

In the study area, the magnesium hazard values falls in the range value of 33.34% to 47.63% with an average value of 38.8 %, i.e. magnesium hazard ratio < 50%, which is recognized as suitable for irrigation.

4.2.8 Sodium Percentage (%Na)

Sodium is an important ion used for the classification of irrigation water due to its reaction with soil, reduces its permeability. The %Na is computed as:

$$\%Na^{+} = \left(\frac{(Na+K)^{+}}{Ca^{2+}+Mg^{2+}+K^{+}+Na^{+}}\right) \times 100$$

Where, all ionic concentrations are expressed in meq/l. According to [47] in all natural waters %Na is a common parameter to assess its suitability for irrigation purpose as shown in Table 9. If the concentration of Na^{+} is high in irrigation water, Na^{+} gets absorbed by clay particles, displacing Mg^{2+} and Ca^{2+} ions. This exchange process of Na^{+} in water for Ca^{2+} and Mg^{2+} in soil reduces the permeability of soil and eventually results in poor internal drainage of the soil, and such soils are usually hard when dry [48, 49]. The values of %Na of the study area varies from 31% to 42.46% with an average value of 35.68% which fall in good to permissible category, showing that the groundwater of the study area is suitable for irrigation.

Table.9: Classification of groundwater based on %Na (Wilcox, 1955).

Water quality	Sodium %
Excellent	<20
Good	20-40
Permissible	40-60
Doubtful	60-80
Unsuitable	>80

4.2.9 Kelly's Ratio

Kelly's ratio is used for the classification of water for irrigation purposes. A Kelly's index (>1) indicates an excess level of sodium in waters [50]. Therefore, water with a KR (<1) is suitable for irrigation. KR is calculated by using the formulae; where all the ions are expressed in meq/l.

$$\text{Kelly's Ratio} = \frac{Na^{+}}{(Ca^{2+}+Mg^{2+})}$$

The values of the KR in the present study varied between 0.45 and 0.75 with an average value of 0.56 which is <1. Accordingly, the groundwater of the study area is suitable for irrigation.

4.2.10 Ion-Exchange Processes

It is essential to identify the various changes in chemical composition occur in groundwater during its travel in subsurface [51]. This can be done by the computation of the chloro-alkaline index -1 which is suggested by [52] to indicate ion exchange between the groundwater and its host environment during residence or travel. The value of the index CAI-1, can be positive or negative. If the value is positive then it explains that the exchange of Na^+ and K^+ ions are from water with Mg^{2+} and Ca^{2+} ions of the rocks. And if the index is negative, then it means that there is an exchange Mg^{2+} and Ca^{2+} of water with Na^+ and K^+ ions from rocks, so the exchange is in indirect base indicating chloro-alkaline disequilibrium. The chloro-alkaline index-1 is calculated using the following formulae:

$$\text{Chloro-alkaline index} = \frac{Cl^- - (Na^+ + K^+)}{Cl^-}$$

Whereas, all ionic concentrations are expressed in meq/l.

The chloro-alkaline index -1 is calculated for the groundwater samples of the study area and it has been found that CAI-1 values all are negative, and range from -0.56 to -0.21,with an average value of -0.21 indicating that all the groundwater samples have indirect base-exchange reaction.

V. CONCLUSION

The interpretation of the hydrochemical analysis of Field-C reveals that the groundwater is brackish and exceeding very hard. The sequence of the major ions is in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and $SO_4^{2-} > Cl^- > HCO^-_3$. Alkali earth exceeds alkalis and strong acids exceed weak acids. The dominated hydrochemical facies of groundwater is Ca-Cl and Ca-Mg-Cl genetic water types. The determination of the saturated index indicated that all groundwater samples of the study area were under-saturated with respect to the sulphate minerals, and oversaturated with respect to carbonate minerals. Gibb's plot revealed that the chemical weathering of rock-forming minerals is the dominant process, where there is an interaction between rock chemistry and percolating waters in the subsurface. The irrigation parameters reveal that the groundwater is good and suitable for irrigation and concentrated along the southwestern and central parts of the study area. Meanwhile, the major ions compositions in groundwater indicate that the water is not suitable for drinking purpose.

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