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Corrosion and Scaling Potential in Drinking Water Distribution of Babol, Northern Iran Based on the Scaling and Corrosion Indices

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Background & Aims of the Study: Corrosion and scaling play undesirable effects on transmission and distribution system of drinking water. The aim of this study was to assess the corrosion and scaling potential of drinking water resources in Babol city, Iran.

Materials and Methods: Totally, 54 water samples were collected from 27 wells in spring and autumn. Calcium hardness, pH, total alkalinity, total dissolved solids, and temperature were measured, using standard methods. The Langelier, Rayzner, Puckhorius, Larson and aggressive indices were calculated and data were analyzed by SPSS 19. To compare the mean values of each index, the results were analyzed using t-test.

Results: The range of temperature, pH, TDS, total alkalinity and calcium hardness were 16-24°c; 6.8-7.89; 445-1331 mg/l; 322.9-396 mg/l and 250.50-490 mg/l, respectively. The mean of Langelier and Ryznar indices in drinking water samples in spring and autumn was 0.14, 0.15; 7.28 and 7.35, respectively. The mean of Puckhorius and Larson indices in these seasons was 11.9, 11.95 and 0.95 and 0.93, respectively. The mean of aggressive index was 6.17 and 6.27, respectively. Overall, 82.2%, 100%, 94.6%, 100% and 85.7% of water samples were corrosive based on the Langelier, Ryznar, Puckhorius, Larson and aggressive indices, respectively.

Conclusion: According to these results, drinking water of Babol city has corrosion potential. Therefore, the water quality should be controlled based on pH, alkalinity and hardness parameters, along with the use of corrosion resisting materials and pipes in drinking water distribution systems.

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Background

Water corrosion and scaling is a phenomenon caused by the contact of materials with surrounding environment (1,2). This phenomenon has been studied in two important branches including erosion and electrochemical corrosions (3). The first type is a degradation of materials by physical factors such as the impact of suspended solids in water or wastewater pipes (4,5). The second type includes producing an electric cell and performing electrochemical reactions between the surrounding environment of pipelines, facilities and constructed materials. Electrochemical corrosion occurs in water transmission and distribution lines due to the nature of the process in metallic materials such as steel pipes (4,6).

Corrosion phenomenon is created by parameters such as carbon dioxide, water hardness, alkalinity, temperature, water flow, TDS, dissolved oxygen, residual chlorine, erosion and abrasion by sand. Scaling also includes a combination of divalent metal ions in water with factors causing water hardness (7). The most important scales in water contain calcium carbonate, magnesium carbonate, calcium sulfate and magnesium chloride (8,9).

The most important health problem is related to corrosion which releases the cadmium and lead into the water and causes a serious health risk to consumers (10,11). Studies have shown that the materials resulted from corrosion can be accumulated or deposited in distribution networks and consequently protected microorganisms against chlorination (12). According to the performed research in the world, chemical corrosion is responsible for over 60% of corrosion in pipes and water supply facilities and the rest is mainly caused by biological factors (13,14).

One of the indirect methods of measurement and simple determination of scaling and corrosion is the use of corrosive indices which indicate water quality parameters (1,4). Accuracy of these indices is based on their ability to determine the conditions of water such as unsaturated, saturated or supersaturated according to calcium carbonate (1,12). These parameters include Langelier, Ryznar, Puckorius, Larson and aggressive indices (15). There are other corrosion indices which not applied due to the non-conventional use in comparison with the above indices.

The total costs of corrosion and scaling are extremely high. Unaccounted water in transmission and distribution systems varies from less than 1% to 32% of the total water production (2,3). A study performed by federal highway administration evaluated that the cost of corrosion in drinking water distribution network in USA outlined 22 billion dollars (16). In Australia, Great Britain, Japan and other countries, it has been estimated that corrosion costs of water distribution systems are nearly 3- 4% of the Gross National Product (14). It has reported that mean uncounted water in Iran is nearly 30% (17). In addition, it has accepted that an important part of uncounted water is related to corrosion (2).

