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Water quality assessment and zoning analysis of Dez eastern aquifer by Schuler and Wilcox diagrams and GIS

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ABSTRACT

Groundwater is an important water source for drinking water and agricultural and industrial uses in the Dez area, Iran. The purpose of this study was the assessment and analysis of Dez eastern water quality for drinking and agricultural uses by Schuler and Wilcox diagrams and zoning water quality in geographic information system (GIS) environment. Data were taken through samplings from water wells in this area. Dez plain is located in the northeastern province of Khouzestan and is between the Dez river and Glala Kohnak. Twenty wells were selected for sampling according to Thiessen polygon method in a GIS environment, and the water quality of samples was analyzed, using physical and chemical parameters. To facilitate the analysis, entering data was done in environmental GIS, using Kriging interpolation method. Results showed that the quality of drinking water based on the Schuler diagram is good and acceptable. According to Wilcox diagram, water quality was a little salty but suitable for agricultural uses. information obtained using GIS maps for water quality assessment, could enhance speed and accuracy of water quality management in this area, whereas the water quality database can be updated easily.

Keywords: Water quality; Groundwater; Schuler diagram; Wilcox diagram; GIS

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1. Introduction

Groundwater is the main and vital source for drinking water and agricultural and industrial uses in the research area [1–8]. Only a small portion (less than 3%) of the Earth's freshwater and about 68% of the freshwater is groundwater; therefore, permanent monitoring of underground aquifers is necessary [9–11]. Water quality analysis is one of the important issues in groundwater studies [12–16]. Variation of groundwater quality in area is a function of physical and chemical parameters [17,18]. Many factors and their interactions affect the groundwater chemistry, including general geology, mineralogy of the watersheds, rock types and quality of recharge water, hydro-geological conditions, evaporation, hydro-chemical processes, lithology, precipitation, and human activities [19–25]. Most human activities such as agriculture, food production, industry, nutrition, and housekeeping are dependent on sufficient and proper quality water [26,27]. During recent years, several studies were conducted to evaluate water quality for drinking and agricultural uses by Schuler and Wilcox diagrams and zoning information in geographic information system (GIS) in different parts of the world [28,29]. GIS as a powerful tool could manage large volumes of spatially distributed data from a variety of sources. It efficiently stores, retrieves, analyzes, and displays information according to user-defined specifications [30].

In a study in Isfahan province, Zayandehrud river basin water quality is classified for drinking, and agricultural and industrial uses based on the Schuler and Wilcox diagrams [10]. Another study has shown associations between water quality regarding qualitative and quantitative evaluation of groundwater with Schuler and Wilcox diagram [28]. In a similar work, the groundwater quality was assessed in Haraz alluvial fan, Iran, by Schuler and Wilcox diagrams [31]. Shams et al. considered water quality zoning based on water quality index and Wilcox index, using geographic information system in Khorramrood river [32]. Required water for all cities, villages, and agricultural activities in the study area is supplied by the underground resources, in addition along with over withdrawing from water wells, this area encountered with the phenomenon of drought in recent years; therefore, the investigation of this trend is important for water quality management in the future. The aim of this study was the quality assessment and analysis of Dez eastern water aquifer for drinking and agricultural uses by Schuler and Wilcox diagrams and zoning information in GIS environment.

2. Materials and methods

Using the Arc GIS software and Thiessen polygon method, 20 wells were selected for sampling [10]. Samples were collected from the selected stations according to standard methods (21_{ed}) during 2014 [10,32]. Factors affecting the quality of samples include equipment, sample sizes, pollution, transfer, and transportation to the laboratory under standard conditions. The parameters were tested according to standard methods [32]. Then, the Schuler and Wilcox diagrams were drawn by the CAD software. In the next stage, the data entered to GIS environment and the necessary layers were prepared by Kriging interpolation method. Location of the water wells in the study area, with networking Thiessen polygons is shown in Fig. 1.

2.1. Geographical features of study area

Dez–Andimeshk Plain with an area of over 2,279 km^2 is the largest plain in the catchment of Dez which is located between 47 and 48˚ 29′ east of Greenwich meridian and between 33 and 36 min to the north of the equator [33] (Fig. 2). The population of the district is 357,294 people of which 263,275 people live in the city and 94,019 people live in towns and villages. Dez eastern plain is located in a dry area of Iran with a hot and semi-arid climate, and its average yearly rainfall is about 321 mm, with an average height of 32 meters above sea level [34,35]. Annual potential evaporation is 1,500 mm. This plain is divided into five non-confined aquifer: Sabiri, Lor, Dez western, Dez eastern, and Daymche (Fig. 2). Dez eastern plain with approximately 680 km^2 is confined from north to Shirinab taghdis and Sabiri plain and from east to Kohnak River and from south and west to Dez river.

