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Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: Case study of Sistan and Baluchistan province (Iran)

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ABSTRACT
The present study evaluates the groundwater quality for drinking and agricultural purposes and determines physicochemical characteristics of groundwater in the Sistan and Baluchistan province in Iran. In order to investigate the water quality, sampling was done in 654 open dug wells, the chemical parameters were analyzed, and water quality index was determined. In this regard, Langelier saturation index (LSI), Ryznar Stability index (RSI), Puckorius scaling index (PSI), Larson–Skold index (LS), and Aggressiveness index (AI) were considered to determine water suitability for industrial purposes. Finally, the analytical results were taken to generate the numerical spatial distribution of the parameters using the geographic information system (GIS) environment. According to the results, water sources were less corrosive based on AI and PSI, low and light corrosion according to RSI, and corrosion according to the Larsson–Sckold index. The results of the drinking water quality index showed that 1.2% shared extraction wells were classified as excellent, 52.1% as good, 39% as poor, 6% as very poor, and 1.7% as unsuitable for drinking purpose classes. In addition, irrigating water quality index illustrated that 19.9% and 80.1% wells were placed in the “excellent” and “Good” classes, respectively. Also, the quality of water in this study was categorized as brackish.

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irrigation; drinking water; water quality index; hydro-geochemistry; GIS

Introduction

In recent years, stress on the natural resources is increasing due to rapid industrialization and population growth and their conservation is one of the major challenges for mankind. Groundwater is a most vital resource for millions of people for both drinking and irrigation uses (Ghalib 2017; Delgado *et al.* 2010; Raju *et al.* 2015; Raju *et al.* 2015; Yousefi *et al.* 2018; Mohammadi *et al.* 2017). In addition, an imprudent extraction of the groundwater resources and consecutive droughts in recent years have also led to expedited descend of the groundwater level and deterioration in

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groundwater quality (Hosseinifard and Aminiyan 2015; Zahedi 2017). Since the quality of groundwater resources is as important as its quantity; thus, it is also necessary that the quality of the ground water resources should be essentially taken into the full consideration (Aghazadeh and Mogaddam 2010; Neisi *et al.* 2018). Besides the scarcity of water resources, intense agricultural and urban development has caused a high demand of groundwater resources in the arid and semiarid regions of Iran while great risk of contamination these resources is the main challenges facing the Iranian government. Accordingly, it is worth noting that monitoring of the quality of groundwater resources in Iran should be included as a vital step for water resources management, since it is considered as a primary source for drinking and irrigation water. Quality and quantity of rainfalls, geological structure, and aquifer mineralogy are the main factors that can affect the chemical quality of groundwater (Mirzabeygi *et al.* 2017; Yousefi *et al.* 2017; Yousefi *et al.* 2018). Corrosion is a physicochemical reaction that may happen between a surface and other materials, surrounding it and cause changes in material properties. Corrosion can lead to some negative influences like reduction of lifetime of equipment, pipe and facility pitting, water losses, and leaking the heavy metals such as lead, zinc, arsenic, and cadmium into the waters thus creating health issues. One of the major factors in the quality of drinking water is corrosion. Another is scaling that is related to the chemical characteristics of water. Scaling is a production of thin layer in the pipe and facilities which is caused by the reaction between divalent cations and water-soluble substances. Scaling can create some issues in the water distribution network like clogging the channel and pipes, reducing the life of equipment, increasing the head loss of eaters in the network, and enhancing the maintenance and operational costs (Mirzabeygi *et al.* 2017; Mirzabeygi *et al.* 2016; Mohammadi *et al.* 2018).

Therefore, several studies must be conducted to assess quality/quantity of underground water in different regions of Iran. According to this, the hydrochemical characteristics of groundwater can indicate that whether groundwater resources are chemically unsuitable for drinking and agricultural irrigations or not (Aghazadeh and Mogaddam 2011). In addition, the study of the quality of groundwater resources shows that the quality of groundwater in the studied area was situated in class "appropriate for agriculture" and concentration of chemical parameters was estimated to be under a predetermined warning level in a great area of the plain (Hosseinzadeh Talaee 2015). Also, the thematic maps of salinity hazard and Na^+ percentage could determine which factors could gradually deteriorate the water quality across the plain (Narany *et al.* 2015). Different techniques of evaluation have been taken to practice the accurate water quality assessment. In this regard, water quality index (WQI) converts the water quality data and understandable information from complexity to simplicity for public and managers. However, some indexes are not comprehensive and need the other water quality parameters to provide an inclusive WQI which is a simple indicator of water quality. This method is specified for use in both surface and ground water quality assessment (Naubi *et al.* 2016; Bora and Goswami 2017). Moreover, developed drinking water quality index (DWQI), Irrigation water Quality Index (IWQI), and Aquatic Life Water Index (ALWI) have been developed for assessment of the water quality in different consumptions (Bora and Goswami 2017; Goher *et al.* 2014; Aher and Gaikwad 2017; Brhane 2016). Altogether, the quality of the irrigation water need to be evaluated in order to avoid or minimize adverse impacts on agriculture (Mohammed Muthanna 2011). This method is similar to the assessment procedure to DWQI released by WHO (2004) World Health Organization 2004). The only difference between these two methods is that the standard value of each chemical parameter is extracted from the reports of FAO in the first one (1994) (Ayers and Westcot 1985). Also, another assessment method has been innovated by Meireles *et al.* (2010) known as IWQI (Meireles *et al.* 2010).

It seems there is a need to study evaluation of the groundwater quality for drinking and agricultural purposes in the Sistan and Baluchistan province in Iran. The aims of present study which has been carried out during the one-year-monitoring period were to determine the physicochemical characteristics of groundwater in a subjected area and its quality assessment for drinking, agricultural, and industrial purposes. Also, the possible sources of pollution were considered in this study which may affect the water quality in the studied area. The results of this study may help the implementation of optimized science-based water health policies by decision makers and also could hold the potential water quality information which can be used in drinking, irrigating, and industrial purposes in Sistan and Baluchistan province.

