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Evaluation of corrosion and scaling potential of drinking water supply sources of Marivan villages, Iran

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Original Article

Abstract

Corrosion and scaling in drinking water sources can lead to economic and health damages. These processes produce by-products in distribution systems, reduce chemical water quality, and are the cause of health issues among consumers. The aim of this study was to evaluate the corrosion and scaling potential of water supply sources of Marivan villages, Iran. In total, 106 water samples were collected through grab sampling from 64 wells and 42 springs in Marivan villages. The values of the Langelier saturation index (LSI), Ryznar stability index (RSI), Aggressive index (AI), and Puckorius index (PI) were calculated using parameters such as temperature, calcium hardness, total alkalinity (TA), total dissolved solids (TDS), and pH according to the last edition of the standard methods. Based on the RSI, 3% of the springs and 9% of the wells were in stable condition, 97% of the springs were corrosive and 90% of the wells had scale forming potential. The LSI was positive for 57% of the springs and 78% of the wells. The AI value of 40% of the springs and 64% of the wells was higher than 12 and the PI value was lower than 6 for all the springs and wells. The results of this study indicated that most of the springs were corrosive and a few of them had scale-forming potential. It was also found that the wells had scaling tendency. Thus, routine monitoring of the sources is necessary to control corrosion and scaling and maintain water quality.

KEYWORDS: Water Quality, Corrosion, Scaling, Natural Springs, Water Wells

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Introduction

The provision of safe drinking water is an essential factor in maintaining and improving the health of a community. To achieve this target, the chemical quality of water is very important. Corrosion and scaling potentials are among the main indicators for water quality assessment. However, these phenomena are essential in the water industry and impact the economic, technical, engineering, and aesthetic dimensions, and consequently, have adverse effects on public health.[1] Scaling results in the formation of a hard deposition on surfaces due to saturation of water with dissolved solids. In this process, divalent metal ions combine with calcium and magnesium deposits and produce calcium carbonate, magnesium carbonate, calcium sulfate, and magnesium chloride.[2] Scaling can clog the pips, reduce the flow and performance of valves, and increase water pressure, energy efficiency, and the pumpage cost.[3] Corrosion is the decaying of a matter resulting from reaction with a media that can occur in the presence of physical, chemical, biological, or electrochemical activities.[1,4] Corrosion is influenced by multiple factors including physical (cavitations, erosion, and

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abrasion by sand), chemical (pH, CO_2, hardness, alkalinity, temperature, dissolved solids, oxygen concentration, residual chlorine, sulfate, and other chemical compounds), and biological agents (sulfate reducing bacteria, and iron bacteria).[5] Corrosive water in the presence of iron, zinc, copper, and manganese in solution can cause secondary pollution and produce odor, taste, and staining in water systems.[6] In addition, the products of corrosion and scaling can settle or accumulate in water sources and distribution networks and protect microbial agents from disinfection.[7] Annually, a significant amount of money is spent on corrosion and scaling problems. In addition to the costs for the repair and replacement of damaged pipes, more than 30% of water volume is lost due to the deterioration of transportation line and water systems.[8] Due to the importance of these processes in chemical water quality, and the health and economic damages caused by these factors, several measures have been proposed to predict the corrosion and scaling potential in water sources. These include the Langelier saturation index (LSI), Ryznar stability index (RSI), Aggressive index (AI), and Puckorius index (PI). Due to the limited application of other indices, they were not used in this research. The evaluation of the indices is based on their ability to determine the undersaturated, unsaturated, and saturated conditions in terms of calcium carbonate and predict the capacity of water for calcium carbonate scaling or dissolution.[9] Due to the importance of this issue, the aim of the present study was to investigate the corrosion and scale forming potential of water in Marivan villages, Iran.

Materials and Methods

Marivan is located in Kurdistan Province, Western Iran (35° 48' to 2° 35' N and 46° 45' 45° to 58' W). The average annual temperature of Marivan is 21 °C and average annual precipitation is about 1050 mm. The current population of Marivan is 178,000, 47,000 of whom are residents of rural areas and living in 145 villages. In general, 106 of the villages (study points of this study) are under the coverage of the Water And Wastewater Management Company of Marivan.

