EVALUATION GROUNDWATER QUALITY BY USING GIS AND WATER QUALITY INDEX TECHNIQUES FOR WELLS IN BARDARASH AREA, NORTHERN IRAQ

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ABSTRACT

Studying groundwater quality in arid and semi-arid regions is essential significant because it is used as a foremost alternative source for various purposes (human and animal consumption, economic, agriculture and irrigation). Geographic Information System and Water Quality Index techniques were utilized for visualizing and evaluating the variations of groundwater quality in the studied area. Total twelve wells were sampled and twelve groundwater quality (chemical) parameters; pH, Total Alkalinity, Total Hardness (TH), Total Dissolved Solid (TDS), Electrical Conductivity (Ec), Potassium (K), Nitrate (NO₃), Sulfate (SO₄), Chloride (Cl), Calcium (Ca), Magnesium (Mg) and Sodium (Na) were analyzed in the laboratory. Inverse Distance Weighted technique was used as a useful tool to create and anticipate spatial variation maps of the chemical parameters. Predicting or anticipating other areas not measured, identifying them and making use of them in the future without examining samples. The results of this research showed that 8.3% of the studied wells have excellent groundwater quality, and almost sampling wells about 75% found in good groundwater quality, while findings of groundwater quality of 16.7% studied wells belong to poor water quality due to standards of Water Quality Index. Moreover, spatial analysis in term of groundwater quality map showed that Excellent groundwater quality was detected in well 3, very good groundwater potential was noticed in six studied wells (wells 2, 6, 8, 10, 11 and 12), and other sampling wells (wells 4 and 7) were observed as good groundwater quality, while poor water quality was observed in wells (well 1 and 5). Hence, spatial distribution maps showed that the almost groundwater quality in the area about 1046.82 km² (99.04%) are suitable for drinking purpose, whereas proximate 10.18 km² (0.96%) are observed as poor water quality and inappropriate for consumptions especially in the southern part of the area.

Keywords: Groundwater; GIS; pH; TDS; Spatial analysis

INTRODUCTION

Water is one of the most significant natural resources for maintaining life and ecosystems on earth. Water resources in term quality and quantity have been influenced and have become more serious scarce since the second half of the twenty century due to the rapid expansion of residential population, increasing demands, wide growth of irrigation, industrial, economical activities and climate change particularly in arid and semi-arid areas (WHO, 2007; Hajalilou and Khaleghi, 2009; UNEP, 2009; Al-Ali and Hassan, 2017). It means that groundwater can be polluted by human activities and natural causes (Nelly and Mutua, 2016). The importance of water resources quality is parallel to their quantity, and water quality means very much based on the water use suitability (Raikar and Sneha, 2012). Quality of groundwater is assessed and investigated depending on the concentration of chemical parameters in collected samples, and consequences of water quality are commonly reported and compared to standards approaches (Khodapanah, et al., 2009; Mahagamage and Manage, 2015). There is a strong relationship between the quality of drinking water and human health, it is generally accepted that a healthy life is desired clean water (Toma et al., 2013). Therefore, water quality classes or fitness of drinking water for several purposes can be defined based on concentration chemical parameters. Shaltami et al., 2020 suggest using several techniques for the removal of heavy metals from drinking water such as ion exchange, reverse osmosis and nano filtration to save human health. Water quality has been described by different methods including traditional techniques and moderate procedures by several researchers. Water Quality Index (WQI) was initially proposed by Horton (1965) and it has been used for describing water quality as a number with regards to mathematics formula (Horton, 1965; Al Obaidy et al., 2015; Al-Ali and Hassan, 2017 and Kadhim, 2018). The single numerical value of WQI is extracted by mathematics formula to simplify and reduce the enormous amount of data which belongs to a new technique that is used for describing the WQI and identifying water quality types due to the effect of concentration and significance of different related water quality parameters in water consumption (Naubi et al., 2016; Al-Ali and Hassan, 2017). Therefore, WQI is one of the most powerful tools to investigate, evaluate and manage groundwater quality, and the definition of WQI is a rating reflecting the compound effect of various physical and chemical parameters of water (Ramakrishnaiah et al., 2009). Additionally, in the recent decades, Geographical Information System (GIS) technique is an effective tool in groundwater studies, and plays a key role in spatial variation prediction maps for groundwater vulnerability to contamination, determining water availability, assessing water quality