Northern parts of Dez eastern plain are formed by alluvial deposits with depths of 100–150 meters with coarse destruction conglomerate. It is not that thick (less than 60 m) in the sediment despite the presence of rubble and sand. In the east of study area, the aggregation of alluvial plain dose is appropriate, and Bakhtiari conglomerate is the result of erosion and chemical condition of the freshwater and is suitable for general southern and eastern parts of the marginal dose plain with clayey sediments that have been confirmed by geophysical studies. The areas with high groundwater levels and poor chemical quality are weaker than discharge from previous areas [1,36]. There are 164 wells in the study area. Sixty-three of them are used for agriculture, 55 for urban and rural water supply, and 46 for industrial uses.

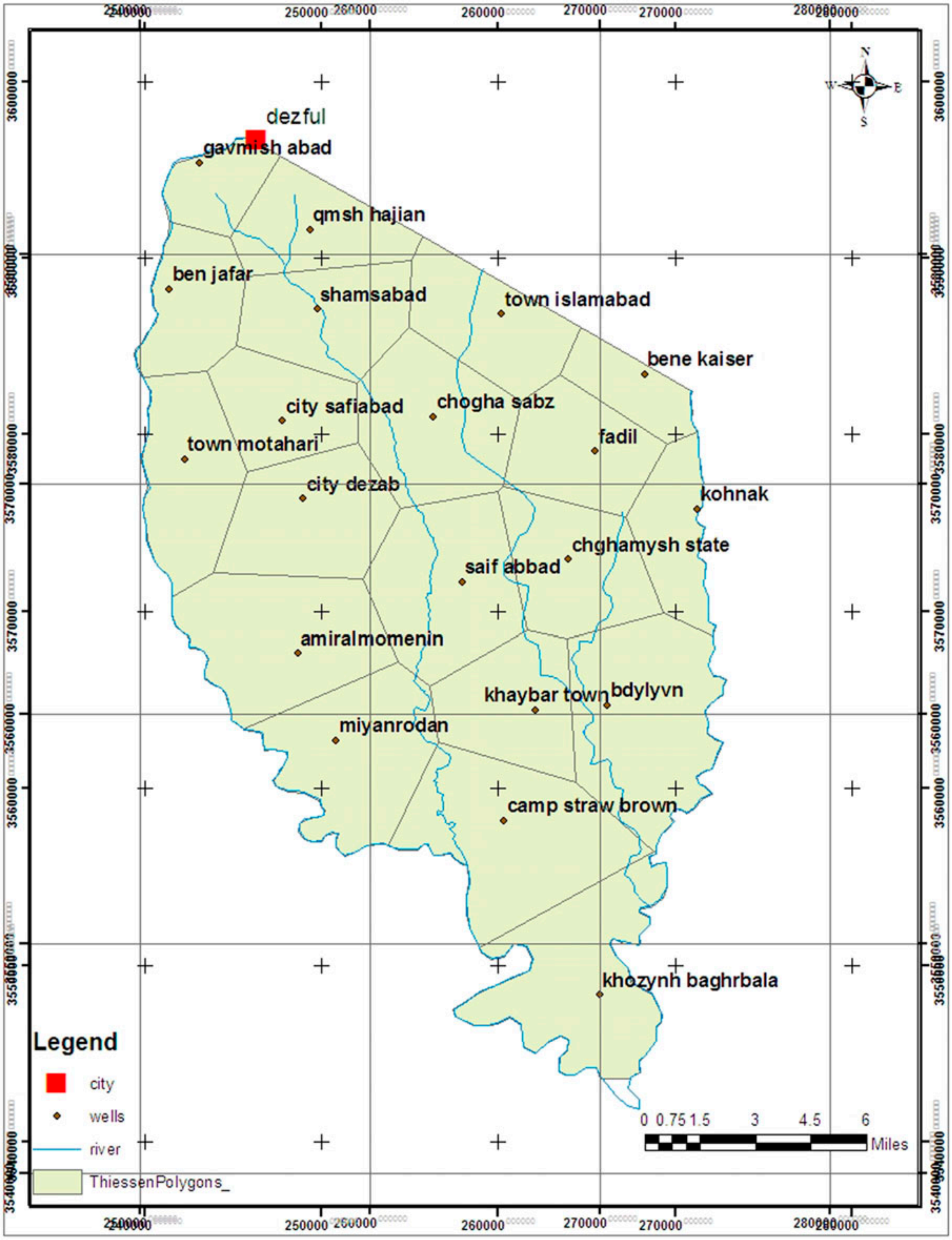

Fig. 1. Location of the water wells in the study area, with networking Thiessen polygons.

