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Evaluation of corrosion and scaling potential of drinking groundwater in Gonbad-e Kavus

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ABSTRACT

The present study has been undertaken to assess the corrosion and scaling potential of groundwater quality in Gonbad-e Kavus. The water quality indicators used were temperature, pH, total hardness, electrical conductivity, total dissolved solids (TDS), Cl^-, SO_4^{2-}, and Ca^{2+}. The important of water quality indices including Langelier saturation index (LSI), the Ryznar stability index (RSI), aggressiveness index (AI), Puckorius scaling index (PSI), and Larson–Skold index (LRI) has been investigated for 20 water wells supplying the drinking water of study area in 2018. The mean values of LSI, RSI, AI, PSI, and LRI were obtained to be 0.15 ± 0.01, 7.0 ± 0.06, 10.12 ± 1.49, 6.18 ± 0.08, and 0.41 ± 0.05, respectively. The result of the preset study showed that all water resources in Gonbad-e Kavus were corrosive based on the RSI, AI, and PSI indices. But according to LSI, water of the resources was scale forming. LRI index was in not corrosive condition. Therefore, water in these areas will need a special attention. This study demonstrated the application of water quality indices for the estimation water chemical stability and appeared to be promising techniques regarding water quality management that would be useful to environmental experts and policymakers for proper management and treatment of water.

Keywords: Drinking water; Corrosion and scaling; Water quality indices; Gonbad-e Kavus; Iran

1. Introduction

Adequate and safe quality of water is essential for human life and its quality is a matter of universal concern since it provides a basis for economic development and ecological integrity [1–3]. As noted above, water quality deterioration has become a serious issue in many regions of the world both in developing and developed countries [4,5]. Thus, many freshwater resources may become scarce in the near future, which would endanger water resource use, especially for drinking water and economic development purposes. Therefore, groundwater quality should be regularly monitored for drinking purpose and domestic and industrial uses so that health risks from contaminants resulted from human activities (e.g., agricultural, urban, and industrial activities) and natural processes (e.g., weathering, precipitation, soil erosion, etc.) can be reduced by appropriate treatment techniques [6,7]. Two major problems of water are the possibility of corrosion and scale [8–12]. Internal corrosion of metal pipes is usually seen in water distribution systems of many communities [13–16]. Corrosion occurs when water reacts with or dissolves metal plumbing [17,18]. Corrosion may cause the leaching of contaminants which increase

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the concentrations of metals in drinking water [19–21]. The type of pipe materials in the water supply system determine which contaminants are most likely to be found in drinking water [22]. The main contaminants of concern for human health that can leach in drinking water supply system are aluminum, antimony, arsenic, bismuth, cadmium, copper, iron, lead, nickel, selenium, tin, vinyl chloride, and zinc [23–25]. Furthermore, corrosive water may increase the deterioration and damage of the pipes, increase amount of leaks, make stain in laundry, induce bitter taste to water and increase the levels of metals and other impurities in water [26–29]. The accumulation of corrosion scales inside the pipes provides habitation for pathogenic and opportunistic bacteria increasing the infections of gastrointestinal tract, skin, and lymph nodes in human. Some factors including water quality parameters such as (e.g., pH, temperature, aqueous ions, and alkalinity) and types of applied pipe in which water flows affects on the magnitude and the rate of scaling and corrosion [30–32]. When water contain high levels of calcium carbonate, the rate of building scales on the internal surfaces of pipes increase. Low levels of scales protect the internal surfaces of pipe against corrosion. But, high levels of scaling is problematic which result in reduced efficiency of hot-water heaters, reduced, or blocked flow to appliances or increased the water head loss, and leaky valves [33]. Scaling deposit a layer of minerals inside pipe walls and reduces or prevents corrosion of metallic surfaces. When scale extremely grows, it may clog pipes. Thus, the most preferable water is one that is just slightly scaling [34,35]. To the best of our knowledge, there was no information about corrosion and scaling potential, which describes various indices to estimate the scale formation (protective layer), and corrosivity of water in Gonbad-e Kavus. Therefore, in this paper, the most common indices of water quality such as Langelier saturation index (LSI), Ryznar stability index (RSI), aggressiveness index (AI), Puckorius scaling index (PSI), and Larson–Skold index (LRI) has been investigated for evaluating corrosion and scaling potential of 20 water wells of Gonbad-e Kavus.

