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Assessment of Groundwater Quality for Drinking Purposes Using Water Quality Index, and Identifying the Affecting Mechanism in Rashdiya, Central Iraq

Ayad Ali Faris Beg¹, Salih M. Awadh², Mohammed Bahjat Thamer¹ and Ahmed H. Al-Sulttani^{3,*}

¹ Department of Geography, College of Education, Mustansiriyah University, Baghdad, Iraq

² Department of Geology, College of Science, University of Baghdad, Baghdad, Iraq

³ Department of Environmental Planning, Faculty of Physical Planning, University of Kufa, Najaf, Iraq

* Correspondence: ahmedh.alsulttani@uokufa.edu.iq

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Abstract

Groundwater is an important resource that can be used for various purposes. Various factors can change the chemistry of the GW, such as the chemical composition of an aquifer as well as the leaching of human waste into groundwater. The study area is a barren land covered by some sabkhas, in addition to some agricultural fields. The study aims to assess groundwater quality for drinking purposes using the Water Quality Index. The groundwater is chemically heterogeneous and has a wide quality range from very poor to excellent. Evaporation appears to be the controlling factor among the other shallow waters, while relatively deep water is related to rock-soil dominance. Rocks, land use and land cover have helped control the groundwater quality. Moreover, the heavy use of fertilizers, pesticides and irrigation, in addition to the presence of sabkhas, contributed to the deterioration of the groundwater quality. The water-rock interaction and evaporation are the dominant mechanisms that are controlling the groundwater quality in the study area.

Keywords: Groundwater; Water quality; Aquifer; Drinking water

1. Introduction

The study of groundwater quality (GWQ) is extremely important. The exploitation and deterioration of GWQ are the main reasons to continue conducting studies over the world. Many physical, chemical and biological processes affect the properties of the groundwater (GW), such as decomposition of organic matter, iron reduction, precipitation, ion exchange, and dissolution during the movement of GW (Kumar et al., 2014; Machiwal and Jha, 2015; Mohapatra et al., 2011). The result of pollutants induced by human activity and anthropogenic pollutant sources are additional factors of GWQ deterioration (Gnanachandrasamy et al., 2020; Venkatramanan et al., 2016). The deterioration of GW is due to uncontrolled use of agricultural pesticides, fertilizers, soil amendments, leaching the domestic, and industrial wastes to the water table (Rao, 2014; Al-Hamdani and Awadh, 2016; Al-Hamadani et al., 2016). In agricultural areas, the hydrodynamic properties of GW usually change due to the existence of a link between surface water, irrigation water, and GW (Hui et al., 2020). Various

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factors control the GWQ and suitability for different purposes as it is affected by interactions between water, rocks or soil, agricultural fertilizers, pesticides, anthropogenic activities, runoff and infiltration system, industrial waste, rainfall, evaporation, and topography (Karunanidhi et al., 2020; Mahmud et al., 2020). Any increase in the concentration of chemical elements, i.e., major cations, anions, and heavy metals, will induce GW pollution and deteriorate the GWQ (Zhang et al., 2020; Al-Jaberi et al., 2016).

Usually, GW is often classified and clarified for the main hydro-geochemical characteristics through the use of the Piper diagram, which is one of the most suitable tools for this purpose (Gnanachandrasamy et al., 2020; Kumar et al., 2014; Rekha et al., 2013; Awadh and Ahmed, 2013; Todd and Mays, 2004). Three main mechanisms control the chemistry of GW; precipitation, rock dominance, and the process of evaporation fractional crystallization (Gibbs, 1970). The GW and aquifer lithology's reaction plays an important role in assessing the WQ (Gnanachandrasamy et al., 2020; Rao, 2006; Yenugu et al., 2020). The WQI was initially found by Brown et al., (1970), developed by the National Sanitation Foundation (NSF) (McClelland, 1974) and later modified by Backman et al., (1998). It is a simplified and specific quantitative method for measuring the WQ. The application of WQI helps the decision-makers in the possibility of successful management of WQ and supplied more details about the WQ for various uses by public people (Yenugu et al., 2020). It is an integrated classification technique to define the effect of some chemical elements' standards into a single valuable value that summarizes water quality (Awadh et al., 2016; Bhuiyan et al., 2016; Rawat et al., 2018; Vasanthavigar et al., 2010; Yenugu et al., 2020). The WQI can also be used as a tool that grouped the hydro-geochemical parameters as a reference to give integrated information on the GWQ (Gnanachandrasamy et al., 2020). The geographical information system (GIS) technique can be integrated with WQI for mapping the GWQ (Gharbia et al., 2016; Hasan and Rai, 2020). This work has been carried out on the unconfined aquifer in the Rashidiya region. The dominant activity in the area is the agriculture of seasonal crops and orchards, having many fertilizers, stimulants and agricultural pesticides that all are acting for the deterioration of the GWQ. In the rural areas, many people are insensible to GW pollution; particularly, the GW wells are not subjected to continuous monitoring of WQ. The main information that is used in this study is based on field surveying, Land use/land cover (LULC), interpretation of the chemistry of the GW. The present work aims to evaluate the GWQ, distribution of chemical facies together with mapping of the GWQ using GIS and an illustration of the controlling mechanism of the GWQ.

