Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.24999

179 (2020) 19–27
March

Evaluation of quality, scaling and corrosion potential of groundwater resources using stability index; case study Kerman Province (Iran)

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Received 27 April 2019; Accepted 7 October 2019

ABSTRACT

The objective of this descriptive and cross-sectional study was to evaluate the scaling and corrosion potential of groundwater resources of Kerman province (southeast of Iran) in 2015. The values of quality factors including carbonate, bicarbonate, calcium, magnesium, sodium, chloride, sulfate, hardness, alkalinity, pH and temperature were obtained and the Langelier, Ryznar, Puckorius and Aggression indexes were computed and corrosion and scaling potential of the groundwater resources were assessed. The results of this study showed that the most values of physical and chemical parameters were in the range of favorable limit to higher than permissible limits, except pH and temperature which were in the favorable limit. The concentration of sulfate, chloride, and sodium was higher than the standard limit at 34.48%, 31.03%, and 51.72% of samples, respectively. The results of this study showed that the index values in most of the studied areas were placed in the corrosion limits and the average of Langelier, Ryznar, Puckorius, and Aggression index were less than zero, >7.5, >6, and 10 to 12, respectively. The difference between corrosion and scaling potential was analyzed by the Chi-squared test and the results illustrated that most of the studied sites were classified in the corrosive group. The results of this study disclosed that the effects of sulfate and chloride concentration on the water quality, scaling, and corrosion potential were higher than other factors. The comparison of water stability indexes showed that the groundwater resource of Kerman province was corrosive. Therefore, it is suggested that the practice of continuously checking the important parameters and adjusting pH of water resources using lime could be proposed in order to control the corrosion phenomena.

Keywords: Corrosion; Scaling potential; Stability index; Groundwater resources; Kerman province

1. Introduction

Corrosion phenomenon as a consequence of some physical–chemical reactions leads a series of changes in the qualitative properties of metal equipment, such as tanks, pipes, valves, and special pumps employed for water transfer [1–3]. In other words, the physical–chemical reactions, in particular, electrochemical reactions occurring between the equipment and its surrounding environment and, in parallel, causing the dissolution of metal alloys, are known to be responsible for corrosion phenomenon according to the definition of the ISO 8044 standard. Cavity creating, reducing the resistance and durability of equipment, and water loss are the main complications resulted from the corrosion [4,5].

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In most of the countries, great attention has been paid to this phenomenon due to its health and economic aspects; in contrast, it is poor in continuous inspection and monitoring of the susceptible environment to corrosion [2,6].

From health problems, chronic diseases can be referred to the dissolution of heavy metals such as arsenic, copper, lead, and zinc over corrosion and their accumulation in the body. For example, it can be pointed that the toxicity of copper at high concentrations for the body because of the accumulation of lead in the bone and its subsequent effects on the central nervous system and mental retardation. High concentrations of arsenic cause skin and lung cancer, increasing blood pressure and cardiovascular diseases [7–9]. Another problem related to this phenomenon is color appearance in water that led to increased consumer's complaint and reducing citizen's trust [10,11].

In several studies performed in some countries, such as Japan, United States, Australia, Britain, and some other countries, it has been observed that costs and damages resulted from corrosion have posed further growing than the gross domestic product [10,12,13]. The main factors affecting corrosive and scaling potential of the water include pH, alkalinity, hardness, carbon dioxide, dissolved oxygen (DO), temperature, total dissolved solids (TDS) [14–16].

Scaling process, another problematic phenomenon for the water equipment, is the reaction of divalent cations, such as calcium and magnesium, with carbonate and bicarbonate compounds in the saturated waters, taking a great importance in term of economic view of points because of the formation of a sediment layer on the inner surface of the employed plant and pipes. From the effects of scaling in a water distribution network, it can be referred that pressure drop, flow rate reduction, and pipe obstruction impose additional costs to the relevant authorities at the time of operation [17,18]. With population growth in the world, a more extensive water need was yielded in domestic, agricultural, and industrial sections resulting in overuse of the available water sources, especially groundwater resources [1,19,20].

Groundwater is one of the most important resources of water bodies, encountering with different challenges such as dropping in its water tables and increasing in its natural and synthetic contaminants content. Since Iran is located in an arid and semi-arid region of the world, the qualitative assessment of water resources, especially the groundwater as the most important water resources for southern and eastern regions, has great importance for the country's water resources development projects. Nevertheless, there are no actions for improving the quality of water resources in comparison with the plans of water resources development [3]. Various factors such as geological structure and type of water resources could affect the chemical quality of water and subsequently corrosion and scaling potential of water [10].

