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Investigation of Corrosion and Scaling Potential in Drinking Water in Rafsanjan, Iran

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ABSTRACT

***Introduction*:** Corrosion and scaling are important factors affecting drinking water quality, causing health and economic problems. This study aimed to investigate the indicators of corrosion and scaling in Rafsanjan drinking water.

***Materials and Methods*:** The present descriptive cross-sectional study was conducted in winter 2018 and spring 2019 in Rafsanjan. The 56 samples were randomly taken from the drinking water distribution and transmission networks. Physicochemical parameters, such as pH, temperature, total dissolved solids (TDS), total hardness (TH), calcium hardness (CH), electrical conductivity (EC), and alkalinity were measured. Finally, corrosion and scaling indices, including langelier index (LI), ryznar index (RI), aggressiveness index (AI), and Puckorius index (PI) were calculated and analyzed.

***Results*:** The mean temperature, pH, CH, TH, TDS, alkalinity, and EC were 17.79 ± 0.80 °C, 8.08 ± 0.11, 56.34 ± 2.72 mg/L.$CaCO_3$, 140.86 ± 6.81 mg/L.$CaCO_3$, 530 ± 110 mg/L, 181.21 ± 13.65 mg/L, and 840 ± 180 µs/cm, respectively. The mean corrosion and scaling indices, including LI = 0.18 ± 0.12, RI = 7.72 ± 0.14, AI = 12.09 ± 0.11, and finally PI = 7.96 ± 0.10 were obtained.

***Conclusion*:** Based on the obtained data, drinking water in the transmission and distribution network of Rafsanjan has scaling properties. Water scaling and deposition causes problems, such as blockage of water transmission and distribution pipes, reduction of flow rate and increase of pressure drop in the network, and finally increase of water facilities operation costs. Therefore, measures should be considered to control the scaling of water in this region.

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Introduction

Access to safe and sufficient water is one of the criteria for development, health, and well-being in any society [1, 2]. Water quality is affected by water supply sources, treatment systems, water distribution networks, and etc. Therefore, community health and disease prevention need to identify and control the quality of drinking water resources [3, 4]. One of the effective factors in changing the physicochemical properties of water is water corrosion and scaling [5]. Factors affecting corrosion and deposition include physical factors

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(flow rate, pH, and temperature), chemical factors alkalinity, hardness, electrical conductivity (EC), dissolved oxygen (DO), and the presence of some ions, including sulfate and chloride and biological factors, which are usually affected by iron oxidizing bacteria and sulfate-reducing bacteria [6, 7].

Corrosion in water transmission and distribution systems, in addition to causing a relatively unpleasant taste and odor, dissolves some heavy metals, such as cadmium, copper, lead, and arsenic into the water, causing various diseases. On the other hand, it causes corrosion of water pipes, reducing the pump's life, valves, and tank capacity [8, 9]. Finally, corrosion and decay of water transmission and distribution systems cause water leakage, which is one of the significant causes of water losses in the water supply network [10]. Scaling is a process in which divalent cations, such as calcium and magnesium react with other water-soluble materials and form a layer in the inner pipe wall. The most common scaling layer is composed of calcium carbonate ($CaCO_3$) [9, 11]. The deposition process can cause problems, such as pipes blockage, flow rate reduction, and pressure drop increase in the network, which will also increase the water facility's operation cost [12].

Corrosion and scaling control according to the guidelines of the World Health Organization (WHO) is a necessity for providing safe drinking water in communities [3]. One of the methods for determining the drinking water's corrosion and scaling potential is the use of corrosion and scaling or stability indices [13, 14]. These indices include Langelier index (LI), Ryznar index (RI), Aggressiveness index (AI), and Puckorius index (PI), used in other studies for evaluation of water corrosion and scaling [15].

The study by Davil et al. on the investigation of corrosion potential and scaling of drinking water in Ghamsar city was performed using corrosion and scaling indices. The measuring results of effective physicochemical parameters in determining the drinking water corrosion indices in Ghamsar city were compared with existing standards [16]. The study conducted by Shahbazi et al., examined the indicators of corrosion and deposition of water in Marand-Iran. The results of these researchers showed that more than 50% of the samples in summer and spring have corrosive properties [12]. Also, Teimouri et al. assessed corrosion or scaling potential in supply sources, reservoir, and water distribution network of Kian city located in Chaharmahal Bakhtiari province, using LI and RI indicators. All effective parameters in estimating corrosion indices except mean temperature and pH were outside the standard range. Calculations related to LI and RI corrosion indices in the study showed that the mean corrosion rates were -0.68 and 8.52, respectively. The results showed that the water of Kian city is corrosive [17]. The best workable solutions for the studied water supply systems to reduce the problems caused by water corrosion can be the control of water pH and chlorination mechanism, as well as the use and installation of corrosion-resistant pipes [17].