Babol city with a population of 520,000 people is the most populous city in Mazandaran province located in northern Iran. The city of central Mazandaran in southern Caspian Sea (15 km from Caspian Sea) is located in longitude 52° 44′ 20″, latitude 36° 24′ 15′. Average annual temperature and precipitation are 17.1 °C and 799 mm, respectively. Considering the high chemical parameters affected water corrosion and scaling such as PH, alkalinity, hardness and high concentration of iron and manganese in Babol drinking water, the current study was performed to evaluate the corrosion and scaling potential in drinking water of Babol.

Aims of the study:

In this research, the quality of drinking water in the city of Babol was evaluated on the basis of universal valid indices of corrosion and scaling.

Materials & Methods

In this study, 54 samples from 27 wells collected in spring and autumn. The temperature, pH and TDS were measured based on standard methods (18), using TESTO pH meter and Aqualytic TDS meter, respectively. Determination the hardness and alkalinity of water samples was done by titration method and Merck reagents. Chloride and sulfate ions were analyzed, using a Hach 5000 spectrophotometer. The results of water samples were analyzed, using the following equations by the authors to determine the used indices (Table 1). The Langelier, Rayzner, Puckhorius, Larson and aggressive indices were calculated and data were analyzed by SPSS 19.

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To compare the mean values of each index, the results were analyzed using t-test.

Table 1) Water stability indices for interpreting of water condition (15)

Index name	Equation	Index value	Water condition
a. Langelier saturation index	LSI= pH- pHs	LSI<0	Super-saturated, tend to precipitate $CaCO_3$
		LSI=0	Saturated, $CaCO_3$ is in equilibrium
		LSI>0	Under-saturated, tend to dissolved solids $CaCO_3$
b. Riznar stability index	RSI=2pHs-pH	RSI<6	Super-saturated, tend to precipitate $CaCO_3$
		6 < RSI< 7	Saturated, $CaCO_3$ is in equilibrium
		RSI> 7	Under-saturated, tend to dissolved solids $CaCO_3$
c. Puckorious scaling index	$PSI= 2(pH_{eq}) – pH_s$ $pH_{eq}= 1.465 \times \log_{10}[Alk] + 4.54$ $pH= 1.465 + \log_{10}[Alk] + 4.54$	PSI< 6	Scaling is unlikely to occur
		PSI > 7	likely to dissolve scale
d. Larson- scold index	$LS= (Cl^- + SO_4^{2-}) / (HCO_3^- + CO_2^{2-})$	LS< 0.8	Chloride and sulfate are unlikely to with the formation of protecting film.
		0.8 < LS< 1.2	Corrosion rate may be higher than exposed
		LS > 1.2	High rates of localized corrosion may be exposed
c. Aggressive index	AI= pH + log [(Alk) (H)]	AI> 12	Non- aggressive
		10 < AI < 12	moderately aggressive
		AI< 10	Very aggressive

Results

In this study, the corrosion and scaling of drinking water resources in Babol city were evaluated, using corrosion indices. The used parameters for the calculation of the indices including temperature, pH, TDS, calcium hardness, bicarbonate and total alkalinity, chloride and sulfate concentrations are presented in tables 2 and 3. According to these tables, the range of water temperature was 20 to 24 and 16 to 20 in spring and autumn, respectively. The range of pH was 6.8 to 7.2 and 7.17 to 7.92 in spring and autumn, respectively. The changes of calcium hardness concentration of water were 250.5 to 491 and 2550 to 400.8 mg/l in spring and autumn, respectively. The changes of TDS in water samples were 444.9 to 1113.75 and 456.5 to 1331 mg/l, whereas chloride were 15.96 to 109.9 and 19.5 to 99.3 mg/l and sulfate ions were 84 to 152 and 104 to 147 mg/l in spring and autumn, respectively. The changes of bicarbonate alkalinity were 260 to 300 and 250 to 305 mg/l and that of total alkalinity were from 317 to 365.6 and 335 to 371.7 in spring and autumn, respectively.