Application of corrosive indexes has been widely used due to simplicity in calculating corrosion and scaling potential of water. In general, for this work, there are several indexes such as Langelier, Ryznar, Puckorius and Aggression indexes and Marble Test. The Ryznar index (RSI) has a theoretical basis and in contrast, the Langelier index (LIS) was developed with an empirical basis. These indexes were developed through an error test. The only difference at the Puckorius index rather than the Ryznar index is that the equilibrium pH is used instead of pH value. The Larson–Skold index was developed by chloride-sulfate-induced corrosion, and alkalinity was considered as a limiting factor [21]. So far, a number of studies have been done on the corrosion and scaling status of water resources. According to the study that was conducted in Nigeria, the corrosion and scaling conditions have been investigated by three Langelier, Ryznar, and Larson–Skold indexes. The results indicated a corrosive condition in the water sources of the studied area. It was also observed that there was a direct correlation between changes in iron concentration and these indexes [22]. In another study on the water supply system in Bandar Abbas (south of Iran), the stability conditions of water were assessed using Langelier, Ryznar, Larson–Skold, Puckorius, Marble, and aggressive test. According to the Ryznar index, in 20% of the cases, the water stability was a neutral limit, and in 80% of it tended to be corrosive. According to the Langelier index, 6.6% of the total samples were at the neutral condition, and 93.4% had a tendency to be corrosive [3]. Another research has also been conducted to examine the stability status of groundwater in the villages of Qom province (center of Iran) by assessing and comparing four indexes of water stability determination. It was found that the water condition in the studied areas was in the corrosion limitation [1]. Other work on the health of drinking water in the city of Noor Abad, Lorestan, showed that all the resources of water supply were corrosive based on the Ryznar, Puckorius, Larson–Skold and Aggression indexes [2].

Kerman province, with an area of about 181,785 km^2, is located between 25° 55′ and 32° latitude, and 53° 26′ to 59° 29′ longitude. This area has a semi-arid warm climate with an average annual rainfall of 129 mm. Therefore, considering the geographic and geological conditions and very low rainfall in this province, groundwater resources are considered as the most important resources of water supply. A large part of drinking water in this area is provided through deep and semi-deep wells, aqueducts, and fountains. With regarding problems originated from corrosion and scaling aspects of water sources, it seems to be vital that information about the water quality issue must be promoted for Kerman drinking water supply resources. However, so far, a comprehensive study has not been done on the corrosion and scaling potential of groundwater in Kerman province, Iran. Thus, the aim of this study was to analyze the physical and chemical characteristics and corrosion and scaling potential of the drinking water resources of Kerman province in accordance with Langelier, Ryznar, Puckorius, Larson–Skold, and Aggression indexes.

2. Materials and methods

2.1. Study area

This descriptive cross-sectional study investigated the corrosion and scaling potential of the groundwater aquifers extracted through deep and semi-deep well, aqueduct, and fountain in Kerman province. These resources are applied to supply drinking water. The location of the Kerman province in Iran, as well as the cities of the province, from which the samples were collected, is shown in Fig. 1.

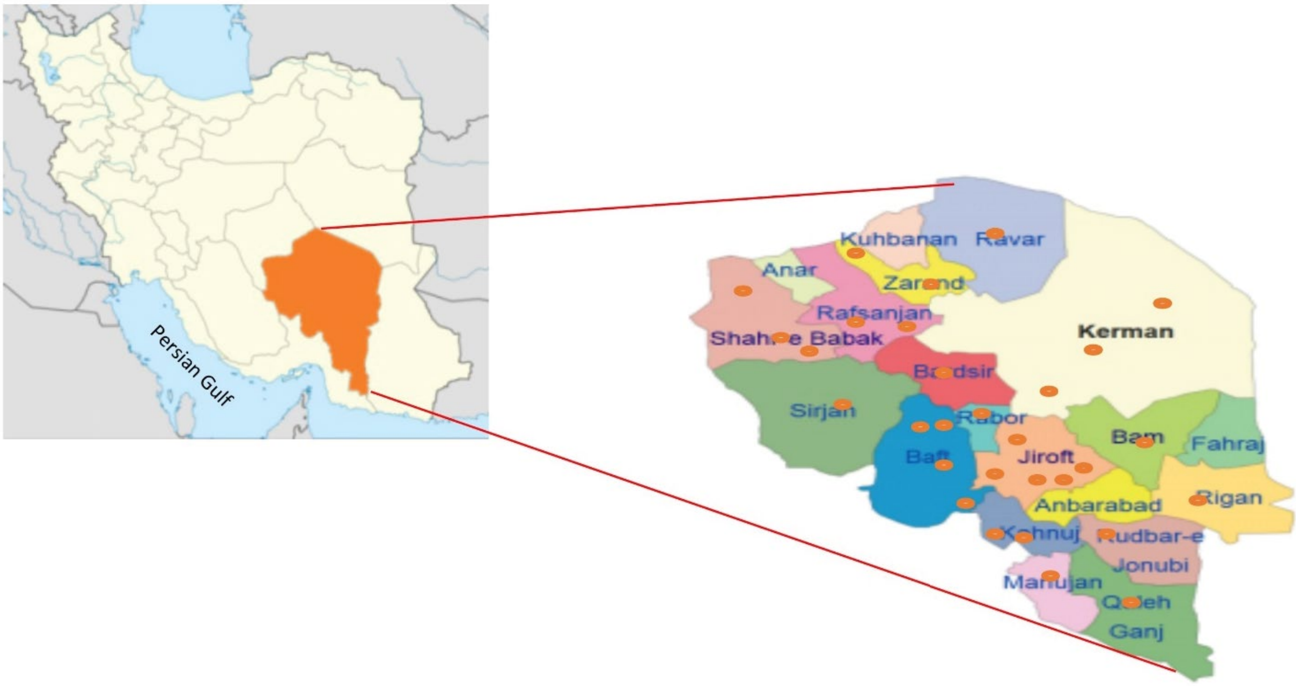

Fig. 1. Location of Kerman province and their cities in Iran.

