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Characterization of the Groundwater within Regional Aquifers and Suitability Assessment for Various Uses and Purposes-Western Iraq

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Abstract:

Groundwater quality investigation has been carried out in the western part of Iraq (west longitude 40°40'). The physicochemical analyses of 64 groundwater samples collected from seven aquifers were used in the determination of groundwater characterization and assessment. The concept of spatial hydrochemical bi-model was prepared for quantitative and qualitative interpretation. Hydrogeochemical data referred that the groundwater is of meteoric origin and has processes responsible for observed brackishness. The geochemical facies of the groundwater reveal that none of the anions and cations pairs exceed 50% and there are practically mixtures of multi-water types (such as Ca–Mg–Cl–HCO_3 and Na+K–SO4–Cl water type) as dominant types. The hydrogeochemical evolution indicates that the groundwater is mainly controlled by the leaching and dissolution process of carbonate minerals. Increasing salt content is observed at different static water levels (groundwater flow) confirming mixing cases with multi water sources. Anthropogenic activities do not have a significant alteration in the geochemical nature of groundwater in aquifer systems. Most of the groundwater is classified within the category of C3S1 and C2S1 denoting admissible to good quality of water for irrigation in 67% of the total samples. On the other hand, 33% of samples are classified as bad to very bad. The groundwater of most aquifers has precedence for irrigation, agricultural purposes, animal drinking, and good to fair class for natural preserve activities. While the groundwater of Mullusi and Jeed-Rattga aquifers are suggested for human drinking purposes. Also, the groundwater within the hydrogeologic system can be used in low-pressure boilers, mining, construction industry, and unsafe in high-pressure boilers due to the relatively high total hardness (237 to 1456 mg/l). Corrosively ratio indicates that 83 % of exploited groundwater from boreholes is safe for long transport through metallic pipelines.

Keywords: Groundwater uses, Hydrochemical facies, Standard limit, Water-type.

Introduction:

The concept of hydrochemical characterization and assessment of the groundwater was studied in many parts of the world as a vital tool for visualizing the sensitivity of groundwater resources in their environment and is useful for decision making and planning. Spatial analysis techniques can help to estimate, and manage the groundwater assessment; for example in India and Nigeria, the assessment is essential for strategies to protect groundwater and land use (1). The recent international practices in groundwater characterization have been reviewed by several studies (2-4). Mohamed and Allia (5) have studied the geochemistry of the aquifer based on the ionic components, hydrochemical facies, and the factors controlling groundwater chemistry in the Souf valley of Sepentrional Saha (Algeria), using different graphical plots. Suma et al. (6) presented a geochemical modeling technique using PHREEQC in demarcating the main factors and mechanisms controlling the chemistry of groundwater in the Chinnar sub-basin. Also, Bruce et al. (7) identified the hydrogeochemical characteristics and evolution of groundwater in the Heihe River Basin, northwest China and its relationship with the surface water. Many previous hydrogeological and groundwater quality studies were conducted for different purposes within the study area Al-Jabbari et al. (8);

Jassim and Goff (9). Such studies were taken into consideration in this paper. Hussien (10) defined eight hydrogeologic provinces within the study area, depending on the groundwater occurrence, hydraulic parameters such as permeability, transmissivity, storativity, groundwater depths, and hydrodynamic activity (groundwater velocity).

In Iraq, groundwater is a major importance where the population in western Iraq depends on the groundwater for drinking and domestic purposes. Therefore, this study aims to the identification of the geochemical assessment of groundwater western Iraq. Also, it is evaluating hydrochemical characteristics for different purposes and suitable uses, which would be quite useful for the planners in validating groundwater quality models.

Geology and Hydrogeology

The study area located to the west of longitude (40º40'00") within the borders of Iraq with a total area of 38,900 km^2 and elevation ranges between 252 and 850 meters above sea level. The area is characterized by desert climate during the last sixty years (11). Valleys of seasonal flow forming several plateaus with pediment sediments. The main valleys are Hauran, Walaj, Ghadf, Alubayidh, Rattga, Swab, Akash, etc. These valleys form important drainage basins feeder for groundwater (Fig. 1).

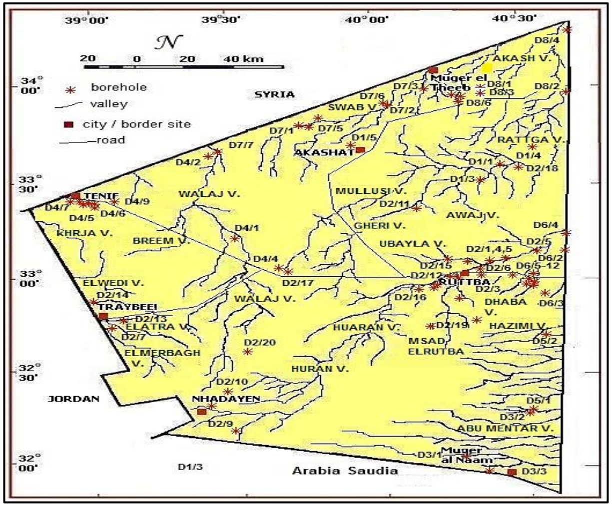

Figure1. Location map of the study region.

Structurally, the investigated area is located in the western part of the stable shelf within the Arabic-African plate. Rutba uplift is attributed to the tectonic movements within geological periods that affect the stratigraphic and structural status for Hauran anticlinorium. (12), this indicates that the aquifers are influenced by Hauran anticlinorium, where the dip of fold flanks ranging between 1.0° to 2.0° ESE WSW and between 2.0° to 6.0° towards the NWN and NEN. Hauran anticlinorium (Rutba Uplift) extends in the E and NE direction (9) contributed to the base blocks movement within the Hail arch during the Paleozoic.

The territory of the fold axis represents the groundwater divide belt, which acts as a deviation of groundwater movement towards the NW and SE. The dip of Permian, Triassic, and Jurassic beds within Hauran fold is towards S and SE, while the dips of Cretaceous-Paleocene layers are towards the N and NE within Anah-Syrian border and to the E and SE in the eastern portions of the study area.

The geological studies proceeded by Buday and Hack (13); Sessakian and Mohamed (14) are summarized in Table 1. Groundwater occurs in different water-bearing formations belonging to Eocene, Cretaceous, Jurrasic, and Permian. Depending on the occurrence of groundwater within the geological Formations, seven aquifers are defined in the study region as classified by Hussien and Fayyadh (15), (Fig. 2) are identified in the study region obtaining Ga'ra, Mullusi, Hartha, Digma-Tayarat (Jeed), Muhaywir-Ubaid, Ubaid-Mullusi, and Rattga-Jeed aquifers.

Al Hamad Province represents the main recharge zone of the aquifers related to study area (11), this study also confirmed the recharge and replenishment of aquifer water from rain and runoff waters that penetrated throughout the rock exposures within the valley catchment area. The available groundwater resources in an Al Hamad physiographic zone are distinguished as the water of older origin. The recharge of high-frequency precipitation dated back to more than 30000 Years BP (16) may come across a southern pluvial period (late Pleistocene age). The amount of infiltration water to all aquifers is equal to 204.36 x 10^6 m^3/year (17). The Lateral hydraulic connection between aquifers is also considered as a dominated recharge inflow that occurred beneath adjacent aquifers.

Hydraulic characteristics and flow were assessed for aquifers based on the available information on the hydrogeological studies (15). The hydrogeologic system is classified as aquifers of low permeability (Fig. 2), low to high transmissivity compared with the Laboutka classification (18). The groundwater of Ga'ra, Hartha, Muhaywir-Ubaid, Ubaid-Mullusi, Rattga, and Jeed aquifers are characterized by unconfined to semi-confined conditions, while the groundwater of other aquifers is distinguished by confining to semi-confined conditions.

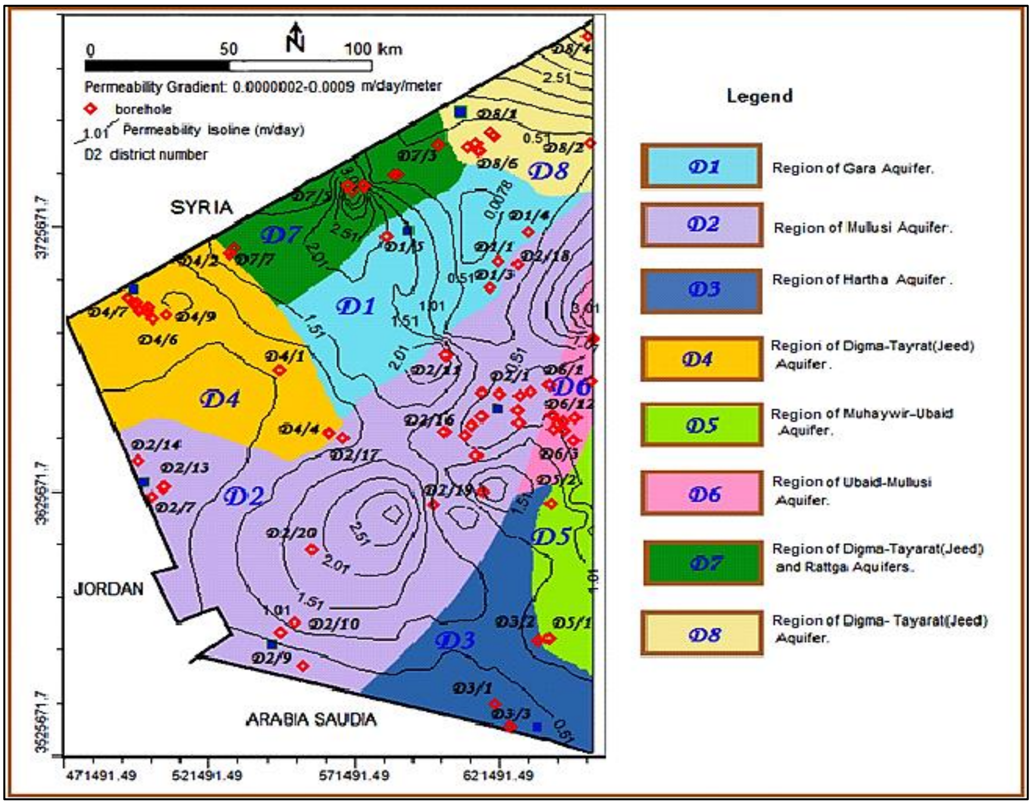

Figure 2. Compiled map of aquifers and permeability (15).