(Balakrishnan et al., 2011; Shakak, 2015; Shabbir and Ahmad, 2015). GIS is commonly utilized for sorting, management, manipulations and spatial analysis for evaluating and mapping the distribution suitable and unsuitable zones of groundwater for several land use (LU) such as agriculture, domestic, industrial activities based on groundwater quality parameters (Selvam et al., 2014; Khosravi et al., 2017), and it is used for assessing groundwater quality and helping decision makers to find the solution for vulnerability regions to contamination (Latha and Rao, 2010; Konkey et al., 2014; Jhariya et al., 2017). In several studies at local and international levels, WQI and GIS are used for analyzing and assessing the quality of groundwater for various purposes (Latha and Rao, 2010; Magesh et al., 2013; Konkey et al., 2014 and Jhariya et al., 2017). Hence, the valuation of groundwater quality is essential for the nominated area in the present study. The objectives of this study are evaluating and mapping the spatial distribution of groundwater quality of some wells in the Bardarash region with regards to chemical parameters of groundwater by using GIS and WQI and comparing it with the standards quality to detect the appropriateness of groundwater samples for various usages.

DESCRIPTION OF STUDY AREA

Bardarash area is selected as a study area for the present study which is located south-east of Duhok, Northern of Iraq. The area is bounded by latitudes $36^{\circ} 30' - 36^{\circ} 55' N$, and longitudes $43^{\circ} 20' - 43^{\circ} 60' E$. To obtain the accuracy in calculating the region of the study area, the spherical coordinate system was converted to the plane state by using the Universal Transverse Mercator projection. The study area covers an area of approximately 1057 km² (Fig. 1).

Topographically, the terrain in the area is a mostly flat or gentle slope but only interrupted by infrequent hills whereas occurrence some mountains in the region Maqlob mountain in the west part and Bakrman mountain in the north part. Therefore, elevation range of the area is between 171 and 1665 m above sea level (Fig. 1). The climate of the study area is generally characterized as arid and semi-arid regions which are divided into two seasons: hot-dry summer and cold winter, and they are reported that annual mean precipitation and a temperature range between 450 and 1000 mm and $18 - 24^{\circ} C$, respectively, monthly mean temperature exceeds up to $48^{\circ} C$ in summer season and reaches below $0^{\circ} C$ in winter season (Qader et al., 2015; Al-Basrawi and Al-Jiburi, 2014 and Mohammed, 2010). Geologically, the main outcropped units in the study area are Bai-Hasan, Mukdadiya, Injana, Fatha formations and Quaternary deposit. Also, in the mountain area some older formations are exposed (such

as; Pila Spi Fm. and Gercus Fm.). Tectonically, the study region is situated in Foothill Zone within the unstable shelf (Jassim and Goff, 2006 and Balaki and Omar, 2018). Hydrogeology of the area includes the main source of nutrition of unconfined aquifer and the semi-confined aquifer is precipitation and snow falling. There are many agriculture, economic and industrial activities in the selected area such as using the wide-area for farming different yields and using the number of fertilization materials which require water and also influencing the groundwater. Also, the oil well is located in the study area which is producing the hydrocarbon materials. The twelve random wells were sampled for this study, and important information about wells including their X and Y coordinates and depth are given in Table 1.

Fig. 1. Location map of the study area

Table 1. Geographic coordinates (UTM system), depth of the wells and chemical parameters of groundwater samples in Brdarash Area in (mg/l)

