www.czasopisma.pan.pl PAN www.journals.pan.pl

JOURNAL OF WATER AND LAND DEVELOPMENT

e-ISSN 2083-4535

Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2021.138183
2021, No. 50 (VI–IX): 274–280

Groundwater quality assessment for drinking purposes using water quality index in Ali Al-Gharbi District, Iraq

Sarteel Hamid Enad Al-Shammary ✉, Sattar Obaid Maiws Al-Mayyahi

Wasit University, College of Science, Department of Geology, Al-Kut city, Wasit Province, Iraq

RECEIVED 01.02.2021 REVIEWED 11.03.2021 ACCEPTED 31.06.2021

Abstract: The present study aimed to assess groundwater quality according to the water quality index (*WQI*) in Ali Al-Gharbi district of the Maysan Governorate in eastern Iraq. For this purpose, 10 physical parameters such as pH, total hardness (*TH*), magnesium (Mg^{2+}), calcium (Ca^{2+}), potassium (K^+), sodium (Na^+), sulphate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-), and total dissolved solids (*TDS*s) were examined since 2019 from 16 different locations (viz. wells). The analysis results indicated that 18.75% of the water samples were of good quality, 56.25% of them had low quality, and 25% of such samples were very poor. The *WQI* also varied from 69.67 and 297.6. Therefore, prior to water use, there is a dire need for some treatments, as protecting this district from pollution is significant.

Keywords: drinking water, groundwater, Iraq, water quality index

INTRODUCTION

The world's arid and semi-arid regions heavily depend on groundwater as one of the main water supplies, which is also among the most important sources for drinking purposes as well as agricultural and industrial activities [Afshar *et al.* 2021; Molajou *et al.* 2021]. In this sense, the water quality index (*WQI*), classified as a rating scale, represents the spillover effect of the water quality parameters, and is calculated for the purposes of human consumption based on the health of groundwater [Afshar *et al.* 2020; Jha *et al.* 2020; Owamah 2020; Ramakrishnaiah *et al.* 2009]. Besides, groundwater resources are the most notable ones used for agriculture and drinking in many countries across the world, especially in nations such as Iraq, characterized with an arid and semi-arid climate. On the other hand, the risk of less pollution in these resources compared with those resulting from other water treatment methods has led to their use to flourish even in regions where there is no shortage of surface water.

To determine the suitability of groundwater resources for human use, some parameters for groundwater samples should be analysed. In this line, the *WQI* digitally summarizes the single-value water quality parameters utilized to assess temporal changes [Krishan *et al.* 2016; Shirazi *et al.* 2015]. The *WQI* as a highly efficient gadget is the commonly used method for measuring water quality worldwide to communicate it completely [Al-Mohammed, Mutasher 2013; Benrabah *et al.* 2016; Hernandez Cordero *et al.* 2020]. The *WQI* is also one of the most important references for people and decision-makers to communicate water quality knowledge [Sukumaran *et al.* 2015].

In several places, the scarcity of surface water contributes to an urgent need for groundwater, wherein it is considered as the primary source [Pichaiah *et al.* 2015]. Accordingly, awareness of physical, chemical, and biological characteristics of water is related to water quality knowledge [Santhosh, Revathi 2014; Zayed, ElHdad 2017]. Several factors, including environment, rock form, soil characteristics, human activities, and terrain, can thus influence water quality [Kelmendi *et al.* 2018; Prasanna *et al.* 2010].

In this regard, groundwater is a significant reservoir as a fresh water source, and even an important one to be exploited optimally by policy-makers. Natural soil and sediment filtration also make it free of impurities [Karanth 1989]. Regional geological conditions, rock and soil geochemistry, along with land-use trends are thus the key factors influencing groundwater chemistry [Kumar *et al.* 2006].

The present study was to apply the *WQI* and its relevance for human consumption to groundwater in Ali Al-Gharbi district of the Maysan Governorate, eastern Iraq. For this purpose, pH, total hardness (*TH*), total dissolved solids (*TDS*s), cations (Ca, Mg, Na, K), and anions (K, Cl, bicarbonate [HCO_3], SO_4, NO_3) were analysed in sixteen samples from the water wells located in the study area (i.e., one sample for each well). According to the *WQI*, water quality in these wells was clarified.