2. The Study Area Location and Description

The study area is located in Rashidiya, north of Baghdad, bounded by the latitude (33° 24 '00 " and 33° 36 '30") N, and longitudes (44° 18' 00 " and 44° 24 '25") E (Fig. 1). The study area is a part of the alluvial plain located to the east of the Tigris River. The river levee soil and river basin soil-silted phase are the main alluvial soil that covered the study area. The river levee soil consists mainly of a relatively coarse texture layer of fine sand to silty clay loam and the texture becomes finer with depth. The wells' depth is not exceeded (54 m) and the water table is fluctuated between (6.5 to 14.5 m) from the surface according to the amount of Tigris River discharge and elevation. The covered soil is well-drained, and excess water drains to the river. The river basin soil consists of silty clay loam, silty clay, and clay with 50 to 70% of clay containing high calcite grains, so it is characterized by poorly drained with the high water table and fair to very poor soil with high to strongly saline (Buringh, 1960).

Fig.1. Location map of the study area

3. Materials and Methods

3.1. Area Category

The spatial variation of the WQ for drinking purposes in the study area is need data of GW chemistry, LULC, soil type, and agriculture activities. The GW samples were collected from an area extended to about 257 km². The LULC map was prepared from the Sentinel-2 satellite, collected on 18th Nov 2019. The classification was carried out using ENVI v 5.3 software. The training data of 6 LULC types were selected and verified in the field. The supervised classification algorithm, i.e., Spectral Angle Mapper (SAM) was also applied. Barren lands occupying about 32.3% have been identified. They are used for seasonal crops, to which intensive fertilizers are added in surplus quantities. The building area covers about 31.6%, representing cities and villages with some dispersed population around. The orchard fields cover about 31.1%, requiring intensive irrigation, more fertilizers, and pesticides, while wheat crops account for about 2.2%. The Tigris River's wetlands are covered of about 1.5%, and the remaining parts represent the water bodies that occupy about 2.2%.

3.2. GW Sampling

Thirty samples of GW were collected from the shallow aquifer in the study area on 18, 20, and 21st Dec 2019. Samples were collected by using polyethylene bottles of 1L capacity after preliminary pumping around 10 min. The GW wells were selected to represent the study area, well depth ranges from 10 to 54 m. The sample sites were documented by using the Global Positioning System (GPS).

3.3. Chemical analysis of GW

Chemical analysis of GW was carried out using several analysis methods as given in Table 1. The samples were analyzed in the Ministry of Science and Technology Labs.

Table 1. Instruments and tools used in the chemical analyses of the GW

Factor	Method
Fe, Cl ⁻ , HCO ₃ ⁻ , CO ₃ ⁻ , SO ₄ ⁻ , Mg ²⁺ , Ca ²⁺	Titration method
K ⁺ , Na ⁺	Flame photometer
NO ₃ ⁻	Spectrophotometer
B, Cu,	Plasma Atomic absorption
Ec	Ec Meter
pH	pH Meter
TDS	TDS Meter

The error of balance is checked after converting the mg/l to meq/l (Todd and Mays, 2004), and then was checked according to equation 1 (Freeze and Cherry, 1979; Fritz, 1994).

$$\text{Error of balance (\%)} = \frac{\sum \text{cation} - \sum \text{Anion}}{\sum \text{cations} + \sum \text{Anion}} \times 100 \quad (1)$$

The percentage of error must not exceed (5%) to be accepted (Fritz, 1994). Otherwise, the results are not reliable (Todd and Mays, 2004). The error rate indicates high reliability.