Well	Y	X	Depth	pH	EC	T.D. S	Ca	Mg	Na	K	Hardness	Alkal.	Cl	NO ₃	SO ₄
1	379053	4049265	399	8	1014	694.72	95	58	58	1.8	403	263	58	61	163.52
2	378799	4051440	402	6.98	405	259.2	58	42	15	0.1	320	225	24	27	91.91
3	377969	4050055	387	7	414	264.96	52	41.28	26	0.5	302	217	30	19	85.08
4	377834	4049757	398	7.36	549	351.36	88	32.64	30	0.8	356	247	36	51	131.12
5	377802	4049357	397	7.8	924	635.3	96	54	56	0.4	419	384	46	67	202.79
6	374675	4062514	397	7.3	496	317.44	83	25.8	17	0.4	315	308	21	42	38.89
7	363923	4067931	372	7.38	544	348.16	86	32.4	41	0.4	350	340	35	63	47.95
8	368476	4055486	365	7.28	486	311.04	91	41.16	26	0.4	399	380	28	18	61.03
9	384416	4060592	373	7.33	445	284.8	92	40.32	22	0.4	398	320	25	31	101.71
10	386814	4056698	390	7.27	423	270.72	92	25.92	31	0.3	338	310	29	26	59.49
11	384297	4043928	403	7.1	500	459.2	58	42	15	0.1	320	225	24	18	91.91
12	378952	4059309	403	7.7	414	264.96	52	41.28	26	0.5	302	217	34	15	85.08

MATERIALS AND METHODS

Sampling

The groundwater samples were collected from 12 wells in the study area that are widely used for multipurpose, and GPS which is used for determining the locations of studied wells. According to APHA (1999), the standard analytical method is used for analyzing each of the groundwater samples with respects to desirable instruments in the laboratory for 12 chemical parameters such as pH, Total Alkalinity, Total Hardness, Total Dissolved Solids (TDS), Electrical Conductivity (EC), Potassium (K), Nitrate (NO₃), Sulfate (SO₄), Chloride (Cl), Calcium (Ca), Magnesium (Mg) and Sodium (Na) for the study area (Table 1). The unit of all concentrations of the parameters is in Milligrams per liter (mg/L), except the pH which does not have unit and Ec measured by mS/cm, or miliSeimens per centimeter. The results of groundwater quality were evaluated based on integration of various standards of WHO (2007), IQS (2009) and GIZ (2019) for determining suitability of groundwater quality for usages (Table 2).

WQI Procedure

WQI has been developed to assess the integrated influence of various chemical parameters on quality of groundwater for multiple uses in the area. WQI is calculated to minimize the large quantity of groundwater parameters data to a single number. The three steps are considered for computing WQI (Konkey et al., 2014; Al Obaidy et al., 2015 and Kadhim, 2018). At the first step, each of the 12 parameters has been assigned a specific weight (W_i) based on its relative significance in the overall groundwater quality for consumption purposes and the weight ranges from 1 to 5 due to their importance in assessing groundwater quality; the maximum and minimum weights of 5 and 1 have been given to nitrate (NO_3) and Potassium (K) parameters due to their major and less importance on the assessment of groundwater quality respectively, and the weight of each other parameters have been shown in Table 2. In the second step, equation 1 is used for computing relative weight (W_r) for every 12 parameters;

$$W_r = \frac{W_i}{\sum_{i=1}^n W_i} \quad (1)$$

Where, W_r is the relative weight of parameter; W_i is the weight assigned to each parameter; and n is the number of parameters considered.

Table 2. Drinking water standards, unit weight and relative weight of the water quality parameters

Parameter (mg/l)	(IQS,2009) Standard	(WHO,2007) Standard	GIZ (2019) Standard	Standard used for this study	Weight (W_i)	Relative weight (W_r)
pH	6.5-8.5	7.0-8.0	6.5-8.5	6.5-8.5	4	0.111
EC	1000	1000	1000	1000	4	0.111
T.D. S	1000	1000	500	500	4	0.111
Ca	150	75-200	100	100	2	0.056
Mg	50	30-150	30	50	2	0.056
Na	200	200	200	200	2	0.056
K		12	2.0-3.0	12	1	0.028
Hardness	500	100-500	200	200	2	0.056
Alkalinty	200	200	200	200	3	0.083
CL	250	250	250	250	3	0.083
NO_3	50	50	50	50	5	0.139
SO_4	250	250	250	250	4	0.111
Summation					$\sum W_i=36$	$\sum W_r=1.001$

At the third step, equation 2 is used for calculating a quality rating scale (q_i) for each of the 12 parameters; consequently, the concentration value of each parameter in the sample was divided by its own standard according to the guidelines laid down in Table 2 which is selected standard and the result was multiplied by 100 (Table 3).