MATERIALS AND METHODS

STUDY AREA

The study area covers 659.74 km^2 northwest of the Maysan Governorate, eastern Iraq, between the latitude 31.8734° N and the longitude 47.1362° E, bordering Iran (Fig. 1).

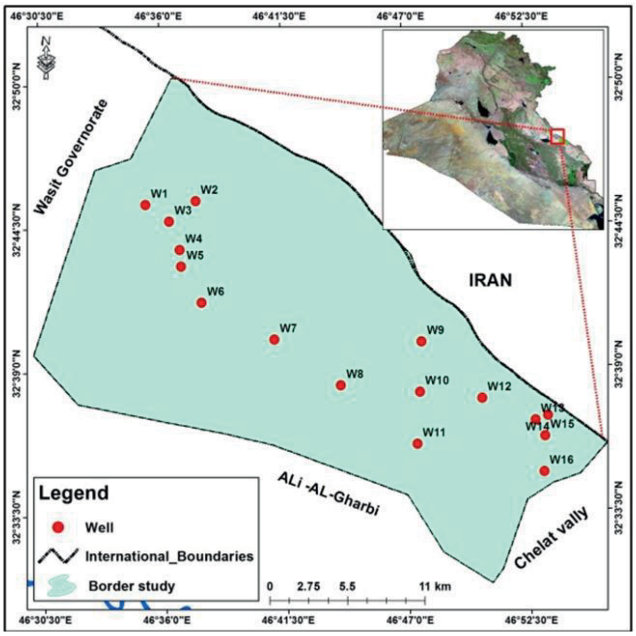

Fig. 1. Study area location; source: own elaboration

FIELD GEOLOGY

The geology of the study area involves numerous geological units dating back to the recent period. Sandstone, silt, conglomerate, gray and red marls, and modern glacial ice [PIRASTEH *et al.* 2010] also dominate the rocks in this area. Besides, the geological formation of the study area is the "Injana formation" characterized with siltstone, sandstone, and conglomerate as its constituent. As well, the "Mukdadiya formation" consists of siltstone, marl, and conglomerate rocks, and the "Bai Hassan formation" is comprised of conglomerate wherein recent sediments are finally deposited [BUDAY 1980].

CHEMICAL ANALYSIS AND SAMPLE SELECTION

The samples collected from the wells were placed in glass containers in the summer of 2019 (Tab. 1). They were then put in an icebox in accordance with normal protocols and transported to the laboratory.

The chemical analysis findings were then compared the World Health Organization [WHO 1993] and Iraqi requirements for drinking water [Drinking-Water Standard IQS 2001]. Total pH and *TDS* measurements were further taken as defined by the Global Positioning System (GPS) for each well field and geographic position. Both concentrations of the chemicals were expressed in mg·dm^{-3}. Total pH and *TDS* measurements were also taken as defined by the GPS for each well field and geographic position. Both concentrations of the chemicals were expressed in mg·dm^{-3}. In Figure 1, sampling sites in Table 1 were identified.

Table 1. Geographic coordinates about wells in Ali Al-Gharbi district, the Maysan Governorate, Iraq

Well No.	Well name	Longitude	Latitude
1	Khzeena / 2	32°47'53"	46°34'58"
2	Khzeena / 1	32°48'53"	46°36'37"
3	Khzeena old	32°48'10"	46°35'10"
4	Arian Barghash	32°45'57"	46°36'03"
5	Abdul Wahid Karim	32°45'38"	46°36'40"
6	Hamid Massoud	32°43'15"	46°36'06"
7	Chifta /1	32°39'45"	46°39'04"
8	Manar / 1	32°36'00"	46°50'00"
9	Janna / 1	32°38'08"	46°49'43"
10	Janna	32°36'29"	46°49'55"
11	Jirwa / 1	32°33'00"	46°50'00"
12	Janna / 2	32°37'00"	46°53'00"
13	Chilat / 1	32°35'50"	46°56'00"
14	Chilat / 3	32°35'02"	46°55'31"
15	Chilat / 2	32°35'00"	46°55'40"
16	Mohsen Faeel	32°31'07"	46°57'23"

Source: own elaboration.

WATER QUALITY INDEX (*WQI*) EVALUATION

The *WQI*, as a digital rating scale that begins from 0 to 100 [SALEEM *et al.* 2016], is an efficient water-contamination treatment method that can be used to improve groundwater quality with high efficiency. In this analysis, the *WQI* was designed using 11 parameters.