2.2. Water sampling

In order to determine the corrosion and scaling indexes, the water quality data, including 11,767 experiments, were obtained from the Iran Water Resources Management Company (IWRMC) for all the seasons from March 2015 to March 2016. The sampling was carried out as monthly in each station and based on the quality analysis performed in IWRMC, the obtained data presented the values of carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), chlorine (Cl^-), sulfate (SO_4^{2-}), hardness, alkalinity, pH, and temperature over the study period. In the company, the sampling and analyzing tests have been carried out in accordance with the instructions given in the book of the Standard Methods for the Examination of Water and Wastewater [Federation, 2005 #19]. Some factors such as electrical conductivity (EC), pH, and temperature were measured at sampling point (in situ) by Water Checker U-10 and other parameters were analyzed at a laboratory. In addition, the parameter TDS was computed based on the following equation:

$$TDS = 0.55 - 0.7EC \quad (1)$$

2.3. Determination of corrosion and scaling trend

The purpose of analysis of the values of the variables was to compare the water quality of the studied area in the aspect of stability characteristic with the drinking water indices and became aware of the water quality conditions. In this study, some of these variables were utilized to develop Langelier, Ryznar, Puckorius, Larson–Skold, and Aggression indexes programmed in Excel software (2010). The studied indexes based on their variation limitations and their associations to the corrosion and scaling conditions were divided into several levels. A summary of how to calculate studied indexes and other information is given in Table 1.

2.4. Statistical analysis

Chi-squared test implemented by SPSS (version 16) at the 95% confidence level was employed to compare the study areas in terms of corrosion and scaling condition.

3. Results and discussion

Corrosion and scaling phenomena are the most important problems associated with the supply of drinking water. In addition, these phenomena can cause undesirable health effects as well as adverse economic consequences [23,24]. According to the studies, derivatives produced from corrosion of water types of equipment, reservoir tanks, and distributing pipes surfaces can accumulate or precipitate in the distribution networks and ultimately protect microorganisms from the effects of disinfectants. The proliferation of these microorganisms results in a number of problems such as producing the unfavorable taste and smells, and encouraging the corrosion intensification [24,25]. Table 2 shows the average and standard deviation values of the physical and chemical parameters of the water samples collected from groundwater resources.

The results related to the studied sites exhibited that the mean values of the parameters in comparison with the standard values recommended by national guideline fluctuated from favorable or permissible limits to impermissible limits. However, pH levels for all the studied areas were in the favorable limit (7–8 given by WHO [26]), and temperature values were in the desirable limit in esthetic aspects.

Table 1
Calculation indexes of corrosion and scaling potential in the groundwater resources of Kerman province [9]

Index	Calculation formula	Index value	Water stability
Langelier	LSI = pH – pH_S	LSI > 0	Corrosive
		LSI = 0	Neutral
		LSI < 0	Saturation
Ryznar	RSI = $2pH_S$ – pH	RSI < 4	Highly saturation
		5 < RSI < 6	Saturation
		6 < RSI < 7	Neutral
		7 < RSI < 7.5	Corrosive
		7.5 < RSI < 8.5	Highly corrosive
Puckorius	PSI = 2(pHeq) – pH_S	PSI < 6	Tendency to initiate and progress scaling
	pHeq = 1.465 × log (T.ALK) + 4.54	PSI > 6	Tendency to corrode
Aggression index	AI = pH + Log((A^a)(H^b))	AI < 10	Highly corrosive
		10 < AI < 12	Corrosive
		AI > 12	Saturation
Larson–Skold Index (LS)	LS = (Cl^- + SO_4^{2-}/(HCO_3^- + CO_3^{2-})	LS > 1.2	Heavy corrosion
		0.8 < LS < 1.2	Significant corrosion
		LS < 0.8	Non-corrosive water
pH in saturation condition	pHs = (9.3 + A + B) – (C + D)	A = (Log_{10} (TDS) – 1)/10	
		B = –13.12 × Log_{10} (C^0 + 273) + 34.55	
		C = Log_{10} (Ca^2 as $CaCO_3$) – 0.4	
		D = Log_{10} (alkalinity as $CaCO_3$	

[a] A is the total alkalinity (mg/L as $CaCO_3$).
[b] H is the calcium hardness (mg/L as $CaCO_3$).

In this study, a remarkable percentage of samples revealed that the values of TDS and EC were higher than the permissible limit. TH in 34.48% of samples was higher than the permissible limit. It was emphasized in the former studies; TH in high levels in water could be deposited and finally cause the obstruction of pipes and then limit the use of this type of water in the boilers [27].

In the survey of Na^+, Cl^-, SO_4^{2-} concentrations, it was observed that 51.72%, 31.3%, and 34.48% of samples had a concentration higher than the permissible limit. The increment of Cl^-, SO_4^{2-} of water can result in an increase in corrosion intensity [22,28].

The obtained results revealed that the presence of the agents producing TH and ALK in the water and the influence of factors such as Cl^-, SO_4^{2-} can be suggested as the main reason of the tendency of the samples to be corrosive [22].

Overall, assessing the values of the parameters to describe which study site has water that is corrosive, scaling or not is difficult. So that for this propose, Langelier, Ryznar, Puckorius, and Aggression indices were applied, and their results with respect to studied areas were described in Figs. 2–4, respectively.