Table 1. Geologic sequences within the study area (15).

Era	Period	Age	Formation	Explanation
Cenozoic	Quaternary	Holocene- Pleistocene	Recent sediments, Hauran Sandy gravel.	Alluvial valley and depression fill sediments.
	Tertiary	Late Miocene-Pliocene	Zahra Fn.	Limestone, sandy Limestone.
		Middle Miocene	Nefile Fn.	Marl, silty claystone, Limestone.
		Late Miocene	Ghar Fn.	Sandstone & calcareous silty Sandstone.
		Early Oligocene	Shurau/shiekh Alas Fns.	Carbonate rocks.
		Early-Late Eocene	Rattga Fn.	Fossiliferous dolomitic chalky, Limestone(phosphatic)
		Middle-Late Paleocene	Akashat Fn.	Phosphatic limestone, marly Dolomite. Fossiliferous Chalky Limestone.
Mesozoic	Cretaceous	Early-Late Maastrichtian	Digma Fn.	Argillaceous limestone embedded with silty sandstone. Marl and Dolomite.
		Late Campanian-Late Maastrichtian	Hartha-Tayarat Fns.	Dolostone, silty clay Limestone sandy Marl.
		Cenomanian-Turonian	Rutba-Msad Fns.	Dolomitic Limestone- silty sandstones
		Albian-Cenomanian	Naher Umer – Maudod Fns.	Siltstone, Sandstone, Marl, dolomitic Limestone
	Jurassic	Bathonian	Muhaywir Fn	Marly carbonate, sandstones,
		Lias	Amij – Hussayniyat Fns.	Ferigenous Clayey sandstones, Iron Ore and dolostone
		Lias	Ubaid Fn.	Dolomite, Gypsious Marl, Dolostones.
	Triassic	Rhaetic	Zor Huran Fn	Marl, marly Dolostone, Gypsious Marl
		Carnian-Norian	Mullusi Fn.	Limestone, dolomite limestone, and dolostone.
Paleozoic	Permo-carboniferous	Early-late Permian	Ga’ra Fn.	Interbedded of clay stones and sandstones

Materials and Methods:

The program of groundwater sampling was implemented for the 64 wells within the Western Sahara region in accordance with the field procedures described by USEPA and Nielsen (19, 20). This study was carried out during May 2013 for one time and did not include successive monitoring periods for hydrochemical variations during the seasons of the year. Electric sounder was used in measuring groundwater levels in accordance with the procedure (21). Before the collection of the samples, each borehole was flushed for about 3 minutes to avoid collecting the water that was initially in the casing pipe. The groundwater samples were collected in polyethylene bottles previously washed with distilled water and rinsed again with water samples to ensure the elimination of contaminants (22). Field physicochemical variables (Table 2) were measured for all the samples collected from either daily continuous or weekly intermittent production wells.

The discharge of sampled wells ranged between 60 to 2160 m^3 /day with an average of 864 m^3 /day, classified as wells of medium productivity depending on Laboutka (18) classification. Synchronized with pumping, the values of groundwater drawdown (Δs) range between 11 to 112 meters with an average of 56 meters. Accordingly, the specific capacity of the production wells is relatively low, with an average of 15.2 m^3 /day/m, this may be attributed to decrease in the rates of recharge due to drought and low rainfall offset by an increase in the rates of pumping from wells and drilling new wells. The exploitation of the groundwater is nearly constant (within the amount of safe yield) except for Dhabaa Site, which is characterized by intense pumping for the Rutba city water supply (12).

Chemical analyses of water samples were performed in Soil and Water Laboratory (University of Anbar). Field parameters including water temperature, electrical conductivity and pH, were measured in situ using a pH-EC multimeter device. Bicarbonate (HCO_3^-) was measured by the titration method; Ca^{+2} and Mg^{+2} were measured by EDTA complex metric titration; K^+ and Na^+ concentration were measured by flame photometer; Cl^- concentration was measured by the silver nitrate method; the SO_4^{-2} concentration was determined using turbidity method. The reliability of the Chemical components was examined by the charge balance method (23). Anions, cations, total dissolved solids (TDS) and total Hardness are presented in Tables 2. Overall procedures were as per the standard methods of analysis of water and wastewater.

Groundwater quality was statistically assessed (24) to recognize the hydrogeochemical mechanisms that affect the origin of groundwater and facies (25), using the statistical application of the Curve expert v1.3 program. The interpretations of hydrochemical phenomena are based on Piper trilinear, expanded Durov plots (26), and spatial analysis maps of hydrochemical variables using Groundwater Contour software. Saturation indices of some common minerals were calculated using the program PHREEQC (27).

The groundwater uses assessment was performed according to the quality criteria of water for domestic, drinking, Livestock purposes, which have been suggested by international agencies such as the agency of the World Health Organization (WHO) (28) and the Department of Water Affairs and Forestry (DWAF) (29 and 30), USEPA (31), (Table 3). Groundwater was evaluated for animal drinking water purposes using the US. Public Health Service classification, Crist and Lowry (32); Lewen and King (33), while Wilcox (34) and USSLS 1954 plots Hem (35).

Results and Discussion:

Hydrochemical Characteristics

The groundwater of the aquifers within the study region has pH values ranging between 7.0 and 8.1. Also, the groundwater can be classified as neutral to slightly alkaline behavior. The spatial variation of pH is limited between 0.00000005 and 0.00009 pH/ meter within all aquifers. The measured electrical conductivity of the groundwater (Table 2) indicates large fluctuation with spatial space variation ranged between 0.00025 and 0.32 μScm^{-1}/ meter. The variation reflected the effectiveness of the hydrogeochemical process. The TDS of the groundwater ranges from 514 to 3150 mg/l. Therefore the groundwater classified as fresh to slightly saline water according to TDS classification Matthess (36).

TDS spatial distribution map (Fig. 3), illustrates an increasing of TDS values to the northwest part and to the northeast direction corresponding with the flow direction, detected by leaching grade of 0.0002 to 0.19 mg/ liter/m, while the values of TDS decrease within Swab and Hauran valley catchment areas which represent the zone of groundwater replenishment. The groundwater temperature of aquifers ranged from 21 to 26°C, classified as tepid to slightly warm water (18, 37).

Bicarbonate ion (HCO_3) in the collected samples of aquifers fluctuates between 164.7 and 861.9 mg/l. The high rate of HCO_3 prevailed by alkaline earths Ca+Mg related to other anions may indicate leaching of limestone and dolomite.

Bicarbonate water types are referring to the interaction between water and aquifer sediment, as well as the influence of the groundwater flow path. The relation of HCO_3/Cl versus TDS (Fig. 4) illustrates an inclined curve trend. This relation detects that Bicarbonate concentration of the water samples is slightly decreased with the increase of total dissolved solids (with the flow direction) represented by 3rd-degree Polynomial Fit:

$$HCO_3/Cl = a + b\,(TDS) + c\,(TDS)^2 + d\,(TDS)^3.$$

a =0.622; b =0.0024; c =-1.7e-006; d =3.2e^{-010}

This relation elucidates the extraction of bicarbonate from the groundwater synchronized with the long residence time because of the precipitation process. The phenomenon is also proved by the saturation indices related to aragonite, Calcite, and Dolomite (SI) (Table 4), calculated by PHREEQC software (27), where the groundwater classified as slightly saturated to supersaturated concerning with calcite, aragonite, dolomite mineral phase, which has positive indices (SI> 0), (Fig. 5).

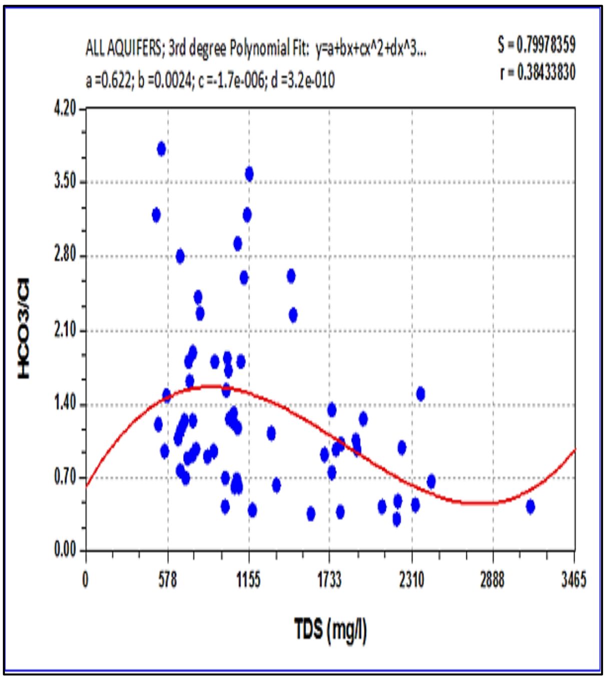

Figure 4. TDS versus HCO_3/Cl scatter plot.