3.4. Hydrochemical Facies and Water Quality Index

3.4.1. Water chemistry and hydrochemical facies and controlling mechanisms

The GW types and hydrochemical facies were assessed based on the Piper diagram using AquaChem V.9 software, while the mechanism that affected the GW composition was identified according to Gibb's diagrams using GraphPad Prism 5 software. The plotting of Gibbs ratios of cations and anions against the total dissolved solids (TDS), predicts the mechanisms controlling the source of chemical constituents of GW. There are two Gibb's ratios computed according to equations 2 and 3 (Gibbs, 1970; Gnanachandrasamy et al., 2020; Kumar et al., 2014; Kumar et al., 2009).

$$\text{Gibb's ratio - I} = \frac{Cl}{(Cl + HCO_3)} \quad (2)$$

$$\text{Gibb's ratio - II} = \frac{Na + K}{(Na + K + Ca)} \quad (3)$$

3.4.2. Water quality index (WQI)

The computing of the WQI requires weighting the chemical variables based on their relative importance in the overall quality of water for drinking purposes (Abbasnia et al., 2018; Kumar et al., 2014). Relative weights are calculated according to the weight given in Table 2 (Bhuiyan et al., 2016; Vasanthavigar et al., 2010) using the equation 4.

$$Wi = wi / \sum_{i=1}^n wi \quad (4)$$

Where Wi is the weight of i^{th} parameter, wi is the relative weight of i^{th} parameter and n is the number of parameters. The ratio of parameter concentration in water samples (Ci) to the World health organization (WHO) standard of the parameter (Si) assigned as quality rating index (qi) of i^{th} parameter which is computed according to the following equation 5.

$$qi = \frac{Ci}{Si} \times 100 \quad (5)$$

The sub-index of each parameter (SI_i) is computed by multiplying of quality rating index (qi) by the relative weight (Wi) of each parameter, as given in equation 6.

$$SI_i = Wi \times qi \quad (6)$$

The summation of SI_i of all parameters; represents the value of WQI as in equation (7).

$$WQI = \sum_{i=1}^n SI_i \quad (7)$$

According to the values of WQI, the GW samples were classified into five classes Table 3 (Mahmud et al., 2020; Tiwari et al., 2014; Vasanthavigar et al., 2010; Verma et al., 2020).

Table 2. Weights and percentage weights of hydrochemical parameters

Variable	Unit	WHO standards (2017)	Weight (wi)	Percentage weight (Wi)
pH	Unitless	8.2	4	0.0769
Ec	µm/cm	1000	5	0.0962
TDS	mg/l	500	5	0.0962
Na ⁺	mg/l	200	4	0.0769
Ca ²⁺	mg/l	75	3	0.0577
Mg ²⁺	mg/l	50	3	0.0577
K ⁺	mg/l	12	2	0.0385
SO ₄ ²⁻	mg/l	200	4	0.0769
CL ⁻	mg/l	250	3	0.0577
NO ₃ ⁻	mg/l	50	5	0.0962
HCO ₃ ⁻	mg/l	120	1	0.0192
Fe ²⁺	mg/l	0.3	4	0.0769
Cu ²⁺	mg/l	0.05	5	0.0962
B	mg/l	0.5	4	0.0769
Sum			52	1.0

Source: after (WHO, 2017) and Equation 2

Table 3. Classification of WQ for drinking purposes based on WQI.

WQI range	WQ	Abbreviation
< 50	Excellent	E
50-100	Good	G
100.1-200	Poor	P
200.1-300	Very poor	Vp
> 300	Unsuitable	U