Methods and material

Study area

Sistan and Baluchistan province with several cities (Zabol, Zahedan, Kash, Iranshahr, Saravan, Nikshar, Sarbaz, and Chabahar) is a semi-flat plain with a gentle slope toward the south encompassing an area of about 18,175 km^2 (Figure 1) and its aquifers are located in South-East Iran between the latitudes 25°4′–31°25′ N and longitudes 58°55′–63°20′ E. This area has a warm, temperate climate, so that the highest and lowest of air temperatures are 50°C and −7°C, respectively, with an annual average of 25°C. The climate of the subjected area is semiarid with an annual range of precipitation of 70–130 mm and the annual evaporation rate of 4000 mm (four times as high as Iran's average).

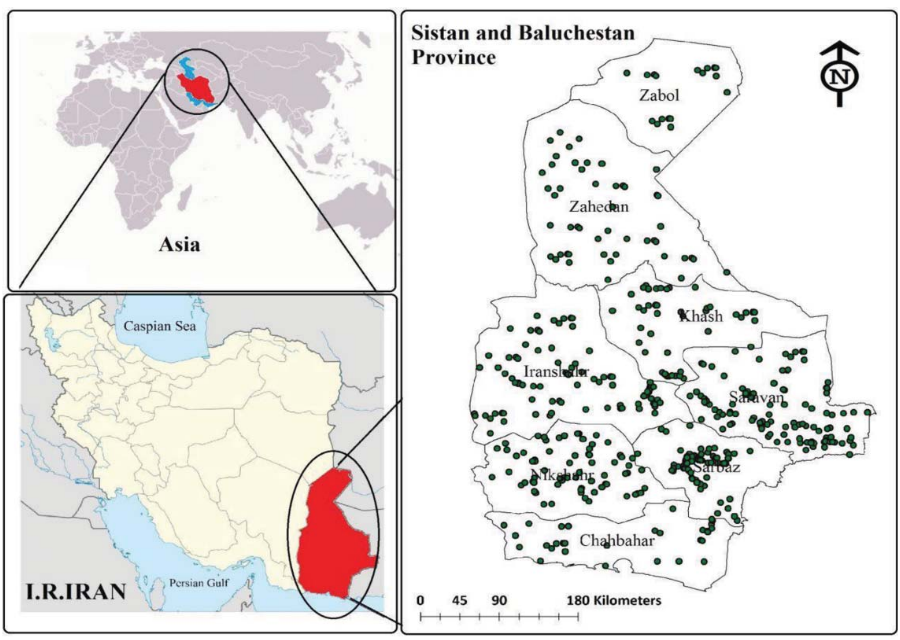

Figure 1. Location of Iran, Sistan, and Baluchistan provinces and water sampling sites in the studied area.

Sample analysis

Water samples were collected from 654 open dug wells, located in nine cities in Sistan and Baluchistan province, within the one-year-monitoring period (2012–2013). Figure 1 shows the location of Iran, Sistan and Baluchistan province' and water sampling situations. The samples were analyzed for major ions according to the standard method examinations for water and wastewater (Apha 1995). Electrical conductivity and the concentration of hydrogen ion (pH) were analyzed with a turbidity meter (model Hach 50161/co 150 model P2100Hach, USA) and pH meter (model wtw, Esimetrwb), respectively. Total dissolved solids (TDS) were obtained by multiplying the EC by a factor (0.55–0.75) based on the relative ion concentrations (Apha 1995; Metcalf *et al.* 2003). Sodium (Na^+) and potassium (K^-) were measured by flame photometer. Sulfate (SO_4^{2-}), nitrate (NO_3^-), and fluoride (F^-) were analyzed with spectrophotometer. It is important to mention that all parameters are expressed as milliequivalents per liter (except pH) (Yousefi *et al.* 2017; KazemiMoghadam *et al.* 2018; Yousefi *et al.* 2018; Saeedi *et al.* 2012).

Drinking water quality index (DWQI)

Water quality assessment was carried out using WQI, which is widely used for evaluating drinking water quality. The WQI index is also specified for use in ground water quality assessment. The WQI was initially invented by Brown *et al.* (1970) and then modified by Backman *et al.* (1998). According to the reports by the "World Health Organization (WHO)" in 2004, using WQI would help to clarify combinatorial effect of each parameter as well as all qualitative parameters on drinking water quality (World Health Organization 2004). Therefore, WQI can be applied as a reliable tool for assessment and rating quality of water wells. Each qualitative parameter's value is determined based on the recommended standards and correlated to other parameters. In order to calculate the WQI, the value of physiochemical parameters has been assigned according to the relative importance of parameters in the overall quality of water for drinking purposes. The relative weight was computed using the following equation:

$$W_i = \sum \frac{W_i}{\sum_{i=1}^{n} W_i} \tag{1}$$

where W_i is the relative weight of each parameter, n refers to the number of parameters. The weight (wi) and relative weight (Wi) of each chemical parameter are shown in Table 1. For each parameter, the quality rating scale was calculated by dividing its concentration in each water sample to its respective standards (released by World Health Organization 2011) (Edition 2011) and finally multiplied the results by 100.

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \tag{2}$$

where q_i represents the quality rating, C_i is the concentration of each chemical parameter in each sample (mg/L), and S_i refers to the standard limit for each chemical parameter (mg/L) according to the guidelines of the WHO released in 2011. In the final stage of WQI

Table 1. The weight (*wi*) and relative weight (*Wi*) of each chemical parameter calculated based on the standard values reported by the World Health Organization (WHO, 2004) and Food and Agriculture Organization (FAO, 1994).

Parameter	WHO standards (mg/L)	FAO standards (mg/L)	Weight (*wi*)	Relative weights (*Wi*)
[K]	12	2	2	0.056
[Na]	200	919	4	0.111
[Mg]	50	60	3	0.083
[Ca]	75	400	3	0.083
[HCO3]	120	610	1	0.028
[Cl]	250	1063	5	0.139
[SO4]	250	960	5	0.139
[pH]	8.5	8.5	3	0.083
[TDS]	500	2000	5	0.139
[NO3]	11	10	5	0.139
Σ	—	—	—	1

computing, the SI_i was first determined for each parameter and then the sum of Si values gave the WQI for each sample.

$$SI_i = W_i \times q_i \tag{3}$$

$$WQI = \sum\nolimits_{i=1}^{n} SI_i \tag{4}$$

where SI_i is the subindex of parameter, q_i represents the rating based on concentration of its parameter, and n is the number of parameters (Abbasnia *et al.* 2018). Based on the results of WQI, water quality can be classified into five classes, as listed in Table 1.

