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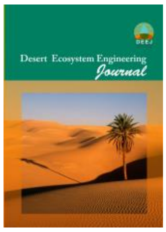

Groundwater Quality and Suitability for Different Purposes in the SirjanPlain

Mohsen pourkhosravani[1*], Fatemeh Jamshidi Gohari[2], Nasrin sayari[3]

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Abstract

The management of groundwater resources requires their accurate quantitative and qualitative assessment, accessibility in each region, and knowledge of their governing environmental processes. Accordingly, this study sought to evaluate and analyze the chemical quality of groundwater resources in Sirjan Plain .To realize this study's aims, first, the statistics and information concerning water quality indicators of the year 2018 were collected from the Kerman's Regional Water Company. Then, the quality of drinking and agricultural water was evaluated using Schuler and Wilcox diagrams. Finally, the classification map of each effective parameter involved in the Schuler and Wilcox method was prepared using Arc GIS software's inverse distance weighted (IDW) model. The results of the Schuler diagram indicated that the quality of drinking water was good to moderate in 47% of the examined wells. Moreover, the groundwater quality's classification map used for drinking purposes suggested that the good, acceptable, moderate, unsuitable, completely unsuitable, and non-potable water quality classes covered3.84%, 19.96%, 32.81%, 20.58%,13.29%, and 9.52% of the aquifer area, respectively. Also, the results of the Wilcox diagram showed that 8.82%, 38.23%, and 52.94% of the wells were in the good, medium, and unsuitable range, respectively. Furthermore, the groundwater quality classification map used for agricultural purposes indicated that the good, moderate, unsuitable quality class covered 9.59%, 50.54, and 39.87% of the aquifer area. In general, the study's results showed that groundwater quality in the northwestern, western, and southern parts of the aquifer was lower than in other parts.

Keywords: Groundwater, Water Quality, Schuler Diagram, Wilcox Diagram, SirjanPlain.

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1. Introduction

Groundwater is an important and valuable water resource in most countries, particularly those located in arid and semi-arid areas, including Iran(Neshat et al. 2014; Baghapour et al. 2016;Malakootian and Nozari 2019). It is avaluable natural water resource that is useful for the secure provision of potable water supply and economic development in human settlements(Ghezelsofloo and Valizadeh Ardalan 2012; Wakode et al. 2014). In recent years, groundwater pollution has become one of the most serious problems in countriesworldwide. Agricultural activity, urbanization, and industrialization affect thegroundwater qualitatively and quantitatively(Jat et al. 2009; Khan and Jhariya 2016).

Water pollution threatens economic development, human health, and social success (Wakode et al., 2014). Improper management in terms of extractions made from such resources hasbrought aboutquantitative and qualitative changes inthem and led to thedestruction of other resources directly or indirectly. Therefore, as only less than 3% of the Earth's freshwater is made of groundwater, it is necessary to permanently monitor underground aquifers (Simeonov et al. 2003; Salarian et al. 2015; Vosoughi Niri et al. 2015).

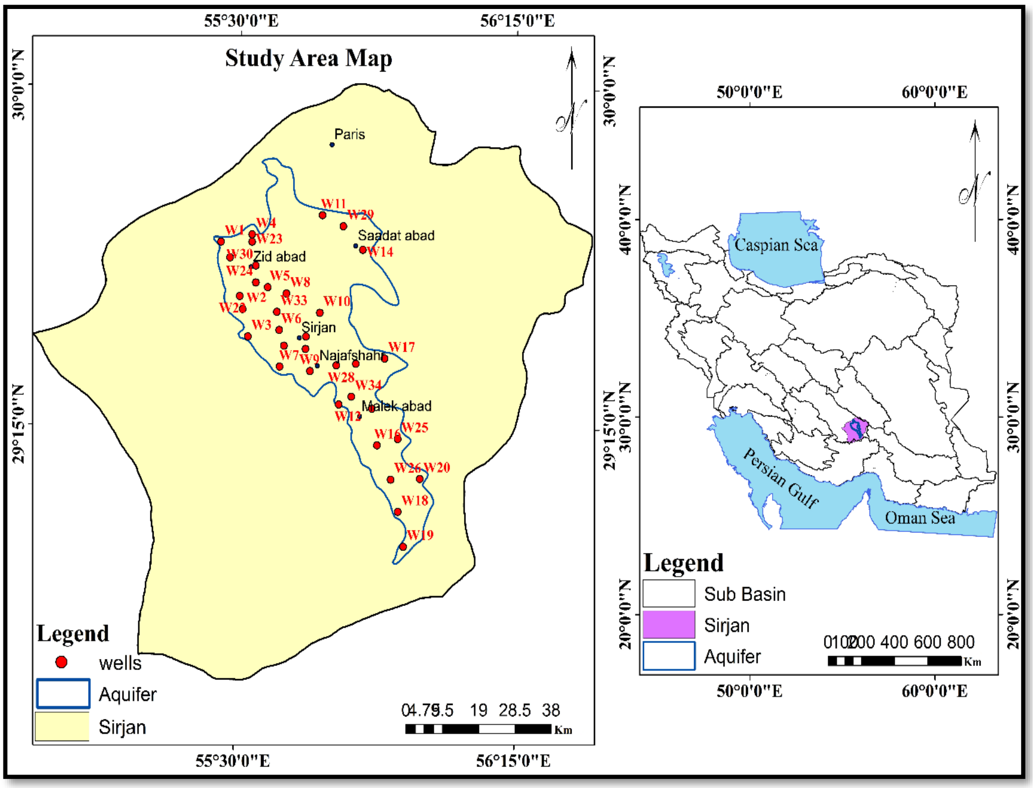
Due to the importance of groundwater resources in arid and semi-arid regions, several studies have been conducted in different parts of the worldon evaluating the water quality used for drinking and agricultural purposes using Schuler and Wilcox diagrams and zoning information in geographic information systems (GIS). For instance, in a study carried out by Yari et al. (2016)to examine the physical and chemical quality of groundwater in the villages of Qom province, it was found that in almost all villages, most of the physicochemical parameters such as fluoride and is some wells of the city elements such as sulfates, chloride, magnesium, sodium, calcium, nitrate, TDS, and EC has exceeded the permissible limit (Yari et al. 2016). Moreover, in their study on assessing the Water quality of Dez's eastern aquifer according to Schuler and Wilcox diagrams and GIS, Alavi et al. (2016) concluded that the quality of drinking water was good and acceptable according to the Schuler diagram and that it was a little salty yetsuitable for agricultural purposes according to the Wilcox diagram.