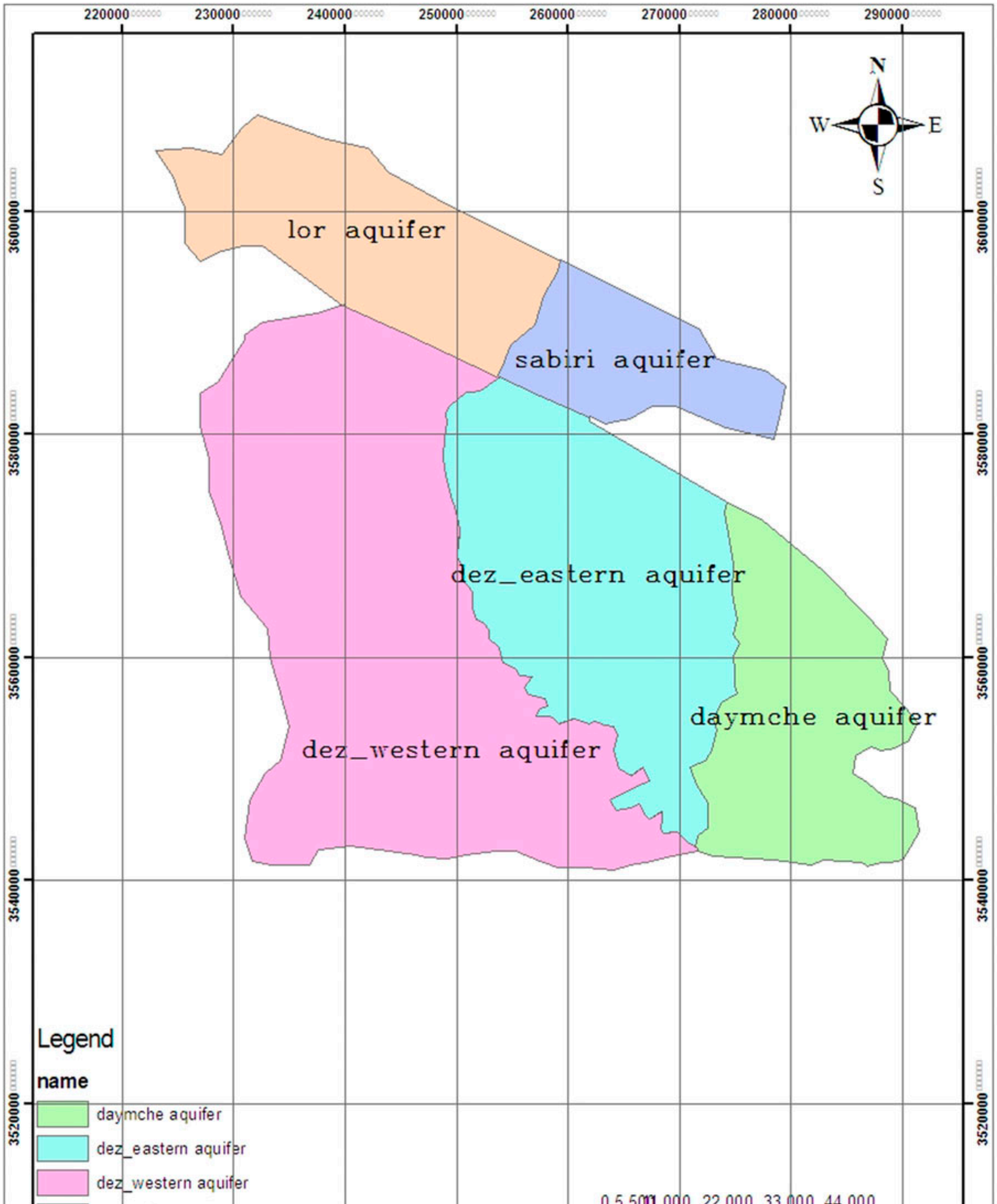

Fig. 2. Location of study area and geological map of the study area.