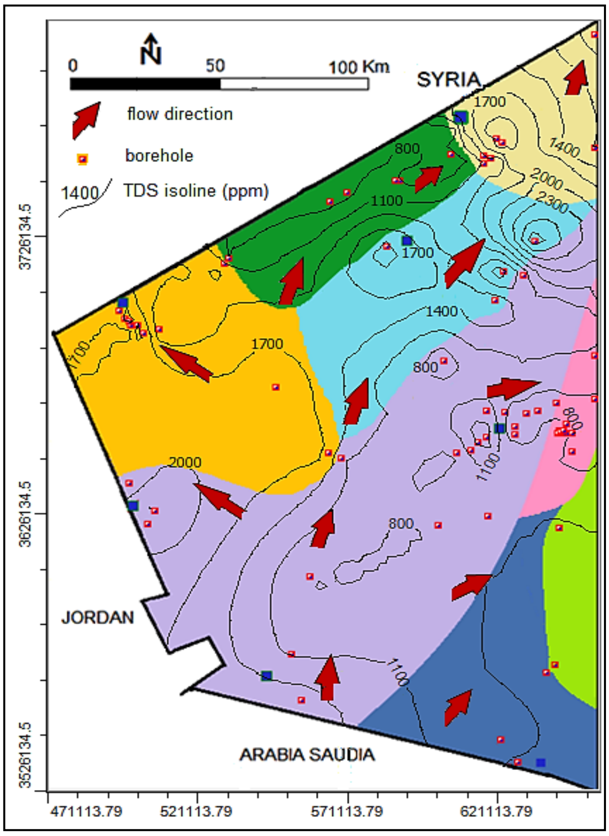

Figure3. TDS map compiled with groundwater flow (17).

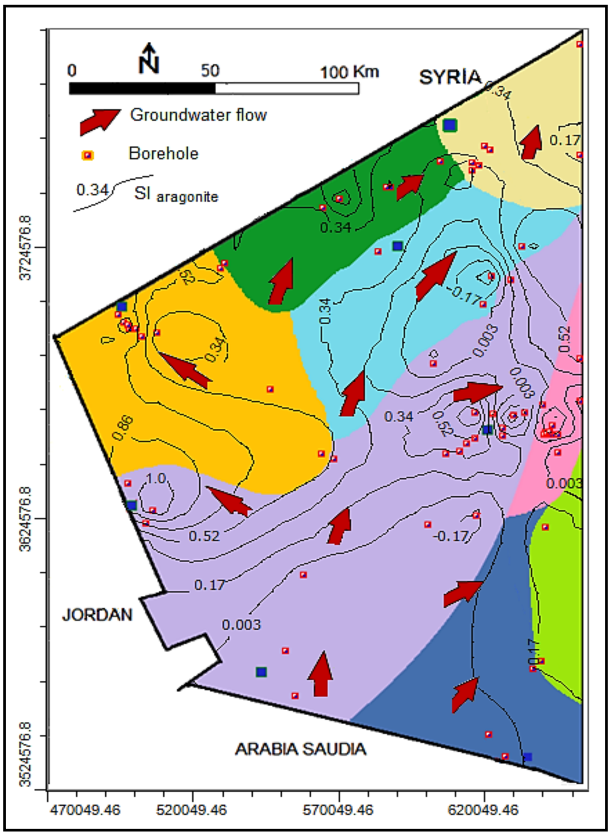

Figure 5. Map of SI $_{aragonite}$ compiled with groundwater flow.

Table 2. Chemical analyses and field measurements of the groundwater samples (17).

Station ID	X coordinate m	Y coordinate M	Elevation m asl	SWL m asl	EC µS/cm	T °C	pH	K^+ mg/L	Na^+ mg/L	Ca^{++} mg/L	Mg^{++} mg/L	Cl^- mg/L	$SO_4^=$ mg/L	HCO_3^- mg/L	TDS mg/L	H_T mg/L
D1/1	622232.6739	3713038.972	495.5	437.7	720	22.5	7.3	6.26	25.3	48.9	50.7	82.4	151.2	171.4	514	330.1
D1/2	622232.6739	3713038.972	495.5	412	3709	21	7.3	12.9	336.7	193.4	105.3	581.5	501.6	488.6	2208	915.2
D1/3	619263.6507	3702836.155	518	503	2520	22	7.3	10.56	272.8	124.3	104.9	437.7	499.7	284.3	1800	741
D1/4	632910.7522	3724271.096	453	255.1	4500	23	7.5	36.75	423.2	283.8	166.4	733.4	944.6	540.5	3150	1125
D1/5	583647.1768	3722174.598	610	417	3200	22	7.6	19.94	253.7	238.1	127.9	540.3	631.2	295.2	2200	1119
D2/1	633750.1859	3663286.77	584.6	543	1209	22	7.2	4.3	69.5	99.4	32.8	153.4	152.6	235.5	720	382.9
D2/2	616751.3575	3653828.621	622.1	597	2929	23	7.3	20.33	282.2	151.7	69.9	332	264	771.7	1844	665.8
D2/3	626084.259	3654560.083	621	564	840	26	7.5	7.82	64.4	82.4	35.4	78.5	101.3	378.8	688	351.1
D2/4	622611.1985	3662524.842	610	573	1518	25	7.4	5.47	87.2	103	39.5	187.1	191.5	304.4	904	419.4
D2/5	629878.1175	3662002.465	596	/	967	24	7	7.04	65.1	68.9	28.9	87	144	222	576	290.7
D2/6	626048.649	3657331.915	619.3	580	672	25	7.1	3.13	37	67.7	31.6	57.2	61.9	314.2	545	298.8
D2/7	503150.234	3618414.677	807	509.4	3045	23	7.3	12.51	289.3	217.4	93.7	517.6	588.5	383.7	2100	927.6
D2/8	655467.0825	3667304.593	561	507	1070	25	7.05	8.99	63	109.8	36.1	77	277.9	250.7	760	422.5
D2/9	554999.1939	3559058.736	840	769	2610	25	7.4	18.77	270	115.2	72.8	367.1	533	231.2	1598	586.5
D2/10	551771.1707	3575669.523	850	451	1753	26	7.3	5.87	211.1	77.9	30.6	128.5	388.3	290.4	1044	320.2
D2/11	602321.3803	3681265.209	670	435	939	24	7.4	3.13	78.2	63.9	19	108.6	103.7	176.9	559	237.6
D2/13	506242.6316	3627269.64	820	529	3200	26	7.7	9.38	190.4	320	160.1	316.7	715.2	814.4	2373	1456
D2/14	497661.0048	3637245.085	780	499	3400	25.5	7.8	10.56	178	220.2	98.6	273.7	621.1	482.5	1830	954.7
D2/15	616641.3848	3663067.946	640	575	1912	25	7.8	24.24	176	229.9	93.1	240	615.8	464.2	1814	956.5
D2/16	606745.721	3648047.454	650	616	900	25	7.3	6.26	71.3	130.9	20.4	124.3	160.8	345.9	790	410.9
D2/17	568544.0607	3645982.553	776	736	1926	26	7.3	10.17	63.3	155.1	77.9	97.3	317.3	534.4	1197	707.1
D2/18	629134.1665	3711958.476	511	421	1574	24	7.5	12.51	168.8	120.8	31.7	249.6	279.8	261.1	1086	431.9
D2/19	617090.7007	3625187.46	647	531	1383	25	7.4	11.73	181	71.3	37.9	237.9	284.6	180.6	988	333.6
D2/20	557886.5842	3603416.92	422	226.8	1098	23	7.2	4.69	59.3	106	45.7	162.6	160.3	271.5	784	452.4
D3/1	621178.0129	3544850.345	750	646	1060	23	7.4	4.69	112.7	67.9	39.7	160.8	154.6	254.4	756	332.5
D3/2	636593.3807	3569069.274	750	289	2260	24	7.3	23.85	209.3	145.9	39.4	309.9	337.4	337.9	1350	526.3
D3/3	626013.5278	3535669.577	731	/	1720	24	7.4	7.04	139.6	132.3	60.7	268.7	381.1	180	1180	579.6
D4/1	546611.0505	3671722.908	755.5	445.8	3212	22	7.4	22.68	112.7	179.2	140.1	284.7	616.3	521	1912	1022
D4/2	529385.2798	3716003.286	688	455	2800	23	7.4	8.21	120.1	188.2	93.1	143.1	401.8	641.1	1453	582.2
D4/3	494241.3736	3698960.148	721	/	2760	22	7.6	20.72	226.1	188.2	111.3	433.8	291.4	735.1	1923	926.8
D4/4	563858.5001	3647798.836	807	735	2800	23	7.6	16.42	133.4	201.8	137.5	298.2	547.2	496.5	1776	1068
D4/5	500774.8028	3693938.636	723	472	3075	24	7.5	11.73	244	200.8	103.9	396.9	275.5	861.9	1968	927.9
D4/6	502532.3506	3691167.267	726	489	3497	22.5	7.3	37.53	285.9	222.8	113.3	491.3	369.6	840	2438	1021
D4/7	496435.3338	3696433.773	718	476	2641	24.5	7.5	14.86	250.9	151.1	84.4	358.9	344.6	567.9	1690	723.8
D4/8	498191.2445	3693969.57	730	487	2100	24	7.5	8.21	136.9	184.4	80.7	161.2	406.6	621	1470	791.8
D4/9	507544.8448	3692524.911	722	485	1500	23	7.4	6.26	99.4	104.9	73.2	148.4	347	314.2	1050	562.3
D4/10	497623.1797	3695263.142	722	476	3500	23	7.4	14.86	294.6	279.4	128.1	535	649.4	613.1	2450	1223
D5/1	636593.3807	3569069.274	750	289	2260	22	7.3	12.51	167.2	76.2	53.8	193.8	347	206.2	1056	411
D5/2	640576.3624	3620872.001	745	648	1624	21	7.25	6.65	103.7	139.1	69.6	65	473.8	400.8	1190	633.1
D6/1	639983.8816	3666146.441	580	529	1016	24	7.5	4.3	50.1	82.8	54.2	105.8	148.3	328.2	726	429.2
D6/2	655467.0825	3667304.593	561	515	2529	25	7.3	20.33	66	261.7	117.4	268.7	687.4	344	1744	1135.
D6/3	644855.9594	3648657.964	600	521	1000	24.3	7.4	1.95	49.9	82	55.1	153	169.9	183	706	430.9
D6/4	655216.7814	3683012.969	521	331	1400	23	7.7	5.87	59.1	145.3	79.1	87.3	353.8	439.8	1480	687.5
D6/5	643206.1755	3654948.94	610	520	1445	23.5	7.5	5.87	101	100.2	41	165.1	227.5	256.2	860	418.6
D6/6	640956.2682	3656210.2	590.3	492	1025	22	7.45	3.13	91.1	112	48.6	142	54.7	438.6	911	479.2
D6/7	643103.06	3658459.288	580	498.3	1324	21	7.9	5.08	99	101.6	48.9	122.1	109.9	477.6	874	454.5
D6/8	642217.5614	3655119.4	593	/	1277	23	7.41	23.85	94.8	112	58.3	142	203	447.7	1003	519
D6/10	644914.9591	3655220.464	591.3	480	3760	22	7.07	13.29	93.4	84	92.4	149.1	192	439.2	2497	588.8
D6/11	640455.0544	3654970.802	595.27	512	1333	21	7.42	17.2	91.3	104	48.6	156.2	105.6	414.2	1100	459.2
D6/12	641381.105	3655538.593	598.32	489.4	1395	24	7.29	19.55	91.1	111.8	77.8	148.7	149.8	439.2	997	598.5
D7/1	564551.3628	3738197.231	608	443	1142	25	7.8	5.87	92	76.2	36.5	127.4	141.1	274.5	700	340.1
D7/2	587809.6617	3745806.431	437	345	1155	24	8.1	8.99	69.9	57.9	49.1	114	168	232.4	688	346.1
D7/3	604744.8976	3755342.489	470	316	780	23	7.7	1.56	33.6	67.3	39.3	45.8	110.4	300.7	578	329.4
D7/4	570440.4063	3741781.031	627	417	1130	22	7.4	2.35	78.9	87.6	27	124.6	189.6	164.7	673	329.7
D7/5	564551.3628	3738197.231	609	579	954	24	7.7	14.08	94.1	71.9	22	134.9	118.6	250.1	658	269.9