The meaning of the parameters (namely, weights) was associated with the expected water use, which was why the quality of water was formulated. The present study examined the quality requirements of water as acceptable for human use [ABDUL HAMEED *et al.* 2010]. The criteria (i.e., the values permitted for various parameters) in this analysis were those recommended in Iraqi drinking water standards.

RESULTS AND DISCUSSION

In this analysis, the *WQI* was employed to determine the suitability of groundwater for drinking purposes in Ali Al-Gharbi district of the Maysan Governorate, eastern Iraq. To reach accurate estimations, the *WQI* included many parameters. The physical and chemical properties of groundwater sampling could also provide certain parameters. Ten parameters were thus evaluated for each sample, including *TDS*s, pH, *TH*, Ca^{2+}, Na^{+}, Mg^{2+}, K^{+}, SO_4^{2-}, Cl^{-}, and NO_3^{-1} (Fig. 2). Mathematically, the effects of such parameters were used to calculate the *WQI*. Table 2 illustrates the chemical and physical parameters of water quality in the study area.

Three measures were also included in estimating the *WQI*. As the first step, the weight of the chemical parameters was determined according to the relative value of the overall water quality for human use, ranging from one to five. It becomes obvious that the groundwater quality for human use, for example, the NO_3 parameter is of utmost importance (Tab. 3) for other parameters and then gives it higher strength than other cases. In contrast, Mg has less strength because it does not affect water in terms of human use [RAMAKRISHNAIAH *et al.* 2009].

The relative weight (W_r) was established in the second point, based on the following equation [AL-ALI *et al.* 2017]:

$$W_r = \frac{W_i}{\sum W_i} \tag{1}$$

where: W_r represents the relative weight, W_i shows the weight of each parameter, *i* is the parameter number.