Another study conducted by Salifu et al. (2017)to evaluate the suitability of groundwater used for agricultural purposes in some selected districts of the upper west Region of Ghana showed that the groundwater in the study area was generally good for agriculture and irrigation purposes. However, there were a few instances that were problematic and required special irrigation methods. Also, Ndoye et al. (2018)investigated thequality and suitability ofgroundwater for different purposes in the Saloum Area of Senegal, concluding that according to the indicesof water irrigation, most of the Saloum groundwater samples fall within the suitable range of irrigation compared to the standard limits(Ndoye et al. 2018). Parvez and Sultana Pritul assessed the Ground Water Quality in the Savar (Akrain) Area, concluding that approximately 62.5 percent of the wells are suitable for human consumption within the specific area. Also, the analysis suggests that groundwater of the selected area needs some degree of treatmentand purification before consumption.

Generally, adopting carefully-developed plans for protecting water resources has become much more important (Pourkhosravani 2016). In this regard, the first step in managing groundwater resources is to identify the vulnerable areas (Modabberi et al., 2017). Therefore, the vulnerability evaluationseeks to prevent potential risks of pollution by delimitating sensitive areas to control the activities made at the ground surface to protect the groundwater quality (Djémin et al., 2016). Thus, this study sought to evaluate and analyze the quality of groundwater resources in SirjanPlain using Schuler and Wilcox diagrams and a geographic information system.

2. Materials and methods

SirjanPlain is located 180 km southwest of Kerman, between 54° 56′ E to 56° 27′ Elongitude and 28° 41′ N to 30° 01′ N latitude. Also, the city's aquifer with an area of about 2009.33 km² is located between 55° 25′ E to 56° 02′ E longitude and 28° 57′ N to 29° 50′ N latitude. The average annual rainfall in the study area is 142 mm. In this region, the relative humidity and the maximum and minimum temperature are 36%, 37°C, and -1 °C, respectively (Kerman Meteorological Organization, 2018). Figure 1 shows the location of the study area and the sampling wells.



Figure(1): Location of the study area and the sampling wells

The present study is based on descriptive and analytical methods. In order to analyze the quality characteristics of the selected water wells in SirjanPlain, annual statistics and information concerning quality indicators such as Electrical Conductivity (EC), Sulfate, Total Dissolved Solids (TDS), Sodium, Calcium, Magnesium, Bicarbonate, and Chlorine of 34 wells were used. These wells had already been sampled by Kerman's Regional Water Company, and their full chemical analysis was completed in 2018.Using the Chemistry software, Schuler and Wilcox,whichare highly recommended methods, were utilized to check the quality of drinking and agricultural water. In the next step, a classification map of each effective parameter in the Schuler and Wilcox method was prepared for the study area based on the influential criteria of the two methods (Tables 1 and 2) using the IDW method and

Arc GIS software. Then, the classification map of the groundwater quality was prepared for drinking and agricultural purposes based on the overlaying method.

Schuler diagram is a graphical method for classifying the quality of drinking water, which is also suitable for Iran's climate. In this diagram, thewater samples under study are divided into six groups, including the good, acceptable, moderate, unsuitable, quite unpleasant, and non-potable. In the Schuler diagram, a separate axis is considered for each value of Cations and Anions and Water Hardness, the determination of which specifies the quality of drinking water (Baba 2015). Table 1 shows the water quality classification using the Schuler method.

The Wilcox classification method is the most practical method for classifying water in terms of agriculture, irrigation, and hydrological studies. In this method, letter C indicates Salinity, and letter S indicates Sodium level, Sodicity, or Alkalinity, and the numbers 1 to 4 indicate the intensity of those elements. According to Wilcox's classification, very good water qualityhas an EC of less than 250 micromhos per centimeter which is classified as C1-S1. Good water quality fallswithin the C1-S2, C2-S1, and C2-S2 classes, moderate water quality falls within C3-S3, C1-S3, C3-S2, and C3-S1 classes, and unsuitable water quality is placed in other classes (Baba 2015). Table 2 lists the water quality classification using the Wilcox method.

Table (1): Water quality classification using the Schuler method

Classification of water quality for drinking	Water quality	SO4 (mg/l)	Cl (mg/l)	Na (mg/l)	TH (mg/l)	TDS (mg/l)
1	Good	<144	<177.5	<115	<250	<500
2	Acceptable	144-288	177.5-350	115-230	250-500	500-1000
3	Average	288-576	350-710	230-460	500-1000	1000-2000
4	Inappropriate	576-1152	710-1420	460-920	1000-2000	2000-4000
5	Completely inappropriate	1152-2340	1420-2840	920-1840	2000-4000	4000-8000
6	Non potable	>2340	>2840	>1840	>4000	>8000

Table (2): Water quality classification using the Wilcox method

Classification of water quality for drinking	Water quality	SO4 (mg/l)	Cl (mg/l)	Na (mg/l)	TH (mg/l)	TDS (mg/l)
1	Good	<144	<177.5	<115	<250	<500
2	Acceptable	144-288	177.5-350	115-230	250-500	500-1000
3	Average	288-576	350-710	230-460	500-1000	1000-2000
4	Inappropriate	576-1152	710-1420	460-920	1000-2000	2000-4000
5	Completely inappropriate	1152-2340	1420-2840	920-1840	2000-4000	4000-8000
6	Non potable	>2340	>2840	>1840	>4000	>8000

3. Results

Table (3) shows the evaluated quality indicators in the studied wells and the comparison of values with the permissiblelimits defined by the ISIRI[1] (Organization, 2006) and the WHO[2] (Organization, 1993) In this table, the green color indicates the desired limit, the blue color

1.Institute of Standards and Industrial Research of Iran
2.World Health Organization

indicates a limit higherthan the desired limit, which is yet within the permissible limit, and the red color indicates the maximum limit according to the ISIRI.

Table (3): Thequality indicators evaluated in the studied wells and the comparison of values with thepermissible limitsdefined by the ISIRI and the WHO