Table 1
Classification criteria for the drinking water according to Schuler classification (mg/l)

Class	Water quality	SO_4 (mg/l)	Cl (mg/l)	Na (mg/l)	TH (mg/l)	TDS (mg/l)
1	Good	145<	175<	115<	250<	500<
2	Acceptable	145–280	175–350	115–230	250–500	500–1,000
3	Inappropriate	280–580	350–700	230–460	500–1,000	1,000–2000
4	Bad	580–1,150	700–1,400	460–920	1,000–2000	2000–4,000
5	Can be consumed in emergency situations	1,150–2,240	1,400–2,800	920–1840	2000–4,000	4,000–8,000
6	Non-drinkable	2,240>	2,800>	1840>	4,000>	8,000>

Table 2
Schuler classification of the wells in the study area for drinking

Situation water wells	Class					
	Na	Cl	SO_4	TDS	TH	Water class
Ben Ja'far	1	1	1	1	1	1
Shamsabad	1	1	1	1	2	2
Qomesh Hajian	1	1	1	1	2	2
Sayfabad	1	1	1	1	2	2
Motahari	1	1	1	1	1	1
Dzab	1	1	1	1	1	1
Eslamabad	2	1	1	2	2	2
Choghasabz	1	1	1	2	2	2
Bene Kaysar	3	3	3	4	4	4
Kohnak	3	3	2	3	3	3
Fozali	2	2	2	3	2	3
Choghamish	2	1	2	2	2	2
Safiabad	1	1	1	2	2	2
Nayboran	1	1	1	2	2	2
Amiral Momenin	1	1	1	1	2	2
Miyanrodan	1	1	1	2	2	2
Gavmishabad	1	1	1	1	1	1
Khaybar	1	1	1	2	2	2
Amir	2	2	2	3	3	3
Badilian	2	2	1	2	2	2

Table 3
Water classification for agricultural uses according to Wilcox classification

Class	Water quality for agriculture
C1S1	Sweet—completely ineffective for agriculture
C1S2-C2S2-C2S1	Brackish—approximate perfect for agriculture
C1S3-C2S3-C3S1-C3S2-C3S3	Passion—usable for agriculture
C4S4-C4S1-C1S4-C2S4-C3S4–4S4-C4S3	Very passion—harmful to agriculture

2.2. Water analysis

Before the analysis of water quality data, the degree of accuracy and the accuracy of chemical data is determined by calculating ionic charge balance error (Response Error: RE), using the following equation:

$$RE = \frac{\sum \text{Cations} - \sum \text{Anions}}{\sum (\text{Anions} + \text{Cations})} \times 100 \quad (1)$$

If this value is greater than 5%, data reliability will be questionable. Schuler and Wilcox diagrams are used