Irrigation water quality index (IWQIM)

IWQIM, developed by Meireles et al in 2010, is a specified method primarily used for water quality assessment for agricultural purposes (Meireles *et al.* 2010). There are differences between these methods and the WQI-based method was employed by the WHO. Estimated values of each parameter originating from the irrigation water quality data according to University of California Committee of Consultants (UCCC) as well as Ayers and Westcot Criteria (1999) should be used for calculating relative weight in this method (Ayers and Westcot 1985). In the IWQI model, first, the parameters which play an important role in the water quality for agricultural purposes must be identified (EC, Na^+, Ci^-, and $HCO_3^-$and SAR). Second, the weight of water quality parameters including: the water quality measurement parameter value (*Qi*), the accumulation witness (*Wi*) were determined depending on each individual parameter value and finally taking into account the criteria which were proposed by Ayers and Wescot, 1999 (Table 2) (Ayers and Westcot 1985). As previously mentioned in this model, lower value represents the poor quality of water and vice versa. The value of *Qi* was calculated based on the following equation:

$$q_i = q_{\max} - \left(\frac{[(x_{ij} - x_{\inf}) \times q_{imap}]}{x_{amp}}\right) \tag{5}$$

where $q_{\max}$ is the maximum value of qi for each class; x_{ij} represents the observed value of each parameter; x_{inf} refers the lower limit value of the class to which the parameter belongs; q_{imap} presents the class amplitude, and x_{amp} is corresponding to class amplitude to which

Table 2. General DWQI and IWQIF classifications.

Range	Type of groundwater
<50	Excellent water
50–99.99	Good water
100–199.99	Poor water
200–299.99	Very poor water
≥300	Unsuitable for drinking/Irrigation purpose

the parameter belongs. In this regard, the upper limit was considered to be the highest value determined in the analysis of the water samples which is required in order to evaluate x_{amp} of the last class of each parameter. Ultimately, w_i values were normalized and their final sums equal 1, according to Eq. (6):

$$w_i = \frac{\sum_{j=1}^{k} F_j A_{ij}.}{\sum_{j=1}^{k} \sum_{i=1}^{n} F_i A_{ij}} \tag{6}$$

The University of California Committee of Consultants (UCCC) estimated the values of (qi) according to factor amount, tolerance limit, and irrigation water quality parameters which are shown in Table 3. The parameter of water quality was non-dimensional number and the higher parameter value indicates the better quality water. The results of water quality were determined at the laboratory.

Based on this equation, w_i and F correspond to the relative weight of the parameter for WQI and a constant value of component 1, respectively. Aij defines to what extent parameter i can be explained with factor j; i represents the number of physiochemical and chemical parameters selected in IWQIM varied from 1 to n and j is the number of factors chosen in IWQIM, ranged from 1 to k. Table 4 shows relative weight of each parameter. As a result of the above procedure, the IWQIM value which is obtained from Eq. (7) and Table 5 indicated characteristics of IWQIM for each class.

$$\text{IWQIM} = \sum_{i=1}^{n} q_i w_i. \tag{7}$$

In this equation, IWQI is nondimensional irrigation WQI that ranged from 0 to 100; Qi represents the quality of ith parameter from 0 to 100 and corresponding to function of its measurement or concentration; w_i refers to the normalized weight of the ith parameter and is related to the function of importance in explaining the global variability in water quality which is shown in Table 4. Based on existing WQIs, division in different classes based on

Table 3. Parameter limiting values for quality measurement (*Qi*) calculation (Meireles *et al.* 2010).

q_i	E.C (μs/m)	SAR ((mmol.L^{-1})$^{0.5}$)	Na^+ (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)
85-100	[200,750)	[2,3)	[2,3)	[1,4)	[1,1.5)
60-85	[750,1500)	[3,6)	[3,6)	[4,7)	[1.5,4.5)
35-60	[1500,3000)	[6,12)	[6,9)	[7,10)	[4.5,8.5)
0-35	EC < 200 or EC ≥ 3000	SAR < 2 or SAR ≥ 12	Na < 2 or Na ≥ 9	Cl < 1 or Cl ≥ 10	HCO3 < 1 or HCO3 ≥ 8.5

Table 4. Weights for the IWQI parameters (Meireles *et al.* 2010).

Parameters	wi
[EC]	0.211
[Na]	0.204
[HCO3]	0.202
[CL]	0.194
[SAR]	0.189
Total	1

the proposed WQI has been carried out and considering the risk of salinity problems, soil water infiltration reduction, as well as toxicity to plants, classes were defined as observed in the classification presented by Bernardo (1995) and Holanda and Amorim (1997) (Holanda and Amorim 1997; Salassier *et al.* 1995). Restriction to water use classes were characterized based on Meireles *et al.* 2010 (Table 5).

Suitability of groundwater for industrial uses

Water with low quality entering the drinking water distribution network often provides requirement for corrosion and scaling in rural areas. Subsequently, it leads to different problems including: pipe clogging, reducing the longevity of the equipment as well as health and economic issues caused by dissolved compounds in the water (Mirzabeygi *et al.* 2017).

In this regard, Langelier saturation index (LSI), Ryznar Stability index (RSI), Puckorius scaling index (PSI), Larson-Skold index (LS), and Aggressiveness index (AI) were considered to determine water suitability for industrial purposes. Table 6 presented the indexes, equation, and some definition and criteria for categorizing the stability of the water (Mirzabeygi *et al.* 2016; Abbasnia *et al.* 2018; Asghari *et al.* 2018).

Table 5. Classifications and characteristics of general IWQI (Meireles *et al.* 2010).