This cross-sectional study was conducted on samples from 64 wells and 42 springs in 2015. Temperature, conductivity, turbidity, and pH were measured on site. Sample volumes of 3 l were collected in prewashed polyethylene (PE) containers and immediately transferred to the laboratory for total dissolved solids (TDS), total hardness (TH), calcium hardness, and alkalinity measurements. All used chemicals and reagents were of analytical grade (Merck, Germany). The collection, preservation, and analysis of samples were performed according to standard methods.[10] Corrosion and scaling potential were calculated using the LSI, RSI, AI, and PI. The results of all the sampling locations and water supplies were recorded separately for each of the 4 corrosion indices. To increase the accuracy of the experiments and control experimental errors, all four indices were used in this study.

Water quality parameters were analyzed for each of the 106 water sources, and then, accordingly corrosion indices were calculated. First, the saturation pH (pHs) was calculated using the values of alkalinity, temperature, and pH according to equation (1).[11]

$$pH_s = (9.3 + A + B) - (C + D) \quad (1)$$

In this equation the values of A, B, C, and D were calculated using equations (2), (3), (4), and (5), respectively.[11]

$$A = (\text{Log}[TDS] - 1)/10 \quad (2)$$
$$B = -3.12 \times \text{Log}\,(°C + 273) + 34.55 \quad (3)$$
$$C = \text{Log}^{10} - 0.4 \quad (4)$$
$$D = \text{Log}^{10} \quad (5)$$

In the above equations, A was TDS (mg/l), B temperature (°C), C TH (mg/l of calcium carbonate), and D was total alkalinity (TA) (mg/l of calcium carbonate). After calculating pHs, corrosion and scaling potential were calculated using the following formula:

$$LSI = pH - pH_s \quad (6)$$

The interpretation of LSI equation (6) is presented in table 1.[11]

The RSI equation (7) is presented below and its interpretation is presented in table 2.[12]

$$RI = 2\,(pH_s) - pH \quad (7)$$

Table 1. Langelier saturation index range

LSI value	State
LSI < 0	Corrosive
LSI = 0	Noncorrosive and no scaling
LSI > 0	Scaling

LSI: Langelier saturation index

Table 2. Ryznar saturation index range

RSI value	State
RSI < 5.5	Highly scaling
5.5 < RSI < 6.2	Scaling and slightly corrosive
6.2 < RSI < 6.8	Noncorrosive and no scaling
6.8 < RSI < 8.5	Corrosive and slightly scaling
RSI > 8.5	Highly corrosive

RSI: Ryznar stability index

The AI and its interpretation are presented in equation (8) and table 3, respectively.[13,14]

$$AI = pH - Log\,(A.H) \quad (8)$$

The PI equation (9) is presented below:

$$PI = 2\,pH_s - pH_{eq} \quad (9)$$

Where pH_{eq} is the pH of water calculated using equation (10).[15]

$$pH_{eq} = 1.465\,Log\,(T - AIK) + 4.54 \quad (10)$$

The interpretation of PI is presented in table 4.[15]

Table 3. Aggressive index values range

AI value	State
AI < 10	Highly corrosive
10 < AI < 12	Moderately corrosive
AI > 12	Slightly corrosive

AI: Aggressive index

Table 4. Interpretation of Puckorius index values

PI value	State
PI < 6	Scaling
PI > 6	Corrosive

PI: Puckorius index

The indices were calculated using Excel software and the results were analyzed using SPSS software (version 16, SPSS Inc., Chicago, IL, USA). Finally, the scaling and corrosion status of water sources was evaluated.

Results and Discussion

In order to assess the corrosion and scaling potential of drinking water supplies of Marivan rural areas, temperature, pH, TDS, calcium hardness, and TA were measured. Physical and chemical factors were examined for each of the sources and are presented in table 5 as the minimum, average, maximum, and standard deviation (SD).