Sample wells		EC (µ mho/cm)	Mg (Mg/L)	Ca (Mg/L)	TDS (Mg/L)	SO_4 (Mg/L)	Cl (Mg/L)	Na (Mg/L)	HCO_3 (Mg/L)
Dehbiyabani	(W1)	17500	291/6	920	11375	3283/2	6390	4140	97/6
Hafez abad	(W2)	20000	729	1200	13000	1814/4	8165	3450	134/2
Naseriyeh	(W3)	15450	279/45	840	10043	2544	5680	3450	122
Roodestani	(W4)	8000	121/5	600	5200	628/8	2570/2	1092/5	122
Behaabad	(W5)	1240	15/795	70	806	225/6	198/8	195/5	183
Fakhrabad	(W6)	1235	26/73	60	803	201/6	198/8	179/4	195/2
Ali abad	(W7)	14950	194/4	360	9718	1228/8	5538	3450	146/4
Mahmoodabad	(W8)	1370	14/58	80	891	264	205/9	204/7	170/8
Kahamkan	(W9)	5200	143/37	180	3380	1075/2	1278	920	146/4
Najafshahr	(W10)	1100	12/15	50	715	172/8	159/75	188/6	219/6
Keranstoodeh	(W11)	2450	36/45	110	1593	739/2	319/5	434/7	183
Sahebi	(W12)	10800	145/8	480	7020	1171/2	3905	2300	97/6
Kohanshahrivar	(W13)	1477	12/15	28	960	268/8	227/2	312/8	244
Yahyaabad	(W14)	730	19/44	40	475	124/8	56/8	82/8	183
Askarabad	(W15)	1135	12/15	68	738	283/2	88/75	161	183
Amir abad	(W16)	1280	12/15	48	832	134/4	198/8	211/6	256/2
Kohanshahr	(W17)	1155	29/16	60	751	201/6	163/3	156/4	207/4
Taghi	(W18)	15800	583/2	880	10270	1896	5325	2300	152/5
Nokohan	(W19)	6400	174/96	240	4160	1113/6	1562	1016/6	207/4
ShilaheydariSheibani	(W20)	3260	60/75	132	2119	801/6	532/5	512/9	134/2
Hashemabad	(W21)	17700	243	400	12155	1296	5680	3450	207/4
Abbas abad	(W22)	20000	194/4	640	13000	912	7668	4370	183
Kamjoo	(W23)	7100	121/5	480	4615	705/6	2272	1074/1	122
Kazemabad	(W24)	13500	243	520	8775	912	4899	2599	122
Kafriz	(W25)	500	8/505	30	325	67/2	42/6	69	158/6
BaniasadiShilaheydari	(W26)	960	12/15	50	624	163/2	124/25	147/2	183
Maki abad	(W27)	2900	103/275	120	1885	580/8	568	368	158/6
Imamzadeh Ali	(W28)	1795	24/3	70	1167	240	390/5	296/7	146/4
Ishaqabad	(W29)	685	19/44	72	445	86/4	78/1	41/4	183
Baba haji	(W30)	20000	194/4	400	13000	2544	6390	4600	183
Beheshti Street	(W31)	3450	85/05	220	2243	724/8	639	402/5	146/4
Hojjatabad	(W32)	920	48/6	60	598	168	124/25	69	183
Nusratabad	(W33)	1444	18/225	70	939	259/2	234/3	216/2	146/4
Ibrahim abad	(W34)	6770	255/15	260	4401	624	1917	821/1	146/4
ISIRI	Favorable Limit	1500	30	75	100	250	250	200	150
	Admittable Limit	2000	150	250	1500	400	400	200	150
WHO		600	50	75	600	200	200	200	150

The results presented in Table 3 show that the amount of EC[1], Mg, Ca, TDS[2], SO_4, Cl, and Na parameters are higher than the standard limit of the ISIRIin 41.29% of the studied wells. Also, the amount of those parametersfall

1.Electrical conductivity
2.Total Dissolved Solids

within the desired level of the ISIRI standard

3.1. Altitudedistribution of the studied wells

The altitude of the study area varies from 1581 to 3529 meters.The sample wells are located at an altitude of 1660 to 2044 meters (figure 2).In this regard, "W1, W2, W3, W7, W18, W21, W22, W24, W30, and W34" wells in which the amount of EC, Mg, Ca, TDS, So4, Cl, and Na parameters are higher than the standard of the ISIRI,are located in parts of the aquifer that are of lower altitude.

in 52.23% of the wells.

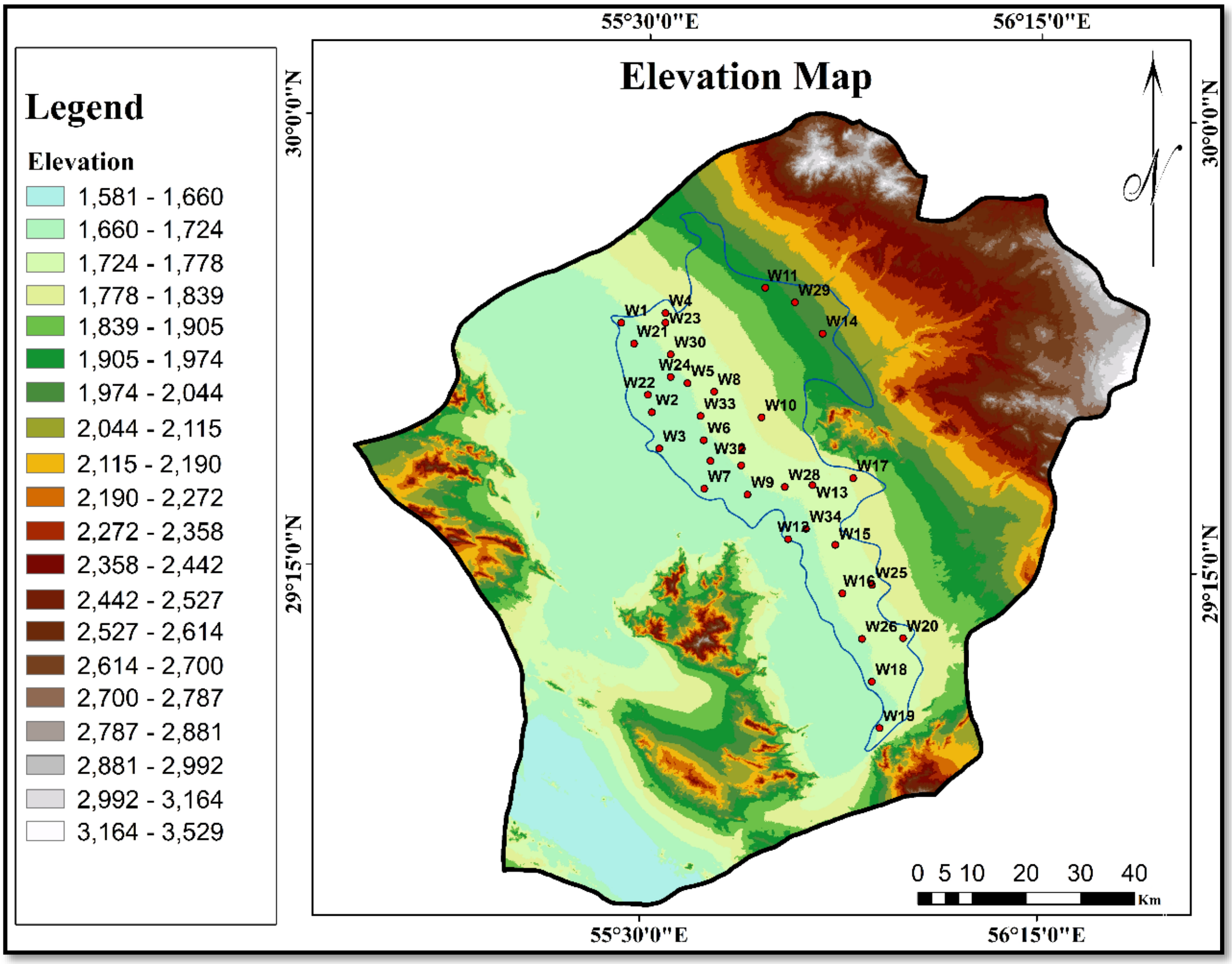


Figure (2):Altitude distribution of the studied wells

3.2. Geology of the studied wells

According to the geological map of the study area, the main geological formations in the area are alluvial sediments.EC, Mg, Ca, TDS, and Na parameters are higher in wells "W1, W2, W3, W7, W21, W22, W24, W30, and W34"than the standard permitted by the ISIRI. The wells mentioned aboveare located in fine-grained sediments near Sirjanplaya.