2. Materials and methods

2.1. Study area description, data gathering, and analysis

This cross sectional study was performed in Gonbad-e Kavus County. Gonbad-e Kavus County is located in the province of Golestān in the northeast of Iran. It covers an area of 5,071.32 km^2. Its population was 325,789 in 2011 census. All people in the area of the country have access to piped water and rely on groundwater for domestic use. Map of sampling sites in Gonbad-e Kavus is shown in Fig. 1. The parameters including temperature, pH, total hardness, electrical conductivity (EC), total dissolved solids (TDS), Cl^-, SO_4^{2-}, and Ca^{2+} of 20 water wells supplying the drinking water of study area were measured in 2018. The values of pH and temperature of each sample were taken in the sampling sites. Totally 40 samples (two samples from each well) were taken during 2018. The samples were stored in an ice box at 5°C, transported to the chemistry laboratory, and analyzed for total hardness, EC, TDS, Cl^-, SO_4^{2-}, and Ca^{2+} within 24 h using standard methods of APHA [36]. The values of EC were measured using conductometry. Total hardness, Cl^- and Ca^{2+} are measured using titrimetric method. SO_4^{2-} was analyzed by a spectrophotometry (DR 5000; HACH, Cananda). Finally, the average values were reported. The analysis of the data was done using Excel software.

2.2. Water quality indices

In this study the applicability of LSI, the RSI, AI, PSI, and LRI for the characterization of the corrosive characteristics of drinking water is explored.

The LSI can be obtained from the following equation [12,37]:

$$LSI = pH - pHs \tag{1}$$

where pH is the actual pH value of the water, and pHs is the value of pH in saturation conditions with $CaCO_3$. pHs is calculated from the following equation [38]:

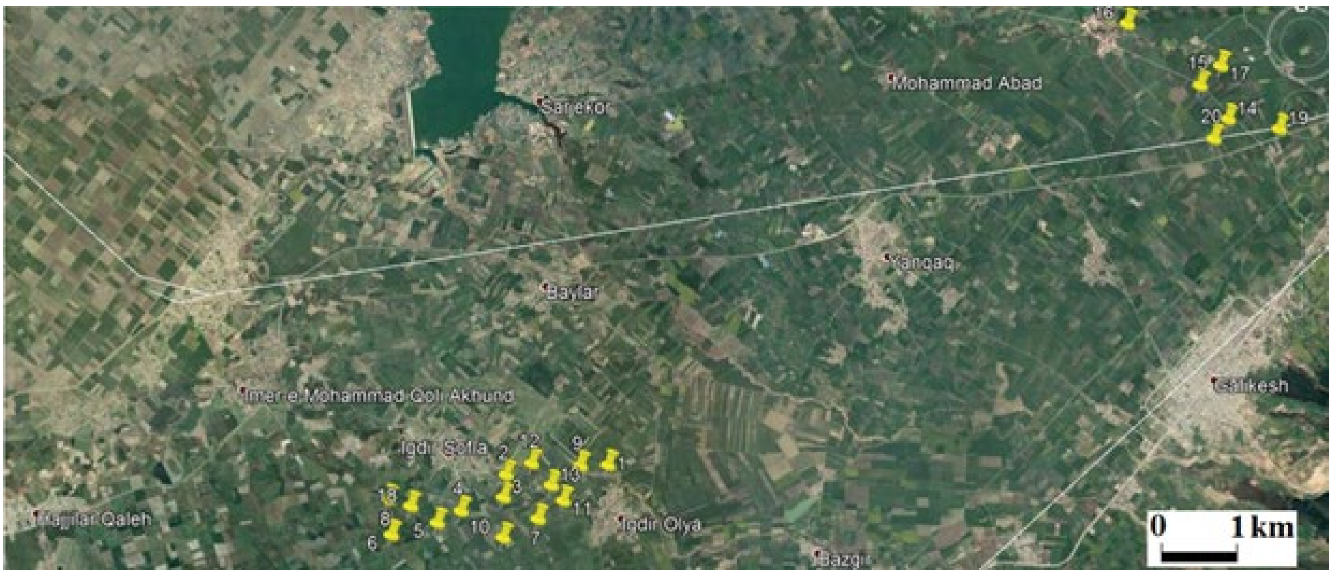

Fig. 1. Map of sampling sites in Gonbad-e Kavus.

$$pHs = (9.3 + A + B) - (C + D) \quad (2)$$

where A, B, C, and D are coefficients representing TDS in mg/L, water temperature in °C, calcium hardness in mg/L $CaCO_3$ and total alkalinity in mg/L $CaCO_3$, respectively.

For the calculation of the RSI, the following equation can be used [39,40]:

$$RSI = 2pHS - pH \quad (3)$$

where pHs and pH are mentioned above in Eq. (1).