Based on Langelier index, 74% and 90% of samples have been corrosive in spring and autumn, respectively. According to Ryznar index, 100% of samples have been corrosive in spring and autumn. Based on Aggressive Index (AI), 85.7% of 56 samples had moderate corrosivity and only 8 samples had no corrosivity. About 95% of samples were corrosive and only 3 samples were corrosion free based on Puckorius index. According to Larson index, about 93% of water samples had moderate corrosion and 4 samples had high corrosion. As a result all samples had corrosion (Tables 4 and 5).

Table 2) Parameters associated with corrosion and scaling in drinking water (Spring)

Sampling site	Total Alkalinity	Bicarbonate Alkalinity	SO_4^{2-}	Cl^-	TDS (mg/L)	Ca Hardnes	pH	Temp(C°)
well 4	316.84	260	140	21.28	445.5	250.5	7.1	20
well 1	322.93	265	142	21.28	455.5	255.51	7.1	20
well 10	317	265	134	24.82	449.9	250.5	7	22
well 11	341.46	280	146	23.05	486.75	265.53	7.05	22
well 12	335.12	275	146	26.6	483.46	265.53	6.8	22
well 13	353.39	290	145	21.28	488.96	265.53	6.9	22
well 14	347.3	285	148	19.5	479.6	270.54	7.2	20
well 15	335.12	275	134	19.5	453.75	260.52	7	20
well 16	365.58	300	144	46.1	527	295.59	7.1	20
well 17	365.58	300	152	24.82	505	285.57	6.9	20
well 18	341.21	280	142	24.82	477.96	270.54	7	20
well 19	335.12	275	140	44.33	498.3	270.54	6.9	24
well 1-talut	347.3	285	122	49.65	521.95	295.59	6.95	20
well 2	322.93	265	144	21.28	458.8	260.52	6.98	20
well 20	347.3	285	148	23.05	481.25	270.54	7.03	20
well 21	347.3	285	122	15.96	444.96	255.51	7.05	20
well 2-talut	350.35	287.5	112	42.55	510.5	265.53	7.01	20
well 3	322.93	265	142	19.5	459.8	255.51	7.07	20
well 3-talut	359.49	295	84	41.35	1113.75	490.98	7	20
well 4-talut	353.39	290	128	49.65	544	290.58	7	20
well 5	322.93	265	142	21.28	457.6	255.51	7.06	20
well 6	316.84	260	146	19.5	456.5	255.51	7	20
well 6-talut	365.58	300	120	70.92	558.25	290.56	7	20
well 7	341.21	280	140	19.5	470.8	270.54	7.08	20
well 7-talut	365.58	300	124	109.93	638	350.7	7.1	20
well 8	322.93	265	144	19.5	455.5	255.51	6.9	20
well 9	366.	260	133	46	449.9	250.5	6.99	20

Table 3) Parameters associated with corrosion and scaling in drinking water (Autumn)

Sampling site	Total Alkalinity	Bicarbonate Alkalinity	SO_4^{2-}	Cl^-	TDS (mg/L)	Ca Hardnes	pH	Temp(C°)
well 4	353.4	290	132	21.3	472.5	260.5	7.24	18
well 1	335.1	275	130	21.3	454.9	255.5	7.26	18
well 10	322.9	265	132	23	451.6	246.5	7.64	19
well 11	341.2	280	144	21.3	494.5	260.5	7.6	18
well 12	335.1	275	138	26.6	475.8	255.5	7.61	18
well 13	353.4	290	147	23	498.3	265.5	7.57	18
well 14	359.5	295	140	21.3	484	270.5	7.61	18
well 15	341.2	280	136	21	500.5	260.5	7.23	18
well 16	359.5	295	136	47.9	530.8	285.5	7.59	18
well 18	341.2	280	135	24.8	469.8	260.5	7.74	18
well 19	347.3	285	138	23	481.3	265.5	7.92	19
well 1-talut	353.4	290	122	51.4	538	295.6	7.44	20
well 2	335.1	275	134	21.3	464.8	260.5	7.22	18
well 20	341.2	280	134	23	465.3	255.5	7.89	18
well 21	347.3	285	123	21.3	457.6	255.5	7.83	18
well 22	396	325	134	36.7	983.5	290.6	7.58	16