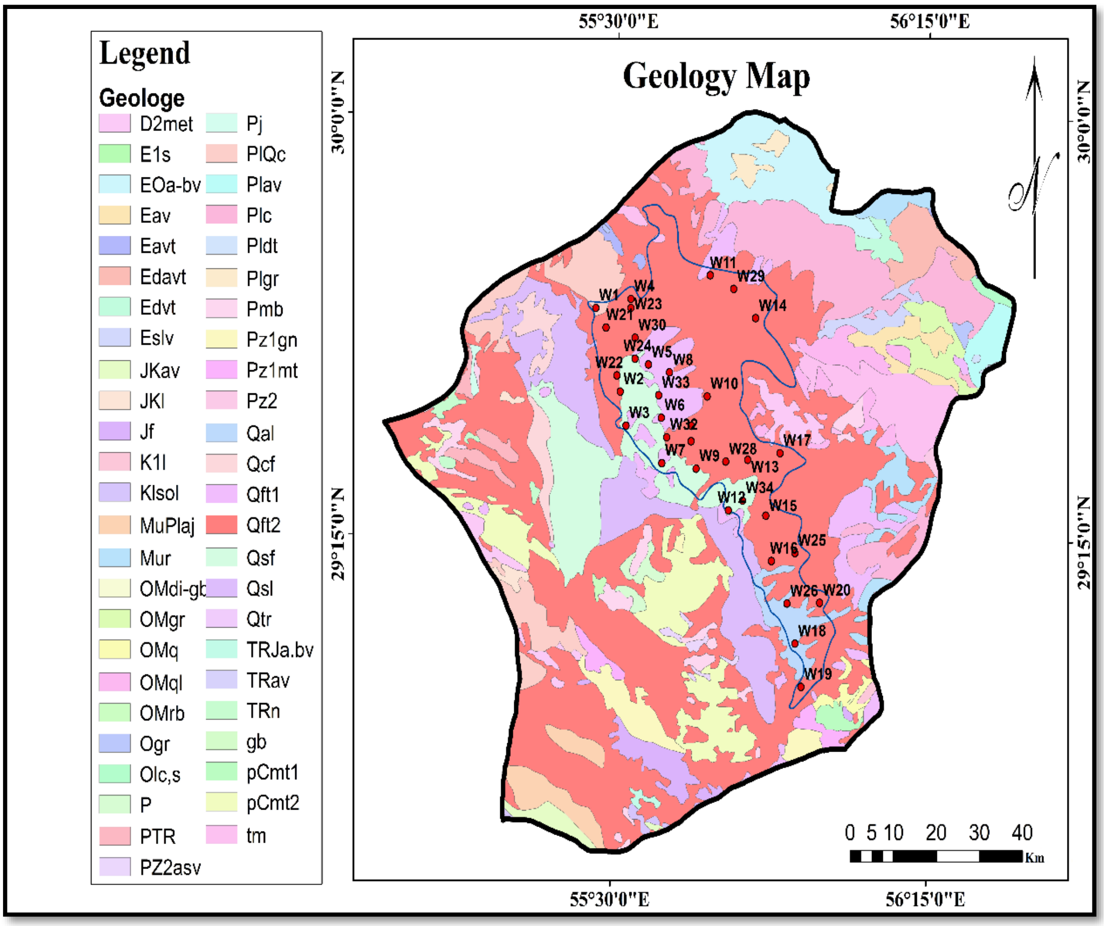


Figure (3):Geology of the studied wells

Table (4):Geological units of the study area

GEO_UNIT	DESCRIPTIO
D2met	Alternation of marble, micaschist, amphibolite and quartzite
E1s	Sandstone, conglomerate, marl and sandy limestone
Eav	Andesitic volcanics
Eavt	Andesitic volcanic tuff
Edavt	Dacitic andesitic volcanic tuff
Edvt	Rhyolitic to rhyodacitic volcanic tuff
EOa-bv	Andesitic to basaltic volcanic
Eslv	Red shale, pelagic limestone and amigdaloidal basic volcanic rocks
gb	Layered and isotropic gabbro
Jf	Flyschturbidites sandstone, shale, conglomerate, volcanic rocks and limestone ; this unit transgresivly overlies the metamorphic rocks
JKav	Andesitic flows and their associated pyroclastics with or without intercalations of limestone
JKl	Crystalized limestone and calc- schist
K1l	Massive to thick - bedded orbitolina limestone
Klsol	Grey thick - bedded to massive orbitolina limestone
MuPlaj	Brown to grey, calcareous, feature-forming sandstone and low weathering,

	gypsum- veined, red marl and siltstone (AGHAJARI FM)
Mur	Red marl, gypsiferous marl, sandstone and conglomerate (Upper red Fm.)
Ogr	Granite
Olc,s	Conglomerate and sandstone
OMdi-gb	Diorite to gabbro
OMgr	Oligo - Miocene granite and granodiorite
OMq	Limestone, marl, gypsiferous marl, sandymarl and sandstone (QOM FM)
OMql	Massive to thick - bedded reefal limestone
OMrb	Red Beds composed of red conglomerate, sandstone, marl, gypsiferous marl and gypsum
P	Undifferentiated Permian rocks
pCmt1	Meddium - grade, regional metamorphic rocks (Amphibolite Facies)
pCmt2	Low - grade, regional metamorphic rocks (Green Schist Facies)
Pj	Massive to thick - bedded, dark - grey, partly reef type limestone and a thick yellow dolomite band in the upper part (JAMAL FOR)
Plav	Andesitic lavas with minor basaltic andesite, tuff and brecciasinterbedded with volcanoclastic sandstone and boulder conglomerate (Bazman Volcanism)
Plc	Polymictic conglomerate and sandstone
Pldt	Rhyolitic to rhyodacitic tuff
Plgr	Granite
PlQc	Fluvial conglomerate, Piedmont conglomerate and sandstone.
Pmb	Marble
PTR	Undifferentiated Permo - Triassic sedimentary rocks
Pz1gn	Gneiss and anatectic granite
Pz1mt	Gneiss, anatectic granite, amphibolite, kyanite, staurolite schist, quartzite and minor marble (BarrehKoshan Complex and Rutchan Complex)
Pz2	Undifferentiated Upper Paleozoic rocks
PZ2asv	Andesitic subvolcanic
Qal	Stream channel, braided channel and flood plain deposites
Qcf	Clay flat
Qft1	High level piedmont fan and vally terrace deposits
Qft2	Low level piedment fan and vally terrace deposits
Qsf	Salt flat
Qsl	salt lake
Qtr	Teravertine
tm	Tectonic melange - association of ophiolitic components, pelagic limestone, radiolarian chert and shale with or without Eocene sedimentary rocks
TRav	Andesitic Volcanic
TRJa.bv	Andesitic to Basaltic Volcanic
TRn	Sandstone, quartz arenite, shale and fossiliferous limestone (NAIBAND FOR)

3.3. Investigating the water quality of the studied wells for drinking purposes (Schuler)

The Schuler diagram classifies water quality into good, acceptable, average, inappropriate, completely inappropriate, and non-potable. In general, according to the results of the Schuler diagram, about 47% of the studied wells are of good to medium quality in terms of drinkingpurposes. Figure 4 shows the Schuler diagram of the studied wells.