The AI is expressed as follows:

$$AI = pH + \log[(Alkalinity) \cdot (Hardness)] \quad (4)$$

The PSI is represented as the following equation [23]:

$$PSI = 2(pHs) - pHeq \quad (5)$$

The value of pHeq can be obtained from:

$$pHeq = 1.465 \times \log[Alkalinity] + 4.54 \quad (6)$$

The LRI refers to an empirical scale applied to indicate the degree of corrosiveness of water for mild steel metal surfaces. It is obtained from the following equation [41]:

$$LRI = \frac{\left(C\left(Cl^-\right) + C\left(SO_4^{2-}\right)\right)}{\left(C\left(HCO_3^-\right) + C\left(CO_3^{2-}\right)\right)} \quad (7)$$

In this equation, the concentrations of each of the parameters should be in meq/L.

Table 1
Summary of different indices used in this study

Index	Index value	Condition
Langelier [37]	LSI > 0	Scale tendency
	LSI = 0	Neutral or at chemical equilibrium
	LSI < 0	Tendency to be corrosive
Ryznar stability [31]	RSI < 6	Scale tendency
	6 < RSI < 7	Neutral
	RSI > 7	Corrosion tendency
Aggressiveness [31]	AI > 12	Nonaggressive water
	10 < AI < 12	Moderately aggressive water
	AI < 10	Highly aggressive water
Puckorius scaling [23]	PSI < 10	Strongly corrosive
	PSI < 6	Scale tendency
	PSI > 6	Corrosion tendency
Larson–Skold [41]	LRI < 0.8	Not corrosive
	0.8 < LRI < 1.2	Corrosive
	LRI > 1.2	Highly corrosive

3. Results and discussion

After sampling LSI, RSI, AI, PSI, and LRI indices were calculated. The mean values of LSI, RSI, AI, PSI, and LRI were 0.15, 7.06, 10.06, 6.21, and 0.41, respectively. The results of analyzed parameters in Gonbad-e Kavus are given in Table 1. As shown in the Table 1, values of pH, total hardness, TDS, Cl^-, SO_4^{2-}, and Ca^{2+} were in the range of drinking water standards of Iran and the WHO.

The results of different indices are given in Table 2. The results showed that most of the parameters were within the Iranian drinking water standards and WHO guidelines. The mean value of pH was 7.4. The values of TDS, Cl^-, SO_4^{2-}, and EC were lower than the limits. The Langelier index showed that 95% of the samples were scale forming. The mean value of Langelier index was obtained to be 0.15 ± 0.01. When Langelier index in lower than zero, the water has the tendency to be corrosive, whereas Langelier index, is above zero, the water is supersaturated with respect to $CaCO_3$ and may result in the formation of a scale layer of $CaCO_3$. Malakootian et al. [42], evaluated the scaling and corrosion potential of drinking water supplied from wells and qanats in Rafsanjan and reported that the values Langelier index in 90.01% of wells and 92.21% of the studied qanats were positive and have scaling potential [42]. Since the scaling and corrosion potential of water varies with pH, temperature, calcium hardness, alkalinity, and TDS, therefore any variation of these parameters can affect the stability of water [43]. Accordingly, variations in the water quality of water resources in Rafsanjan and Gonbad-e Kavus can be the reason for difference in the water stability in these areas. Motesaddi Zarandi et al. [44] evaluated the scaling and corrosion potential of drinking water of Bojnurd, the mean value of Langelier index was obtained to be 0.42, showing the scaling potential of this water. Their study showed that 3.3% and 96.7% of water samples exhibited corrosive and scaling potential, respectively. Scale formation result in the blockage of pipes, reduce the water flow in the pipes, and increase the maintenance costs [26]. Scale creates a thermal transfer barrier which in turn requires more fuel to achieve the same heat transfer which itself increase the emission of pollutants into the environment. For example, a deposited thickness of 0.5, 1.6, and 3.2 mm of precipitated solids increase 7%, 18%, and 39% the amount of required fuel [45]. The mean value of PSI for the Gonbad-e Kavus was 6.18 ± 0.08, indicating the corrosion tendency of water. But by considering neutral pH of water in Gonbad-e Kavus, this index cannot be proposed as an appropriate index for showing the scaling and corrosion potential of water in this area. Farzadkia et al. [26], reported a corrosive water for Malekshahi city based on PSI [26]. Moreover, Zazouli et al. [46] reported a PSI of 11.85 for drinking water of Yasuj. The mean value of AI in water samples in the present study was 10.12 ± 1.49, showing a slight corrosive water for all the samples. According to Table 3, the range of RSI was 6.77–7.31 (mean 7.0 ± 0.06) and in 75% of the samples showed a corrosion tendency. In a study, the scaling and corrosion potential of water in distribution system of Bushehr was investigated and the mean value of Ryznar index was 7.24. The mean