Table 5. Minimum, average, maximum, and mean and standard deviation of the sources

Source	Parameter	Unit	Minimum	Average	Maximum	SD	National standard	
							Desirable	Permissible
Spring	T	°C	16.60	24.49	31.40	4.03	15	23
	pH	-	6.93	7.76	8.77	0.35	7-8.5	6.5-9
	TDS	mg/l	83.00	267.90	484.00	86.36	500	1500
	Ca	mg/l	18.30	67.88	94.45	18.68	25	200
	TA	mg/l as $Caco_3$	81.15	231.30	402.00	70.18	-	500
Well	T	°C	16.50	24.13	31.60	4.11	15	23
	pH	-	7.19	7.79	8.86	0.37	7-8.5	6.5-9
	TDS	mg/l	162.30	269.40	389.40	51.20	500	1500
	Ca	mg/l	44.50	85.34	138.10	18.67	25	200
	TA	mg/l as $Caco_3$	182.40	270.70	389.40	49.90	-	500

T: temperature; TDS: total dissolved solids; TA: total alkalinity

Among the 106 villages, the water supply sources of 64 rural areas (60.37%) were wells and 42 villages (39.63%) were springs. Based on the measured parameters (Table 5), the minimum, average, and maximum values of temperature in the two water supply sources (spring and wells) were almost equal. Moreover, pH values of the two supply sources were almost equal. The higher solubility of solids in the wells can be explained by the higher TDS of wells than springs. The average calcium in wells (67.88 mg/l) was higher than that of spring (85.34 mg/l). The average of TA (carbonate, bicarbonate, and hydroxides) in the well water supplies (270.7 mg/l $CaCO_3$) was also higher than that of springs (231.3 mg/l $CaCO_3$). The minimum, maximum, and average values of measured parameters in Marivan drinking water sources are presented in table 5. The result of analysis for each of the sources of drinking water was calculated according to the formulas listed for corrosion and scaling indices (LSI, RSI, AI, and PI) calculations. For each village, water supplies were coded according to their type, wells or springs. The calculated indices for each location code are presented in table 6. The minimum, average, maximum and standard deviation values for each index for both sources (well and spring) are presented in table 7.

Distributions of the indices were assessed according to the type of water supply. The results are presented in table 8. LSI of springs with corrosion value of 40.47% and scaling value of 57.14% revealed that some sources are corrosive and others are scale forming. However, a balanced state was only observed in location code S10. It is clear that the scaling location codes of wells (78.13%) are much more than corrosive codes (21.78%). RSI highlights that many springs (96.62%) were corrosive and none of the springs were scale forming. In sources provided by wells, RSI were different, scaling was 0, and sources were mostly corrosive (90.62%). Gupta et al. evaluated the groundwater of Kota city in Rajasthan, India, and assessed RSI and LSI.[15] They showed scale forming property to be the dominant characteristic of the groundwater resources.[15] Rabbani et al. studied the scaling and corrosion potential of rural water sources of Kashan, Iran, and showed that of the 39 sources, the sources in 18 villages were corrosive and in 21 villages were scaling.[16]

PI in both sources showed that 100% of all the sources were corrosive and none of the sources were scale forming. The PI of water samples with a pH of greater than 8 was more suitable; in this case, the results based on this index will be more accurate than other indices. Malakootian et al. examined scaling and corrosion potential of drinking water in Kerman, Iran, and reported that 40% of water supplies had PI values of greater than 6 and had corrosive potential.[17]

AI values, as a measure of the tendency of water to deteriorate the asbestos-cement pipes, revealed no corrosion potential in either source, while 40.48% and 59.52% of spring sources were scale forming and stable, respectively. However, 64.04% and 35.96% of well sources were scale forming and stable, respectively, and their scaling state was lower than springs. Shams et al. studied corrosion potential using AI.[18] They showed that AI with an average value of 12.1 indicated the low tendency of water supplies to corrosion state.[18]

Results of LSI, PI, and AI in the two types of water sources confirmed that there was almost no significant difference between the two sources. However, RSI revealed significant differences between corrosion and scaling potential of the sources; 97.62% of the springs tended to be corrosive, and scaling was 0, while well sources' tendency toward corrosion was 0 and their tendency toward scale forming was 90.62%.