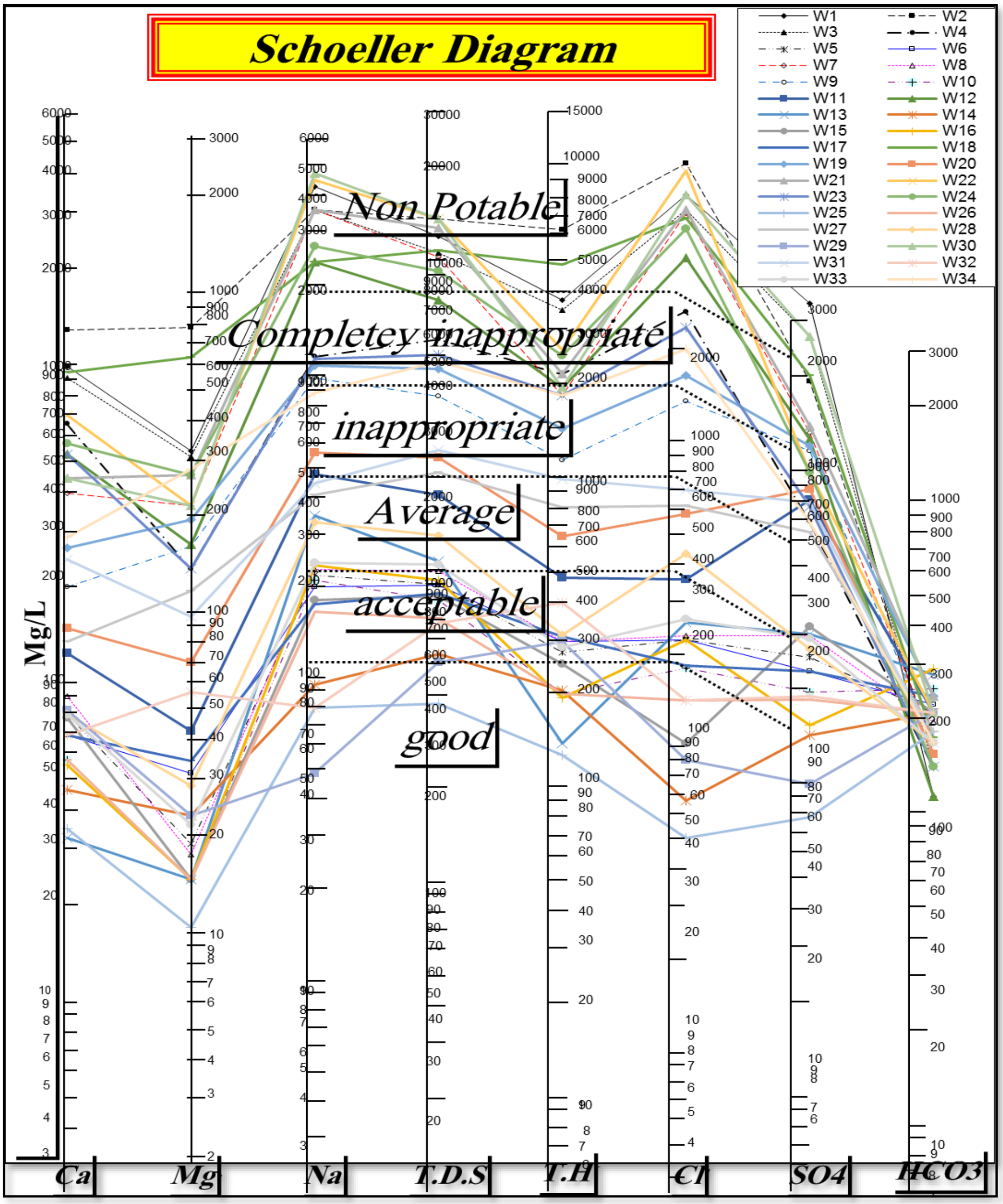


Figure (4): The Schuler diagram of the studied wells

3.4. Classification map of Sulfate, Chlorine, Sodium, and TDS parameters using Schuler method

According to the results obtained from the Schuler method for the studied wells, the classification map of each effective parameter in the Schuler method was prepared using the criteria specified in Table 1. According to the results presented in Figure 5, the concentration of Sulfate, Chlorine, Sodium, and TDS increases as we move from the northeast and east of the aquifer to its northwest and west and from the southeast to the south of the aquifer.Figure 5 shows the classification map of Sulfate, Chlorine, Sodium, and TDS parameters.