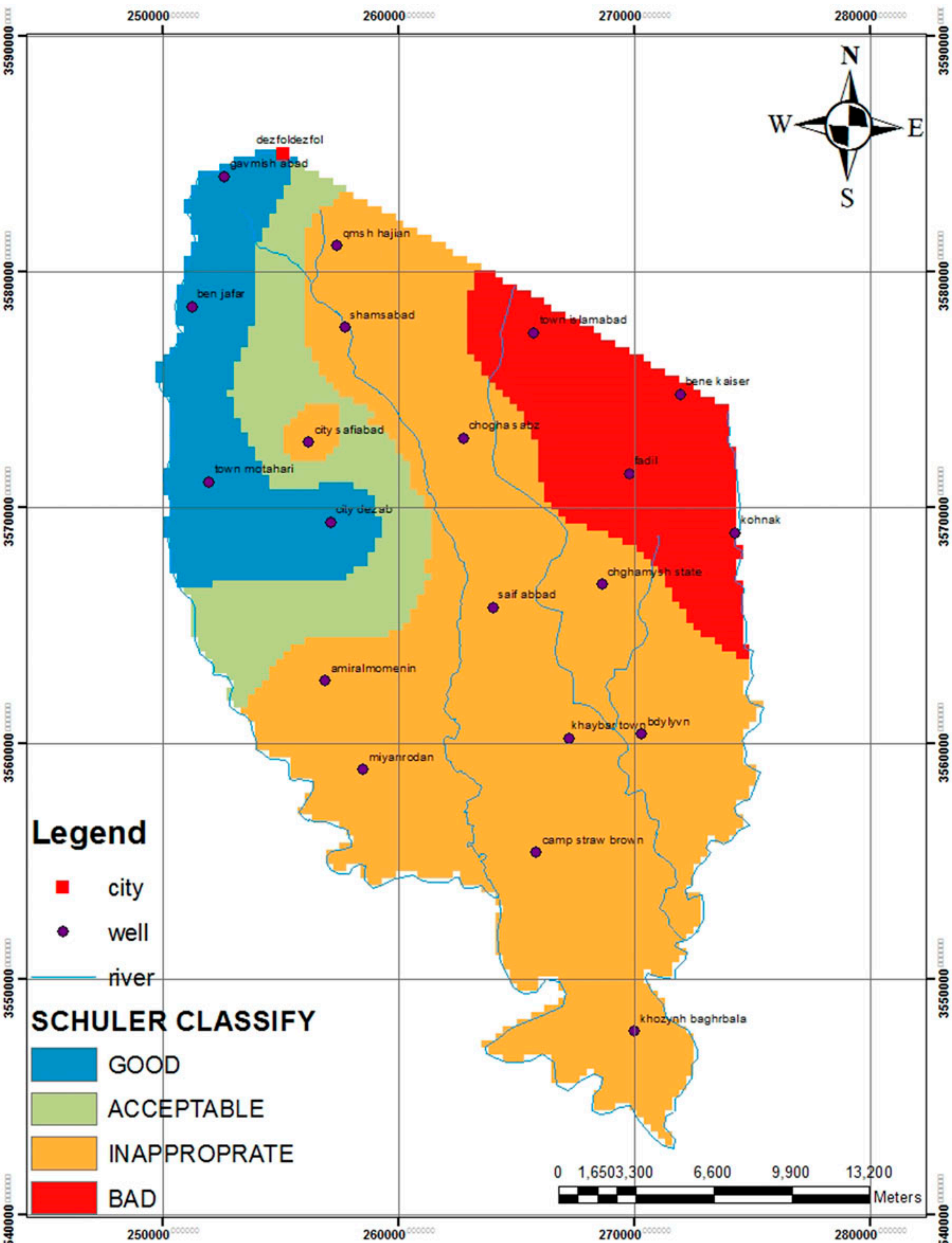

Fig. 3. Map of water classification based on Schuler diagram for drinking in the study area.

Table 4
SAR and EC values of groundwater resources and qualitative classification Dez eastern aquifer stations for agriculture uses based on Wilcox diagram

Number of wells	Situation water wells	Parameters		
		EC	SAR	Classification
1	Ben Ja'far	605	0.9	C2S1
2	Shamsabad	829	1	C3S1
3	Qomesh Hajian	750	1.2	C3S1
4	Sayfabad	785	0.9	C2S1
5	Motahari	589	0.9	C2S1
6	Dzab	733	3.5	C2S1
7	Eslamabad	1,475	3.3	C3S1
8	Choghasabz	924	2.9	C3S1
9	Bene Kaysar	4,000	3.6	C4S2
10	Kohnak	2,795	4.9	C4S2
11	Fozali	2,328	6.5	C4S2
12	Choghamish	1,440	4.6	C3S1
13	Safiabad	922	1.9	C3S1
14	Nayboran	935	2.6	C3S1
15	Amiral Momenin	683	1.2	C2S1
16	Miyanrodan	878	1.5	C3S1
17	Gavmishabad	641	1.7	C2S1
18	Khaybar	1985	6.6	C3S2
19	Amir	2,810	6.6	C3S2
20	Badilian	1,530	5	C3S2

for the classification of basin water quality (Table 1). The following is a brief description of them.

2.2.1. Schuler diagram

Schuler diagram is used to show the total hardness of water resources and total dry residue base on meq/L. It is used for the classification of drinking water. The main groups in the classification of drinking water are good, acceptable, average, inappropriate, quite undesirable, and non-potable (Table 2).

2.2.2. Wilcox diagram

Wilcox in 1948 and Torn in 1951 proposed and completed this index, and nowadays, it is commonly used for the classification of waters in agriculture. The main factors in this index are sodium adsorption ratio (SAR) and electrical conductivity (EC) (Table 3). The horizontal axis in Wilcox diagram shows salinity of water (as micromohs/cm), and the vertical axis shows the SAR. Wilcox diagram using parameters including salinity and sodium adsorption ratio is used to evaluate the water for agriculture uses. Salinity is measured by EC and SAR. SAR is calculated by the following equation.

$$\mathrm{SAR} = \frac{\mathrm{Na}}{\sqrt{\frac{\mathrm{Ca}+\mathrm{Mg}}{2}}} \quad (2)$$

Concentrations of cations in the above equation are as milli-equivalent.