Table 6. Corrosion and scaling potential values of rural drinking water sources

Code	LSI	RSI	PI	AI	code	LSI	RSI	PI	AI
W1	0.27	7.44	7.46	12.23	W54	-0.13	7.88	7.35	11.94
W2	0.22	7.46	7.33	12.18	W55	-0.03	7.84	7.59	12.02
W3	0.25	7.34	7.08	12.22	W56	-0.09	7.97	7.76	11.95
W4	0.08	7.49	7.08	12.07	W57	-0.07	7.85	7.56	11.97
W5	0.28	7.26	6.99	12.25	W58	-0.52	8.34	7.60	11.55
W6	0.15	7.39	6.99	12.13	W59	0.21	7.11	6.32	12.26
W7	0.80	6.69	6.93	12.79	W60	0.19	7.16	6.38	12.26
W8	0.38	7.26	7.32	12.35	W61	0.23	7.26	6.77	12.27
W9	0.62	6.96	7.12	12.59	W62	-0.02	7.49	6.78	11.97
W10	0.40	7.24	7.19	12.34	W63	0.02	7.45	6.82	12.01
W11	0.34	7.13	6.73	12.28	W64	0.11	7.25	6.45	12.13
W12	0.29	7.18	6.70	12.25	S1	0.11	7.54	7.33	12.07
W13	1.05	6.68	7.46	12.97	S2	0.12	7.46	7.03	12.10
W14	1.17	6.48	7.32	13.09	S3	0.34	7.31	7.25	12.31
W15	0.36	7.12	6.91	12.23	S4	0.33	7.51	7.84	12.28
W16	1.07	6.67	7.46	13.00	S5	-0.08	8.19	8.44	11.88
W17	-0.01	7.61	7.20	11.87	S6	-0.80	9.49	10.04	11.10
W18	-0.06	7.70	7.30	11.82	S7	-0.45	8.69	8.90	11.48
W19	0.02	7.53	7.04	11.93	S8	0.28	7.41	7.41	12.18
W20	0.14	7.30	6.74	12.01	S9	-0.68	8.94	8.45	11.23
W21	0.01	7.43	6.67	11.88	S10	0.00	7.42	6.49	11.95
W22	0.42	7.17	7.13	12.27	S11	0.09	7.57	7.36	12.00
W23	0.31	7.16	6.84	12.19	S12	0.06	7.65	7.46	11.96
W24	0.33	7.17	6.89	12.20	S13	0.27	7.15	6.52	12.24
W25	0.28	7.21	6.92	12.15	S14	0.42	7.10	6.83	12.37
W26	0.35	7.08	6.70	12.23	S15	1.07	6.63	7.38	12.99
W27	0.37	7.06	6.67	12.24	S16	0.84	6.87	7.42	12.76
W28	1.20	6.45	7.33	13.13	S17	0.09	7.49	7.24	11.95
W29	0.10	7.28	6.48	12.01	S18	0.16	7.34	6.92	12.01
W30	0.02	7.39	6.55	11.94	S19	-0.24	8.50	9.11	11.54
W31	-0.25	7.93	7.34	11.55	S20	-0.03	7.71	7.39	11.80
W32	0.09	7.70	7.72	11.97	S21	-0.21	8.03	7.81	11.62
W33	0.04	7.51	7.13	11.80	S22	0.07	7.67	7.64	11.88
W34	0.09	7.43	7.05	11.86	S23	-0.10	7.71	7.29	11.68
W35	0.14	7.26	6.79	11.91	S24	-0.18	7.77	7.21	11.62
W36	1.18	6.31	6.90	12.95	S25	-0.95	8.84	8.07	10.76
W37	0.69	7.05	7.53	12.41	S26	-0.90	8.80	8.08	10.81
W38	0.27	7.15	6.68	12.11	S27	0.83	6.83	7.28	12.59
W39	0.20	7.15	6.47	12.05	S28	0.34	7.26	7.13	12.10
W40	0.11	7.42	6.96	11.92	S29	0.17	7.29	6.71	11.97
W41	-0.33	7.86	6.74	11.48	S30	0.14	7.35	6.80	11.96
W42	-0.19	7.66	6.69	11.63	S31	0.04	7.39	6.61	11.87
W43	-0.13	7.59	6.66	11.69	S32	-0.12	7.55	6.63	11.70
W44	0.31	7.43	7.56	12.17	S33	-0.02	7.56	6.99	11.84
W45	0.26	7.44	7.48	12.12	S34	0.33	7.28	7.25	12.18
W46	0.05	7.65	7.40	11.92	S35	0.40	7.24	7.34	12.25
W47	0.04	7.37	6.53	11.95	S36	0.03	7.86	7.97	11.94
W48	-0.04	7.53	6.80	11.86	S37	0.18	7.61	7.72	12.09
W49	0.28	7.21	6.89	12.16	S38	-0.74	8.72	8.20	11.17
W50	-0.13	7.85	7.56	11.74	S39	0.25	7.28	6.95	12.19
W51	0.19	7.42	7.15	12.08	S40	-0.11	7.85	7.33	11.97
W52	0.24	7.37	7.15	12.13	S41	-0.13	8.06	7.85	11.91
W53	0.18	7.43	7.13	12.12	S42	-0.11	7.74	7.14	11.91