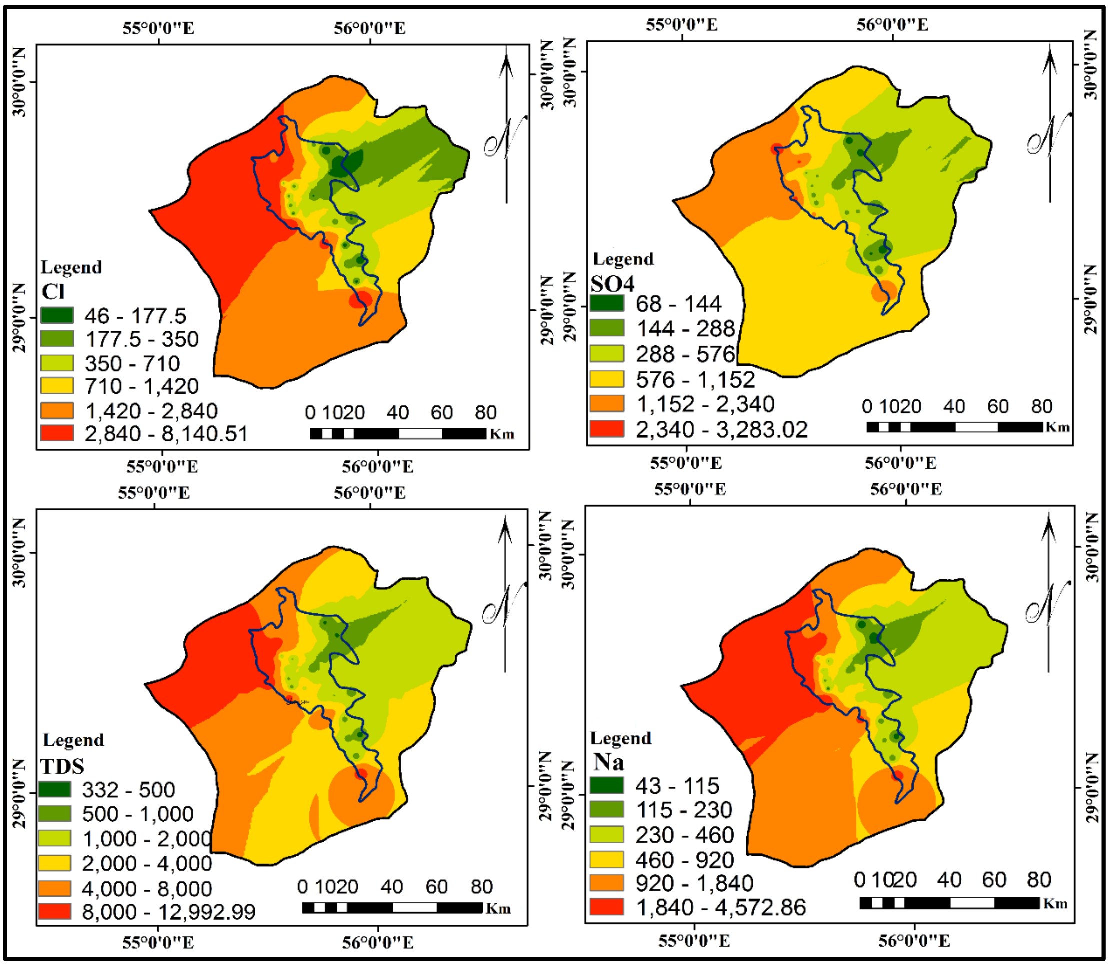


Figure (5): Classification map of Sulfate, Chlorine, Sodium, and TDS parameters using Schuler method

3.5. Classification map of Total Hardness parameters (TH) using Schuler method

According to Figure 6, the concentration of the total hardness parameter increases as we move from northeast and east of the aquifer to northwest and west of the aquifer and from the southeast to the south of the aquifer. Figure 6 shows the classification map of the total hardness parameter.

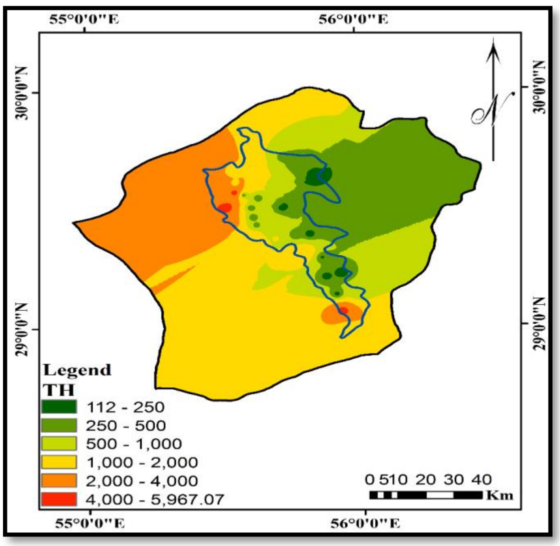


Figure (6): Classification map of TH parameter using Schuler method

3.6. Quality classification map of Sirjan plain's groundwater resources used for drinking purposes (Schuler)

According to Figure 7, the quality of Sirjanplain's groundwater resources for drinking purposes is classified into six classes: good, acceptable, average, inappropriate, completely inappropriate, and non-potable. Table 5 shows the area of each of these classes at the Sirjanaquifer. According to Figure 7, the quality of groundwater resources decreases as we move from the northeast and east of the aquifer to the northwest and west of the aquifer and from the southeast to the south of the aquifer. In this regard, the study's results conducted by Fathi and Rahnama (2019) indicated that the quality of groundwater resources in the western parts of Sirjan plain was lower than in other parts, which are consistent with the results found in the present study. Figure 7 shows the quality classification map of Sirjan plain's groundwater resources used for drinking purposes.

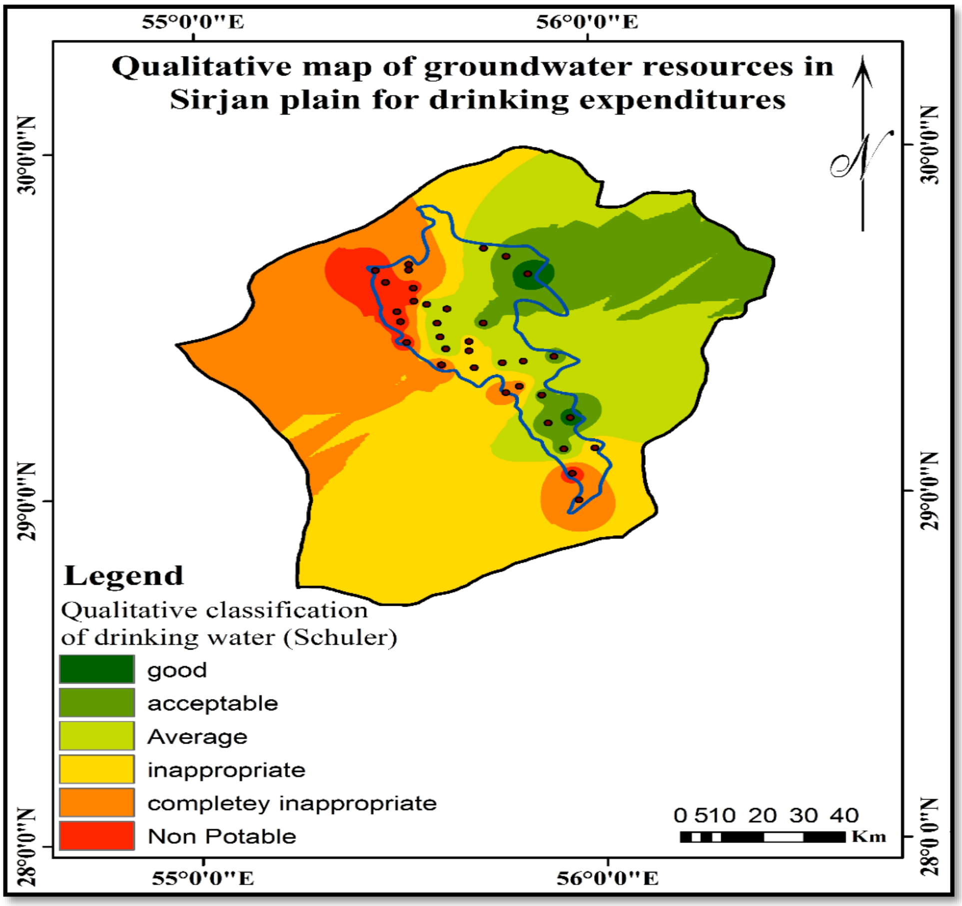


Figure (7):Quality classification map of Sirjan plain's groundwater resources used for drinking purposes

Table (5): Area of each groundwater quality classused for drinking purposes

Quality classification of drinking water (Schuler)	Area (Km^2)	Area (%)
good	77/27	3/84
acceptable	400/99	19/96
average	659/47	32/81
inappropriate	413/58	20/58
completely inappropriate	267/10	13/29
non-potable	191/29	9/52

3.7. Assessing the studied wells'water quality for agricultural purposes (Wilcox)

The Wilcox diagram classifies the water quality as very good (C1-S1), good (C1- S2, C2-S1, C2-S2), average (C3-S1, C3-S2, C1-S3, C3-S3), and inappropriate classes. According to the results of the Wilcox diagram, 8.82% of the studied wells fell in the good class, 38.23% of the wells were in the average class,and 52.94% of the wells were in the inappropriate class. Figure 8 shows the Wilcox diagram for the studied wells.