		Recommendation	
IWQIM	Exploitation restrictions	Soil	Plant
[85,100]	No restriction (NR)	Water can be used for almost all types of soil. Soil is exposed to lower risks of salinity/sodicity problems	No toxicity risk for most plants
[70,85]	Low restriction (LR)	Irrigated soils with a light texture or moderate permeability can be adapted to this range. To avoid soil sodicity in heavy textures, soil leaching is recommended.	Elevated risks for salt-sensitive plants
[55,70]	Moderate restriction (MR)	The water in this range would be better used for soils with moderate to high permeability values. Moderate leaching of salts is highly recommended to avoid soil degradation.	Plants with moderate tolerance to salts may be grow
[40,55]	High restriction (HR)	This range of water can be used in soils with high permeability without compact layers. High-frequency irrigation schedule	Suitable for irrigation of plants with moderate to high tolerance to salts with special salinity control practices, except water with low Na, Cl, and HCO_3 values
[0,40]	Severe restriction (SR)	Using this range of water for irrigation under normal conditions should be avoided.	Only plants with high salt tolerance, except for waters with extremely low values of Na, Cl, and HCO_3.

Table 6. Corrosion and saturation indices, equation, and criteria for categorizing the stability of the water used in the study.

Index	Equation	Index value	Water condition
Langelier saturation index (LSI)	LSI = pH − pHs	LSI > 0	Supersaturated, tend to precipitate $CaCO_3$
	pHs = A + B − log (Ca^{2+}) − log (Alk) pH < = 9.3	LSI = 0	Saturated, $CaCO_3$ is in equilibrium
	pHs = (9.3 + A + B) − (C + D) (3) pH > 9.3	LSI < 0	Undersaturated, tend to dissolve solid $CaCO_3$
Ryznar stability index (RSI)	RSI = 2pHs − pH	RSI < 6	Supersaturated, tend to precipitate CaCO3
		6 < RSI < 7	Saturated, CaCO3 is in equilibrium
		RSI > 7	Undersaturated, tend to dissolve solid$CaCO_3$
Puckorius scaling index (PSI)	PSI = 2 (pHeq) − pHs	PSI < 6	Scaling is unlikely to occur
	pH = 1.465 + log (T.ALK) + 4.54	PSI > 7	Likely to dissolve scale
	pHeq = 1.465 × log(T.ALK) + 4.54		
Larson-skold index (LS)	Ls = (Cl− + SO_4^{2})/(HCO3 + CO_3^{2})	LS < 0.8	Chloride and sulfate are unlikely to interfere with the formation of protecting film
		0.8 < LS < 1.2	Corrosion rates may be higher than expected
		LS > 1.2	High rates of localized corrosion may be expected
Aggressive index (AI)	AI = pH + log[(Alk)(H)]	AI > 12	Nonaggressive
		10 < AI < 12	Moderately aggressive
		AI < 10	Very aggressive

Data analysis

Correlation analysis was performed using the Pearson correlation coefficient. All data were analyzed using SPSS (IBM Corp. Released 2016. IBM SPSS Statistics for Windows, Version 24.0. Armonk, NY: IBM Corp) and also all significance tests were at 95% confidence level.

Finally, the analytical results were taken to generate the numerical spatial distribution of the parameters using the GIS environment and IDW (Inverse Distance weight) technique was employed for developing the spatial distribution maps of water quality parameters. It is important to note that DWQI, IWQI, and the severity of corrosion in different water supply systems of villages in Sistan and Baluchestan province were determined.

Result and discussion

Physicochemical characteristics

The results of the statistical factors of physicochemical parameters of water in Sistan and Baluchistan province are presented in Table 7. The temperature fluctuated from 19 to 24°C with an average of 21.3°C. The pH of solution almost was in the natural range which shows the water can react with base or acidic materials exiting in the water. According to the WHO guideline, the standard limit of pH in the water is 6.5–8.5. Electrical conductivity in this study varied from 428–9860 μS/cm which presents the high amount of salts in the groundwater. In addition, TDS in the ground water studied in this research was high due to enrichment of salts in the water. It might be also because of the interaction of rock and water and agricultural activities. The maximum amount of TDS in the water is 1500 mg/L based on

Table 7. Statistics of phisico-chemical characteristics and hydro-geochemistry base concentrations (meq/L) of water quality of Sistan and Baluchistan province.