Rafsanjan is situated in the north of Kerman province, Iran. The region has an annual precipitation of about 81 mm, and it has hot and dry climate. Sarcheshmeh copper mine, which is considered to be the second-largest copper deposit worldwide, is situated south of Rafsanjan. One of the main products of Rafsanjan is pistachio, which is known as the center of pistachio cultivation in Iran and one of the most important pistachio production areas worldwide. The rivers in this area are mostly seasonal, because of low rainfall and precipitation, indicating the dependence of the study region on groundwater. Therefore, the most important source of water supply in industrial, agricultural, and domestic sectors in Rafsanjan city is groundwater. However, in recent years, groundwater irregular water withdrawal has been growing, which has affected the groundwater of aquifer both quantitatively and qualitatively. It demonstrates the critical point of this study and the role of groundwater in the region [18, 19]. Therefore, it is necessary to study the physicochemical quality of water to determine the phenomenon of corrosion and scaling that causes health and economic damage. Therefore, in the present study, physicochemical parameters were studied as water corrosion and scaling potential in the Rafsanjan

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transmission and distribution network.

Materials and Methods

The study area

Rafsanjan is located in the central region of Iran, 110 km west of Kerman, in a low-altitude area with an area of 5459.36 Km^2. The city is located between longitudes 54° 30' to 56° 30' and latitude 29° 52' to 29 ° 15'. The region climate is arid and semi-arid, according to the De Martonne method, with an average annual rainfall of 80.3 mm.

Sampling and analysis

In this study, sampling was done randomly from reservoirs and the drinking water distribution network of Rafsanjan in winter (28 samples) and spring (28 samples) in 2018-2019. The samples were collected in polyethylene containers with 1 liter of effective volume and in accordance with the standard method. The desired parameters, including pH, temperature, total dissolved solids (TDS), total hardness (TH), calcium hardness (CH), EC, and alkalinity of the samples were measured. All the chemicals used in the study were of high purity and laboratory grade. The pH and temperature of the sample were measured at the sampling site (Hanna pH meter and temperature sensors, model HI207, made in Italy). The TDS and EC were measured using EC meter (Hanna EC meter model HI9813-5, made in Italy), and TH and CH were measured by the complexometric method using EDTA standard solution in the presence of black chromium and murexide indicator [15, 20].

Studied indicators

Corrosion and scaling indices, LI, RI, AI, and PI were used to determine the corrosion and scaling potential of water in the Rafsanjan transmission and distribution network. The reason for using different indicators was to increase the study accuracy and control the laboratory errors. Table 1 presents the studied corrosion and scaling indices.

Table 1: Corrosion and scaling indices

Indices	Equation	Interpretation		Reference
LI	LI = pH - pHs • pHs= 9.3 +A +B – C – D • A= (log_{10} TDS -1) / 10 • B = −13.12 log_{10} (T °C+273)+34.55 • C = log_{10} [Ca^{2+} as $CaCO_3$ mg/L] • D= log_{10} [Alk as $CaCO_3$ mg/L]	0 > LI 0 = LI 0 < LI	Saturated/corrosive Neutral Supersaturation/scaling	21-23
RI	RI = 2pHs - pH	6 > RI 6 < RI < 7 RI > 7	 Neutral scaling	24, 25
AI	AI = pH + log[(Alk)(H)]	AI < 10 10 < AI < 12 AI > 12	High corrosive Moderate corrosive Low corrosive	15, 26, 27
PI	PSI = 2 (pH_{eq}) –pH_s pH_{eq} = 1.465 × log10[T.ALK] + 4.54	PI < 6 PI = 6 PI > 6	Moderate corrosive Neutral scaling	15, 28

LI is one of the most common indicators for determining scaling and corrosion in water supply networks, which is based on the effect of pH on the formation of calcium carbonate scaling. The saturation pH for calcium carbonate in water is known as the saturation pH or pH, at which the pH of the protective layer is in equilibrium. This index is important because calcium carbonate is used as a protective layer, as a valuable parameter of network monitoring. RI was presented with a slight change in the LI. Based on this index, the deposition or corrosion status of the steel pipe is determined. The PI provides the maximum sedimentable scaling under equilibrium conditions or in terms of water buffering capacity. The AI was developed at the request of US consulting engineers to select the appropriate type of asbestos cement pipe and ensure the structural durability of these pipes [29, 30].