The corrosion or deposition properties of water could be evaluated with Langelier index. Langelier index for 89.7% of the areas was in the range of corrosive condition and 10.3% was in the scaling limitation (Fig. 2). The comparison of the mean difference insignificance in a view of the corrosion, stable and scaling conditions is shown in Table 3. Chi-square test indicated a significant difference in the corrosion in comparison with the scaling conditions ($p < 0.05$). Alternatively, Fig. 2 appropriately confirmed these results.

The Ryznar index can be used for determining the corrosion severity in the water tubes. The main factors for determination of corrosivity or scaling potential of the water are the capacity of buffer for groundwater. In the study of Ryznar index, it was observed that this index was in a corrosive range (75.9% of the study areas), the corrosive range (17.2% of the areas), and the neutral and stable ranges for the other areas (Fig. 3). Chi-square test for this index showed significant differences among the observed number areas in the highly corrosive and corrosive and stable conditions ($p < 0.05$), as summarized in Table 3.

The Puckorius index can be given the water with scaling and/or saturated state [29]. In the study of Puckorius index as seen in Fig. 4, results illustrated that in 96.6% of the samples, water stability tended to be corrosive, and in other areas (3.4%) tended to be precipitative. Moreover, it can be seen from Table 3 that the Chi-square test confirmed the significant differences between the number of water samples in the corrosion and scaling conditions ($p < 0.05$).

Also, the Aggression index results were similar to the above results related to the other studied indexes [30]. In this way, the highest percentage, 72.4% of samples, assigned to the corrosion conditions and the other samples were in the scaling range. Fig. 5 exhibits the difference between the number of areas with water having corrosion and scaling conditions confirmed by the Chi-square test ($p < 0.05$; Table 3).

Table 2
Average amounts of physical and chemical parameters for the groundwater sampling locations