4. Results and Discussion

4.1. Water Chemistry and Hydrochemical Facies

The chemical results of GW in mg/l and meq/l are presented in Tables 4 and 5, respectively. The results of Piper diagrams show six types of water (Figs. 2 and 3a). The water types are mainly controlled by cations (Ca, Mg, Na) and anions (Cl and SO₄). Meanwhile, three hydrochemical facies were identified on Piper diagram; in terms of cations, two facies were identified. Alkalies exceed alkaline earths including samples (ws2, ws3, ws4, ws6, ws14, ws15, ws17, ws21, ws22, ws29), whereas, the other samples are of alkaline earths (Ca, Mg) exceed alkalis (Na, K). Based on Anions, all the water samples come in the facies of strong acids (SO₄, Cl) exceed weak acids (HCO₃). This could be attributed to the infiltrating of the saline water from sabkha and irrigation waters to the water table. The source of GW chemistry was recognized based on Gibb's diagrams (Fig. 4). The analysis of charts was obtained by plotting Gibb's ratio of anions against TDS. Fig. 4a identified the chemical compositions of nine GW samples (ws2, ws7, ws8, ws9, ws13, ws14, ws19, ws21, and ws29) are attributed to the soil-rock dominance as shown in Fig. 3b. These samples (soil-rock dominance) are mostly collected from wells with a depth ranges from 19-54 m, while the rest of the samples (evaporation dominance) are collected from wells with depth ranging from 12-18 m. The process of evaporation-precipitation is recommended to be reported to interpret the factor controlling the GWQ (Awadh et al., 2006).

Table 4. The hydrochemistry of GW (mg/l)

S.N.	pH	Ec ($\mu\text{c}/\text{cm}$)	Concentration in mg/l											
			TDS	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Cl ⁻	NO ₃ ⁻	HCO ₃ ⁻	Fe	Cu	B
ws1	7.2	1499*	973	89	5	109	67	427	185	1.7	50	0.0081	0.0109	0.07
ws2	7.12	1703	1540	266	7.3	101	71	322	335	1.5	250	0.0761	0.0252	0.05
ws3	7.11	1353	3500	245	15	110	55	520	198	1.3	146	0.0274	0.0851	0.09
ws4	8.28	2570	3500	254	11	104	51	423	220	1.5	214	0.0684	0.0512	0.07
ws5	7.14	2050	3500	141	14	134	91	570	260	1.4	77	0.0134	0.0265	0.03
ws6	7.18	4530	2930	560	90	130	110	902	500	1.6	561	0.1321	0.0345	0.05
ws7	7.13	810	340	50	0.9	38	20	113	98	0.12	19	0.0629	0.0673	0.04
ws8	7.11	825	365	54	0.11	41	32	121	112	0.16	42	0.032	0.0691	0.05
ws9	7.41	1567	1050	138	2.73	116	27	305	185	0.15	147	0.0698	0.0571	0.02
ws10	7.32	4250	2800	333	3.91	360	122	920	760	0.5	110	0.0092	0.0203	0.09
ws11	7.21	2390	1298	132	14	122	75	512	215	1.3	54	0.0016	0.0211	0.05
ws12	7.18	2450	1101	142	1.22	160	87	403	465	0.4	87	0.0031	0.0114	0.05
ws13	7.1	510	340	50	0.9	38	20	113	98	1.1	19	0.0051	0.0576	0.01
ws14	7.14	2160	1393	219	12	120	53	560	195	1.2	168	0.0925	0.0187	0.08
ws15	7.13	4821	3102	578	98	142	118	934	515	1.8	582	0.1344	0.0377	0.02
ws16	7.12	1960	1272	136	12	129	89	561	252	1.3	65	0.1224	0.0251	0.02
ws17	7.2	5200	3350	542	62	243	138	1113	621	2.1	494	0.0101	0.0022	0.01
ws18	7.3	3240	2090	130	16	130	91	560	249	1.7	59	0.0115	0.0125	0.02
ws19	7.1	1354	845	77	6	101	46	390	164	1.6	47	0.0088	0.0134	0.09
ws20	7.23	1609	1040	94	7	112	70	442	190	1.4	55	0.0685	0.0244	0.03
ws21	7.19	2030	1330	220	10	110	45	532	184	1.6	164	0.0071	0.0011	0.01
ws22	7.16	2280	1510	571	33	173	121	920	545	1.16	314	0.0982	0.0212	0.04
ws23	7.14	4440	3100	508	6	302	122	1074	664	1.4	354	0.0954	0.0199	0.04
ws24	7.22	8770	5700	830	34	500	270	1720	1070	1.2	562	0.0099	0.0165	0.09
ws25	7.3	2160	1115	105	17	77	27	115	228	2	77	0.0697	0.0101	0.01
ws26	7.15	2400	1550	186	9.8	148	97	520	368	2	166	0.0848	0.0256	0.04
ws27	7.17	1504	980	90	5.6	111	68	430	187	1.6	51	0.0711	0.0136	0.01
ws28	7.11	1992	3120	122	10	101	88	490	210	1.3	56	0.0288	0.092	0.09
ws29	7.16	2101	1310	212	9	105	49	522	156	1.4	140	0.0011	0.0114	0.02
ws30	7.11	3112	1401	132	22	100	98	498	200	1.9	110	0.0313	0.0112	0.01
WHO (PL)	6.5-8.5	400	100-500	<20	10- 12	75	<30	10_50	200	<25		0.1 -0.3	0.05	0.5
WHO (MCL)	<9.5	1250	<1500	<200		200	150	<200	600	<50	600	0.3	2 mg/l	2.4 mg/l