Table 2
Summary of the stability indices used in the present study

Well NO.	LSI	Condition	RSI	Condition	AI	Condition	PSI	Condition	LRI	Condition
1	0.08	Scaling	7.19	Corrosive	12.04	Non-corrosive	6.36	Corrosive	0.45	Not corrosive
2	0.21	Scaling	6.94	Neutral	10.08	Moderately corrosive	6.01	Corrosive	0.39	Not corrosive
3	0.29	Scaling	6.83	Neutral	10.16	Moderately corrosive	5.93	Scaling	0.35	Not corrosive
4	0.08	Scaling	7.15	Corrosive	9.94	Highly corrosive	6.20	Corrosive	0.37	Not corrosive
5	–0.02	Corrosive	7.31	Corrosive	9.84	Highly corrosive	6.52	Corrosive	0.54	Not corrosive
6	0.16	Scaling	7.01	Corrosive	10.03	Moderately corrosive	6.09	Corrosive	0.38	Not corrosive
7	0.17	Scaling	7.02	Corrosive	10.03	Moderately corrosive	6.22	Corrosive	0.47	Not corrosive
8	0.17	Scaling	6.97	Neutral	10.04	Moderately corrosive	6.00	Scaling	0.39	Not corrosive
9	0.08	Scaling	7.20	Corrosive	9.95	Highly corrosive	6.31	Corrosive	0.40	Not corrosive
10	0.11	Scaling	7.16	Corrosive	9.98	Highly corrosive	6.34	Corrosive	0.53	Not corrosive
11	0.20	Scaling	7.03	Corrosive	10.05	Moderately corrosive	6.24	Corrosive	0.29	Not corrosive
12	0.12	Scaling	7.11	Corrosive	9.99	Highly corrosive	6.22	Corrosive	0.38	Not corrosive
13	0.21	Scaling	6.97	Neutral	10.08	Moderately corrosive	6.08	Corrosive	0.34	Not corrosive
14	0.14	Scaling	7.10	Corrosive	10.00	Moderately corrosive	6.29	Corrosive	0.42	Not corrosive
15	0.17	Scaling	7.03	Corrosive	10.04	Moderately corrosive	6.15	Corrosive	0.38	Not corrosive
16	0.12	Scaling	7.12	Corrosive	9.99	Highly corrosive	6.27	Corrosive	0.51	Not corrosive
17	0.17	Scaling	7.02	Corrosive	10.04	Moderately corrosive	6.09	Corrosive	0.37	Not corrosive
18	0.29	Scaling	6.77	Neutral	10.17	Moderately corrosive	5.81	Scaling	0.38	Not corrosive
19	0.15	Scaling	7.04	Corrosive	10.01	Moderately corrosive	6.16	Corrosive	0.41	Not corrosive
20	0.07	Scaling	7.18	Corrosive	9.94	Highly corrosive	6.25	Corrosive	0.39	Not corrosive

values of Langelier index, Aggressive index, and PSI were 0.28 (scale forming), 12.02 (non-aggressive water), and 7.81 (corrosive), respectively. Based on the mean values of calculated indices, the water of Bushehr was corrosive [47]. In the present study, the mean value of the Larson–Skold was 0.41 ± 0.05. Based on the index, 60% of the water samples were corrosive, 5% were scale forming, and 35% were highly corrosive. Because the index is more than 1.2, the water is highly corrosive [37]. When the value of LRI lies between 0.8 < LR < 1.2, Cl^- and SO_4^{2-} ions form a protective layer against corrosion. The higher the LRI index, the more corrosive is the water. Recently, numerous studies have been done regarding the scaling and corrosion potential of water in different areas of Iran. A survey associated with corrosion and scaling potential in drinking water resources of the villages in Qom province showed a corrosive water for all the villages [48]. In their study adjustment of water pH by adding lime in the studied areas was proposed for the formation of a protective $CaCO_3$ layer against corrosion inside the pipes [49]. The result of the preset study showed that water in Gonbad-e Kavus was corrosive based on the Ryznar, Aggressive, and Puckorius indices. But according to Langelier index, water of the resources were scale forming. LRI index showed a not corrosive condition.