City	Parameter	Na^+	K^+	Ca^{2+}	Mg^{2+}	SO_4	HCO_3^-	PO_4^{3-}	NO_3	NO_2	Cl^-	F^-	TH	TA	TDS	EC(μS/cm)	T(°C)	pH
Zahedan	Min	36	3	18	14	19	36.6	0	5.5	0	5	0.2	144	36.6	300	468	20	5.83
	Max	1236	13	448	118	1500	541	1	67	0.1	1305	1.6	1567	541	6310	9860	23	8.28
	Ave	403	7.5	128	48	507	308	0.2	17	0	408	0.9	517	308	1887	2948	21.9	7.76
	SD	299	3	113	27	397	111	0.2	12	0	335	0.4	355	111	1455	2274	0.87	0.56
Khash	Min	27	2	35.2	7.7	60	156	0	6	0	57	0.2	120	156	439	686	20	7.07
	Max	707	30	1523.8	97	750	730	0.6	37	0.1	905	1.7	4204	730	2573	4020	24	8.35
	Ave	219	7.1	132	35	273	312	0.2	16	0	253	0.8	475	312	1097	1713	21.5	7.72
	SD	152	4.6	201	21	178	129	0.1	8.4	0	165	0.3	557	129	500	781	1.26	0.26
Chabahar	Min	71	3	31.2	11	70	117	0	2.5	0	64	0.1	131	124	349	546	19	7.1
	Max	698	13	400	274	1150	427	0.2	72	2.8	1210	1.5	2086	427	5485	8750	24	8.59
	Ave	270	8.3	114	43	414	235	0.1	12	0.1	300	0.5	461	236	1318	2059	20.5	7.85
	SD	164	2.3	80.4	45	281	70.3	0.1	14	0.4	250	0.3	369	69.4	884	1380	1.08	0.33
Sarbaz	Min	31	2	5.4	8.6	30	134	0	5	0	40	0.2	64.9	134	274	428	20	7.42
	Max	360	10	146	44	740	490	0.3	54	0	641	1	468	490	1965	3070	24	8.23
	Ave	101	4.6	63.6	16	105	234	0.1	16	0	98.8	0.4	226	234	568	888	21.5	7.81
	SD	65	1.6	21.2	5.4	105	57.3	0.1	9.1	0	75.4	0.1	65.1	57.3	268	419	1.11	0.19
Nikshahr	Min	18	1	26.4	9.6	30	142	0	5	0	41	0.1	142	142	339	529	19	7.2
	Max	386	10	162	51	540	2215	17	68	0.1	415	1.4	2215	2215	1542	2410	24	8.37
	Ave	151	4.5	72.8	21	152	278	0.3	15	0	153	0.5	278	278	742	1160	21.9	7.75
	SD	86	2.3	26.9	8.8	105	187	1.5	9.2	0	85.3	0.2	187	187	1160	456	1.34	0.3
Zabol	Min	4	2	31.2	3.1	30	22	0	1.7	0	62	0.2	189	176	426	665	20	8.28
	Max	625	30	808	76	1050	549	0.5	56	1.4	545	0.9	449	256	2016	3150	23	8.59
	Ave	206	4.7	73.2	24	255	288	0.1	14	0	106	0.5	247	195	580	906	21.8	8.41
	SD	129	2.8	63	14	199	84.3	0.1	8.9	0.1	111	0.2	62.6	21.9	368	574	0.92	0.08
Iranshahr	Min	50	2	16	4.8	40	85.4	0	6	0	40	0.2	61.7	85.4	276	432	20	7.3
	Max	1065	30	178	62	1100	693	0.6	49	0.1	954	1.7	609	705	3130	4890	24	8.57
	Ave	309	5.6	68.9	19	308	246	0.1	15	0	284	0.6	252	247	1164	1818	22	7.88
	SD	224	4.2	32.8	11	227	99.6	0.1	6	0	205	0.3	117	99.9	667	1041	1.09	0.31
Saravan	Min	4	2	31.2	3.1	30	22	0	1.7	0	35	0.1	121	22	4.98	7.78	18	6.49
	Max	625	30	808	76	1050	549	0.5	56	1.4	773	1.8	2320	549	2362	3690	24	8.5
	Ave	206	4.7	73.2	24	255	288	0.1	14	0	190	0.5	281	288	963	1505	21.6	7.49
	SD	129	2.8	63	14	199	84.3	0.1	8.9	0.1	123	0.2	186	84.3	478	747	1.25	0.55

the WHO guideline. The classification of groundwater indicates that fresh for TDS < 1000 mg/L; brackish for 1000 < TDS < 10,000 mg/L; saline for 10000 < TDS < 1,000,000 mg/L and brine for TDS > 1,000,000 mg/L. Therefore, the quality of water in this study was categorized as brackish (Logeshkumaran *et al.* 2015).

The temperature, pH, TDS, and the amount of cations and anions could affect the concentration of carbonates. Most groundwaters have high carbonate and bicarbonate. The high chloride concentration in the groundwater might be due to interaction between water and soil and rock and weathering and anthropological activities like effluent of wastewaters. The amount of chloride concentration in the present study was in the range of 5–1305 mg/L which indicates that it exceeds the WHO and Iranian standard limit (250 mg/L). The high amount of sulfate and magnesium could cause some adverse effects on the human like laxative effect. The concentration of sulfate was 19–1500 mg/L which is higher than the WHO standard level (400 mg/L). High amount of chloride and sulfate in the groundwater could influence the corrosion phenomenon and network systems (Logeshkumaran *et al.* 2015). Nitrate could enter into the water sources through excessive consumption of fertilizers in the agricultural activities and nonpoint sources. Nitrogen compounds might cause adverse effect on the human health and destroy the quality of groundwater. Previous studies disclose that high amount of the nitrate could create blue baby syndrome in children, thyroid disease, hypertension, diabetes, and carcinogenicity effect due to nitrosamide and nitrosamine generated in the human body. The standard limit of nitrate in the drinking water quality is 50 mg/L as NO_3 based on the WHO guideline. The results showed that the nitrate concentration were in the range of 1.7–68 mg/L which exceeded the permissible level in some parts of studied area. The amount of nitrite in the groundwater was negligible and lower than the standard level (Yousefi *et al.* 2016).

Hardness of the water is directly created with calcium and magnesium cations and these cations exist in the high amount in the groundwater. The concentration of calcium and magnesium were between 5.4–808 and 3.1–278 mg/L as $CaCO_3$. High amount of calcium and magnesium could cause some negative effects like health effect such as abdominal ailments as well as economic and hydraulic effect such as scaling. Also, the maximum total hardness of water samples was 4204 mg/L as CaCO3 which was much more than WHO limit (300 mg/L). Therefore, the water could be hard due to presence of calcium and magnesium cations. The concentration of sodium was in the range of 4–707 mg/L. Sodium ions could naturally exist in the water due to some phenomena such as evaporation, agricultural activities and manmade activities, and clay weathering. In addition, ion exchange of sodium and calcium and other cations could cause the high amount of sodium in the water. The concentration of potassium in the water samples of present study was 1–30 mg/L. the concentration of potassium in this study was lower than other cations (Logeshkumaran *et al.* 2015; Malakootian and Yousefi 2009).

Piper trilinear diagram

Majority of the critical issues related to the hydrogeochemical of groundwater have been evaluated through piper diagram. In this graphical presentation, cations and anions are shown in two triangles in the bottom and a diamond (rhombus) shape (composition of all ions) at the top (Logeshkumaran *et al.* 2015). The piper diagram of hydrogeochemical of groundwater studied in the present study is shown in Figure 2.