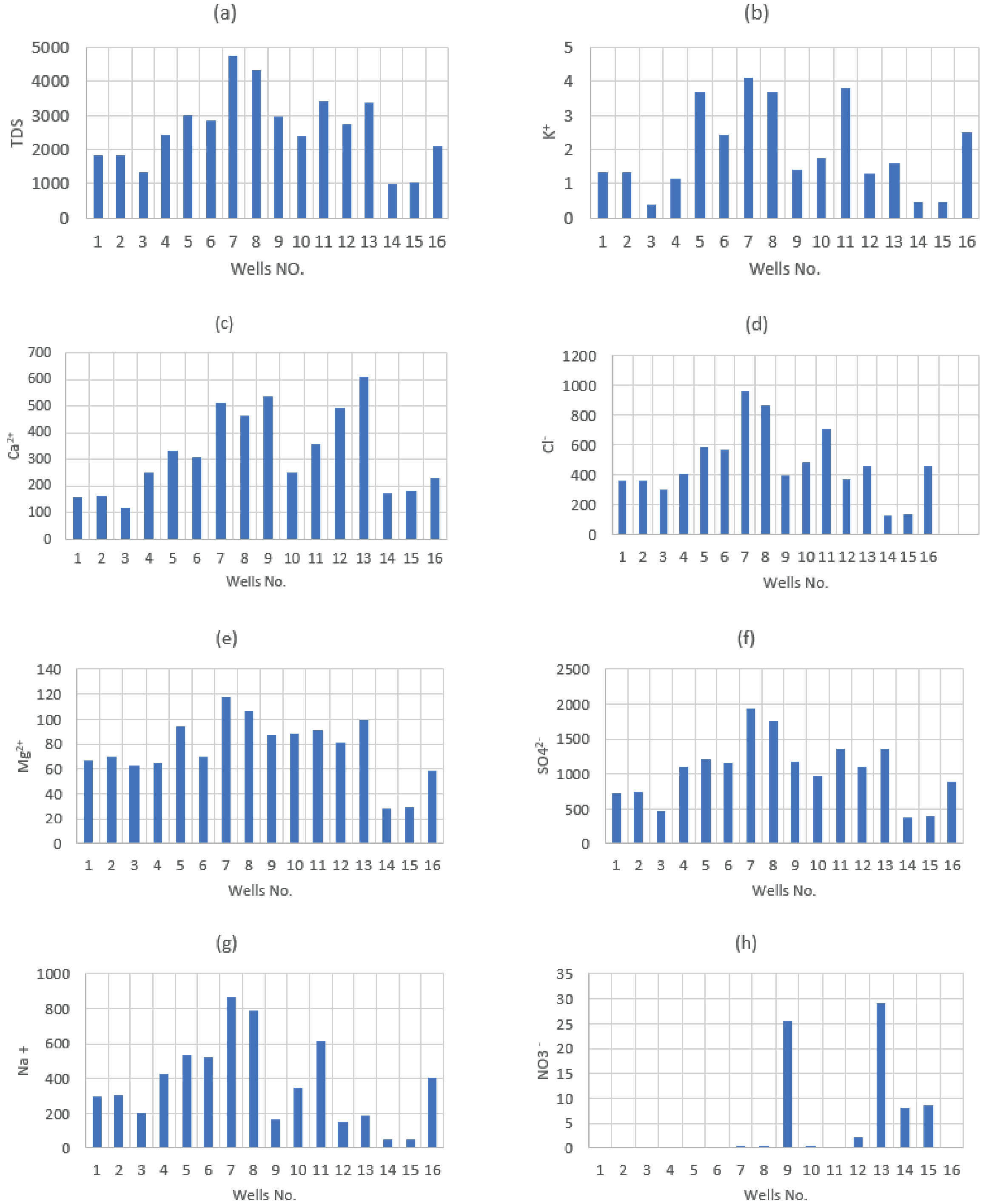

Fig. 2. Concentration of selected components: a) total dissolved solids (*TDS*s), b) K^{+}, c) Ca^{2+}, d) Cl^{-}, e) Mg^{2+}, f) SO_4^{2-}, g) Na^{+}, h) NO_3^{-}; source: own study

Table 2. Physical-chemical parameters of water in study area

Well No.	Parameter										
	pH	*TH*	*TDSs*	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-
			mg·dm^{-3}								
1	7.2	664.5	1813	156.7	66.4	295.5	1.32	50.6	361.9	730.4	0.33
2	7.3	700.0	1826	165.0	70.0	300.0	1.33	51.0	364.0	734.8	0.33
3	7.2	552.0	1330	117.1	63.1	200.0	0.37	70.7	302.5	476.0	0.19
4	7.2	886.0	2450	248.4	64.6	423.2	1.15	57.5	408.7	1 094.8	0.05
5	7.1	1219.3	2990	333.4	94.0	535.0	3.70	73.0	588.3	1 218.3	0.28
6	7.1	1053.8	2850	306.7	70.0	517.6	2.44	92.1	571.8	1 149.5	0.27
7	7.0	1762.6	4736	512.1	117.6	870.9	4.10	155.0	962.2	1 934.3	0.45
8	7.0	1190.5	4321	466.4	106.3	787.0	3.70	140.1	870.0	1 747.7	0.41
9	7.1	1365.5	2953	535.0	87.2	164.3	1.40	406.1	401.0	1 182.8	25.5
10	7.1	993.0	2414	252.8	88.4	349.2	1.77	67.4	481.7	972.4	0.44
11	7.1	1265.3	3420	356.6	91.1	618.2	3.80	82.7	710.6	1 366.3	0.13
12	7.1	1568.5	2757	495.8	80.8	152.3	1.30	376.5	371.8	1 096.4	2.34
13	7.1	1933.1	3402	610.2	99.5	187.5	1.60	463.3	457.6	1 349.4	29.1
14	7.4	544.5	980	171.9	28.0	50.4	0.45	130.5	128.7	379.5	8.10
15	7.3	574.6	1042	181.5	29.5	53.2	0.47	137.5	135.8	400.6	8.55
16	7.3	822.5	2100	231.8	59.2	402.0	2.52	53.7	462.0	888.3	0.08

Explanations: *TDSs* = total dissolved solids, *TH* = total hardness.
Source: own study.