City	T (°C)	pH	TDS (mg/L)	EC (µs/cm)	TH (mg/L)	T.ALK (mg/L)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Na^{+} (mg/L)	Cl^{-} (mg/L)	SO_4^{2-} (mg/L)
Dovlat-Abad	20.0 ± 0.9	7.7 ± 0.8	884.2 ± 879.6	1,410.8 ± 1,318.3	355.5 ± 317.1	221.7 ± 58.7	65.0 ± 45.9	46.9 ± 51.5	182.6 ± 227.0	189.3 ± 269.0	291.7 ± 388.2
Sooghan	22.0 ± 0.6	8.0 ± 0.1	357.5 ± 130.2	547.7 ± 198.5	200.8 ± 63.9	178.5 ± 27.3	30.6 ± 11.6	30.2 ± 12.7	39.3 ± 20.7	52.6 ± 31.0	63.2 ± 51.0
Deh-Kohan	22.0 ± 0.7	7.6 ± 0.4	435.4 ± 252.0	713.3 ± 333.9	221.5 ± 70.6	189.8 ± 28.2	47.0 ± 15.6	25.2 ± 10.2	69.5 ± 48.7	95.1 ± 90.8	79.6 ± 47.9
Faryab	21.1 ± 0.7	7.9 ± 0.3	864.4 ± 577.1	1,459.4 ± 815.9	230.7 ± 120.5	178.5 ± 55.6	49.3 ± 29.3	26.1 ± 17.1	248.1 ± 161.2	248.2 ± 183.6	261.9 ± 193.6
Shahr-Babak	20.0 ± 0.7	7.5 ± 0.3	2,911.6 ± 1,678.3	4,458.0 ± 2,573.8	1,019.4 ± 659.1	233.8 ± 121.9	274.6 ± 185.2	80.9 ± 56.8	665.6 ± 417.6	1,114.7 ± 885.8	674.1 ± 356.8
Khation-Abad	24.0 ± 0.5	7.5 ± 0.6	3,110.6 ± 3,087.9	4,758.4 ± 4,723.9	1,041.8 ± 1,058.9	229.8 ± 119.4	291.6 ± 304.8	76.0 ± 77.2	808.0 ± 877.3	1,335.3 ± 1,544.8	698.6 ± 793.1
Sirjan	21.0 ± 0.3	7.7 ± 0.9	3,114.0 ± 4,003.7	4,785.0 ± 5,916.0	851.7 ± 936.5	190.6 ± 40.8	183.7 ± 204.2	95.4 ± 109.6	964.8 ± 1495.8	1,525.8 ± 2477.9	614.4 ± 667.4
Rodbar-Jirof	22.0 ± 0.1	7.7 ± 0.2	1,232.0 ± 785.9	2,086.1 ± 1,149.0	313.7 ± 208.2	225.5 ± 65.3	72.3 ± 49.8	32.3 ± 24.3	367.4 ± 217.8	336.8 ± 244.1	432.7 ± 288.9
Faryab-Sharghi	20.0 ± 0.6	7.8 ± 0.2	560.5 ± 320.7	859.7 ± 493.5	201.1 ± 77.5	230.4 ± 56.2	48.3 ± 18.3	19.6 ± 9.2	114.4 ± 99.8	83.9 ± 112.6	135.6 ± 106.5
Jiroft	21.0 ± 0.1	7.7 ± 0.1	616.4 ± 378.1	952.2 ± 582.6	234.2 ± 127.9	195.3 ± 48.9	61.6 ± 40.1	19.4 ± 10.1	120.3 ± 101.6	116.9 ± 141.2	163.4 ± 131.9
Sfandaghi	19.0 ± 0.6	7.8 ± 0.3	497.6 ± 271.9	761.3 ± 416.3	208.1 ± 87.4	222.6 ± 42.7	51.6 ± 24.5	19.3 ± 9.7	89.4 ± 70.5	59.0 ± 59.0	129.6 ± 140.0
Bzahnajn	20.1 ± 0.6	7.9 ± 0.3	347.0 ± 84.8	531.8 ± 130.1	192.3 ± 26.5	228.8 ± 29.0	45.0 ± 7.5	19.4 ± 6.8	37.8 ± 22.2	25.6 ± 16.9	48.9 ± 36.7
Baft	18.1 ± 0.7	7.8 ± 0.4	755.3 ± 270.6	1,156.3 ± 412.7	372.4 ± 127.0	364.3 ± 62.7	57.0 ± 18.1	55.8 ± 23.7	110.8 ± 99.2	94.4 ± 63.9	173.0 ± 142.0
Dashtab	21.0 ± 0.6	7.8 ± 0.3	1,033.6 ± 625.0	1,583.8 ± 959.9	390.5 ± 229.4	205.4 ± 35.1	78.9 ± 45.3	47.0 ± 30.2	201.4 ± 157.0	212.2 ± 199.8	343.4 ± 271.8
Soltani	20.0 ± 0.7	7.8 ± 0.4	256.0 ± 84.7	392.9 ± 130.1	175.3 ± 52.3	207.3 ± 63.3	39.2 ± 15.1	18.8 ± 8.8	14.6 ± 8.2	13.5 ± 6.5	17.8 ± 17.7
Radbar	21.0 ± 0.7	7.8 ± 0.4	280.1 ± 114.3	428.8 ± 175.8	183.6 ± 63.4	176.7 ± 55.7	47.0 ± 16.8	16.1 ± 8.7	16.9 ± 14.2	19.1 ± 12.0	46.4 ± 39.7
Sorab-Hill	22.1 ± 0.1	7.7 ± 0.3	242.4 ± 56.0	371.3 ± 86.0	172.8 ± 38.5	188.4 ± 54.8	48.0 ± 16.4	12.8 ± 3.3	10.0 ± 3.6	10.7 ± 2.5	24.0 ± 10.2
Degh-Sarjangal	20.8 ± 0.8	7.8 ± 0.2	1,566.5 ± 631.2	2,410.0 ± 971.0	567.5 ± 140.1	233.3 ± 41.8	124.5 ± 41.0	62.3 ± 10.4	312.8 ± 173.5	276.9 ± 185.2	642.0 ± 288.7
Rabar	21.0 ± 0.7	7.5 ± 0.3	4,911.4 ± 3,828.4	7,520.5 ± 5,852.7	1,447.7 ± 1,195.2	200.2 ± 45.8	284.6 ± 240.2	178.9 ± 150.4	1,379.0 ± 1,244.2	2,201.4 ± 2,099.0	1,126.6 ± 952.0
Shahdad	20.0 ± 0.6	7.6 ± 0.4	2,115.2 ± 784.1	3,238.3 ± 1,200.5	798.2 ± 250.7	201.6 ± 105.9	147.0 ± 52.1	104.7 ± 33.8	452.0 ± 221.3	614.1 ± 362.6	716.4 ± 253.4
Bam Narmashir	20.1 ± 0.8	7.8 ± 0.4	743.0 ± 837.4	1,300.5 ± 1,288.5	213.7 ± 202.6	219.9 ± 114.1	51.8 ± 45.5	20.5 ± 23.7	213.4 ± 235.3	219.1 ± 350.0	180.9 ± 169.4
Rayn	21.0 ± 0.7	7.0 ± 0.5	1,680.1 ± 918.1	2,812.3 ± 1,247.2	828.5 ± 351.4	626.2 ± 356.2	191.2 ± 73.3	85.2 ± 49.3	324.6 ± 192.0	473.2 ± 350.0	339.5 ± 214.8
Saradoeye	20.0 ± 0.4	7.7 ± 0.7	325.8 ± 173.8	504.0 ± 260.4	178.1 ± 63.9	215.0 ± 67.5	45.7 ± 17.1	15.5 ± 7.0	39.4 ± 43.8	25.3 ± 27.5	49.0 ± 57.1
Rahmat Abad	19.0 ± 0.7	7.5 ± 0.4	1,086.7 ± 581.0	1,663.4 ± 890.6	282.5 ± 137.3	162.4 ± 48.6	73.1 ± 40.5	24.3 ± 14.3	267.2 ± 169.2	333.5 ± 235.2	248.7 ± 150.3
Rafsanjan	21.0 ± 0.6	7.5 ± 0.5	3,796.3 ± 2,823.1	5,856.6 ± 4,339.0	1,283.9 ± 1,290.5	233.8 ± 162.1	247.9 ± 260.0	161.4 ± 163.1	946.7 ± 718.6	1,744.6 ± 1,703.4	660.7 ± 415.0
Arnan Dehej	20.9 ± 0.3	7.7 ± 0.3	642.1 ± 292.4	983.2 ± 448.1	266.3 ± 93.9	258.7 ± 69.0	64.7 ± 27.4	25.4 ± 9.9	112.1 ± 77.0	89.4 ± 74.7	163.9 ± 92.5
Bardsir	18.0 ± 0.8	7.3 ± 0.5	1,258.3 ± 787.3	1,927.9 ± 1,206	508.5 ± 320.5	397.0 ± 277.8	110.6 ± 77.5	56.4 ± 42.3	244.7 ± 192.3	342.2 ± 317.5	223.5 ± 185.4
Siriz-Toghrol	20.0 ± 0.6	7.5 ± 0.8	5,610.9 ± 4,108.9	9,000.8 ± 6,057.2	1,929.8 ± 1,419.7	242.7 ± 60.6	334.8 ± 258.1	265.5 ± 198.6	1,639.8 ± 1,192.7	2,565.7 ± 2,045.7	1,602.2 ± 1,071.0
Zarand	21.0 ± 0.6	7.3 ± 0.4	3,067.1 ± 1,934	4,695.5 ± 2,951	1,188.2 ± 696.9	331.8 ± 169.1	218.1 ± 131.3	156.2 ± 96.1	694.5 ± 545.3	1,061.1 ± 944.9	887.4 ± 510.7