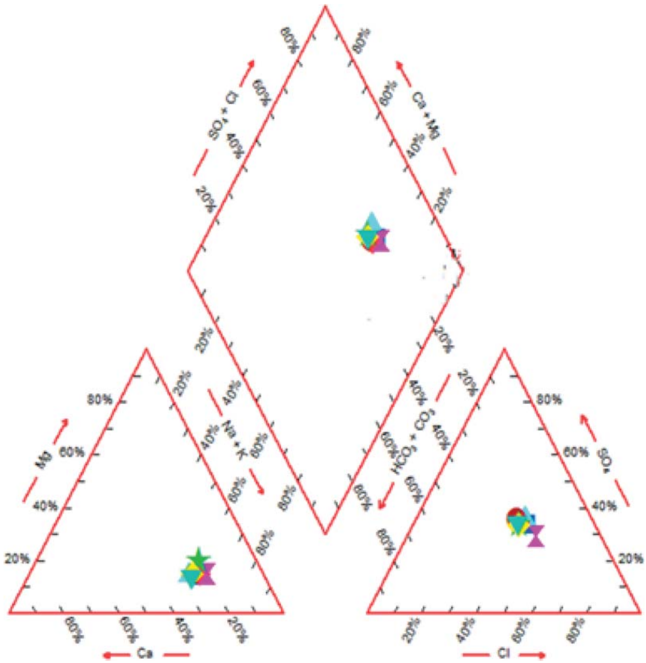

Figure 2. The Piper diagram indicates for hydrogeochemical type of water.

According to the results, the Piper diagram indicated that the Hydrochemical type of water is NaCl type followed by $CaSo_4^{2-}Cl$. In addition, high concentration of sodium paired with low concentration of calcium indicated that ion exchange is a significant process in the groundwater studied.

Correlation matrix

Understanding the relationship and variations between the physicochemical characteristics and ion concentration of groundwater samples and explaining the data and interaction between them could be carried out based on the statistical analysis (Meireles *et al.* 2010). Table 8 shows the statistical analysis of the ion concentrations and physicochemical parameters. All analyzed data were reported on average value. According to the results, calcium and hardness; sodium and TDS; sodium and EC; sulfate and TDS; chloride and TDS; sulfate and EC; chloride and EC; alkalinity and carbonate; TDS and EC; sodium and chloride; and sulfate and sodium indicate high correlations (above 0.8). These results showed that water quality could be influenced by seasonal and evaporation effects. Bicarbonate concentration was high during the rainy seasons and salts like sodium and chloride and sulfate could be high at dry season. Totally, high correlation coefficient between water quality parameters illustrates that sulfate and chloride had significant interaction with other parameters. Therefore, these two parameters had high concentrations as a result of natural and rock and soil materials as well as anthropological activities.

Table 8. Correlation matrix of physicochemical parameters for the analyzed factors.

	pH	Ca	Mg	Na^+	K^+	F^-	NO_3	NO_2^-	SO_4^{2-}	Cl	HCO_3	PO_4	TDS	EC	ALK	TH
pH	1															
Ca^{2+}	−0.138**	1														
Mg^{2+}	−0.206**	0.534**	1													
Na^+	−0.036	0.211**	0.412**	1												
K^+	−0.107**	0.32**	0.404**	0.313**	1											
F^-	0.016	0.181**	0.272**	0.488**	0.157**	1										
NO_3	−0.102**	0.16**	0.311**	0.138**	0.076	0.154**	1									
NO_2	−0.026	0.063	0.115**	0.092*	0.067	0.009	0.141**	1								
SO_4	−0.051	0.437**	0.602**	0.813**	0.463**	0.443**	0.193**	0.157**	1							
Cl^-	−0.12**	0.396**	0.633**	0.84**	0.382**	0.44**	0.243**	0.123**	0.814**	1						
HCO_3^-	−0.205**	0.119**	0.208**	0.263**	0.077*	0.218**	0.01	0.022	0.187**	0.198**	1					
PO_4	0.025	0.026	−0.01	0.012	0.049	−0.14	−0.008	0.001	0.004	0.015	0.045	1				
TDS	−0.063	0.393**	0.608**	0.802**	0.394**	0.473**	0.268**	0.138**	0.854**	0.874**	0.286**	0.015	1			
EC	−0.063	0.393**	0.608**	0.802**	0.394**	0.473**	0.268**	0.138**	0.854**	0.874**	0.286**	0.015	1.000**	1		
ALK	−0.199**	0.117**	0.208**	0.263**	0.076	0.22**	0.009	0.022	0.186**	0.196**	1.000**	0.044	0.285**	0.285**	1	
TH	−0.176**	0.96**	0.75**	0.302**	0.385**	0.232**	0.229**	0.087*	0.542**	0.52**	0.162**	0.019	0.51**	0.51**	0.161	1

*Correlation is significant at the 0.05 level (two-tailed).
**Correlation is significant at the 0.01 level (two-tailed).

Drinking water quality index (DWQI) and irrigating water quality index (IWQIF)

Suitability of water quality for various proposes like drinking or irrigation could be distinguished based on the chemistry parameters and indexes. Rating of water in the aspect of quality and consumption using the effect of individual parameters can be helpful in making decision by managers and administrative organizations (Zahedi 2017). According to interpolated results of the DWQI method which are shown in Figure 3(a) and Table 9, 654 shared extraction wells were studied in the study area; of that 1.2% wells were classified in the 'Excellent' class, 52.1% as a "Good" class, 39% as a "Poor" class, 6% as a "very poor", and 1.7% as a "Unsuitable for drinking purpose" classes. In addition, in order to evaluate water quality by means of IWQIF, 19.9% and 80.1% wells of the shared extraction wells were placed in the "Excellent" class and "Good" class, respectively; and none of them were placed in the "poor", "Very poor" class and "Unsuitable for irrigation" class (Figure 3(b) and Table 9). Leaching of elements from rocks and gypsum rocks might be the main reason of high electrical conductivity, TDS and other parameters in the water. Also, excessive extraction of water as well as excessive use of agricultural fertilizer may be the other reasons for decreasing the water quality. Differences between DWQI and IWQIF may be due to differences between relative weights of DWQI and IWQIF. High concentration of sodium content and increasing the exchange of this element can reduce the permeability of soil. In addition, high concentration of $Na+$ can lead to increase in the adsorption and ion exchange of sodium into the clay particles and decrease the soil permeability and drainage (Zahedi 2017; Meireles *et al.* 2010; Mirzabeygi *et al.* 2018; Neisi *et al.* 2018).