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

Where q_i is the quality rating of each parameter; C_i is the concentration value of each parameter in the sample (mg/L); and S_i is the selected standard for each parameter (mg/L), see Table 2.

Finally, for calculating the WQI, initially sub-index Sl_i should be determined for the each of 12 groundwater quality parameters by using equation 3 (Table 4), which is then utilized to determine the WQI by equation 4.

$$Sl_i = W_r \times q_i \quad (3)$$

$$WQI = \sum Sl_i \quad (4)$$

Where WQI is water quality index; Sl_i is the sub index of each parameter; q_i is the quality rating based on concentration of each parameter; W_r is the relative weight of each parameter; and n is the number of the parameters.

The computed values of WQI are classified into five types (Konkey et al., 2014; Al-Ali and Hassan, 2017 and Muralitharan and Palanivel, 2018) (Table 5).

GIS Mapping of WQI

The study area was mapped based on using Aster DEM in ArcGIS 10.6 technique. The exact sample's locations were determined by handheld GPS for each well and combined with concentrations of chemical parameters; then the combination file was imported into GIS platform. The spatial distribution maps of the nominated chemical parameters for this study were generated with regards to spatial analyst tools in ArcGIS 10.6 version. Interpolation maps were created via Inverse distance weighted (IDW) interpolation procedure, and it is used for prediction of unknown values through known values (Burrough et al, 2015). The selected standards have been used for classifying the values of the groundwater quality parameters (Selvam et al., 2014 and Khosravi et al., 2017). The IDW is an algorithm that is utilized for interpolating data in a spatial pattern, and it estimates the distances or values between sampling points according to the weighted average of each parameter and distances with surrounding sampling points. It also uses prediction of unknown values through known

values. Weights are calculated by taking the inverse of the distance from a known data point to the location of the unknown point that is being estimated (Burrough and McDonnell, 1998). The parameters were reclassified and weighted to identify their influences on mapping groundwater quality. The final potential map of groundwater quality was created by overlaying all weighted parameters to delineate the quality of groundwater in the area for consumption.

RESULTS AND DISCUSSION

The Findings show the spatial distribution maps of investigated groundwater quality (chemical parameters) based on the locations of samples or wells with regards to using the IDW interpolation technique, (Table 1) and (Figs. 2 and 3). The classification of groundwater quality and spatial variation map of the groundwater quality index has shown in Table 5 and Fig. 4.

Spatial Distribution of Chemical Parameters

Spatial variation maps for investigated groundwater quality (Chemical parameters) were generated by IDW interpolation tool to delineate the distribution form of their concentration in the study area (Figs. 2 and 3). The concentration values of the parameters are categorized based on the selected standards for consumption water.

pH

The IDW map showed in Fig. 2A which displays the spatial variation of PH value in the entire study area, and indicates that pH of all wells in the study area within the permissible range of selected standards, while the highest concentration of pH has distributed around well 1 and 12 in north and south parts of the area.

Total alkalinity

The spatial variation map of total alkalinity in the study area is shown in Fig. 2B. It indicates that the alkalinity of all the groundwater well samples in the study area is a higher level than the selected standards. The maximum concentration of total alkalinity can be seen in the west and northwest part of the study area nearby well 8 and 7.

Total hardness (TH)

The high level of total hardness was detected in all sampling wells of the study area which greater than standard level. The spatial distribution map of total hardness in the study area is presented in Fig. 2C. The high concentration of total hardness indicates that groundwater goes through carbonate beds and assembles the carbonate in addition to bicarbonate ions that

accumulate in the groundwater resources. The highest concentration of the total hardness has distributed around well 1, 8 and 9.

Total dissolved solids (TDS)

The spatial variation map of TDS in the study region is demonstrated in Fig. 2D. Approximately 16.7 % of the sampling wells are beyond the desirable level, all well under desirable limit except well 1 and 5, and other around 83.3% samples fall within the acceptable standards. Hence, the highest concentration of TDS has dispersed surrounding well 1 and 5 as can be seen in Fig. 2D. High level of TDS in the samples of groundwater is due to human activities and leaching of salts from soil.