well 23	353.4	250	141	53.9	1331	325.7	7.62	20
well 2-talut	359.5	295	102	42.6	518.1	265.5	7.29	18
well 3	341.2	280	128	21.3	453.8	260.5	7.23	18
well 3-talut	371.7	305	104	25.53	858	400.8	7.17	18
well 4-talut	353.4	290	118	53.2	543.5	285.6	7.27	18
well 5	347.3	285	132	23	475.8	260.5	7.21	18
well 6	335.1	275	132	21.3	456	255.5	7.24	18
well 6-talut	341.2	280	106	85.1	560	275.6	7.28	19
well 7	347.3	285	140	21.3	470.5	265.5	7.24	18
well 7-talut	359.5	295	112	99.3	609.5	315.6	7.26	18
well 8	335.12	275	138	19.5	462	255.5	7.68	19
well 9	322.93	275	117	19.5	456.5	255.5	7.26	18

Table 4) Corrosion and scaling indices in drinking water resources (Spring)

	Interpretation of 5-index results					5-index values				
Sampling site	**Larson**	**Puckorius**	**Aggressive**	**Rizner**	**Langelier**	**Larson**	**Puckorius**	**Aggressive**	**Rizner**	**Langelier**
well 4	MC	C	MC	C	C	0.95	6.35	11.91	7.33	-0.11
well 1	MC	C	MC	C	C	0.95	6.31	11.93	7.30	-0.10
well 10	HC	C	MC	C	C	1.35	6.23	11.82	7.32	-0.16
well 11	MC	C	MC	C	N	0.92	6.12	11.92	7.19	-0.07
well 12	MC	C	MC	C	C	0.95	6.14	11.66	7.46	-0.33
well 13	MC	C	MC	C	C	0.88	6.07	11.79	7.31	-0.21
well 14	MC	C	NC	C	N	0.91	6.16	12.09	7.10	0.05
well 15	MC	C	MC	C	C	0.86	6.24	11.86	7.35	-0.17
well 16	MC	C	NC	C	N	0.91	6.03	12.05	7.10	0.00
well 17	MC	C	MC	C	C	0.90	6.05	11.83	7.32	-0.21
well 18	MC	C	MC	C	C	0.91	6.19	11.88	7.31	-0.16
well 19	MC	C	MC	C	C	0.97	6.05	11.77	7.26	-0.18
well 1-talut	MC	C	MC	C	C	0.85	6.10	11.88	7.29	-0.17
well 2	MC	C	MC	C	C	0.96	6.29	11.82	7.40	-0.21
well 20	MC	C	MC	C	C	0.92	6.16	11.92	7.27	-0.12
well 21	MC	C	MC	C	C	0.75	6.20	11.91	7.28	-0.12
well 2-talut	MC	C	MC	C	C	0.76	6.18	11.89	7.31	-0.15
well 3	MC	C	MC	C	C	0.94	6.31	11.90	7.33	-0.13
well 3-talut	HC	N	NC	C	N	1.61	5.81	12.16	6.97	0.01
well 4-talut	MC	C	MC	C	C	0.86	6.10	11.93	7.25	-0.12
well 5	MC	C	MC	C	C	0.95	6.31	11.89	7.34	-0.14
well 6	MC	C	MC	C	C	0.98	6.34	11.82	7.42	-0.21
well 6-talut	MC	C	MC	C	C	0.85	6.06	11.94	7.23	-0.11
well 7	MC	C	MC	C	N	0.88	6.18	11.96	7.23	-0.07
well 7-talut	MC	N	NC	C	N	0.98	5.93	12.12	6.99	0.05
well 8	MC	C	MC	C	C	0.95	6.31	11.73	7.50	-0.30
well 9	MC	C	MC	C	C	0.85	6.35	11.80	7.44	-0.23