Table 3. Relative weight (W_r) for each parameter [Ramakrishnaiah *et al.* 2009]

Parameter	Iraqi standard; Drinking-Water Standard IQS [2001]	Standard value of WHO [1993]	Weight (W_i)	Relative weight (W_r)
pH	6.5–8.5	7–8	4	0.1333
TH	500	100–500	2	0.0666
TDSs (mg·dm^{-3})	1000	1000	4	0.1333
Ca^{2+} (mg·dm^{-3})	150	75–200	2	0.0666
Mg^{2+} (mg·dm^{-3})	50	30–150	2	0.0666
Na^{+} (mg·dm^{-3})	200	200	2	0.0666
K^{+} (mg·dm^{-3})	–	12	2	0.0666
Cl^{-} (mg·dm^{-3})	250	250	3	0.1
SO_4^{2-} (mg·dm^{-3})	250	250	4	0.1333
NO_3^{-} (mg·dm^{-3})	50	50	5	0.1666
Total	$\sum W_i = 30$			

Explanations: *TH*, *TDSs* as in Tab. 1.
Source: own study.

The W_r values were further determined for each parameter, as shown in Table 3.

In the third step, the q_i for each parameter was ascertained by dividing its concentration by its criterion for each water sample (Tab. 4) in accordance with the guidelines set out in the Iraqi standards (Tab. 4) and multiplying the outcome by 100 [Gebrehiwot *et al.* 2011].

$$q_i = \frac{C_i - C_o}{S_i - C_o}100 \tag{2}$$

where: q_i refers to the quality scale, C_i denotes the value of the water quality parameter obtained from the laboratory study (mg·dm^{-3}), C_o indicates the perfect value for each chemical parameter of this parameter in pure water (C_o = 0 excepting pH = 7), S_i is the parameter of the index.

$$Sl_i = W_r q_i \tag{3}$$

Sl_i was also first defined for each parameter used to calculate the *WQI*, and was then employed to estimate the *WQI* value, as expressed in the following equations:

$$WQI = \sum_{i=1}^{n} Sl_i \tag{4}$$

where: Sl_i represents the parameter of the index, as shown in Table 4.

Table 4. Values of quality scale (q_i), parameter of the index (Sl_i), and water quality index (WQI) for each parameter in water samples

Well No.	Specification	pH	*TH*	*TDSs*	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}	NO_3^{-}	*WQI*
1	q_i	40.0	132.9	181.3	104.4	132.8	147.7	11.00	144.7	292.1	0.66	
	Sl_i	5.33	8.85	24.1	6.95	8.84	9.83	0.73	14.5	38.9	0.11	118.1
2	q_i	60.0	140.0	182.6	110.0	140.0	150.0	11.10	145.6	293.9	0.66	
	Sl_i	7.99	9.32	24.3	7.32	9.32	10.0	0.73	14.5	39.1	0.10	122.7
3	q_i	40.0	110.4	133.0	78.0	126.2	100.	3.10	121.0	190.4	0.38	
	Sl_i	5.33	7.35	17.7	5.2	8.4	6.66	0.20	12.1	25.4	0.06	88.4
4	q_i	40.0	177.2	245.0	165.6	129.2	211.6	9.50	163.5	438.0	0.10	
	Sl_i	5.33	11.8	32.6	11.02	8.6	14.1	0.60	16.3	58.3	0.01	158.6
5	q_i	20.0	243.8	299.0	222.2	188.0	267.5	30.80	235.3	487.3	0.56	
	Sl_i	2.66	16.2	39.8	14.8	12.5	17.8	2.00	23.5	64.9	0.09	194.2
6	q_i	20.0	210.7	285.0	204.4	140.0	258.8	20.30	228.7	459.8	0.54	
	Sl_i	2.66	14.0	37.9	13.6	9.3	17.2	1.30	22.8	61.2	0.08	180.0
7	q_i	0.0	238.0	432.1	310.9	212.6	393.5	30.80	348.	699.0	0.80	
	Sl_i	0.0	23.4	63.1	22.7	15.6	29.0	2.20	38.4	103.1	0.10	297.6
8	q_i	0.0	238.1	432.1	310.9	212.6	393.5	30.80	348.0	699.0	0.80	
	Sl_i	0.0	15.8	57.0	20.7	14.1	26.0	2.00	34.8	93.1	0.13	263.5
9	q_i	20.0	273.1	295.3	356.6	174.4	82.0	11.60	160.4	473.1	51.00	
	Sl_i	2.6	18.1	39.3	23.7	11.6	5.40	0.70	16.0	63.0	8.50	187.9
10	q_i	20.0	198.6	241.4	168.5	176.8	174.6	14.70	192.6	388.9	0.88	
	Sl_i	2.6	13.2	32.1	11.2	11.7	11.6	0.90	19.2	51.8	0.14	154.4
11	q_i	20.0	253.0	342.0	237.7	182.2	309.1	31.60	284.2	546.5	0.26	
	Sl_i	2.6	16.8	45.5	15.8	12.1	20.5	2.10	28.4	72.8	0.04	216.6
12	q_i	20.0	313.7	275.7	330.5	161.6	76.1	10.80	148.7	438.5	4.60	
	Sl_i	2.6	20.8	36.7	22.0	10.7	5.0	0.70	14.8	58.4	0.77	172.4
13	q_i	20.0	386.6	340.2	406.8	199.0	93.7	13.30	183.0	539.7	58.2	
	Sl_i	2.6	25.7	45.3	27.0	13.2	6.2	0.80	18.3	71.9	9.70	220.7
14	q_i	80.0	108.9	98.0	114.6	56.0	25.2	3.75	51.5	151.8	16.20	
	Sl_i	10.66	7.25	13.06	7.63	3.7	1.67	0.24	5.1	20.2	2.70	72.2
15	q_i	35.0	114.9	104.2	121.0	59.0	26.6	3.90	54.3	160.2	17.10	
	Sl_i	4.66	7.65	13.88	8.05	3.9	1.77	0.26	5.4	21.3	2.80	69.6
16	q_i	60.0	164.5	210.0	154.5	118.4	210.0	21.00	184.8	355.3	0.16	
	Sl_i	7.90	10.9	27.9	10.3	7.8	13.3	1.40	18.4	47.3	0.02	145.2