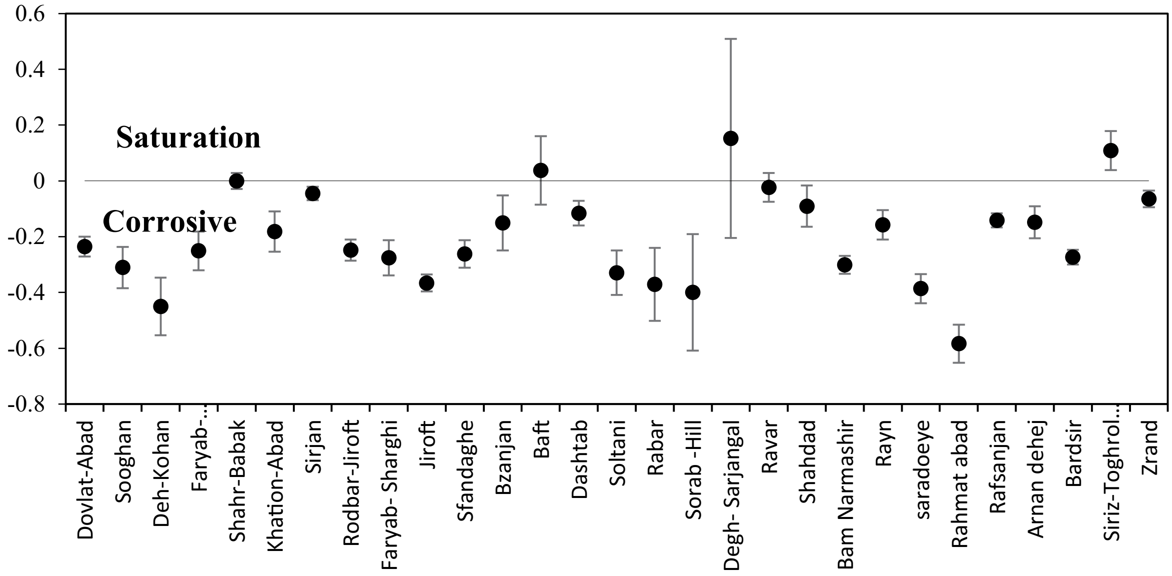

Fig. 2. Variations of the average and confidence interval ($p < 0.05$) of the Langelier index compared with the stable condition in sampling locations.

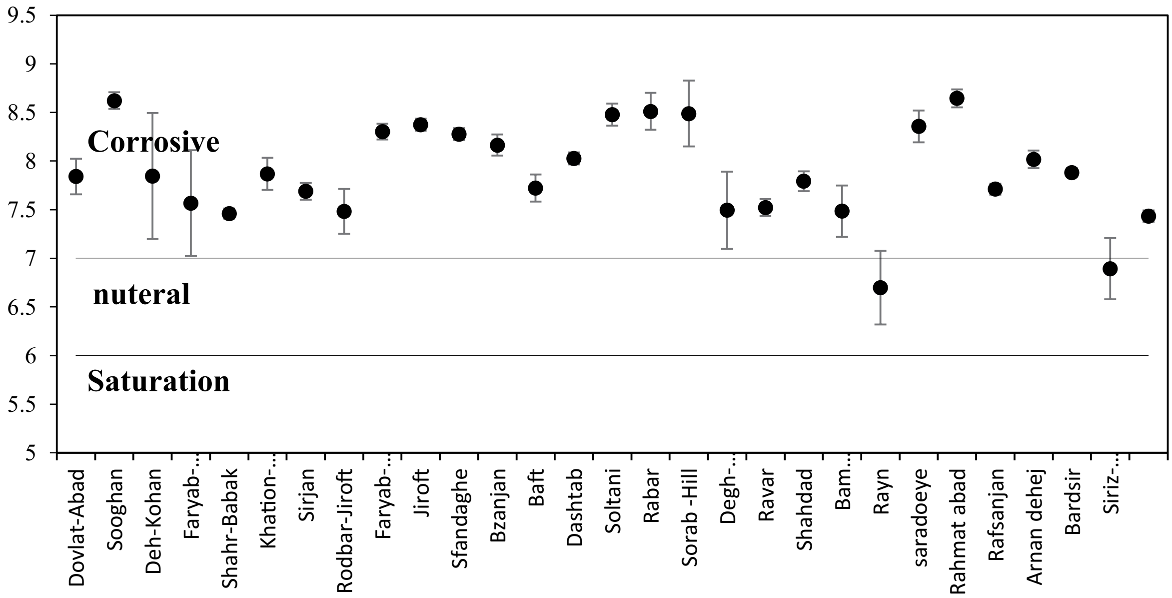

Fig. 3. Variations of the average and confidence interval ($p < 0.05$) of Ryznar index compared with the stable condition in sampling locations.