Results

To investigate the water corrosion and scaling potential of the Rafsanjan transmission and distribution network, physicochemical parameters of water, including temperature, pH, CH, TH, TDS, alkalinity, and EC were measured. Statistical indicators, such as the minimum, maximum, mean, and standard deviation (SD) of the mentioned parameters are presented in Table 2.

Then, corrosion and scaling indices were studied and calculated using the equation mentioned in Table 1. The calculations showed that the mean and SD of LI, RI, AI, PI were 0.18 ± 0.12, 7.72 ± 0.14, 12.09 ± 0.11, and 7.96 ± 0.10, respectively. Table 3 reveals the obtained statistical indices, including the minimum, maximum, mean, and SD of the studied indices.

Figure 1 shows the LI, RI, AI, and PI obtained for each of the taken water samples (58 samples in total).

Table 2: Statistical characteristics of the sampled water physicochemical parameters

Parameters	Iranian standard Optimal Value	Iranian standard Optimal Value	Unit	Max	Min	Mean	SD
T	-	-	°C	18.90	16.20	17.78	0.80
pH	6.5-9.0	6.5-9	-	8.30	7.90	8.08	0.11
Ca^{2+}	75	75	mg/L	61.60	52.00	56.34	2.72
TH	200	200	mg/L, $CaCO_3$	145.00	130.00	140.86	6.81
TDS	1000	1000	mg/L	710	420	530	110
ALK	-	-	mg/L	204.00	160.00	181.21	13.65
EC	-	-	µs/cm	1120	660	840	180

Table 3: Statistical parameters of corrosion indices and sampled water

Index	Max	Min	Mean	SD
LI	0.43	0.00	0.18	0.12
RI	7.94	7.44	7.72	0.14
AI	1234	11.93	12.09	0.11
PI	8.17	7.81	7.96	0.10

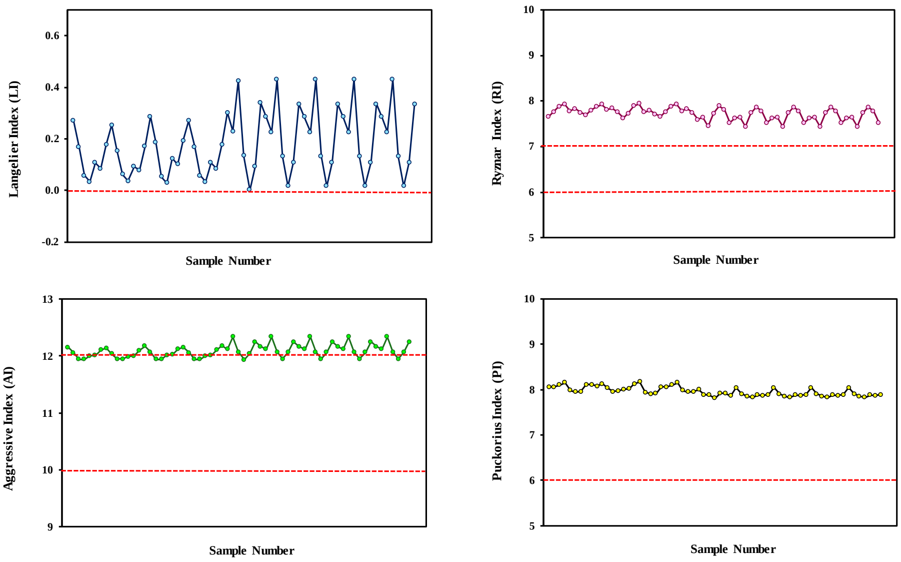

Figure 1: LI, RI, AI, and PI index versus analyzed samples

Discussion

Studies have shown that significant amounts of treated water are wasted as a result of pipe leaks in the water distribution networks. The water loss rate in some countries, such as Iran is more than 20% [31]. One of the effective factors in water loss is leakages caused by corrosion of water distribution systems. Therefore, monitoring the chemical quality of water and controlling its equilibrium can increase the useful life of water supply facilities and reduce the possibility of water leakage and waste to a large extent [32]. These requirements are very important in water-scarce countries, such as Iran. On the other hand, scaling in the inner wall of pipes is one of the important issues that cause distribution systems pressure drop and in addition to consumer dissatisfaction will impose high pumping costs for distribution systems. These conditions also reduce the efficiency of distribution systems as well as the efficiency of heating systems and hot water suppliers [15,33].