C: corrosive, N: natural, MC: moderate corrosion, NC: no corrosion, HC: high corrosion, LP: low participate

In Table 6, the minimum, maximum and mean of Langelier, Ryznar, aggressive, Puckorius and Larson indices are presented in spring and autumn. According to this table, the range of Langelier, Ryznar aggressive, Puckorius and Larson indices were -0.33 to -0.16, 6.97 to 7.63, 11.66 to 12.26, 5.81 to 6.48 and 0.69 to 1.99, respectively.

Table 5) Corrosion and scaling indices in drinking water resources (Autumn)

	Interpretation of 5-index results					5-index values				
Sampling site	**Larson**	**Puckorius**	**Aggressive**	**Rizner**	**Langelier**	**Larson**	**Puckorius**	**Aggressive**	**Rizner**	**Langelier**
well 4	MC	C	MC	C	C	0.81	6.2	11.98	7.30	-0.10
well 1	MC	C	NC	C	N	0.84	6.3	12.15	7.16	0.07
well 10	MC	C	MC	C	C	0.89	6.3	11.90	7.38	-0.15
well 11	MC	C	NC	C	N	0.91	6.3	12.06	7.24	-0.02
well 12	MC	C	MC	C	C	0.90	6.3	11.75	7.57	-0.33
well 13	MC	C	MC	C	C	0.90	6.2	11.92	7.37	-0.17
well 14	MC	C	MC	C	C	0.84	6.2	11.90	7.36	-0.18
well 15	MC	C	MC	C	C	0.86	6.3	11.97	7.34	-0.11
well 16	MC	C	NC	C	LP	0.89	6.1	12.26	7.01	0.16
well 17	MC	C	MC	C	C	0.86	6.3	11.88	7.41	-0.20
well 18	MC	C	MC	C	C	0.86	6.2	11.93	7.31	-0.13
well 19	MC	C	MC	C	C	0.84	6.0	11.94	7.22	-0.11
well 1-talut	MC	C	MC	C	C	0.86	6.3	11.86	7.45	-0.22
well 2	MC	C	MC	C	C	0.85	6.3	11.95	7.35	-0.12
well 20	MC	C	MC	C	C	0.77	6.2	11.96	7.33	-0.11
well 21	MC	C	MC	C	C	0.92	6.2	11.95	7.52	-0.28
well 2-talut	HC	C	MC	C	C	1.60	6.4	11.81	7.63	-0.37
well 3	MC	C	MC	C	C	0.81	6.2	11.98	7.30	-0.10
well 3-talut	MC	C	NC	C	N	0.84	6.3	12.15	7.16	0.07
well 4-talut	MC	C	MC	C	C	0.89	6.3	11.90	7.38	-0.15
well 5	MC	C	NC	C	N	0.91	6.3	12.06	7.24	-0.02
well 6	MC	C	MC	C	C	0.90	6.3	11.75	7.57	-0.33
well 6-talut	MC	C	MC	C	C	0.90	6.2	11.92	7.37	-0.17
well 7	MC	C	MC	C	C	0.84	6.2	11.90	7.36	-0.18
well 7-talut	MC	C	MC	C	C	0.86	6.3	11.97	7.34	-0.11
well 8	MC	C	MC	C	C	0.88	6.3	11.85	7.42	-0.21
well 9	MC	C	MC	C	C	0.79	6.2	11.96	7.40	-0.17

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Table 6) Corrosion and scaling calculated in drinking water resources

Position	Index	Spring	Automn
Minimum index	Langelier	-0.33	-0.37
	Rizner	6.97	7.01
	Aggressive	11.66	11.75
	Puckorius	5.81	5.95
	Larson	0.75	0.69
Maximum index	Langelier	0.05	0.16
	Rizner	7.5	7.63
	Aggressive	12.16	12.26
	Puckorius	6.35	6.48
	Larson	1.61	1.99
Mean index	Langelier	-0.14	-0.15
	Rizner	7.28	7.35
	Aggressive	11.9	11.95
	Puckorius	6.17	6.27
	Larson	0.95	0.93