Electrical conductivity (EC)

The EC value of all studied wells for this study within allowable level excluding (about 8.3% of samples) well 1 which has a higher concentration of EC than standard. Fig. 2E illustrates the spatial variation map of EC values of the selected area, and the highest distribution has been seen around well 1 and 5 while the lowest concentration of the EC has been distributed in east and northeast part of the study area around well 9, 10 and 12.

Potassium (K)

The spatial distribution map of potassium concentration in the study area is presented in Fig. 2F. Although the highest concentration of K has distributed around well 1 in south and southwest parts of the area, the potassium value of whole sampling wells in the study area is under the allowable boundary. The concentration of potassium is decreased toward north and southeast parts of study area.

Nitrate (NO₃)

NO₃ parameter plays a significant role in determining the groundwater quality comparing to other selected parameters and maximum weight was assigned to NO₃ parameters. About 33.4 % of the groundwater well samples in the study have a higher concentration than permissible standard, and 66.6 % of well samples fall in the allowable limit. The spatial distribution map of NO₃ concentration in study area has been shown in Fig. 3A. The highest concentration of NO₃ has been distributed around well 1 and 5 in south and well 7 in south and northwest parts of the study area which is higher than the permissible standard while the concentration of NO₃ in southeast, northeast and west parts of the area falls in the allowable limit.

Sulfate (SO₄)

The concentrations of SO₄ for all groundwater well samples have lie within the permissible level, and its spatial distribution map is presented in Fig. 3B. However, it can be seen that

concentration of SO_4 in the study area falls within the acceptable standards; south part of the study area about well 1 and 5 has maximum concentration of SO_4 , and it is decreased toward north, particularly in the northwest part of the area.

Chloride (Cl)

Total groundwater well samples fall within the highest permissible limit. Fig. 3C demonstrates the spatial variation map of Cl in the study area. The maximum concentration of Cl has distributed around well 1 from south, and Cl concentration decreases toward north direction.

Calcium (Ca)

The calcium concentrations of all groundwater well samples have lie within the permissible limit. The spatial distribution map of the Ca parameter in the study area is shown in Fig. 3D. The minimum concentration of Ca has distributed around center and southeast parts of the study area nearby well 11 and 12.

Magnesium (Mg)

The high values of Mg were observed in about 16.7 % of well samples (well 1 and 5) which exceed the recommended standards, and 83.3% of well samples fall in the desirable limit. Fig. 3E illustrates the spatial distribution map of Mg concentration in the selected area. The maximum concentration of Mg had been distributed around well 1 and 5 which are located at lower part of the study area and its concentration has decreased toward upper part of the area.

Sodium (Na)

The observed values of Na in all groundwater well samples lie within allowable level which recommended by the selected standards. The spatial distribution map of Na concentration in groundwater of the study area is shown in Fig. 3F. The highest concentration of Na has distributed in surrounding well 1, particularly in south part of the area while it falls within acceptable standards.

Assessment of Water Quality Index

The values of weight, relative weight and different standards (including WHO, IQS and GIZ) which combined in this study for each investigated parameter are required for computing the first step of the WQI (Table 2). Table 3 presents the results of the quality rating of each parameter which observed in the second step of calculating WQI, and the findings of sub-index which is the last step of calculating WQI are shown in Table 4. Furthermore, Table 5 demonstrates the classification of WQI.

Fig. 2. Spatial distribution map based on IDW technique for (A) pH, (B) Total alkalinity, (C) Total hardness, (D) TDS, (E) EC and (F) Potassium

Fig. 3. Spatial distribution map based on IDW technique for (A) NO₃, (B) SO₄, (C) Chloride, (D) Calcium, (E) Magnesium and (F) Sodium

The WQI value of groundwater sampling wells in the study area ranges from 46.291 to 105.718. The outcomes of WQI showed that in a total of 12 groundwater sampling wells, about 8.3% one sampling well (well 3) has observed that belongs to an excellent class of groundwater quality because its WQI value is 46.291 below to 50 (Table 5). Moreover, approximately 75 % of sampling wells (nine sampling wells such as Well (2), (4), (6), (7), (8), (9), (10), (11) and (12) have WQI values ranged between 56.721 and 79.011, consequently those sampling wells have located in the second class as considered a good groundwater quality (Table 5). Although, 16.7% of sampling wells (two remain wells such as well 1 and 5) have observed in the third class of WQI because of their WQI values of 100.605 and 105.718 respectively that ranges between 100 and 200. There are no sampling wells belong to very poor and unsuitable water in the study area (Table 5). Table 6 presents the statistic of spatial variation map of WQI based on the GIS tools, and the spatial distribution map of WQI in the study area (Fig. 4).