*Unsuitable value

Table 5. Chemistry of GW (meq/l) and the analytical errors

S.N.	Concentration (meq/l)								Analytical error (%)
	Na ⁺	K ⁺	Ca ²⁺	Mg ²⁺	SO ₄ ²⁻	Cl ⁻	CO ₃ ²⁻	HCO ₃ ⁻	
ws1	3.872	0.128	5.439	5.511	8.89	5.219	0.027	0.82	-0.02
ws2	11.571	0.187	5.04	5.84	6.704	9.45	0.024	4.098	5.5
ws3	10.658	0.384	5.489	4.524	10.826	5.586	0.021	2.393	5.59
ws4	11.049	0.281	5.19	4.195	8.807	6.206	0.024	3.507	5.53
ws5	6.134	0.358	6.687	7.486	11.867	7.335	0.023	1.262	0.43
ws6	24.36	2.301	6.487	9.049	18.78	14.105	0.026	9.195	0.11
ws7	2.175	0.023	1.896	1.645	2.353	2.765	0.002	0.311	2.76
ws8	2.349	0.003	2.046	2.632	2.519	3.16	0.003	0.688	4.93
ws9	6.003	0.07	5.788	2.221	6.35	5.219	0.002	2.409	0.36
ws10	14.486	0.1	17.964	10.03	19.154	21.44	0.008	1.803	0.21
ws11	5.742	0.358	6.088	6.17	10.66	6.065	0.021	0.885	2.02
ws12	6.177	0.031	7.984	7.157	8.39	13.118	0.006	1.426	-3.59
ws13	2.175	0.023	1.896	1.645	2.353	2.765	0.018	0.311	2.62
ws14	9.527	0.307	5.988	4.36	11.659	5.501	0.019	2.754	0.62
ws15	25.143	2.506	7.086	9.707	19.446	14.528	0.029	9.539	1.02
ws16	5.916	0.307	6.437	7.321	11.68	7.109	0.021	1.065	0.27
ws17	23.577	1.585	12.126	11.352	23.173	17.518	0.034	8.097	-0.19
ws18	5.655	0.409	6.487	7.486	11.659	7.024	0.027	0.967	0.9
ws19	3.35	0.153	5.04	3.784	8.12	4.626	0.026	0.77	-4.7
ws20	4.089	0.179	5.589	5.758	9.202	5.36	0.023	0.901	0.41
ws21	9.57	0.256	5.489	3.702	11.076	5.191	0.026	2.688	0.09
ws22	24.839	0.844	8.633	9.953	19.154	15.374	0.019	5.146	5.45
ws23	22.098	0.153	15.07	10.036	22.361	18.731	0.023	5.802	0.47
ws24	36.105	0.869	24.95	22.21	35.81	30.185	0.019	9.211	5.59
ws25	4.568	0.435	3.842	2.221	2.394	6.432	0.032	1.262	4.46
ws26	8.091	0.251	7.385	7.979	10.826	10.381	0.032	2.721	-0.53
ws27	3.915	0.143	5.539	5.594	8.953	5.275	0.026	0.836	0.33
ws28	5.307	0.256	5.04	7.239	10.202	5.924	0.021	0.918	2.23
ws29	9.222	0.23	5.24	4.031	10.868	4.401	0.023	2.295	3.13
ws30	5.742	0.563	4.99	8.061	10.368	5.642	0.031	1.803	4.06

The composition of other samples comes from evaporation- precipitation dominance because they are located in highly permeable soils. Based on Gibb's $-II$ ratios of anions against TDS (Fig. 4b). The GW wells (ws3, ws4, ws5, ws6, ws15, ws22, ws23, and ws24) are affected by the evaporation dominance, while the others are affected by the rock-soil dominance (Fig. 3c). The Box and Whisker plot has presented the ranges of the chemical concentration of GW parameters shows that iron, and copper have high variations in their minimum and maximum values as well as potassium (Fig. 5). The extreme concentrations can be seen in Na, Ca, K and SO₄ reflecting high variation and heterogeneity.