LSI: Langelier saturation index; RSI: Ryznar stability index, PI: Puckorius index; AI: Aggressive index

Table 7. Minimum, maximum, and average values of calculated indices in drink water sources of Marivan

Source	Index	Minimum	Average	Maximum	SD
Spring	LSI	-0.95	0.03	1.07	0.42
	RSI	6.63	7.71	9.49	0.61
	PI	6.49	7.50	10.04	0.71
	AI	10.76	11.91	12.99	0.44
Well	LSI	-0.52	0.23	1.20	0.34
	RSI	6.31	7.37	8.34	0.37
	PI	6.32	7.03	7.76	0.36
	AI	11.48	12.14	13.13	0.35

LSI: Langelier saturation index; RSI: Ryznar stability index, PI: Puckorius index; AI: Aggressive index; SD: Standard deviation

Table 8. Frequency distribution of scaling and corrosion indices in rural drinking water sources of Marivan

Source	Number	State	Index Number (%)			
			LSI	RSI	PI	AI
Spring	42	Corrosive	17 (40.47)	41 (97.62)	42 (100)	-
		Stable	1 (2.38)	1 (2.38)	-	25 (59.52)
		Scale forming	24 (57.14)	-	-	17 (40.48)
Well	64	Corrosive	14 (21.87)	-	64 (100)	-
		Stable	-	6 (9.38)	-	23 (35.94)
		Scale forming	50 (78.13)	58 (90.62)	-	41 (64.04)

LSI: Langelier saturation index; RSI: Ryznar stability index, PI: Puckorius index; AI: Aggressive index

Conclusion

The comparison of the measured parameters indicated that pH values in both springs and wells (24.49 and 7.76, respectively) were within the national standard range. Average TDS, TA, and total calcium in springs and wells were approximately equal, but the standard deviation of spring water was higher, indicating a significant difference in minimum and maximum values and wider distribution of the data. Comparison of the corrosion and scaling indices showed that, based on LSI, both sources tend to be corrosive. RSI indicated that the spring sources were more inclined toward the corrosion state, but the scaling state was dominant in well sources. PI illustrated that both sources were strongly corrosive, while AI showed that both sources were slightly corrosive. The overall results of this study indicated that spring sources tend to be corrosive and well sources tend to be scale forming. The findings of this study were in accordance with the actual reports of the Office of Operation and Maintenance Division for the Marivan Rural Water and Wastewater Affairs regarding broken cases of pipes, leakage, and constriction of transport lines and distribution networks.

Conflict of Interests

Authors have no conflict of interests.

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