Most locations in the study area have very good groundwater quality which is about 525.84 km² (49.75%) over the entire selected area including six sampling wells, and spatially from north, east and northeast parts which are situated upper part of study area as shown in Fig. 4. (Table 6). Approximately 507.26 km² (47.99%) locations have good groundwater quality of the area (three sampling wells) which located in south, west and northwest parts of the area. Mild groundwater quality covers 13.43 km² (1.27%) of the study area and no sampling well located in the mild's area (Table 6). Moreover, around 0.28 km² (0.03%) is found excellent groundwater quality in the area (one sampling well) which surrounding well 3 because the spatial distribution maps of all chemical parameters show that the area around well 3 is fitting to acceptable limit while poor groundwater quality is found about 10.18 km² (0.96%) in the study area including two sampling wells (Table 6). The concentration of all chemical parameters of samples is the highest concentration nearby the well 1 and 5 in the almost south part of the study area as can be seen in Fig. 4.

Generally, spatial distribution show that about 1046.82 km² (99.04%) groundwater quality of the study area is suitable and can be used for drinking while 10.18 km² (0.96%) groundwater is unfit for usages in the almost south part of the study area, and this poor groundwater quality in the area is caused due to farming and human activities in the region, especially one oil well is located close to the poor groundwater quality area (Fig. 4).

Table 4. The value of quality (q_i) for each parameter in each well

Parameters	pH	EC	T.D. S	Ca	Mg	Na	K	Hardness	Alkalinity	Cl	NO ₃	SO ₄
Well1, q_i	106.667	101.400	138.944	95.000	116.000	29.000	15.000	201.500	131.500	23.200	122.000	65.408
Well2, q_i	93.067	40.500	51.840	58.000	84.000	7.500	0.833	160.000	112.500	9.600	54.000	36.764
Well3, q_i	0.000	41.400	52.992	52.000	82.560	13.000	4.167	151.000	108.500	12.000	38.000	34.032
Well4, q_i	98.133	54.900	70.272	88.000	65.280	15.000	6.667	178.000	123.500	14.400	102.000	52.448
Well5, q_i	104.000	92.400	127.060	96.000	108.000	28.000	3.333	209.500	192.000	18.400	134.000	81.116
Well6, q_i	97.333	49.600	63.488	83.000	51.600	8.500	3.333	157.500	154.000	8.400	84.000	15.556
Well7, q_i	98.400	54.400	69.632	86.000	64.800	20.500	3.333	175.000	170.000	14.000	126.000	19.180
Well8, q_i	97.067	48.600	62.208	91.000	82.320	13.000	3.333	199.500	190.000	11.200	36.000	24.412
Well9, q_i	97.733	44.500	56.960	92.000	80.640	11.000	3.333	199.000	160.000	10.000	62.000	40.684
Well10, q_i	96.933	42.300	54.144	92.000	51.840	15.500	2.500	169.000	155.000	11.600	52.000	23.796
Well11, q_i	94.667	50.000	91.840	58.000	84.000	7.500	0.833	160.000	112.500	9.600	36.000	36.764
Well12, q_i	102.667	41.400	52.992	52.000	82.560	13.000	4.167	151.000	108.500	13.600	30.000	34.032