4.2. Water Quality Index

The WQ sub-index (SI_i) of elements, WQI, and the GWQ are presented in Tables 6 and 7. The WQI was classified the GWQ for drinking purposes as only NO₃, HCO₃, Fe, and B are within the permissible (0.12-2.1, 19-582, 0.0011-0.1344 and 0.01-0.09) mg/l, respectively. The EC values in most GW samples are higher than the maximum contaminant level, with values ranging from 1353 to 8770 except the samples (ws13, ws7, and ws8) within the permissible limit (PL) with values of 510, 810, and 825 respectively. The results of WQI are summarized in the GWQ in an integrative and easy way without the need for the standard details of the chemical elements in their individual status. The only sample ws13 was classified as an excellent type located in the northern east part of the study area near the population center. The samples (ws1, ws7, ws8, ws9, ws19, ws20, ws25, and ws27) are classified as good water located in the middle and northern part of the study area. Most wells are located in river levee soil, having well drain with sandy to silty texture. The Poor water types are dominant over most of the study area, including the samples (ws2, ws3, ws4, ws11, ws14, ws18, ws21, ws22, ws26, ws28, ws29, and ws30), despite these samples are collected from wells located in the river levee soil type that is characterized by good drain as the Tigris River recharges the (GW). However, the area is covered by LU of the orchard (Different types of fruits, date palm trees) with intensive use of fertilizers, pesticides, and irrigation processes along the year seasons. The samples collected from bore wells in the middle and east parts are designated as very poor water because the soils of the area are poorly drained, moist soil with high salinity and bits of accumulated water are common, and the sample ws24 was classified as unsuitable for drinking purpose (Fig.6).

Fig. 2. Groundwater types and facies plotted on Piper diagram

Fig. 3. The QW types and mechanism a) Spatial distribution of water types; b) Gibb's-I ratio and c) Gibb's-II ratio

Fig. 4. Mechanism affected GW composition based on Gibb's diagram a) Gibb's-I; b) Gibb's-II