D7/6	586343.7101	3745916.227	585	430.5	2300	23	7.6	8.99	77.1	118.6	88.1	119.3	267.4	533.1	1120	657.7
D7/7	531003.0633	3717917.84	678	569	1152	24	7.4	5.08	76.82	95.6	44.6	113.2	79.7	469.1	845	421.8
D8/1	615923.0117	3754671.552	464	369	1098	21	7.55	4.3	107.6	83.4	28.8	141.3	142.6	303.8	757	326.6
D8/2	654011.1478	3757863.281	497.6	427.9	1800	24	7.4	10.17	191.6	85.9	40.1	285.8	159.4	336.7	1072	379.1
D8/3	620079.256	3761069.525	412	326.1	3927	25	7.5	25.42	466.7	126.7	100.2	675.9	419	526.4	2338	727.5
D8/4	653347.2526	3798525.859	325	/	961	26	7.6	5.08	94.8	78.1	23.2	129.2	135.4	256.2	672	290.3
D8/5	615897.7113	3754640.437	465	369	1106	23	7.16	25.81	190.7	82.2	45	284	121	340.4	989	390
D8/6	615896.9588	3754702.041	467	370	1137	24	7.45	25.02	183.8	88.2	43.8	213	120.5	463.6	1089	400.1
D8/7	615923.3881	3754640.751	466	368	1200	21	7.67	16.42	194.8	64.1	29.2	216.6	116.2	439.2	1070	279.9

Table 3. Standard limits for using water for various purposes.

Constituents	Domestic purposes DWAF (29)	Drinking			Livestock DWAF (30)	Animal Watering Crist and Lowry (32)	
		European Union (38)	USEPA (31)	WHO (28)		TDS mg/l	Class
pH	9.5	-	6.5-8.5	7-8.5	-	0-1000	Good
TDS mg/L	1000	-	500	500	10000		
K mg/L	50	-	-	-	-	1000-3000	Fair
Na mg/L	200	200	-	200	200		
Ca mg/L	150	-	-	75	1000	3000-5000	Bad
Mg mg/L	100	-	-	30	500		
HCO_3 mg/L	Ns	-	-	200	-	5000-7000	V.bad
Cl mg/L	200	250	250	250	1500		
SO_4 mg/L	400	250	250	200	1000	7000-13000	Un-suitable
NO_3 mg/L	10	50	44	50	-		
H_T mg/L	-	-	-	500	500		

0.059 mg/L/meter within study regions. SO_4 concentration in natural water is usually found between 2 and 80 mg/l (35). The concentration of SO_4 is originated to the leaching of minerals such as gypsum and anhydrite. Gypsum and Anhydrite saturated indices with negative values (SI< 0) in Table 4 indicate that the groundwater is still active to leach SO_4 from sulphate mineral phase.

The amount of calcium (Ca) in the subsurface water of aquifers within the eight districts ranged between 48.9 and 320 mg/L with a regional spatial variation of about 0.000008 to 0.019 mg/L/m, enriched with the flow direction (long residence time). The amount of magnesium (Mg) ranges between 22 and 166.4 mg/l, with a spatial variation of 0.0000085 to 0.01 mg/L/m, saturated by Mg with the groundwater flow direction. These values indicate the supplement of Mg and Ca from carbonate and evaporate rocks, which form aquifers matrix.

The ratio of rCa/rMg (Table 4) ranges from 0.55 to 3.88, which surpasses of connate seawater (equal to 0.18), which indicates the origin of meteoric water. Ca/Mg ratio of water samples shows a dominance dissolution of calcite in the aquifer at a percentile of 65%, where a higher Ca/Mg ratio (>1) is indicative of the greater calcite contribution. Whereas a low Ca/Mg ratio (<1) in 27% of water samples is indicative of dolomite dissolution.

Sodium and Potassium (K) concentration in the collected samples within the study area varies between 25.3 and 466.7 mg/L and 1.9 to 37.5 mg/L with space variation varied from 0.000034 to 0.034 mg/L/m, and between 0.0000007 and 0.004 mg/L/m, respectively enriched with the groundwater flow. The presence of Na and K cations in water samples may originate from the dissolution of ions from evaporating minerals. Saturated indices of halite (NaCl) and sylvite (KCl) with negative values (SI< 0) in Table 4 show that the leaching process is still active for Na and K cations from NaCl and KCl minerals. The water samples that have rNa/rCl ratio (Table 4) less than (1) reflects the weathering of marine salts indicating major mixing mechanism with fossil groundwater of marine origin. The higher values of Na/Cl may originate in water-rock interaction.

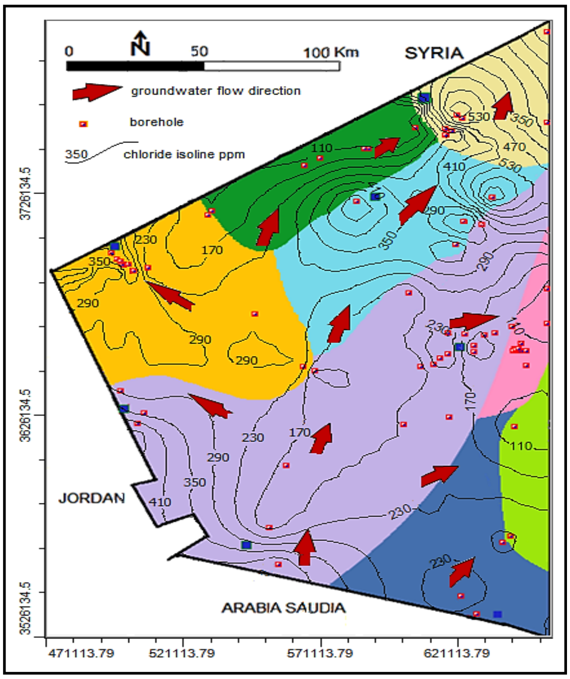

Figure 6. Distribution map of Cl compiled with groundwater flow (17).

Hydrochemical facies and geochemical evolution of groundwater

The statistical distribution diagram (Piper trilinear) is used for characterizing groundwater types of the aquifers. Figure 7 shows that the plotted points of the groundwater samples mainly indicated by ions of alkaline earths (Ca+Mg) exceed alkalies (Na+K) and ions of strong acids (SO_4+Cl) exceeds ions of weak acids (CO_3+HCO_3). There are practically mixtures of multi-types of groundwater (such as Ca–Mg–Cl–HCO_3 and Na+K–SO_4–Cl water type) with variable concentrations of major ions, as might be expected from the chemistry of the lateral groundwater recharge affected by dissolution mechanism along the flow direction.