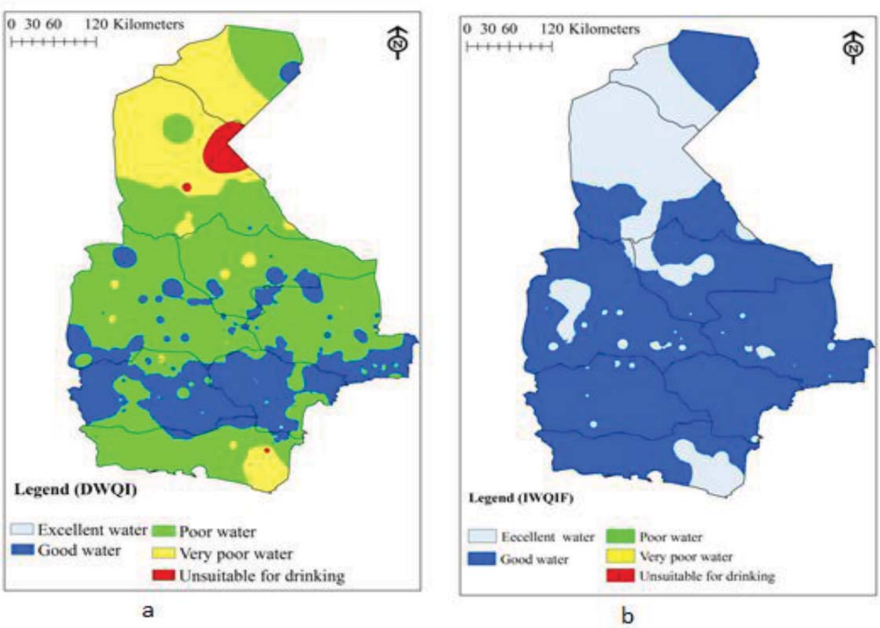

Figure 3. Layout of interpolated results for (a) DWQI and (b) IWQIF.

Table 9. Statistical summary of the calculated indices for the quality of drinking water, irrigation, and industry from the physicochemical parameters of groundwater samples collected from the study area.

		DWQI	IWQIF	LSI	RSI	PSI	L-S	AI	SAR
Zahedan	Min	70.48	38.44	−2.51	5.29	5.29	0.07	7.37	1.78
	Max	494.44	74.87	1.49	11.27	10.69	16.34	12.70	18.14
	Ave	188.18	51.10	0.44	6.90	6.55	3.55	10.58	8.19
	SD	107.48	10.71	0.73	1.06	0.99	3.51	0.86	4.97
Khash	Min	62.42	39.70	0.01	4.28	3.86	0.63	9.98	0.41
	Max	348.23	69.79	1.77	7.54	7.48	6.85	11.83	16.25
	Ave	130.33	56.89	0.43	6.86	6.42	1.84	10.45	5.19
	SD	55.09	8.88	0.30	0.56	0.78	1.22	0.32	3.66
Chabahar	Min	51.92	45.51	−0.12	6.10	5.36	0.40	9.82	1.36
	Max	242.54	77.81	0.95	7.87	7.56	7.12	11.06	9.04
	Ave	98.06	63.41	0.34	7.06	6.82	1.76	10.33	3.53
	SD	42.47	8.48	0.21	0.31	0.41	1.70	0.24	1.58
Sarbaz	Min	39.56	42.82	−0.69	5.15	3.25	0.34	9.27	0.46
	Max	207.50	83.78	1.20	9.31	9.33	5.37	11.30	10.21
	Ave	89.09	62.12	0.22	7.25	6.90	1.19	10.20	3.55
	SD	35.90	8.61	0.27	0.50	0.77	0.94	0.27	2.21
Nikshahr	Min	51.25	45.33	−0.71	5.97	5.77	0.36	9.27	1.15
	Max	201.77	77.35	1.11	9.38	10.82	16.86	11.21	12.90
	Ave	96.16	62.63	0.36	7.08	6.81	1.41	10.33	4.34
	SD	34.03	8.00	0.36	0.50	0.64	1.74	0.38	2.27
Zabol	Min	54.13	37.90	−1.05	4.62	4.19	0.37	8.65	0.12
	Max	290.04	79.77	1.62	8.48	8.64	9.89	11.62	32.53
	Ave	109.88	57.45	0.37	7.15	6.97	1.76	10.37	6.13
	SD	46.72	9.43	0.29	0.46	0.66	1.27	0.32	4.43
Iranshahr	Min	51.92	35.00	−0.16	6.50	6.02	0.99	9.76	2.88
	Max	270.54	73.05	0.80	8.43	8.89	3.53	10.96	25.04
	Ave	109.32	56.58	0.25	7.44	7.38	1.81	10.22	8.95
	SD	49.67	10.09	0.21	0.46	0.90	0.76	0.26	5.67
Saravan	Min	46.54	35.00	−0.55	6.13	5.45	0.55	9.84	1.22
	Max	498.08	81.71	1.07	8.47	8.87	11.69	13.33	32.17
	Ave	137.22	56.46	0.35	7.13	6.93	2.72	12.26	7.15
	SD	83.17	11.28	0.25	0.45	0.75	2.20	0.71	5.19

Water quality indexes

In order to evaluate the water quality, Langelier, Rayner, Aggressive, Larson–Skold, and Puckorius indices for the water resources situation were determined. Table 7 illustrates the calculations related to these indices. According to the results obtained, the values of LSI, RSI, PSI, Larson ratio, and AI were 0.35 ($\pm$0.33), 7.1 ($\pm$0.52), 6.85 ($\pm$0.72), 1.8 ($\pm$1.79), and 10.63 ($\pm$0.80), respectively. The severity of corrosion in the water of different villages of Sistan and Baluchistan province was done using a GIS, as shown in Figure 4 and Table 9. According to the results, water sources were less corrosive based on AI and PSI and low and light corrosion according to RSI. Also, according to the Larsson–Sckold index, most water sources were corrosive. However, according to the Langelier index, water sources presented scaling and low scaling. Langelier saturated index was used for determining the corrosion or deposition of water. In addition, the corrosion severity in the water tubes was evaluated according to the Ryznar index. The capacity of buffer for groundwater is extremely determinative for corrosivity or scaling of the water. The differences between water in the state of scaling and/or saturated have been clearly determined via the Puckorius index. The corrosivity of water in the cast iron and steel pipes with low carbon has been assessed with the Larson–Skold index. While, the invasion scale index which was developed for asbestos-cement pipes has been focused on the damage pipe generated with waters (Mirzabeygi *et al.* 2016).