Explanations: *TH*, *TDSs* as in Tab. 1.
Source: own study.

It was thus possible to classify the computed *WQI* values as [RAMAKRISHNAIAH *et al.* 2009]: *WQI* < 50 → excellent; *WQI* = 50–100 → good; *WQI* = 100–200 → poor; *WQI* = 200–300 → very poor; *WQI* > 300 → unsuitable.

The application of the results to the wells of the Ali Al-Gharbi district, the Maysan Governorate, Iran, from the *WQI*, showed that they varied from good to very poor water. Wells No. 3, 14, and 15 were good; wells No. 1, 2, 4, 5, 6, 9, 10, 12, and 16 were poor ones, and wells No. 7, 8, and 11 were very poor cases (Tab. 5). Figure 3 shows the distribution of the *WQI* in the study area.

Table 5. Classification of water quality based on water quality index (*WQI*) importance acc. to PARMAR and PARMAR [2010]

WQI value	Water quality	Well sample No.
<50	excellent	–
50–100	good	W 3, W 14, W 15
100–200	poor	W 1, W 2, W 4, W 5, W 6, W 9, W 10, W 12, W 16
200–300	very poor	W 7, W 8, W 11, W 13
>300	unsuitable	–

Source: own study.

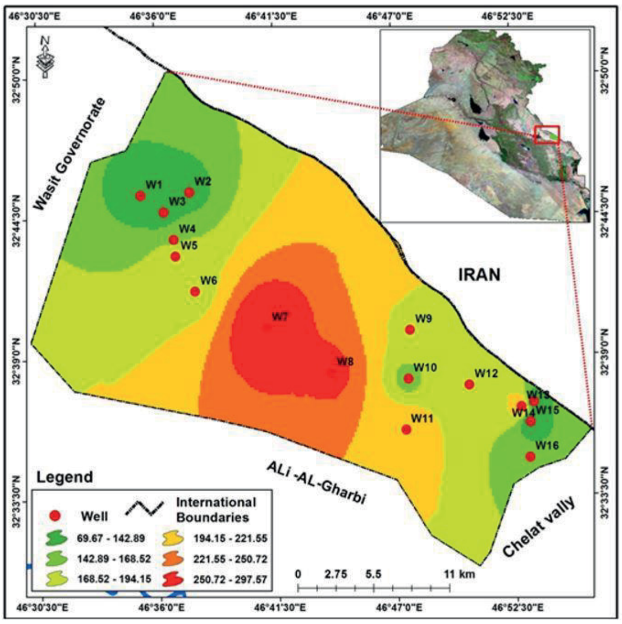

Fig. 3. Distribution of water quality index in study area; source: own study

CONCLUSIONS

The present study was an attempt to assess groundwater quality for drinking purposes in Ali Al-Gharbi district of the Maysan Governorate, eastern Iraq. The results indicated that the high-quality groundwater samples were about 18.75% and the low-quality ones were by 56.25%. As well, 25% of the samples had very poor water quality. The water quality index (*WQI*) also varied from 69.67 and 297.6. Therefore, prior to use, some treatments are needed to protect the environment from pollution. To recharge groundwater and to optimize its supplies, rainwater must be well handled. To sustain the consistency and the quantity of aquifers in this area, the high concentration of chemical components and soluble salts should be reduced. In order to encourage knowledge and understanding of the supply of drinking water to humans around their places of residence, public awareness campaigns should be implemented.

REFERENCES

Abdul Hameed J.A., Haider S.A., Bahram K.M. 2010. Application of water quality index for assessment of Dokan lake ecosystem, Kurdistan region, Iraq. Journal of Water Resource and Protection. Vol. 3. No. 2 p. 17–29. DOI 10.4236/jwarp.2010.29093.

Afshar A., Khosravi M., Molajou A. 2021. Assessing adaptability of cyclic and non-cyclic approach to conjunctive use of groundwater and surface water for sustainable management plans under climate change. Water Resources Management Vol. 35 p. 3463–3479. DOI 10.1007/s11269-021-02887-3.