Chloride and sulfate anions could make the corrosivity properties for waters. These anions were the main reason for the corrosion of water in the studied area. Larson–Skold was modified for comprehending the tendency of water toward corrosivity in cast-iron and steel pipes at pH between 6.6 and 8.8. This index was important due to selection of proper pipe in distribution network. Most cities in studied area (more than 90%) showed corrosivity according to the LS index (Fig. 6). In general, the results revealed that the water used for the drinking purposes in the most studied areas in Kerman province was in the range of producing corrosion. The results of this study were inconsistent with the results of other studies in Iran. The results of the study on the drinking water of Yasuj (Iran) showed that the average of Aggression, Puckorius, and Larson index were 13.58, 8.11, and 29, respectively. These results indicated mild corrosion of the water [28,31]. On the other hand, a study of the evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water samples in Kadkan aquifer, Khorasan, showed that the mean values of indexes obtained for LSI, RSI, PSI, and AI indexes were 0.022 ± 0.12, 7.71 ± 0.2, 12.04 ± 125.0, and 1.7 ± 0.445, respectively. According to the results, the tendency to corrosion for these indexes (LSI, RSI, PSI, and AI) were 40%, 100%, 93.3%, and 33.3%, respectively [32]. Study

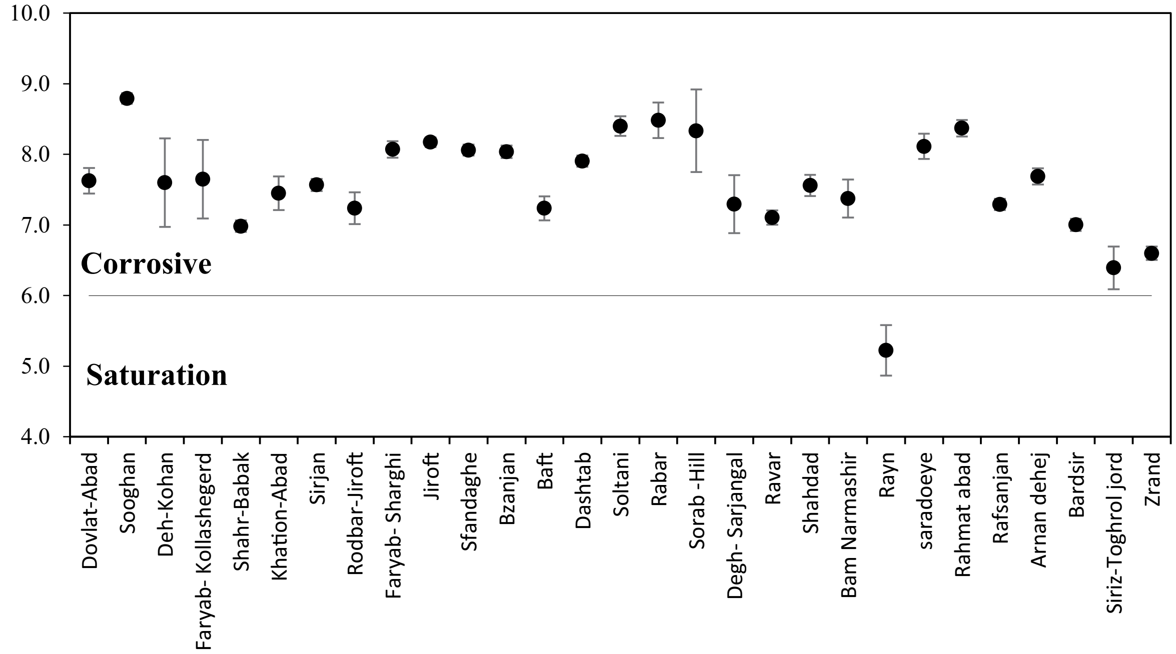

Fig. 4. Variations of the average and confidence interval ($p < 0.05$) of the Puckorius index compared with the stable condition in sampling locations.

Table 3
Comparison of difference among the number of corrosions, stable, and scaling samples

Corrosion and scaling index	Langelier	Ryznar	Puckorius	Larson–Skold	Aggression index
Chi-squared	18.241	24.069	25.138	16.9	5.828
p-value	0.05>	0.05>	0.05>	0.05>	0.05>