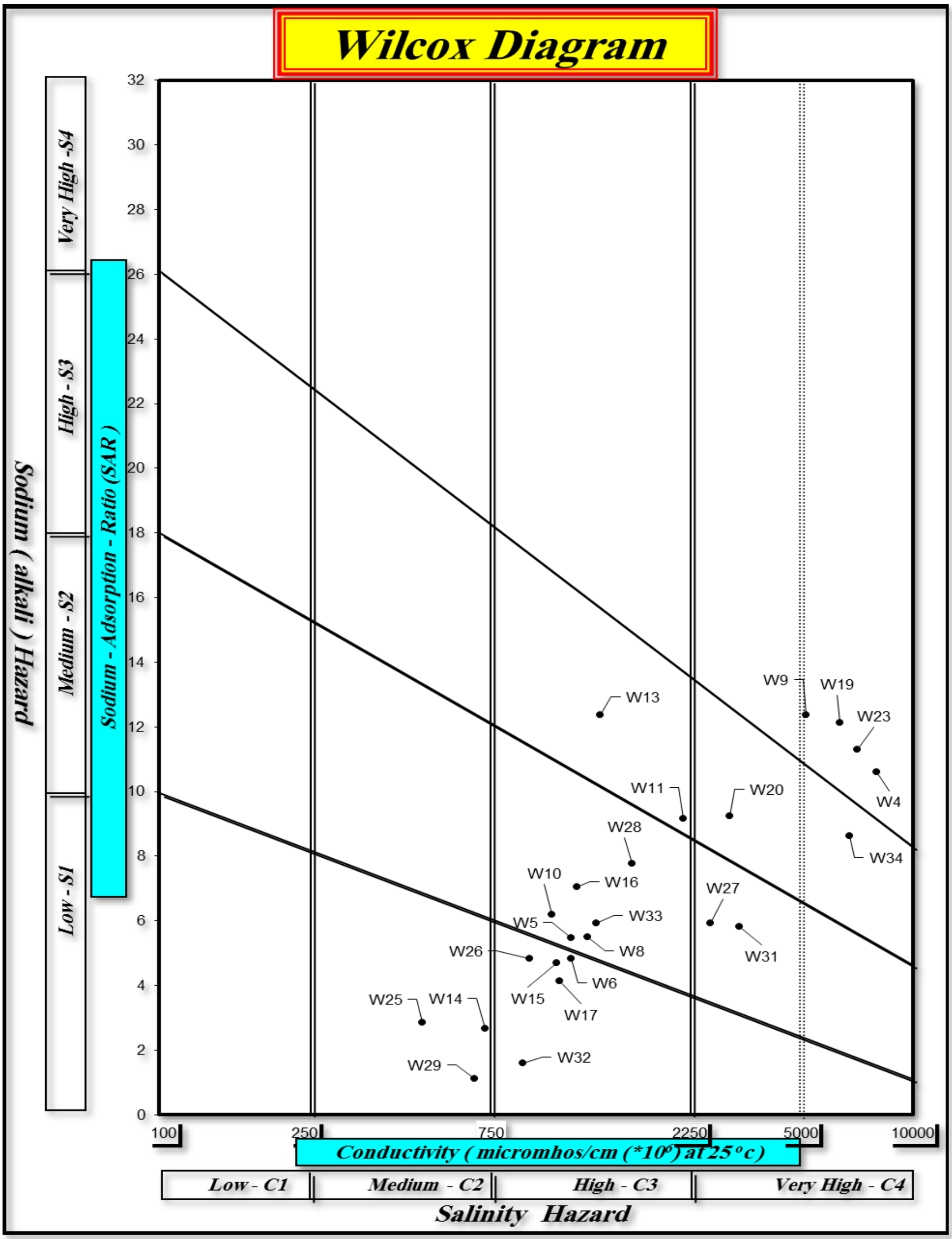


Figure (8): The Wilcox diagram of the studied wells

3.8. Classification map of electrical conductivity (EC) and sodium absorption ratio (SAR) parameters

According to the results obtained from the Wilcox method for the studied wells, the classification map of electrical conductivity and sodium adsorption ratio parameters was prepared using the criteria specified in Table 2. The amount of electrical conductivity and sodium parameters increasesas we move from the northeast and east of the aquifer to the northwest, west, and south of it. Figure9 shows the classification map of the electrical conductivity and the sodium adsorption ratio parameters.