Comparison of the studied physicochemical parameters with the WHO standards showed that the pH and temperature parameters are within the desired range of the set standard. However, the mean CH, TH, and TDS of the samples were lower than the desired level. The study results on LI showed that more than 99% of the samples had the LI above zero. According to the LI interpretation, when this index is higher than zero (LI < 0), water has scaling and supersaturation properties. Therefore, according to this index, the studied water samples showed water scaling evidence in the transmission and distribution network.

In the RI interpretation, when the index is less than 6, water has a corrosion effect, and when it is between 6 and 7, water has no scaling and corrosion properties. In other words, the water is balanced, and when it is more than 7, it has scaling properties. The results obtained for the RI showed that all the samples had an index higher than 7 (RI > 7). The AI results showed that 23% of the samples had an index value in the range of 10 to 12, and 77% had greater than 12. As stated in the interpretation of this index, when the index is 10 < AI < 12, water has moderate corrosion, and when it is more than 12, water has low corrosion. Therefore, it can be concluded that the water of Rafsanjan city has low corrosion based on this index. It should be noted that this index is only for asbestos-cement pipes in the distribution network, so it is not a suitable indicator for the part of the network that has galvanized pipes [30].

The obtained results in the case of PI showed that 100% of the samples had a PI value higher than 6. Therefore, when the index value is more than 6, the studied water has scaling properties. It should be noted that the PI is more accurate and appropriate for waters with a pH > 8 than other indicators, since in more than 92% of the samples, the pH of the water is more than 8, so the use of this index is suitable for the studied samples. The study of the relationship between the type of soil layers and the chemical quality of water showed that the soil texture of Rafsanjan is geologically composed of calcareous layers and increases the hardness and the probability of scaling in water [34, 35]. Table 4 represents the indicators studied in other studies for better comparison.

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Table 4: Comparison of corrosion and scaling indices with other studies in Iran

Parameters	Mean ± SD	Water characteristic	Studied area	Reference
LI	0.30 ± 0.31	Low to medium corrosion	Yazd -Ardakan plain	15
RI	7.12 ± 0.57			
AI	12.74 ± 0.38			
PI	9.5 ± 0.69			
LI	0.22	Nearly corrosive	Takab	36
RI	7.6			
AI	12.63			
PI	7.69			
LI	1.62 ± 0.11	Corrosive	Qom	37
RI	10.50 ± 0.17			
AI	9.92 ± 0.13			
PI	12.04 ± 0.14			
LI	-1.94	Very corrosive	Orumieh	38
RI	12.04			
AI	-			
PI	12.20			
LI	0.14	Corrosive	Babol	39
RI	7.28			
AI	-			
PI	6.17			
LI	0.50 ± 0.34	Neutral	Chabahar - Sistan and Baluchestan	26
RI	6.76 ± 0.6			
AI				
PI	6.5 ± 0.99			
LI	0	Scaling	Kerman	40
RI	< 7			
AI	< 12			
PI	< 6			

Shahbazi et al. reported that time changes can alter the water quality, so, the summer samples compared to spring had low quality [12]. Kinsela et al. conducted a study on the corrosion and scaling potential of drinking water wells in the northern and central regions of Australia. Their results showed that 63% of wells in the northern region had the potential for scaling and formation of calcium carbonate scaling. In arid and central areas, the deposition potential exceeded 91. To control the scaling process, these researchers proposed low-cost and simple technology management solutions, such as diluting groundwater with rainwater, changing reservoir water pH to about 0.7, and using sediment-inhibiting compounds [41]. A study in Kerman conducted by Malakootian et al. showed that the Kerman water has scaling properties [42]. One of the reasons is the soil texture of the region, which contains carbonate salts. Considering that the city of Rafsanjan is one of the cities of Kerman province, the obtained results confirm this issue [40, 43].

Conclusion

Corrosion and scaling phenomenons are important issues that should be carefully studied in monitoring water distribution systems. Not paying attention to the chemical quality of water in terms of chemical balance (corrosion and scaling) and the emergence of any of the mentioned phenomena can cause many health and economic damage. According to the results, the temperature and pH parameters were in the desired range, and the parameters of CH, TH, and TDS were below the desired level of the Iranian standard. Therefore, precise quality control of parameters effective in scaling is necessary. According to the obtained results from the calculations related to corrosion and scaling indices in the samples taken from the Rafsanjan water distribution and transmission network, LI, RI, AI, and PI confirm the scaling properties of water in this region. One of the reasons for the scaling characteristic of that city can be attributed to the existence of calcareous structures as well as the formation of lime marls, sandstones (clastic sedimentary), and red conglomerates in the soil of the Rafsanjan region. This increases the TH and TDS of the solute and ultimately affects the deposition state of water.

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Conflict of interest

The authors declare that there is no conflict of interest.

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