The results showed that water condition obtained with the five indices lead to obtaining of some contradictory results because each of these tools work in different way. For example, LSI index sets the tendency to precipitation of $CaCO_3$ in the natural waters, RSI index is employed to study the corrosive condition of water in the water distribution systems in urban areas, while PSI index is used to determine the level of scale formation for domestic waters. The aggressive index is developed for water flowing in asbestos pipes. For AI index, the values of pH, calcium hardness, and total alkalinity were considered [18]. Since AI does not consider the influences of temperature or dissolved solids, it is less accurate as an analytical index than the LSI. The LRI is usually employed to incorporate the influences of Cl^-, SO_4^{2}, HCO_3^-, and CO_3^{2-} concentrations on the water corrosivity in steel pipes. Due to the usage of steel pipes in the distribution system of studied areas, application of the LRI is much more appropriate for these areas. Generally, the corrosion rate depends on numerous factors including the value of pH, temperature, hardness, acidity, alkalinity, residual chlorine, total dissolved solids, presence of gases (O_2 and CO_2), dissolved salts and microorganisms in water. Chemical or physical methods can be used to reduce the corrosivity of water. In chemical methods, lime, soda ash, or caustic soda is usually added, but among these lime is mostly used since it is cost effective. Sometimes, metal pipes can be replaced with nonmetals (plastic) which are non-conductive and will not corrode or use corrosion-resistant materials such as stainless steels, and special alloys in order to enhance the life span of pipes [50]. Alternatively, inner surface of pipes may be lined with portland cement or bituminous or asphaltic compounds to reduce and prevent the water from reaching the metal. Another method which is more complicated protection method is cathodic protection, which is the use of a different electrical circuit into the pipe. In this study pH adjustment or adding corrosion inhibitors like lime is proposed in wells with corrosive water to produce stable water or slightly scale-forming [43].

Table 3
Values of the analyzed parameters in water wells of Gonbad-e Kavus

No.	Temperature (C◦)	pH	Total hardness	EC (μm hos/cm)	TDS (mg/L)	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Ca^{2+} (mg/L)
1	25	7.35	236	855	505	55	84	64
2	25	7.35	308	919	533	52	84	76.8
3	25	7.4	284	916	541	38	92	78.4
4	25	7.3	244	849	501	36	88	65.6
5	25	7.28	280	800	477	54	86	70.4
6	25	7.32	320	879	515	49	76	76.8
7	25	7.36	276	834	496	45	96	78.4
8	25	7.3	312	927	543	53	86	78.4
9	25	7.36	236	886	523	43	92	57.6
10	25	7.38	228	897	543	46	120	64
11	25	7.43	244	760	445	22	74	64
12	25	7.35	244	848	501	37	88	65.6
13	25	7.39	268	879	514	36	84	68.8
14	25	7.38	236	821	489	42	90	67.2
15	25	7.38	260	875	516	42	90	67.2
16	25	7.36	264	902	537	42	120	67.2
17	25	7.35	272	900	531	40	90	68.8
18	25	7.35	340	975	571	52	90	88
19	25	7.33	292	842	497	38	94	75.2
20	25	7.32	232	872	519	40	92	60.8
Mean ± SD	25 ± 0	7.35 ± 0.02	268.8 ± 2.8	871.8 ± 12	515 ± 9.9	43.1 ± 10.6	90.8 ± 5.65	70.16 ± 2.26
Minimum–maximum	25–25	7.28–7.43	228–340	760–975	445–571	22–55	74–120	57.6–88
WHO (2008)	–	6.5–8.5	100–500	–	500–1,500	200–600	200–400	75–200
Iranian standard	–	6.5–8.5	200–500	–	1,000–1,500	250–400	250–400	300

4. Conclusions

Determination of the scaling and corrosion potential of water in the distribution system seeks to preserve the basic characteristics of water during its conveyance from the point of production and treatment to the communities. In the present study, the corrosion or scale forming potential of the water samples is assessed using five indices including LSI, RSI, AI, PSI, and LRI indices for a number of 20 wells used for water supply of Gonbad-e Kavus, Iran. The results of this study showed that the same sample of water can present the tendency for corrosion using an index, but at the same time it can present scaling tendency by using another index. The result of the preset study showed that all water resources in Gonbad-e Kavus were corrosive based on the RSI, AI, and PSI. But according to LSI, water of the resources was scale forming. LRI index was in not corrosive condition. Due to the usage of steel pipes in the distribution system of studied areas, application of the LRI is much more appropriate for these areas. Water flowing in distribution system should be in stable form regarding its compositional and physical attributes. Thus, more studies are necessary to determine if corrosion or scaling is observed on pipes of the water distribution system. Since the corrosion estimation caused by the water is based solely on the physical chemical parameters given by LSI, RSI, and LRI; this may not be so exact, therefore, considering other parameters or conditions of a typical water, such as levels of dissolved oxygen, residual chlorine and temperature are vital. When water is corrosive, water quality control and replacement of distribution pipes in development of water network should be carried out.

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