Table 5. The value of Sl_i and WQI for each well

Parameters	pH	EC	T.D.S	Ca	Mg	Na	K	Hardness	Alkalinity	Cl	NO ₃	SO ₄	$\sum Sl_i = QW1$
Well1, Sl_i	11.852	11.267	15.438	5.278	6.444	1.611	0.417	11.194	10.958	1.933	16.944	7.268	100.605
Well2, Sl_i	10.341	4.500	5.760	3.222	4.667	0.417	0.023	8.889	9.375	0.800	7.500	4.085	59.578
Well3, Sl_i	0.000	4.600	5.888	2.889	4.587	0.722	0.116	8.389	9.042	1.000	5.278	3.781	46.291
Well4, Sl_i	10.904	6.100	7.808	4.889	3.627	0.833	0.185	9.889	10.292	1.200	14.167	5.828	75.721
Well5, Sl_i	11.556	10.267	14.118	5.333	6.000	1.556	0.093	11.639	16.000	1.533	18.611	9.013	105.718
Well6, Sl_i	10.815	5.511	7.054	4.611	2.867	0.472	0.093	8.750	12.833	0.700	11.667	1.728	67.101
Well7, Sl_i	10.933	6.044	7.737	4.778	3.600	1.139	0.093	9.722	14.167	1.167	17.500	2.131	79.011
Well8, Sl_i	10.785	5.400	6.912	5.056	4.573	0.722	0.093	11.083	15.833	0.933	5.000	2.712	69.103
Well9, Sl_i	10.859	4.944	6.329	5.111	4.480	0.611	0.093	11.056	13.333	0.833	8.611	4.520	70.781
Well10, Sl_i	10.770	4.700	6.016	5.111	2.880	0.861	0.069	9.389	12.917	0.967	7.222	2.644	63.546
Well11, Sl_i	10.519	5.556	10.204	3.222	4.667	0.417	0.023	8.889	9.375	0.800	5.000	4.085	62.756
Well12, Sl_i	11.407	4.600	5.888	2.889	4.587	0.722	0.116	8.389	9.042	1.133	4.167	3.781	56.721

Table 5. Water quality classification according to combination standard in Table 3

Well No.	Water value	class	Water quality classification
(3)	≤ 50	I	Excellent
(2), (4), (6), (7), (8), (9), (10), (11) and (12)	50 to 100	II	Good Water
(1) and (5)	100 to 200	III	Poor Water
Non	200 to 300	IV	Very poor water
Non	≥ 300	V	Unsuitable water

Table 6. Statistic of groundwater quality index by using GIS technique

WQI Classes	Area (km ²)	Area (%)	Well located in each class of WQI
Excellent Water	0.28	0.03	(3)
Very Good Water	525.84	49.75	(2), (6), (8), (10), (11) and (12)
Good Water	507.26	47.99	(4), (7) and (9)
Mild Water	13.43	1.27	Non
Poor Water	10.18	0.96	(1) and (5)
Summation	Σ1057.00	Σ100.00	Σ12 sampling wells

Fig. 4. Spatial distribution map of WQI produced by IDW technique in ArcGIS applications

CONCLUSIONS

This study was undertaken to estimate and characterize the groundwater quality for 12 sampling wells in the Bardarash area, for consumption purposes. The GIS and WQI techniques are effectively used in assessment and mapping the spatial distribution of chemical parameters and groundwater quality in the selected area. The results based on the IDW interpolation method showed the highest concentration of almost chemical parameters distributed around well 1 and 5 in the southern part of the study area, and it has shown that the groundwater quality surrounding those two wells is poor quality. Therefore, it was proven that the IDW interpolation of GIS technique is an influential tool for spatial analyzing and zoning the groundwater quality. The results of the WQI map show that the almost groundwater quality of the study area is suitable for drinking purpose which is approximately 1046.82 km² (99.04%) including (excellent, very good, good and mild groundwater quality classes, whereas about 10.18 km² (0.96%) groundwater quality belongs to poor water quality category in the area especially in the south part.

Moreover, the findings of the WQI technique presented that around 8.5% of sampling wells have located in excellent water category, and the majority of studied wells about 75% laid within good water class, while near 16.7% of sampling wells have observed in the poor water category. The results of WQI indicated that it varies from 46.291 to 105.718, and almost studied wells were found in the good water quality. Although, the high values of WQI were observed in around well 1 and 5 because they have a high concentration of NO₃, TDS, Total Alkalinity, TH, EC, and Mg parameters.

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