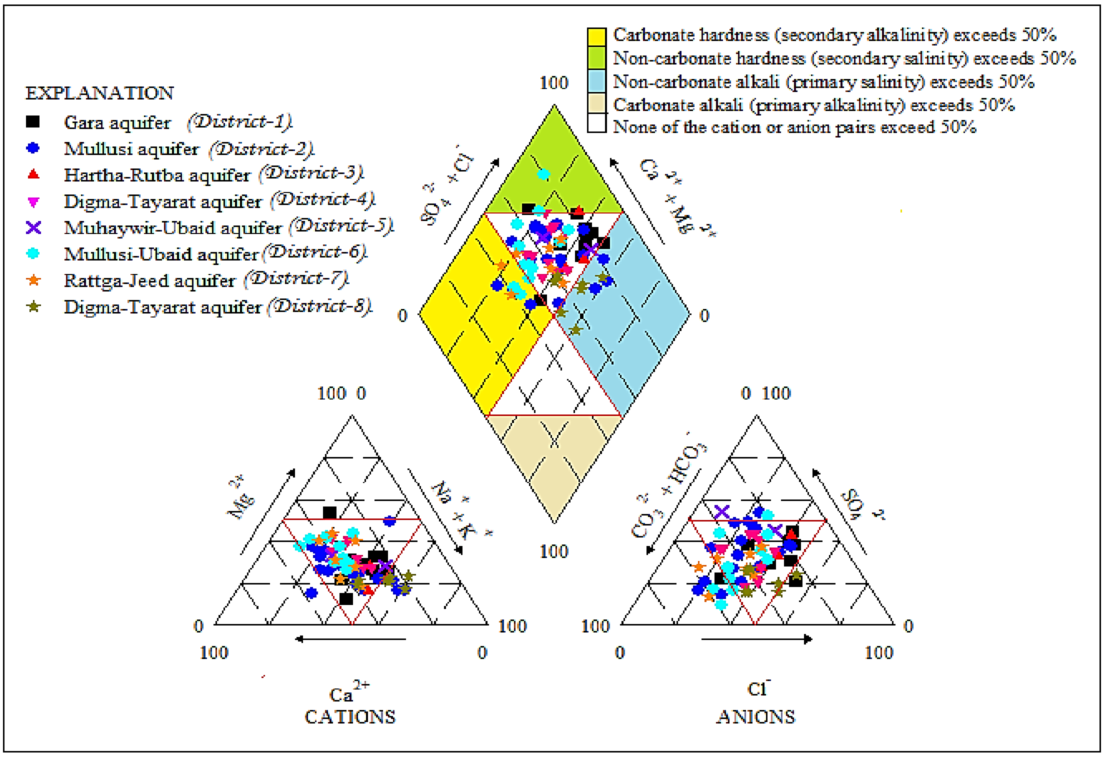

Figure 7. Groundwater quality of aquifers plotted on the Piper diagram.

The results of plotting chemical data on the expanded Durov's diagram (40) are used to identify the evolution of water where the water is initially recharged by Ca-HCO_3 water type and undergoes water-rock interactions (dissolution) and mixing with pre-existing water along the flow path (16). This leads to the evolution of the Ca-SO_4, Mg-SO_4, and Na_2SO_4 water types, reaching an advanced state of geochemical evolution represented by the Na-Cl type. Figure 8 shows that the groundwater of the seven aquifers is mainly plotted in Mg-SO_4 field No.5 represented by Ca–Mg–Cl–HCO_3 and Na+K–SO_4–Cl water types. This indicates the mixing mechanism affected by a dissolution process, which is possibly evolved from Ca-HCO_3 recharge water, then affected by ion exchange process (presence of Mg-HCO_3 in field No.2 and Na_2SO_4 water type in field No.6).

Limited reverse ion exchange has been noticed at two locations within Mullusi aquifer and Mullusi-Ubaid aquifers. Mixing with the underlying dense saltwater is another source of salinization of groundwater from the aquifer, mostly caused by intense pumping (10).

Saturation Index (SI) and Mineral equilibrium calculations are used in predicting and estimating mineral reactivity in the groundwater system. Accordingly, it is possible to estimate the chemical reactivity (water-rocks interaction) from the chemical analyses of the groundwater without collecting the solid phase samples and analyzing mineralogy (41).

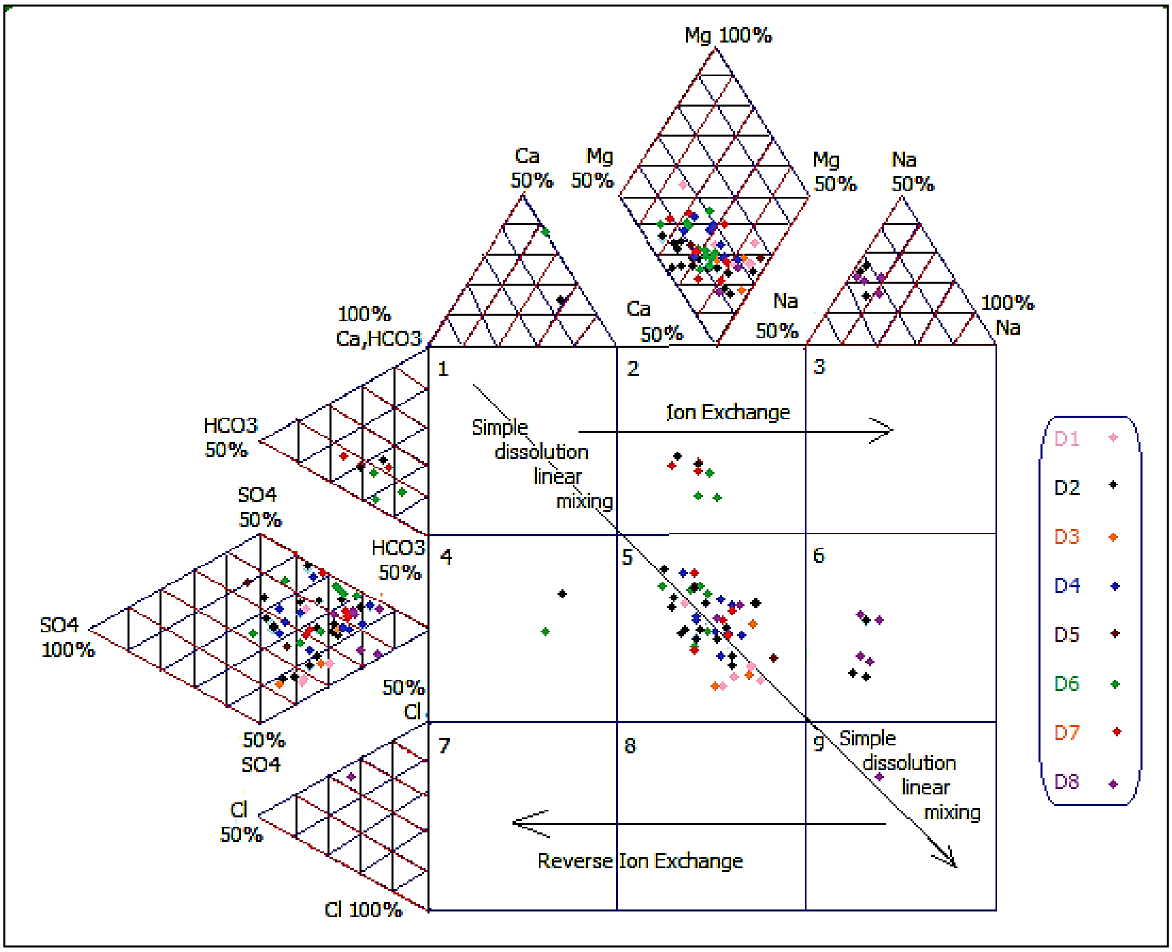

Figure 8. Plotting of groundwater analyses on expanded Durov diagram.

A positive index (SI>0) indicates that the water is supersaturated concerning the particular mineral phase. Therefore, it is incapable of dissolving more mineral under the same physicochemical condition, the mineral phase in equilibrium may precipitate. A neutral SI (SI=0) is in an equilibrium state with the particular mineral phase.

A negative saturation index (SI<0) indicates under saturation conditions and the dissolution of the mineral phase. Such a value could reflect the character of water from a formation with an insufficient amount of mineral for a solution or short residence time. The calculated saturation index values of calcite (SIcal), aragonite (SIara), dolomite (SIdol), gypsum (SIgyp), anhydrite (SIanh), halite (SIhal) and sylvite (SIsyl) (Table 4), demonstrate that nearly all the groundwater samples are saturated concerning dolomite, calcite/aragonite and undersaturated concerning gypsum /anhydrite and halite/sylvite. This result explains the presence of calcite and/or dolomite in the subsurface stratigraphic profile of the study area.

The undersaturation of gypsum/anhydrite and halite/sylvite suggests low dissolution mechanisms of sulphate and chloride mineral phases can happen in the host aquifers (insufficient amount of minerals for a solution or short residence time). This indicates that the evolution of sulphate water types is not reaching the advanced state of geochemical evolution (represented by chloride water types), which means the groundwater existed within the transition zone associated with local replenish charge zones.

Na/Cl ratio is used to identify the evaporation process in groundwater. Evaporation will increase the concentration of TDS in the groundwater, and the Na/Cl ratio remains the same, and it is one of the good indicative factors of evaporation. If evaporation is the dominant process, the Na/Cl ratio should be constant when TDS rises (42). The TDS v's Na/Cl scatter diagram of the groundwater samples within the aquifers (Fig. 9) indicates that the trend line is inclined represented by 3rd-degree Polynomial Fit: Na/Cl =a+b (TDS) +c (TDS) ^2+d (TDS) ^3..., and Na/Cl ratio decreases with increasing salinity (TDS) which seems to be a removal of sodium by the ion-exchange reaction. This observation indicates that evaporation is not being the major geochemical process, which controls the chemistry of groundwater in the study region or ion exchange reaction dominating over evaporation.

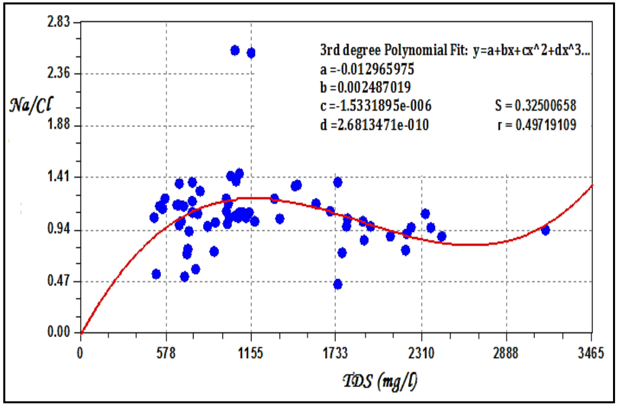

Figure 9. TDS v's Na/Cl scatter diagram of the groundwater within the hydrogeologic system.