3. Results and discussion

Studies on the suitability of groundwater for drinking water are usually classified based on Schuler diagrams. Schuler diagram values for each of the cations (Na^+, K^+, Mg^{2+}, Ca^{2+}) and anions (SO_4, HCO_3, CO_3, Cl) and water hardness (TH) consider a separate axis. By connecting them with the corresponding points on the axes, the degree of the suitability of water for drinking can be determined. The numbers 1 to 6 are used to assign different categories to each parameter.

The results obtained from 20 sampling stations in the Dez eastern aquifer by Schuler classification are given in Table 2. Based on these results, drinking water quality is good and acceptable in this area. Fig. 3 shows the Schuler diagram classify for the wells in the study area.

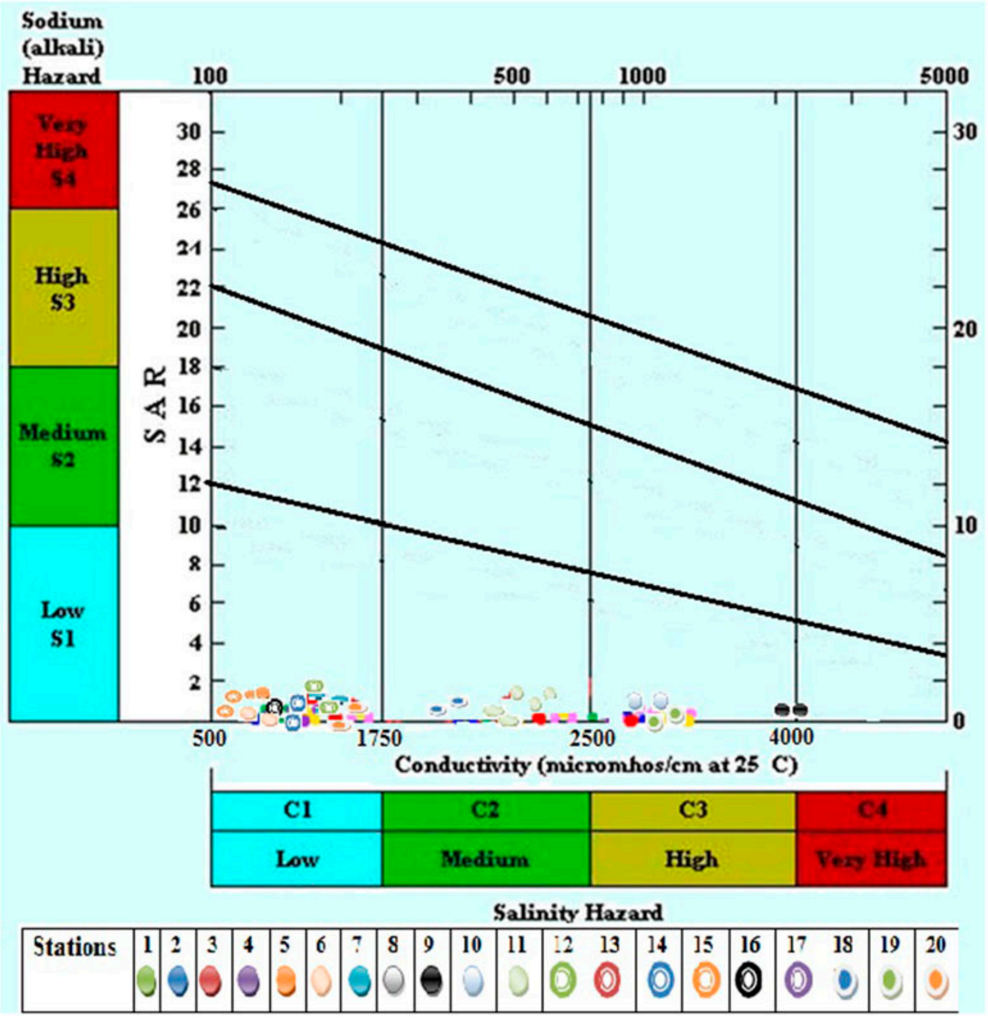

Fig. 4. The classification of the Dez eastern aquifer based on the Wilcox diagram in studied stations.

According to Wilcox diagram, waters are classified to 16 different categories. These categories are divided into four groups. Classification of 16 stations in the Dez eastern aquifer based on Wilcox diagram is shown in Tables 3 and 4. Figs. 4 and 5 show the Wilcox diagram to classify Dez eastern basin water quality.