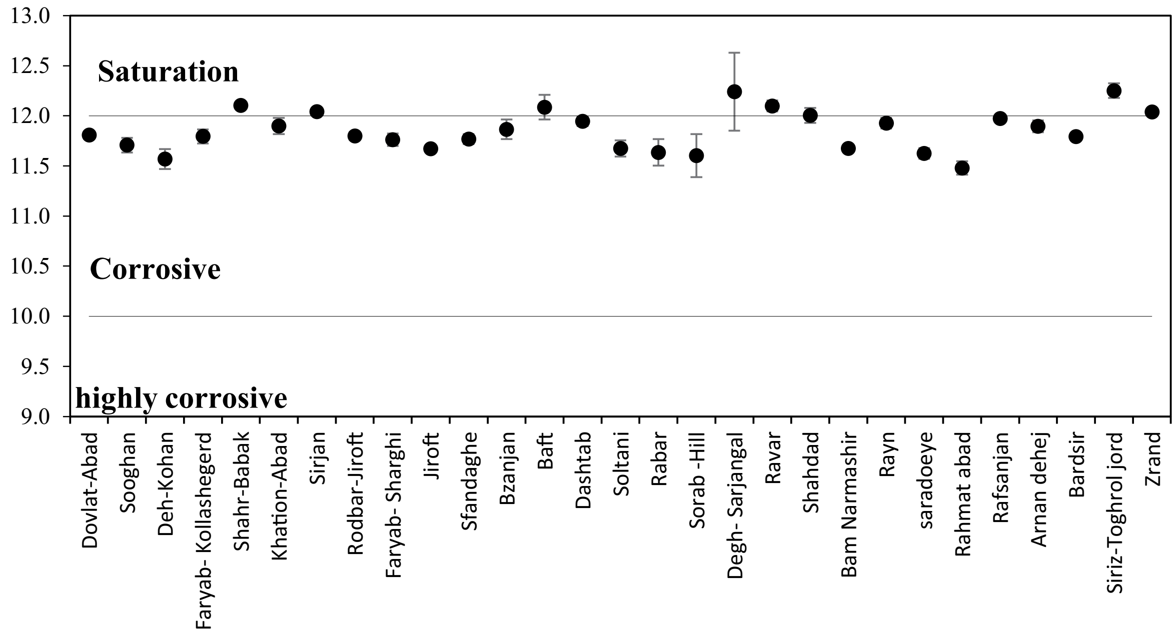

Fig. 5. Variations of the average and confidence interval ($p < 0.05$) of the Aggression index compared with the stable condition in sampling locations.

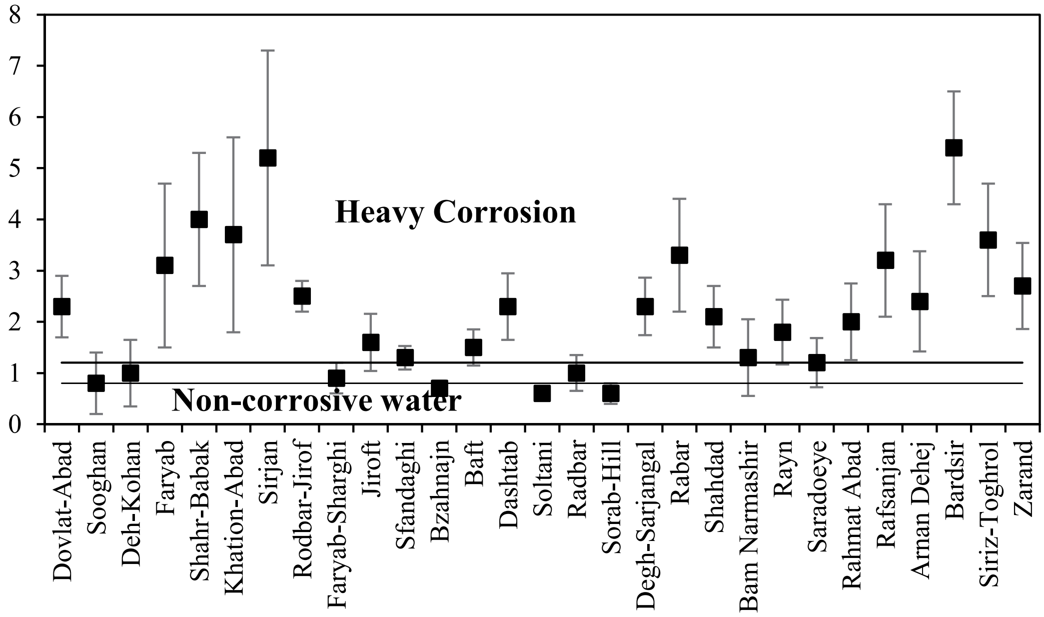

Fig. 6. Variations of the average and confidence interval ($p < 0.05$) of the Larson–Skold index compared with the stable condition in sampling locations.

of evaluation of corrosion and scaling tendency indices in the water distribution system in Torbat Heydariye city (east of Iran) found that corrosion tendency in the water network was 40%, 100%, 93.3%, 94%, and 33.3% according to LSI, RSI, PSI, LS, and AI, respectively [33]. In the same study, evaluation of the potential of scaling and corrosion formation index showed that Langelier index had the negative value from –0.39 to –1.5 and the Ryznar index was 8.7 to 9.8, too [34].

4. Conclusion

The present study was carried out to assess the drinking groundwater resource in province Kerman, Iran, in terms of water quality by some physical and chemical parameters, and corrosion and scaling potential through Langelier, Ryznar, Puckorius, and Aggression indexes. It was observed that the mean values of the parameters in comparison with standards recommended by national guideline were a different quality from favorable or permissible limits to impermissible limits. However, pH levels for all the study areas were in the favorable limit, and temperature values were in a desirable limit in an esthetic aspect. In the evaluation of stability of water, the results of indexes revealed that the water used for drinking purposes in the most study areas of Kerman province was in corrosive range. Thus, considering the economic and health damages resulting by these two phenomena of scaling and corrosion by water, stabilizing operations such as adjusting pH by lime and monitoring processes seem to be essentially required.

Acknowledgment

The authors would like to thank the authorities of Tehran University of Medical Sciences for their comprehensive support for this study.

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