Afshar A., Khosravi M., Ostadrahimi L., Afshar A. 2020. Reliability-based multi-objective optimum design of nonlinear conjunctive use problem; cyclic storage system approach. Journal of Hydrology. Vol. 588 p. 109–120. DOI 10.1016/j.jhydrol.2020.125109.

Al-Ali I., Obaid S., Hassan W. 2017. Estimate groundwater suitability for drinking purposes by using WQI technique in Al-Teeb area, Maysan Governorate, South Iraq. Advances in Natural and Applied Sciences. Vol. 11. No. 14 p. 39–44. DOI 10.22587/anas.2017.11.14.4.

Al-Mohammed F.M., Mutasher A.A. 2013. Application of water quality index for evaluation of groundwater quality for drinking purpose in Dibdiba Aquifer, Kerbala City, Iraq. Journal of Babylon University Engineering Science. Vol. 21 p. 1–14.

Benrabah S., Attoui B., Hannouche M. 2016. Characterization of groundwater quality destined for drinking water supply of Khenchela City (eastern Algeria). Journal of Water and Land Development. Vol. 30. No. 1 p. 13–20. DOI 10.1515/jwld-2016-0016.

Buday T. 1980. The regional geology of Iraq: tectonism, magmatism and metamorphism (Vol. 2). State Organization for Minerals, Directorate General for Geological Survey and Mineral Investigations pp. 445.

Drinking-Water Standard IQS 2001. Central Organization for Quality Control and Standardization, Council of Ministers, Republic of Iraq [In Arabic].

Gebrehiwot A.B., Tadesse N., Jigar E. 2011. Application of water quality index to assess suitablity of groundwater quality for drinking purposes in Hantebet watershed, Tigray, Northern Ethiopia. ISABB Journal of Food and Agricultural Sciences. Vol. 1. No. 1 p. 22–30.

Hernandez Cordero A.L., Tango P.J., Batiuk R.A. 2020. Development of a multimetric water quality indicator for tracking progress towards the achievement of Chesapeake Bay water quality standards. Environmental Monitoring & Assessment. Vol. 192. No. 2 p. 14–24. DOI 10.1007/s10661-019-7969-z.

Jha M.K., Shekhar A., Jenifer M.A. 2020. Assessing groundwater quality for drinking water supply using hybrid fuzzy-GIS-based water quality index. Water Research. Vol. 179, 115867. DOI 10.1016/j.watres.2020.115867

Karanth K.R. 1989. Hydrogeology. New Delhi. Tata McGraw-Hill. ISBN 0074601806 pp. 458.

Kelmendi M., Kadriu S., Sadiku M., Aliu M., Sadriu E., Hyseni S.M. 2018. Assessment of drinking water quality of Kopiliq village in Skenderaj, Kosovo. Journal of Water and Land Development. Vol. 39. No. 1 p. 61–65. DOI 10.2478/jwld-2018-0059.