According to the maps, the quality of drinking water was divided into four categories as good, acceptable, inappropriate, bad, can be drunk in emergency situations, and non-drinkable. According to the maps, the quality is reduced from the west to the east. Results showed that the best and most desirable water quality is related to Ben Ja'far, Motahari, and Gavmishabad. According to Schuler diagrams, they have good quality. Shamsabad, Qomesh Hajian, Eslamabad, Choghasabz, Sayfabad, Nayboran, Amir-alMomenin, Miyanrodan, Khaybar, and Badilian wells have an acceptable water quality which indicates that in most areas of the study, the water for drinking is acceptable. The quality of Kohnak and Fozali water wells is poor because they are located in the northeast region, and this area is known as salty formations. Bene Kaysar well has been the lowest quality because it is located in the northeastern region. The most important agricultural water quality parameters are EC and SAR. According to the Wilcox diagram, groundwaters have 5 classes: C1S1, C2S1, C3S1, C3S2, and C4S2 where the quality is reduced from the west to the east. Also, according to the results, Ben Ja'far, Sayfabad, Motahari, Dezab, Amiral Momenin, and Gavmishabad had the best water quality for agricultural purposes. They are categorized as C2S1 with medium salinity and low hazard sodium. These wells are located in the west and northwest, which indicates that these wells fed with high-quality water of Dez

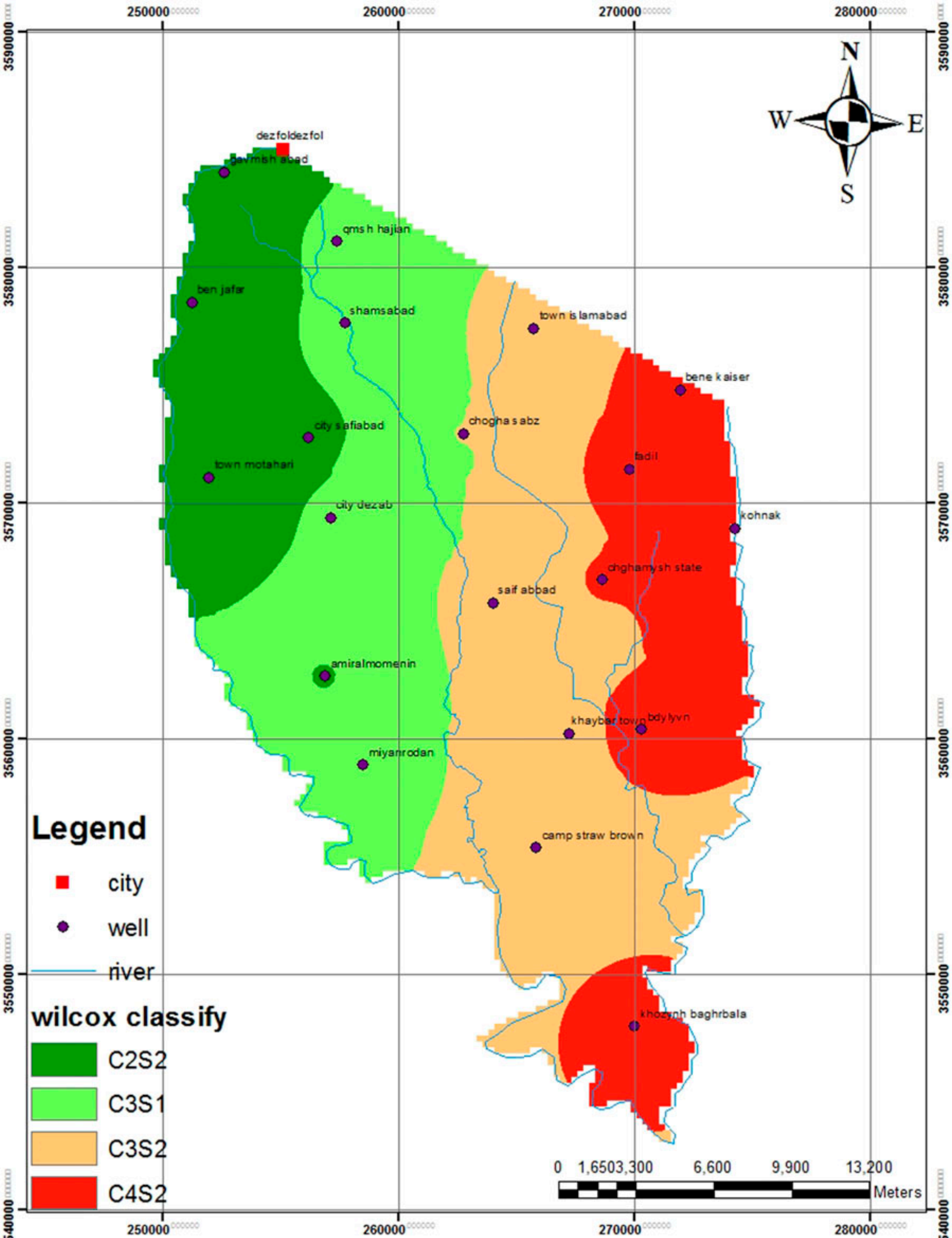

Fig. 5. Map of study area groundwater classification for agricultural purposes based on the Wilcox diagram.