Fig. 5. Box and Whisker plot of chemical compositions of water samples

Table 6. Quality rating index (QI) values of the chemical parameters

S.N.	q_pH	q_Ec	q_TDS	q_Na	q_Ca	q_Mg	q_K	q_SO ₄	q_Cl	q_NO ₃	q_HCO ₃	q_Fe	q_Cu	q_B
ws1	87.8	149.9	194.6	44.5	145.3	134	41.7	213.5	74	3.4	41.7	2.7	21.8	14
ws2	86.8	170.3	308	133	134.7	142	60.8	161	134	3	208.3	25.4	50.4	10
ws3	86.7	135.3	700	122.5	146.7	110	125	260	79.2	2.6	121.7	9.1	170.2	18
ws4	101	257	700	127	138.7	102	91.7	211.5	88	3	178.3	22.8	102.4	14
ws5	87.1	205	700	70.5	178.7	182	116.7	285	104	2.8	64.2	4.5	53	6
ws6	87.6	453	586	280	173.3	220	750	451	200	3.2	467.5	44	69	10
ws7	87	81	68	25	50.7	40	7.5	56.5	39.2	0.24	15.8	21	134.6	8
ws8	86.7	82.5	73	27	54.7	64	0.9	60.5	44.8	0.32	35	10.7	138.2	10
ws9	90.4	156.7	210	69	154.7	54	22.8	152.5	74	0.3	122.5	23.3	114.2	4
ws10	89.3	425	560	166.5	480	244	32.6	460	304	1	91.7	3.1	40.6	18
ws11	87.9	239	259.6	66	162.7	150	116.7	256	86	2.6	45	0.5	42.2	10
ws12	87.6	245	220.2	71	213.3	174	10.2	201.5	186	0.8	72.5	1	22.8	10
ws13	86.6	51	68	25	50.7	40	7.5	56.5	39.2	2.2	15.8	1.7	115.2	2
ws14	87.1	216	278.6	109.5	160	106	100	280	78	2.4	140	30.8	37.4	16
ws15	87	482.1	620.4	289	189.3	236	816.7	467	206	3.6	485	44.8	75.4	4
ws16	86.8	196	254.4	68	172	178	100	280.5	100.8	2.6	54.2	40.8	50.2	4
ws17	87.8	520	670	271	324	276	516.7	556.5	248.4	4.2	411.7	3.4	4.4	2
ws18	89	324	418	65	173.3	182	133.3	280	99.6	3.4	49.2	3.8	25	4
ws19	86.6	135.4	169	38.5	134.7	92	50	195	65.6	3.2	39.2	2.9	26.8	18
ws20	88.2	160.9	208	47	149.3	140	58.3	221	76	2.8	45.8	22.8	48.8	6
ws21	87.7	203	266	110	146.7	90	83.3	266	73.6	3.2	136.7	2.4	2.2	2
ws22	87.3	228	302	285.5	230.7	242	275	460	218	2.32	261.7	32.7	42.4	8
ws23	87.1	444	620	254	402.7	244	50	537	265.6	2.8	295	31.8	39.8	8
ws24	88	877	1140	415	666.7	540	283.3	860	428	2.4	468.3	3.3	33	18
ws25	89	216	223	52.5	102.7	54	141.7	57.5	91.2	4	64.2	23.2	20.2	2
ws26	87.2	240	310	93	197.3	194	81.7	260	147.2	4	138.3	28.3	51.2	8
ws27	87.4	150.4	196	45	148	136	46.7	215	74.8	3.2	42.5	23.7	27.2	2
ws28	86.7	199.2	624	61	134.7	176	83.3	245	84	2.6	46.7	9.6	184	18
ws29	87.3	210.1	262	106	140	98	75	261	62.4	2.8	116.7	0.4	22.8	4
ws30	86.7	311.2	280.2	66	133.3	196	183.3	249	80	3.8	91.7	10.4	22.4	2

Source: Table 4.