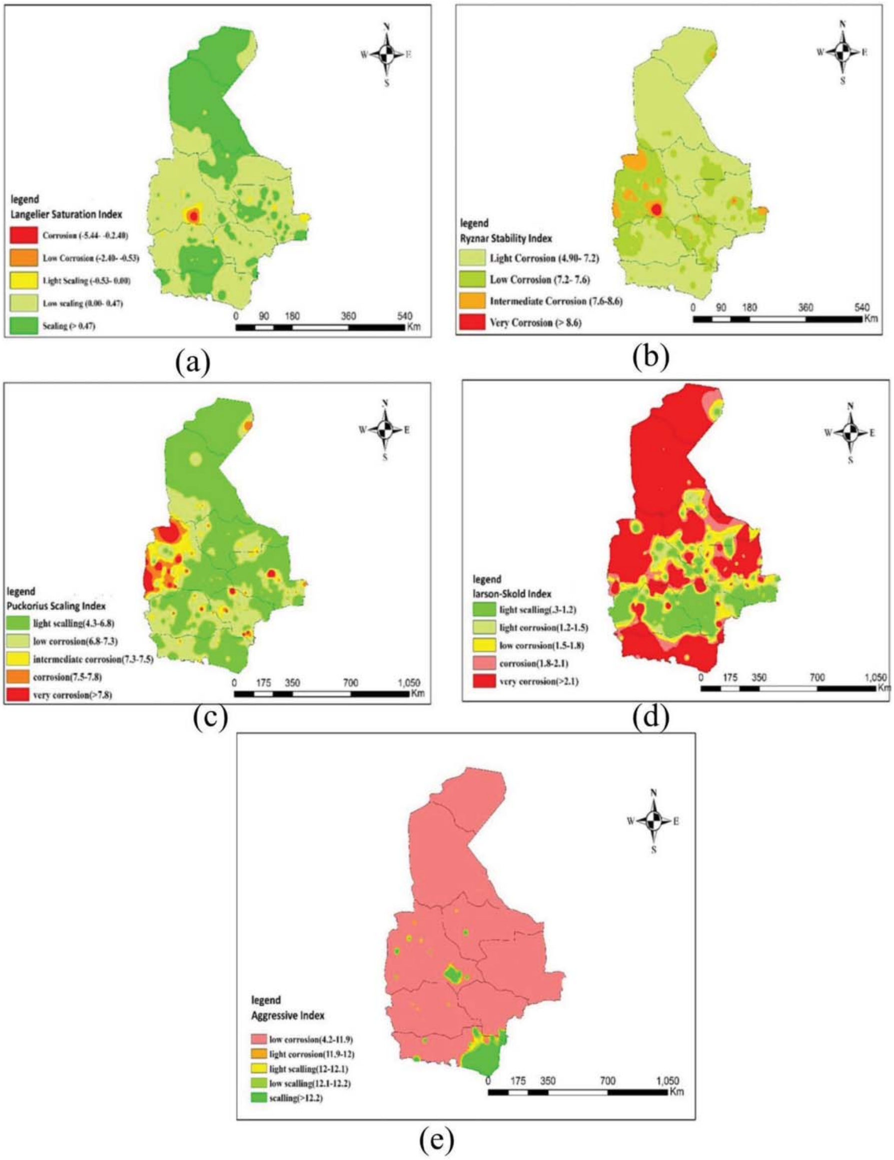

Figure 4. Spatial distribution of (a) Langlier, (b) Ryzner, (c) Puckorius, (d) Larson–Skold, and (e) Aggressive indeces for water resources situation at Sistan and Baluchistan province.

According to the previous studies, water in the Torbat city in Iran has been scaled with no interference of Cl and SO_4^{2-} and formation of chloride and sulfate film can create the protection agent for the pipelines. Water in this study was corrosive based on the PSI. In addition, indexes showed that water was corrosive in study of water in distribution of Tabriz city. Also, it was found that the Ryznar, Langelier, and Puckorius indices indicated that rural water in Urmia city (northwest Iran) was corrosive (Mirzabeygi *et al.* 2017; Mirzabeygi *et al.* 2016).

Finally, a statistical summary of the calculated indices for the quality of drinking water, irrigation, and industry from the physicochemical parameters of groundwater samples collected from the study area is shown in Table 9.

Conclusion

In this study, suitability of the groundwater, as major resource of drinking and irrigation purposes, was investigated in the Sistan and Baluchistan province (southeast of Iran). According to the results, groundwater resources as both aspects of quality and quantity were found to be significantly declined due to excessive extraction, anthropological activities, and mismanagement of water resources. It merits to note that indices used for water quality assessment can be useful for managers and administrative organizations. According to the DWQI, most shared extraction wells were classified as good (52.1%) and poor (39%). In addition, IWQIF showed that most extracted wells were categorized as an excellent and good class and none of them were placed as poor, very poor, and unsuitable for irrigation class. According to the results, water sources were less corrosive based on AI and PSI and low and light corrosive according to RSI and the Larsson-Sckold index presented the most sources of water were corrosion. NaCl followed by Ca- Cl-SO_4 were the main type of the groundwater in the present area. It could be concluded that groundwater resources in this area should be properly managed due to drought that happens in these provinces and water resources which enter the distribution network should be appropriately treated before they used for drinking purposes.

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Conflict of interest

The authors of this article declare that they have no conflict of interests.

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