river water. Wells of Shamsabad, Qomesh Hajian, Eslamabad, Choghasabz, Safiabad, Nayboran, and Miyanrodan are categorized as C3S1 with high salinity and low hazard sodium. Khaybar and Amir wells were classified as C3S2. These waters are encountered with salinity limitation, and with the necessary measures, they are suitable for agriculture. Wells of Kohnak, Bene Kaysar, and Fozali are classified as C4S2. Because of the risk of very high salinity, they have limitation for agricultural uses. The results of Shams et al. showed that according to the average of WQI, the quality of water was good in the station number one, medium in station number two, and bad in the rest of stations. According to the Wilcox Index, quality of water in third station was medium and in the rest was good [32]. The results of this study based on Wilcox Index showed that the water quality in Dez eastern because of high salinity differed from Khorramrood River. Salarian et al. found that there is an association between classification of river basin in Zayandehrud, Isfahan, Iran, and water quality regarding agriculture, drinking, and industrial usage. Their findings showed that drinking water quality based on the Schuler diagram was good and acceptable, and according to Wilcox diagram, water quality was suitable for agriculture [10]. The results of this study showed that the water quality in Dez eastern is similar to Zayandehrud. In other research, Afzali et al. studied the groundwater quality assessment in Haraz Alluvial fan, Iran. Result of this study showed that based on Schuler diagram, water quality was acceptable with high quality. Also, in their study, Wilcox method showed that all water samples had high quality [31]. The water quality in our study showed that it was relatively similar to the groundwater quality assessment in Haraz Alluvial fan. Maleki and et al. in 2012 conducted a study to find the chemical quality relationship of drinking water. The results of this study show that based on Wilcox diagram classification, water characteristics have a good quality for drinking water [37]. The study of Choramin et al. during 2005 to 2014 indicated that according to Schuler and Wilcox diagrams, water quality of the Bahamanshir river in Iran was inappropriate for agriculture and drinking uses [38]. In 2014, Vali Pour et al. by Wilcox diagram for the groundwater aquifer of Najaf Abad in Isfahan showed that only 66.6 of the samples were suitable for agricultural purposes [28].

4. Conclusions

The water quality for drinking was deteriorated from the west to the east of aquifer in the study area. According to Schuler diagram, the best and most desirable water quality was in Ben Ja'far, Motahari and Gavmishabad. Shamsabad, Qomesh Hajian, Eslamabad, Choghasabz, Sayfabad, Nayboran, Amiral Momenin, Miyanrodan, Khaybar, and Badilian wells had acceptable water quality. High and good water quality in these parts of aquifer related to kind of geological formation in this area and feeding this part of aquifer by the Dez river with high water quality. Quality of Kohnak, Fozali, and Bene Kaysar wells had the lowest quality for drinking because they are located in the northeast region, and this area is known as salty formations. According to the Wilcox diagram groundwater, the water quality was deteriorated from the west to the east. Water wells of Ben Ja'far, Sayfabad, Motahari, Dezab, Amiral Momenin, and Gavmishabad had the best water quality for agricultural purposes. These wells were fed with high-quality river water. Besides, the soil and geological formations in these parts did not affect the water quality. Wells of Shamsabad, Qomesh Hajian, Eslamabad, Choghasabz, Safiabad, Nayboran, and Miyanrodan were categorized as C3S1 with high salinity and low hazard sodium. Khaybar and Amir wells were classified as C3S2. Wells of Kohnak, Bene Kaysar, and Fozali are classified as C4S2. Because of the risk of very high salinity, they have limitation for agricultural consumption. Due to the poor quality of water for agriculture in parts of the northeast and the east regions, it is proposed that crops such as wheat, cotton, alfalfa, and grasses, which are resistant to high salt waters, are to be grown in these areas. Data were managed by GIS in order to increase speed and accuracy data processing and zoning in GIS environment.

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