Krishan G., Singh S., Kumar C.P., Garg P.K., Suman G., Ghosh N.C., Chaudhary A. 2016. Assessment of groundwater quality for drinking purpose by using water quality index (WQI) in Muzaffarnagar and Shamli Districts, Uttar Pradesh, India [online]. Hydrology: Current Research. Vol. 7. No. 227 p. 1–4. [Access 10.11.2020]. Available at: http://117.252.14.250:8080/jspui/handle/123456789/3126

Kumar M., Ramanathan A.L., Rao M.S., Kumar B. 2006. Identification and evaluation of hydrogeochemical processes in the groundwater environment of Delhi, India. Environmental Geology. Vol. 50. No. 7 p. 1025–1039. DOI 10.1007/s00254-006-0275-4

Molajou A., Afshar A., Khosravi M., Soleimanian E., Vahabzadeh M., Variani H.A. 2021. A new paradigm of water, food, and energy nexus. Environmental Science and Pollution Research. DOI 10.1007/s11356-021-13034-1.

Owamah H.I. 2020. A comprehensive assessment of groundwater quality for drinking purpose in a Nigerian rural Niger delta community. Groundwater for Sustainable Development. Vol. 10, 100286. DOI 10.1016/j.gsd.2019.100286.

Pichaiah S., Senthil Kumar G.R., Srinivasamoorthy K., Sarma V.S. 2015. Hydrochemical characterization and quality assessment of groundwater in Tirupur Taluk, Tamil Nadu, India: Emphasis on irrigation utility. Journal of Academia and Industrial Research. Vol. 1. No. 12 p. 805–812.

Pirasteh S., Safari H.O., Pradhan B., Attarzadeh I. 2010. Lithomorphotectonics analysis using Landsat ETM data and GIS techniques: Zagros Fold Belt (ZFB), SW Iran. International Geoinformatics Research and Development Journal. Vol. 1. No. 2 p. 28–36.

Prasanna M.V., Chidambaram S., Srinivasamoorthy K. 2010. Statistical analysis of the hydrogeochemical evolution of groundwater in hard and sedimentary aquifers system of Gadilam river basin, South India. Journal of King Saud University-Science. Vol. 22. No. 3 p. 133–145. DOI 10.1016/j.jksus.2010.04.001.

Parmar K., Parmar V. 2010. Evaluation of water quality index for drinking purposes of river Subernarekha in Singhbhum District. International Journal of Environmental Sciences. Vol. 1. No. 1 p. 77–93.

Ramakrishnaiah C.R., Sadashivaiah C., Ranganna G. 2009. Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State, India. E-Journal of Chemistry. Vol. 6. No. 2 p. 523–530. DOI 10.1155/2009/757424.

Saleem M., Hussain A., Mahmood G. 2016. Analysis of groundwater quality using water quality index: A case study of greater Noida (Region), Uttar Pradesh (UP), India. Cogent Engineering. Vol. 3. No. 1, 1237927. DOI 10.1080/23311916.2016.1237927.

Santhosh P., Revathi D. 2014. Geochemical studies on the quality of groundwater in Tirupur District, Tamilnadu, India. Journal of Chemical, Biological and Physical Sciences. Vol. 4. No. 2 p. 1780–1786.

Shirazi S.M., Adham M.I., Zardari N.H., Ismail Z., Imran H.M., Mangrio M.A. 2015. Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia. Journal of Water and Land Development. Vol. 24. No. 1 p. 11–19. DOI 10.1515/jwld-2015-0002.

Sukumaran D., Saha R., Saxena R.C. 2015. Ground water quality index of Patna, the capital city of Bihar, India. American Journal of Water Resources. Vol. 3. No. 1 p. 17–21. DOI 10.12691/ajwr-3-1-3.

WHO 1993. Guidelines for drinking water quality, recommendations. 4th ed. Geneva, Switzerland. World Health Organization. ISBN 9241544600 pp. 458.

Zayed M.A., ElHdad A.M.A. 2017. Assessment of ground water pollution with heavy metals based on pollution index and investigation of groundwater quality using water quality index in Western Nile Delta, Egypt. Internal Journal of Scientific Engineering and Research (IJSER). Vol. 5. No. 9 p. 24–35. DOI 10.21608/ejchem.2019.6975.1582.