The plot of Ca/Mg versus TDS (Fig. 10) shows an inclined trend. This relation reveals that Ca concentration of the groundwater samples within the hydrogeologic system slightly decreases with the increase of salinity represented by rational function: Ca/Mg = (a+b (TDS))/ (1+c (TDS) +d (TDS) ^2).

This indicates the removal of magnesium ions from dolomite and replaced by calcium from groundwater throughout the ion exchange reaction (dedolomitization process).

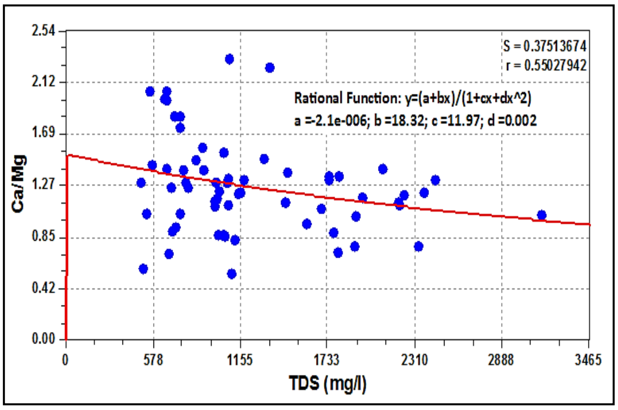

Figure 10. TDS vs Ca/Mg scatter diagram.

Potability of the Groundwater for Human Drinking Uses

To evaluate the potability of the groundwater for drinking and domestic purposes, the chemical analyses of the groundwater (Table 3) have been matched with the standard guideline suggested by WHO (28). The comparison indicated that:

- The pH of the water samples is well (within the safe limit of 6.5-8.5).
- The TDS is more than the desirable limit (500 mg/L), classified as fair water in 43% of the collected samples, exceeding the maximum permissible limit (1000 mg/L), classified as poor to unacceptable in 57% samples.
- The total hardness values of the analyzed subsurface water are more than the desirable limit of 300 mg/L in all samples and more than maximum permissible limit (500 mg/L) in 37% of samples.
- The HCO_3 concentration exceeds the desirable limit (200 mg/L) in 87% of samples and Cl (250 mg/L) in 33% of the subsurface water samples. The high concentration of Chloride in drinking water allows salty taste.
- The sulphates level is exceeding the maximum permissible limit at 56% of water samples. The high concentration of SO_4 in potable water has a laxative effect.
- The Na concentration exceeds the recommended level (200 mg/L) in 22% of collecting water samples. Na concentration is an important ion for human health. High sodium content intake may cause health problems such as heart, kidney diseases, and nervous disorders.
- The magnesium concentrations are exceeding the maximum permissible limit (30 mg/L) in 12% of samples. While calcium concentrations are within the maximum allowable limit of 75 mg/L in 19% of samples, though it exceeds the desirable limit in 81% samples.

Potability of the Groundwater for Domestic Uses

The comparison of the groundwater chemical analyses with the suggested limits for Domestic purposes as prescribed by the Department of Water Affairs and Forestry (DWAF) (28) indicates that the groundwater of aquifers are good and within the safe limit of pH. The TDS within the safe limit at 43% and poor in 57% of boreholes and within the maximum permissible limit of H_T (500 mg/L) in 63% of samples. Very hard water requires the softening of household or commercial uses, which caused high encrustation of $CaCO_3$ in water distribution systems. The groundwater of aquifers is within the desirable limits of HCO_3 concentration and within the permissible limit of Cl and SO_4 at 33% and 80% of water samples, respectively. Furthermore, the groundwater of aquifers is within the desirable limit of Na, Mg, and Ca concentrations in about 78%, 83%, and 69% of the groundwater samples, respectively.

Potability of the Groundwater for Animal Drinking Uses

The concentration of groundwater constituents within the seven aquifers (Table 2) have been compared to the Water Quality Standards for Livestock Use. The comparison indicates that the groundwater of aquifers is good to fair and in the safe limits of pH, TDS and within the maximum recommended limit of H_T (500 mg/L) in 63% of groundwater samples.

Also, the groundwater of aquifers are within the desirable limits of Na in about 73%, and 100% of the groundwater samples for Mg, Ca, $HCO_{3,}$ Cl, and SO_4 ions. Animals have a greater ability for tolerance salinity of 3000 to 10000 mg/L, e.g. poultry, camels, sheep, horses, dairy cattle and beef cattle, according to the classification in (32).

Potability of the Groundwater for Industrial Uses

Low-pressure boilers need water with TDS and $CaCO_3$ hardness up to 5000 and 80 mg/L, respectively, therefore the groundwater within the study area can be used in this application. While in high-pressure boilers, TDS and H_T should be less than 50 and 1 mg/L, respectively. Based on these limits, the groundwater is not suggested for this use.

In the construction industry, the SO_4 content in all water samples is not exceeding the maximum desirable limit (1500 mg/L), proceeded by (43). The corrosivity ratio (CR) refers to the ability of groundwater to corrode and expressed as the ratio of alkaline earths to saline salts in groundwater. The corrosive ratios expressed as CR= $(Cl+SO_4)/\{2(HCO_3+CO_3)\}$ (44) were ranged from 0.19 to 1.98 in the groundwater of the study region (Table 4). This indicates that 83 % of exploited groundwater is safe (CR< 1) against metallic materials and 17 % are unsafe (CR> 1).

Suitability of the Groundwater for Irrigation Uses

The total salt concentration, sodium percentage (%Na), residual sodium carbonate (RSC), sodium adsorption ratio (SAR), and Kelley index (KI) are the remarkable parameters, which define the suitability of water for irrigation uses (45). Criteria values are listed in Table 4.

Residual sodium carbonate (RSC):

Bicarbonate and carbonate concentration in excess of alkaline earth metal cations expressed as residual sodium carbonate (RSC) = $(CO_3+HCO_3)-(Ca+Mg)$, are affecting the water quality for irrigation purposes. The existence of HCO_3 and CO_3 in irrigation water assists in precipitation of calcium and magnesium ions within soil texture causing an increase of sodium ions. Therefore, RSC was defined as an indicator of the sodicity hazard of water. The water having RSC values greater than 2.5 (meq/L) is unsuitable for irrigation. An RSC value between 1.25 and 2.5 meq/L is considered as the marginal quality and value, < 1.25 meq/L as the safe limit for irrigation (46). RSC values in Table 4 show that 98% of the analyzed water samples were below (2.5 meq/L). That means the groundwater is suitable and only the water sample of borehole D8/7 is in the marginal limits for irrigation.

Kelley's index (KI):

Kelley's index represents the ratio of Na+/(Ca+Mg) which is used in the classification of water for irrigation. Water with Kelley's ratio of >1.0 indicates unsuitable for irrigation. Whereas ratios of <1.0 refer to irrigation suitability (47, 48). KI values in the water of the aquifers varied from 0.15 to 1.58. The KI values (Table 4) are <1.0, which means suitable for irrigation. Most of the analyzed groundwater samples of district D2 (85%) and D8 (72%) are also suitable for irrigation, where the KI value exceeds the specified limit (KI>1.0) in 15% and 28% of the groundwater samples in D2 and D8, respectively, classifying it unsuitable for irrigation.

Sodium percentage (Na %):

Sodium Percentage (Na) % was computed as Na%=100(Na+K)/(Ca+Mg+Na+K) (Fig. 11) (49). The ratio of Na+K of the sum of the cations is a remarkable factor in examining water for agriculture purposes. Sodium percent values in the analyzed groundwater samples (Table 4) vary from 13% to 61.35%. The plot of analytical data on the (34) diagram (Fig. 7) shows that groundwater of the study region is excellent and good to permissible quality for irrigation uses in (64% of the samples), doubtful to unsuitable in (17% of the samples) and unsuitable in (19% of the samples).

Sodium Adsorption Ratio (SAR):

The plot of the data (Table 4) on the USSLS (50) diagram (Fig. 12), in which EC represents a salinity hazard and SAR as alkalinity hazard, (Fig. 8) shows that most of the water samples are classified within the category of C3S1 and C2S1 denoting admissible to good quality of water for irrigation in 67% of the total samples. Thirty-three percent of the total groundwater samples from the aquifers are classified as bad to very bad within the categories of C4S1 (14% of the total samples), C4S2 (16% of the total samples), and C4S3 (3% of the total samples). The bad and very bad water with high salinity and medium to high alkalinity is unsuitable for irrigation and such water does not fit to be used on soils of low permeability.

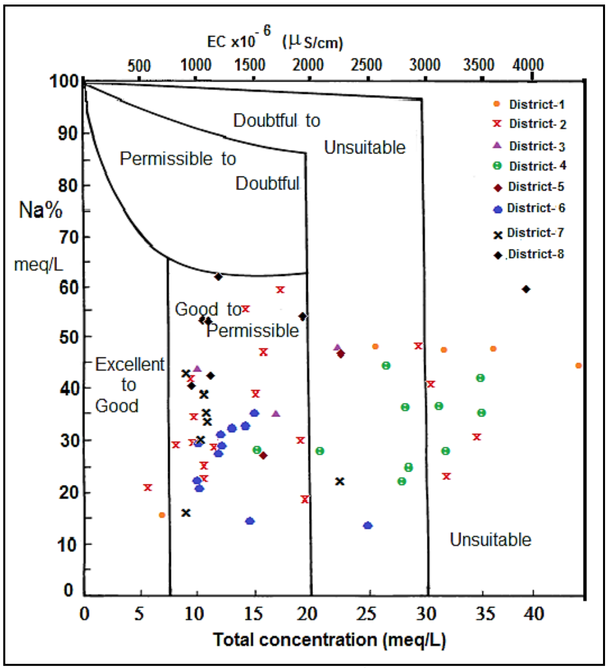

Figure 11. Na% and ECx10^{-6} data on the Wilcox diagram.