Discussion

Corrosion and scaling play an important role in monitoring of water distribution systems because the lack of attention to the water quality in terms of chemical stability and creating the corrosion and scaling causes the serious economic and health problems (4,6). The results of the study and calculations showed that the mean of Langelier index was -0.14 and -0.15 and Ryznar index was 7.28 and 7.35 in drinking water resources of Babol in spring and autumn, respectively. The mean of aggressive corrosion index were 11.9 and 11.95 in drinking water resources in spring and autumn, respectively. The mean of Puckorius and Larson indices were 6.17, 6.27 and 0.93, 0.95 in drinking water resources in spring and autumn, respectively.

In total, 82.2%, 100%, 85.7%, 94. 64% and 100% of the samples taken from drinking water resources of Babol had been corrosive according to the results obtained from Langelier, Ryznar, aggressive, Puckorius and Larson indices. Two studies conducted on water distribution system in Bandar Abbas city indicated that drinking water of this city had corrosive potential (17,19). In a study which is conducted by Zazouli et al. on drinking water resources of Yasouj, the quality of drinking water was measured using Langelier, Ryznar, aggrassive, Puckorius and Larson indices and it was found that more water tends to corrosion (20). Shams et al. showed that 29.03, 90.32, 96.78, 96.77 and 12.1, percent of drinking water distribution networks have corrosion tendency to LSI, RSI, PSI, LS and AI indices, respectively (21). Malakoutian et al. in 2011 conducted a study on the corrosion and scaling of drinking water in Kerman on the basis of the corrosion index and they stated that drinking water of Kerman had scaling property (22). According to the study of Mahvi on the water reservoirs in Zanjan, it was found that 50% of samples were corrosive and the other half ones were scaling based on Langelier index and based on Ryznar index 100% of samples were corrosive (23). In the same study, 53.51% of samples were corrosive based on Langelier saturation index and 45.7% were scaling. Based on Ryznar index, 80.31% of samples were corrosive. The results of these studies and compare them with this study suggest that the quality of drinking water in most cities tend to be corrosive. With the increase of human activities in water resources and the gradual rise of salts concentrations, the corrosion contents will increase in water resources. In the study of

Al- Rawajfeh et al. on drinking water quality in Tafila in southern Jordan, the potential of scaling and corrosion formation based on the Langelier, Ryznar indices and deposition of calcium carbonate were evaluated. In their study, Langelier indices and calcium carbonate precipitation were from –0.39 to -1.5 and -1.7 to-16.76, respectively and the Ryznar indices were 8.7 to 9.8, too (24). Shankar studied the quality of groundwater in Puram Bangalore area of India based on Langelier and Ryznar indices. In the mentioned study, according to the Langelier indices, 27.67% and 13.33% of samples had scaling and little scaling, respectively. 6.67%, 13.33% and 40% of them had little, high and intolerable (severe) corrosion, while based on Ryznar indices, 13.33% of samples were corrosive or slightly scaling, 13.33% and 6.67% of samples had significant and high corrosion, respectively and 6.67% of them had intolerable (severe) corrosion (25).

Conclusion

According to the results which were obtained from the measured scaling and corrosion indices in water resources of Babol, 82.2% of 56 samples taken in spring and autumn were corrosive. The water was corrosive in 20 samples (71%) and 25 samples (89.6%) of 28 ones in spring and autumn, respectively. Overall, 82.2%, 100%, 85.7%, 94.6% and 100% of water samples taken from water resources in Babol were corrosive based on the Langelier, Ryznar, aggressive, Puckorius and Larson indices, respectively. It is necessary to control all quality parameters affecting water corrosion due to the effect of calcium hardness, total alkalinity and TDS of water on its pH and thus on the corrosion and scaling potential of water.

Footnotes

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Conflict of Interest:
The authors stated no conflict of interest.

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