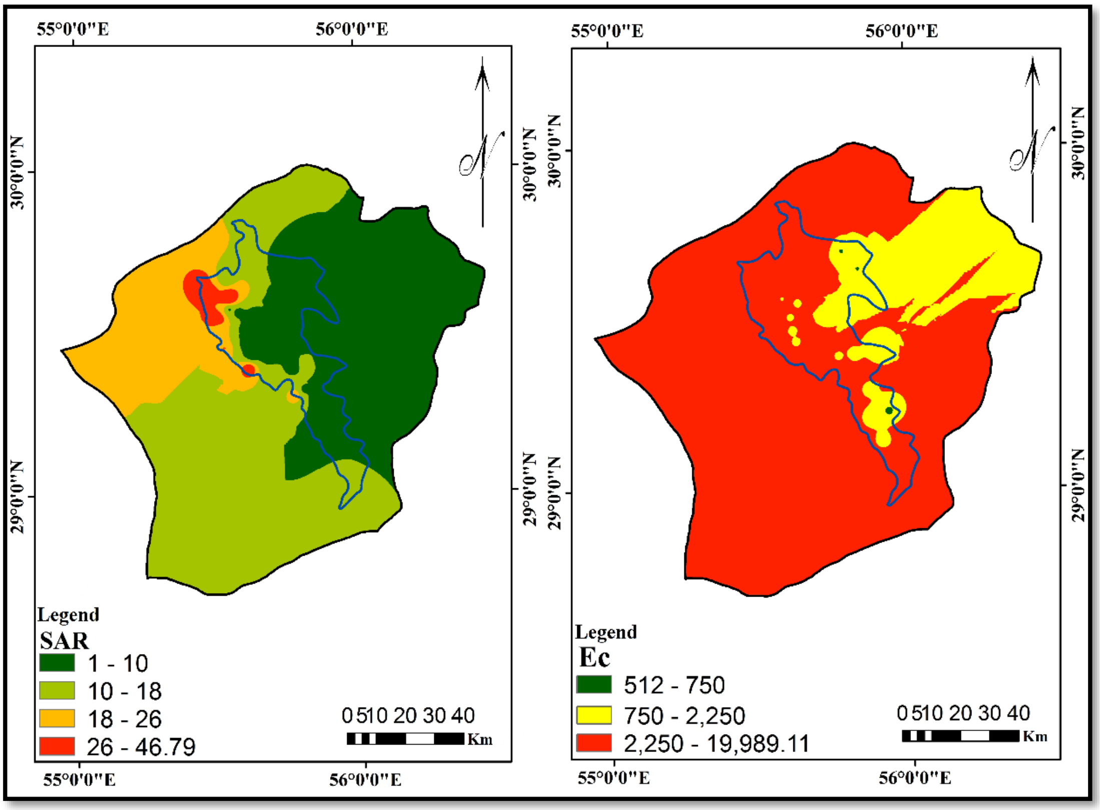


Figure (9): Classification map of electrical conductivity and sodium adsorption ratio parameters using Wilcox

3.9. Quality classification map of groundwater resources in Sirjan plain for agricultural purposes (Wilcox)

According to Figure 10, the quality ofSirjan plain's groundwater resources used for agricultural purposes is divided into three classes:good, average, and inappropriate. Table 6 shows the area of each of these classesin the Sirjanaquifer. According to Figure 10, the quality of groundwater resources decreases as we move from the northeast and east of the aquifer to the northwest and west of the aquifer and from the southeast to the south of the aquifer. In this regard, the results of EbrahimiMoghadam and Abbasnejad's (2020) study showed that the Sirjan plain's groundwater resources used for agricultural purposes were often categorized within the group of saline and very saline water (C3, C4). According to the groundwater quality map for agricultural purposes, in this study, 39% of the aquifer area is of poor quality.

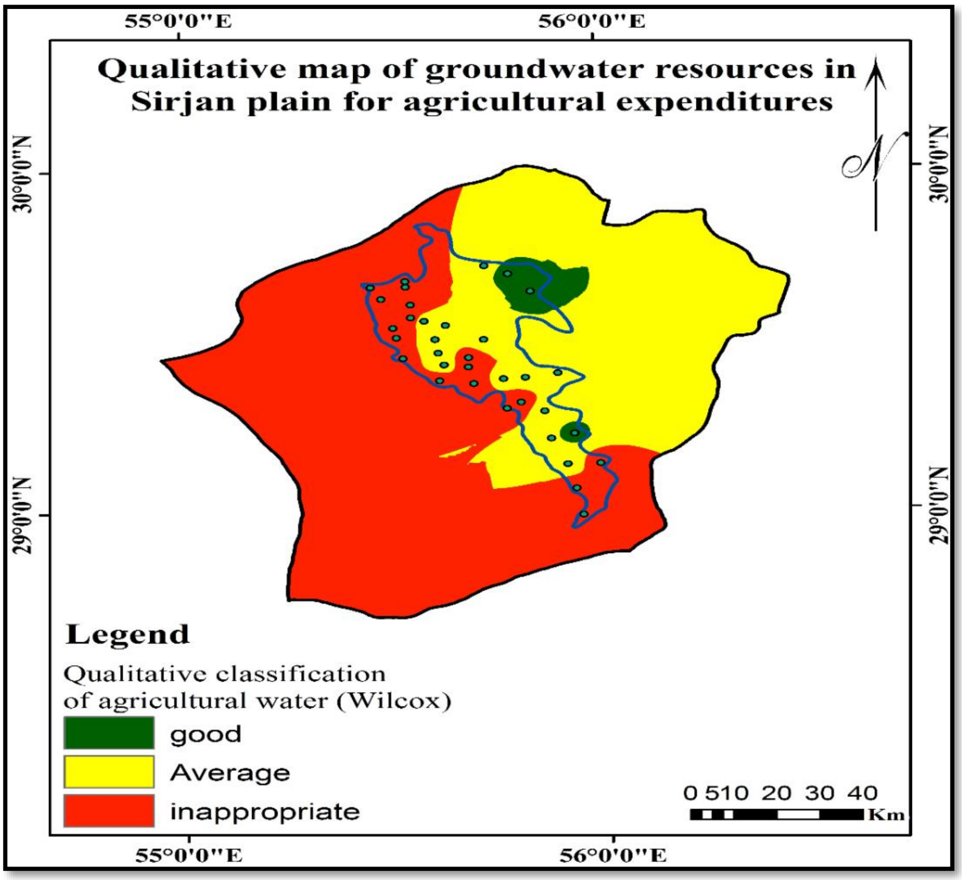


Figure (10):Quality classification map of Sirjan plain's groundwater resources used for agricultural purposes

Table (6): Area of each groundwater quality classused for agricultural purposes

Quality classification of agricultural water (Wilcox)	Area (Km^2)	Area (%)
good	192/70	9/59
Average	1015/83	50/54
inappropriate	801/18	39/87

4. Conclusion

The special climatic and geomorphological conditions of arid and semi-arid regions have made groundwater resources the primary source of water supply in such areas. Accordingly, managing these water resources requires an accurate assessment of the quantity and quality of those resources, the extent of access to them in each region, and knowledge of environmental processes governing them. Accordingly, this study sought to evaluate and analyze the chemical quality of groundwater resources in SirjanPlain using Schuler and Wilcox diagrams and Geographic Information System software. In this regard, the results showed that based on the Schuler diagram, about half of the studied wells were of good to medium quality in terms of drinking purposes.

According to the quality classification map of groundwater resources used for drinking purposes, the quality of groundwater resources in Sirjan plain is classified into six classes: good, acceptable, average, inappropriate, completely inappropriate, and non-potable. The moderateclass with 32.81% of the aquifer area and the good class with 3.84% of the aquifer area make the highest and lowest portion of the aquifer, respectively. Moreover, according to the results of the Wilcox diagram, 47% of the wells are in the good and average range, and 52.94% of the wells are in the inappropriate range of this diagram.

According to the quality classification map of groundwater resources used for agricultural purposes, the quality of groundwater resources in Sirjan plain is classified into three classes:good, average, and unsuitable. The moderate class with 50.54% of the aquifer area and the good classwith a 9.59% portion of the area make the maximum and minimum portion of the aquifer respectively. In general, the results of assessing the quality of Sirjan plain's groundwater resources used for drinking and agricultural purposes show that the quality of groundwater resources decreases as we move from the northeast and east of the aquifer to the northwest and west of the aquifer, and from the southeast to the south of the aquifer.

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