Table 7. The WQ sub-index (SI_i) of parameters and WQI and the GWQ

S.N.	SI _{pH}	SI _{Ec}	SI _{TDS}	SI _{Na}	SI _{Ca}	SI _{Mg}	SI _K	SI _{SO₄}	SI _{Cl}	SI _{NO₃}	SI _{HCO₃}	SI _{Fe}	SI _{Cu}	SI _B	WQI	WQ*
ws1	6.75	14.41	18.71	3.42	8.38	7.73	1.6	16.42	4.27	0.33	0.8	0.21	2.1	1.08	86.22	G
ws2	6.68	16.38	29.62	10.23	7.77	8.19	2.34	12.38	7.73	0.29	4.01	1.95	4.85	0.77	113.18	P
ws3	6.67	13.01	67.31	9.42	8.46	6.35	4.81	20	4.57	0.25	2.34	0.7	16.37	1.38	161.64	P
ws4	7.77	24.71	67.31	9.77	8.0	5.88	3.53	16.27	5.08	0.29	3.43	1.75	9.85	1.08	164.71	P
ws5	6.7	19.71	67.31	5.42	10.3	10.5	4.49	21.92	6	0.27	1.23	0.34	5.1	0.46	159.76	P
ws6	6.74	43.56	56.35	21.5	10.0	12.69	28.8	34.69	11.54	0.31	8.99	3.39	6.63	0.77	246.04	Vp
ws7	6.69	7.79	6.54	1.92	2.92	2.31	0.29	4.35	2.26	0.02	0.3	1.61	12.9	0.62	50.56	G
ws8	6.67	7.93	7.02	2.08	3.15	3.69	0.04	4.65	2.58	0.03	0.67	0.82	13.3	0.77	53.4	G
ws9	6.95	15.07	20.19	5.31	8.92	3.12	0.88	11.73	4.27	0.03	2.36	1.79	10.9	0.31	91.89	G
ws10	6.87	40.87	53.85	12.8	27.7	14.1	1.25	35.38	17.54	0.1	1.76	0.24	3.9	1.38	217.71	Vp
ws11	6.76	22.98	24.96	5.08	9.38	8.65	4.49	19.69	4.96	0.25	0.87	0.04	4.06	0.77	112.95	P
ws12	6.74	23.56	21.17	5.46	12.3	10.04	0.39	15.5	10.73	0.08	1.39	0.08	2.19	0.77	110.41	P
ws13	6.66	4.9	6.54	1.92	2.92	2.31	0.29	4.35	2.26	0.21	0.3	0.13	11.1	0.15	44.03	E
ws14	6.7	20.77	26.79	8.42	9.23	6.12	3.85	21.54	4.5	0.23	2.69	2.37	3.6	1.23	118.03	P
ws15	6.69	46.36	59.65	22.2	10.9	13.62	31.4	35.92	11.88	0.35	9.33	3.45	7.25	0.31	259.36	Vp
ws16	6.68	18.85	24.46	5.23	9.92	10.27	3.85	21.58	5.82	0.25	1.04	3.14	4.83	0.31	116.21	P
ws17	6.75	50.0	64.42	20.9	18.7	15.92	19.9	42.81	14.33	0.4	7.92	0.26	0.42	0.15	262.81	Vp
ws18	6.85	31.15	40.19	5.0	10	10.5	5.13	21.54	5.75	0.33	0.95	0.29	2.4	0.31	140.39	P
ws19	6.66	13.02	16.25	2.96	7.77	5.31	1.92	15.0	3.78	0.31	0.75	0.23	2.58	1.38	77.92	G
ws20	6.78	15.47	20.0	3.62	8.62	8.08	2.24	17.0	4.38	0.27	0.88	1.76	4.69	0.46	94.25	G
ws21	6.74	19.52	25.58	8.46	8.46	5.19	3.21	20.46	4.25	0.31	2.63	0.18	0.21	0.15	105.35	P
ws22	6.72	21.92	29.04	21.9	13.3	13.96	10.6	35.38	12.58	0.22	5.03	2.52	4.08	0.62	177.91	P
ws23	6.7	42.69	59.62	19.5	23.2	14.08	1.92	41.31	15.32	0.27	5.67	2.45	3.83	0.62	237.24	Vp
ws24	6.77	84.33	109.6	31.9	38.5	31.15	10.9	66.15	24.69	0.23	9.01	0.25	3.17	1.38	418.05	U
ws25	6.85	20.77	21.44	4.04	5.92	3.12	5.45	4.42	5.26	0.38	1.23	1.79	1.94	0.15	82.77	G
ws26	6.71	23.08	29.81	7.15	11.4	11.19	3.14	20.0	8.49	0.38	2.66	2.17	4.92	0.62	131.71	P
ws27	6.73	14.46	18.85	3.46	8.54	7.85	1.79	16.54	4.32	0.31	0.82	1.82	2.62	0.15	88.25	G
ws28	6.67	19.15	60.0	4.69	7.77	10.15	3.21	18.85	4.85	0.25	0.9	0.74	17.7	1.38	156.3	P
ws29	6.72	20.2	25.19	8.15	8.08	5.65	2.88	20.08	3.6	0.27	2.24	0.03	2.19	0.31	105.6	P
ws30	6.67	29.92	26.94	5.08	7.69	11.31	7.05	19.15	4.62	0.37	1.76	0.8	2.15	0.15	123.67	P

*Classified based on Table 3.

Fig. 6. a). LULC map based on Sentinel -2 collected on 18th November 2019; b) Soil types, and c) WQ for drinking use based on WQI

5. Conclusions

The study found that the adoption of international standards for each element or specific factor separately and the WQ classification is flawed by deficiencies. The results showed the validity of water in one component and its unfitness in another. The study proved that applying the WQ standard for drinking or irrigation purposes is more accurate and realistic by adopting the results of the WQ for drinking purposes WQI compared to the standards adopted for each component or parameter separately.

The GW wells are varied in their suitability for drinking purposes based on WQI results; only one water sample collected from well located in northern east part of study was classified as excellent water, whereas, the western part of the study area and near Tigris River were classified as good water for drinking purposes. Most of study area is classified as poor water and a significant area to the west of river classified as very poor to unsuitable. The land use and absence of effective drainage network are the main reason of GW degradation in most of study area. The water-rock interaction and evaporation are the dominant mechanisms that are controlling the GWQ in the study area.

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