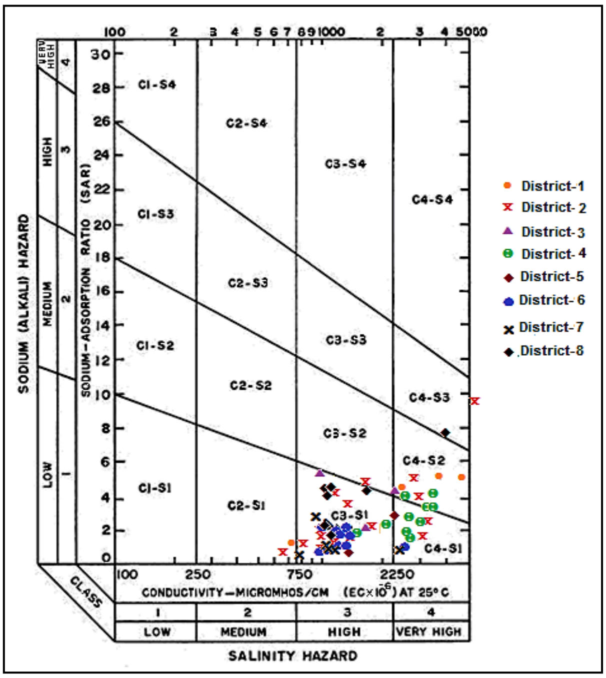

Figure 12. SAR and EC data on USSLS diagram (50).

Table 4. Saturation and Hydrochemical Indices of the groundwater within study the region.

BH. No	SI Calcite	SI Aragonite	SI Dolomite	SI Gypsum	SI Anhydrite	SI Halite	SI Sylvite	Na/ Cl	HCO_3/Cl	SO_4/ Cl	Ca/ Mg	CR	Na%	SAR	RSC	**KI**
D1/1	-0.34	-0.49	-0.35	-1.65	-1.98	-7.26	-7.42	0.54	1.21	1.36	0.59	0.68	16	0.69	-3.8	0.19
D1/2	0.49	0.35	1.01	-0.86	-1.20	-5.35	-6.32	0.91	0.49	0.64	1.11	1.1	45	4.95	-10.3	0.81
D1/3	0.11	-0.04	0.44	-0.99	-1.33	-5.56	-6.52	0.98	0.38	0.84	0.72	1.65	45	4.45	-10.17	0.81
D1/4	0.85	0.70	1.77	-0.55	-0.87	-5.18	-5.80	0.94	0.43	0.95	1.03	1.55	41	5.18	-18.99	0.69
D1/5	0.66	0.52	1.36	-0.70	-1.03	-5.51	-6.17	0.76	0.32	0.86	1.13	1.98	44	3.45	-17.56	0.51
D2/1	-0.03	-0.17	-0.23	-1.38	-1.72	-6.56	-7.32	0.72	0.89	0.74	1.84	0.65	29	1.59	-3.8	0.41
D2/2	0.64	0.50	1.57	-1.22	-1.55	-5.67	-6.36	1.37	1.35	0.59	1.32	0.39	49	4.95	-0.67	0.96
D2/3	0.46	0.32	0.91	-1.63	-1.93	-6.88	-7.37	1.36	2.81	0.95	1.41	0.24	30	1.6	-0.81	0.43
D2/4	0.31	0.17	0.55	-1.31	-1.62	-6.39	-7.15	0.75	0.95	0.76	1.58	0.62	39	1.91	-3.4	0.64
D2/5	-0.36	-0.51	-0.77	-1.52	-1.84	-6.83	-7.35	1.23	1.48	1.22	1.44	0.52	34	1.76	-2.18	0.52
D2/6	-0.08	-0.22	-0.14	-1.88	-2.18	-7.25	-7.89	1.05	3.2	0.8	1.3	0.19	22	0.97	-0.83	0.28
D2/7	0.46	0.32	0.87	-0.74	-1.06	-5.47	-6.39	0.88	0.43	0.84	1.41	1.44	41	4.23	-12.27	0.69
D2/8	-0.10	-0.25	-0.23	-1.14	-1.44	-6.91	-7.32	1.37	1.89	2.67	1.84	0.71	26	1.44	-4.34	0.35
D2/9	1.13	0.99	2.22	-0.52	-0.83	-5.21	-6.02	1.18	0.37	1.07	0.96	0.79	61.3	9.76	-7.11	1.58
D2/10	0.03	-0.11	0.00	-1.17	-1.46	-6.18	-7.30	2.57	1.31	2.23	1.54	0.89	59.3	5.21	-1.65	1.46
D2/11	-0.07	-0.22	-0.35	-1.66	-1.98	-6.65	-7.60	1.13	0.95	0.85	2.04	0.6	42.2	2.25	-1.85	0.73
D2/13	1.34	1.20	2.73	-0.59	-0.88	-5.88	-6.76	0.96	1.5	1.67	1.21	0.63	22.6	2.23	-15.79	0.29
D2/14	1.09	0.95	2.18	-0.71	-1.00	-5.95	-6.75	1.04	1.02	1.68	1.35	0.92	29.5	2.59	-11.19	0.42
D2/15	1.09	0.95	2.13	-0.69	-0.99	-6.01	-6.44	1.22	1.13	1.9	1.49	0.92	30.1	2.67	-11.52	0.43
D2/16	0.44	0.30	0.35	-1.22	-1.52	-6.65	-7.27	0.93	1.62	0.96	3.88	0.41	28.4	1.6	-2.54	0.4
D2/17	0.59	0.44	1.22	-1.03	-1.33	-6.83	-7.19	1.1	3.19	2.41	1.2	0.39	17.5	1.13	-5.39	0.21
D2/18	0.36	0.22	0.47	-1.12	-1.44	-5.98	-6.67	1.09	0.61	0.83	2.31	1.01	47	3.68	-4.36	0.89
D2/19	-0.10	-0.24	-0.13	-1.31	-1.62	-5.97	-6.72	1.22	0.44	0.88	1.14	1.44	55	4.47	-3.72	1.22
D2/20	0.06	-0.08	0.08	-1.37	-1.69	-6.61	-7.27	0.59	0.97	0.73	1.4	0.59	23	1.26	-4.6	0.3
D3/1	0.05	-0.10	0.18	-1.54	-1.87	-6.33	-7.27	1.1	0.92	0.71	1.04	0.62	43	5.02	-2.49	0.75
D3/2	0.33	0.18	0.41	-1.01	-1.33	-5.81	-6.31	1.04	0.63	0.81	2.24	0.96	48	4.23	-4.98	0.92
D3/3	0.12	-0.02	0.22	-1.00	-1.31	-6.04	-6.90	1.02	0.39	1.04	1.32	1.8	35	2.59	-8.64	0.54
D4/1	0.60	0.45	1.39	-0.81	-1.14	-5.94	-6.38	1.02	1.06	1.6	0.77	0.86	28.5	2.55	-11.93	0.4
D4/2	0.73	0.59	1.51	-0.93	-1.26	-6.39	-7.11	1.34	2.61	2.08	1.13	0.42	24.9	1.9	-5.81	0.33
D4/3	0.99	0.85	2.07	-1.08	-1.41	-5.65	-6.23	0.85	0.98	0.5	1.02	0.49	35.8	3.4	-6.5	0.56
D4/4	0.85	0.70	1.85	-0.80	-1.13	-6.04	-6.51	0.74	0.97	1.36	0.89	0.85	22.5	1.9	-13.24	0.29
D4/5	1.02	0.87	2.08	-1.08	-1.40	-5.65	-6.53	0.97	1.26	0.51	1.17	0.39	37	3.58	-4.44	0.59
D4/6	0.81	0.66	1.64	-0.94	-1.27	-5.50	-5.94	0.96	0.99	0.56	1.19	0.51	40.8	4.19	-6.67	0.69
D4/7	0.74	0.59	1.56	-1.06	-1.37	-5.68	-6.47	1.11	0.92	0.71	1.08	0.62	44	4.2	-5.17	0.78
D4/8	0.86	0.71	1.68	-0.90	-1.21	-6.28	-7.06	1.35	2.24	1.86	1.38	0.46	28	2.18	-5.66	0.38

D4/9	0.26	0.11	0.67	-1.12	-1.45	-6.44	-7.20	1.07	1.23	1.73	0.87	0.79	28.5	1.89	-6.1	0.4
D4/10	0.84	0.70	1.66	-0.65	-0.98	-5.46	-6.31	0.88	0.67	0.9	1.32	0.96	35	3.77	-14.43	0.54
D5/1	0.05	-0.10	0.24	-0.78	-1.11	-6.12	-6.80	1.39	0.62	1.32	0.86	1.31	48	3.74	-4.85	0.92
D5/2	0.48	0.33	0.94	-0.47	-0.82	-6.81	-7.56	2.55	3.59	5.39	1.21	0.67	27	1.86	-6.1	0.37
D6/1	0.35	0.21	0.86	-1.50	-1.81	-6.87	-7.49	0.77	1.8	1.03	0.93	0.39	21	1.1	-3.21	0.27
D6/2	0.53	0.38	1.04	-0.60	-0.90	-6.39	-6.47	0.45	0.75	1.89	1.35	1.39	13	1	-17.08	0.15
D6/3	0.01	-0.14	0.17	-1.44	-1.75	-6.71	-7.67	0.52	0.7	0.82	0.9	0.88	20.4	1.07	-5.62	0.26
D6/4	0.83	0.68	1.70	-1.00	-1.33	-6.90	-7.46	1.1	2.93	2.99	1.11	0.5	14.9	1.04	-6.55	0.18
D6/5	0.30	0.15	0.53	-1.25	-1.57	-6.38	-7.17	0.98	0.9	1.02	1.48	0.76	35.1	2.22	-4.17	0.54
D6/6	0.53	0.39	1.02	-1.81	-2.15	-6.48	-7.50	1.01	1.8	0.29	1.4	0.22	29.6	1.84	-2.4	0.44
D6/7	0.94	0.79	1.86	-1.56	-1.91	-6.51	-7.35	1.29	2.27	0.67	1.26	0.24	32.7	2.08	-1.26	0.42
D6/8	0.47	0.33	0.99	-1.30	-1.62	-6.48	-6.63	1.18	1.83	1.06	1.16	0.38	31.2	2.07	-3.05	0.46
D6/10	0.32	0.17	0.98	-1.46	-1.81	-6.48	-6.87	1.1	1.8	1	0.55	0.39	28.4	1.81	-4.59	0.4
D6/11	0.34	0.19	0.68	-1.57	-1.88	-6.44	-6.73	1	1.54	0.5	1.3	0.31	32.4	2.06	-2.4	0.48
D6/12	0.52	0.38	1.21	-1.44	-1.77	-6.47	-6.70	1.06	1.72	0.74	0.87	0.34	28.7	1.82	-4.87	0.4
D7/1	0.56	0.41	1.14	-1.53	-1.83	-6.52	-7.28	1.16	1.25	0.81	1.26	0.49	37.9	2.25	-5.3	0.61
D7/2	0.64	0.50	1.54	-1.58	-1.89	-6.69	-7.13	1.02	1.19	1.09	0.71	0.6	32.1	1.76	-3.12	0.47
D7/3	0.45	0.30	0.98	-1.65	-1.97	-7.39	-8.28	1.16	3.82	1.78	1.04	0.26	18.5	0.83	-1.66	0.23
D7/4	-0.04	-0.18	-0.28	-1.33	-1.66	-6.59	-7.67	0.99	0.77	1.12	1.97	0.95	34.6	1.92	-3.89	0.53
D7/5	0.40	0.25	0.63	-1.60	-1.91	-6.48	-6.86	1.17	1.08	0.65	1.98	0.51	41.8	2.7	-1.3	0.72
D7/6	0.73	0.59	1.66	-1.20	-1.53	-6.65	-7.14	1.06	2.6	1.65	0.82	0.36	21.4	1.39	-4.43	0.27
D7/7	0.47	0.33	0.95	-1.71	-2.02	-6.65	-7.39	1.09	2.41	0.52	1.3	0.21	29.1	1.68	-0.75	0.41
D8/1	0.34	0.19	0.51	-1.48	-1.83	-6.41	-7.35	1.2	1.25	0.75	1.75	0.46	42.2	2.65	-1.55	0.73
D8/2	0.25	0.11	0.51	-1.49	-1.80	-5.87	-6.70	1.06	0.69	0.41	1.3	0.66	53.1	4.41	-2.07	1.13
D8/3	0.59	0.45	1.42	-1.07	-1.37	-5.15	-5.98	1.09	0.45	0.46	0.77	1.03	59	7.76	-5.93	1.44
D8/4	0.37	0.22	0.56	-1.51	-1.81	-6.50	-7.34	1.17	1.15	0.77	2.04	0.25	42.2	2.49	-1.61	0.73
D8/5	-0.01	-0.15	0.05	-1.62	-1.94	-5.87	-6.29	1.11	0.7	0.31	1.1	0.59	53.1	4.53	-2.22	1.13
D8/6	0.45	0.31	0.94	-1.60	-1.91	-6.01	-6.44	1.43	1.26	0.42	1.22	0.36	51.8	4.31	-0.4	1.07
D8/7	0.48	0.34	0.92	-1.70	-2.05	-5.97	-6.59	1.45	1.18	0.4	1.33	0.38	61.3	5.31	1.6	1.58

Conclusions:

The groundwater in the study area is categorized as neutral to slightly alkaline water, fresh to slightly saline water, tepid to slightly warm water, and very hard water. It is classified as saturated somewhat to supersaturate concerning calcite, aragonite, and dolomite mineral phase. The leaching of salt rocks and the dissolution of evaporate minerals is assumed as a major geogenic source of chloride in the groundwater. The hydrochemical processes that most influence the species of groundwater chemistry are the dissolution of surface and subsurface weathered rocks with the impact of ion exchange as a result of water-rock interaction followed by mixing action. Moreover, the evaporation and reduction-oxidation processes have less effect on the evolution of groundwater quality. The concentration of magnesium and calcium is originating from the weathering of limestone, dolomite, and gypsum, which formed aquifers, fractured media .

In the majority of the groundwater samples, each borehole sampled has at least one constituent exceeding human drinking-water standard set by WHO and Maximum Contaminant Levels set by USEPA. However, concentrations of TDS, HT, and major ions have passed the desirable limit in most samples; accordingly, the groundwater requires treatment processes before its utilization. The analyzed parameters of the water samples are within the prescribed limits for animal drinking purposes; therefore, the groundwater is potable for uses. Quality assessment of irrigation suitability confirms that the groundwater belongs good to moderate class and suitable for irrigation purposes. Sodium percent values in the water samples and the plot of analytical data on the Wilcox diagram prove that groundwater is permissible for irrigation in (64% of the samples), doubtful to unsuitable in (17% of the samples) and unsuitable in (19% of the samples). Water samples were analyzed for chemical properties (major inorganic ions), shows that 83 % of pumped water from wells is safe against metallic materials and 17 % are unsafe.

The groundwater production plan in such a system must be developed; taking into consideration the process of water exploitation should be not exceeding the value of safe yield to avoid the deterioration of water quality. The contamination may occur due to the natural mixing process (geogenic source) between water-bearing horizons. Indirectly the study shows the extent to which the groundwater can be invested in a proper pumping method and estimate the period of exploitation optimally. It also gives the planner the ability to distinguish and determine the best area for investment throughout the spatial hydro-chemical distribution map.

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Authors' declaration:

- Conflicts of Interest: None.
- We hereby confirm that all the Figures and Tables in the manuscript are mine ours. Besides, the Figures and images, which are not mine ours, have been given the permission for re-publication attached with the manuscript.
- Ethical Clearance: The project was approved by the local ethical committee in University of Anbar.

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تقييم المياه الجوفية في خزانات المياه الجوفية الإقليمية وتقييم وملاءمتها لمختلف الاستخدامات والأغراض في غرب العراق

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الخلاصة:

تم تقيم نوعية المياه الجوفية في الجزء الغربي من العراق على خط الطول 40 ° 40' من خلال اجراء التحليلات الفيزيائية والكيميائية لـ 64 عينة من المياه الجوفية والتي تم جمعها من ثمانية مقاطعات جيولوجية لغرض تحديد خصائص المياه الجوفية وتقييمها لمختلف الاستخدامات. تم تحضير نموذج الهيد وكيميائي ثنائي الابعاد بالاعتماد على التحليل المكاني الكمي والنوعي. تشير البيانات الهيدروجيوكيميائية إلى أن المياه المدروسة هي من أصل جوي وتكون مسؤولة عن الملوحة الواطئة والتي تتسق مع الترسبات تحت السطحية والحقائق الهيدروكيميائية. كشفت السحنات الجيوكيميائية ان كل من أزواج الايونات الموجبة والسالبة لم يتجاوز 50٪ وقد تواجد مزيج من الانواع المتعددة السائدة في المياه مثل ($Ca – Mg – Cl – HCO_3$ و $Na + K – SO4 – Cl$). لوحظ ان تركيز المتغيرات الكيميائية ناتجة عن عملية خلب واذابة الصخور الجيرية. رصدت زيادة المحتوى الملحي عند مناسيب المياه الساكنة مما يؤكد حالة المزج مع مصادر مياه اخرى بالإضافة الى ذلك لم يرصد أي تأثير للأنشطة البشرية على تغيرات جوهرية في الطبيعة الجيوكيميائية للمياه الجوفية في أنظمة الخزانات الجوفية. تصنف معظم المياه الجوفية ضمن فئة C_3S_1 و C_2S_1 مما يدل على أن المياه الصالحة جيدة النوعية تمثل 67 ٪ من مجموع العينات بينما تمثل 33٪ من العينات على أنها غير صالحة إلى غير صالحة للغاية. اظهرت نتائج الدراسة ان المياه الجوفية لمعظم طبقات المياه المدروسة يمكن استخدامها للأغراض الزراعية وشرب الحيوانات وفئة جيدة يمكن استخدامها لأنشطة المحميات الطبيعية. في حين يوصى باستخدام مياه خزانات مقاطعات 2 و6 و7 لأغراض الشرب البشري بالإضافة إلى ذلك يمكن استخدام المياه الجوفية داخل النظام الهيدروجيولوجي في الغلايات ذات الضغط المنخفض وعمليات التعدين والبناء بينما تكون غير آمنة في الغلايات ذات الضغط العالي بسبب ارتفاع العسرة الكلية (237 إلى 1456 ملغم / لتر). اشار معامل التآكل إلى أن 83٪ من المياه الجوفية المدروسة تعتبر آمنة للنقل الطويل عبر الأنابيب المعدنية.

الكلمات المفتاحية: استخدام المياه الجوفية، الهيدروكيمياء، الحدود القياسية، نوعية المياه.