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Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran

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ABSTRACT

Water quality entering the drinking water distribution network often provides requirements for corrosion and scaling in rural areas due to the lack of suitable treatment methods. It leads to pipe clogging, reducing longevity of the equipment, and health problems caused by dissolved compounds in the water. The present study aims to evaluate the corrosion and scaling potential in water distribution networks of four villages located in different geographical locations of Urmia, Iran. In this descriptive cross-sectional study, 36 samples of water entering the villages of Dizaj-e Siavosh, Dolama, Gogtapeh, and Band distribution networks were analyzed according to standard methods for water and wastewater examinations. The corrosion and scaling potential were evaluated based on Ryznar stability (RSI), Langelier saturation (LSI), Puckorius scaling (PSI), and Larson–Skold (LRI) indices after determination of pH, total dissolved solids, sulfate, alkalinity, calcium hardness, and chloride. The results indicated that the values of LSI, RSI, PSI, and LRI indices were −1.94, 12.05, 12.20, and 0.68 for Gogtapeh water supply; −2.22, 12.72, 13.6, and 0.4 for Dizaj-e Siavosh water supply; −2.03, 12.1, 12.06, and 0.3 for Band water supply; and finally −2.09, 12.30, 12.59, and 0.29 for Dolama water supply, respectivly. Therefore, the water entering Gogtapeh distribution system has a tendency to scaling based on the LRI as an only appropriate index for the corrosion and scaling potential in this village. However, the water entering Dizaj-e Siavosh, Dolama, and Band distribution networks are highly corrosive based on the LSI, RSI, and PSI indices. The concordance between the analysis of chemical water quality and national standards could not be sufficient to confirm the water quality balance in terms of corrosion and scaling potential.

Keywords: Corrosion and scaling potential; Rural water distribution network; Water quality

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1. Introduction

The quality of rural drinking water resources leads to the corrosion in water distribution system due to the incomplete treatment methods [1]. Corrosion in water distribution systems involves the electrochemical or physicochemical interaction between the pipe and the water. Failure of the water distribution network and unwanted alterations in water quality may arise from pipe corrosion. An oxidation reaction causes the deterioration of the interior pipe surface providing there exists a difference in electrical potential at two different points on the pipe surface, whereas scaling can aid corrosion resistance in the water distribution system by creating a barrier between the conductive water and surface of the pipe. It also serves as a reservoir for corrosion products that can be released into the water [2–5].

Moreover, scaling is a multi-phased process during which divalent cations of calcium and magnesium react with water-soluble anions and following the oversaturation of soluble solids, a hard layer forms on the surfaces in contact with water. Studies indicate that a majority of deposits in water distribution systems include calcium carbonate, calcium sulfate, and magnesium chloride [3,6]. The effective factors in corrosion and scaling of water distribution systems include the velocity of water flow, EC, alkalinity, the residual chlorine, hardness, pH, DO, TDS, biological reactions, stagnation time, temperature, and pipe age [2–7].

Tan et al. [8] demonstrated that alkalinity, pH, and monochloramine had significant impacts on iron oxidation rate and suspended iron particle. However, DO, sulfate, and chloride had a slight effect.

Hu et al. [9] indicated that in the presence of goethite as a pipe corrosion product, the formation of disinfection byproducts (DBPs) during chlorination was enhanced as pH and chlorine concentration increased. The enhancement of DBP formation could be attributed to the generation of hydroxyl radical which could oxidize natural organic matter (NOM) in water and produce more DBP precursors to react with chlorine. X-ray diffraction and scanning electron microscope analyses of goethite revealed that it may adsorb NOM on its surface and modify NOM structure.

The damage costs of the corrosion and scaling allocate a remarkable percentage of gross national product in countries. In the US, the total annual direct cost of corrosion for the nation's drinking water and sewer systems was estimated at $36.0 billion [10]. Inattention to corrosion and scaling potential has led to 28% loss in urban water distribution networks of Iran comparing with 8% of world rate. A budget of 500 million dollars is required to reduce the loss to 15%.

A variety of efforts has been undertaken to use indicators for the corrosivity of treated water. Many of these indices represent water's corrosion rate based on the capability of precipitating calcium carbonate ($CaCO_3(s)$). Precipitated calcium carbonate is thought to provide a protective "eggshell" layer along the surface of pipes that prevent the corrosion reaction from proceeding. Such indices include the Langelier saturation index (LSI), the Ryznar stability index (RSI), the Puckorius scaling index (PSI), the aggressiveness index (AI), and the Larson–Skold index (LRI) [4,5].

Ibrahim-Korfali [7] assessed the impact of the corrosion and scaling in metallic water distribution system on the water quality in a coastal region of Beirut, Lebanon. Accordingly, water was oversaturated in terms of calcium carbonate and expected to delay metallic corrosion. However, high chloride levels rendered water to be highly corrosive and to interfere with the formation of $CaCO_3$ scale. The results revealed an inverse relation of Cl^- with metal-scale formation except for lead.

Shankar [1] evaluated the corrosion and scaling rate using the LSI and the RSI for the groundwaters of K.R. Puram area in Bangalore, India. Based on this study, 66.67% of the samples showed intolerable corrosion.

Zhang [5] studied the effect of disinfectant type, sulfate/chloride ratio, nitrate concentration, and magnesium hardness on iron corrosion. For the waters tested, chlorine controlled red water and microbial activity in the bulk solution better than chloramine. Changes in the sulfate/chloride ratio did not have a large effect on iron corrosion. High levels of nitrate increased the rate of chlorine decay as a result of free ammonia formation, and also increased the release of iron. Increased magnesium and zinc decreased the red water caused by high silicate.

Taghipour et al. [11] studied the corrosion and scaling potential of drinking water system in Tabriz, Iran, and the related results revealed the corrosion of water.

The required options to control the corrosion and scaling potential consist of water speed and pH adjustment, cleaning the pipes to remove the slime layer, disinfection of the system, improving the structural quality of metal pipes, utilizing inhibitors such as chromates, polyphosphates, and silicates to prevent cathodic and anodic reactions, cathodic protection, and providing the conditions to form calcium carbonate scales [4–9].

Lakshmi et al. [12] confirmed the influence of sulfamerazine (SMZ) drug as anti-scalant in water containing gypsum salt ($CaSO_4$) and brine water.

Alshehri et al. [13] studied the impact of phosphate-based inhibitors and pH adjustment on iron release in distribution systems. Based on this study, blended orthophosphate (BOP) minimized total iron release followed closely by increasing pH (between 7.9 and 8.1), while orthophosphate (OP) dose did not affect iron release.

Rahman and Gagnon [14] demonstrated that the lowest Fe(II) oxidation rate constant was obtained under pH ≤ 6.5 with chlorine doses less than 2.2 mg/L and a phosphate-to-Fe(II) mole ratio ≈ 0.3 in iron pipes.

There has not yet been a comprehensive study of corrosion and scaling potential of drinking water distribution network in rural areas of Urmia, Iran. This study, therefore, aims to examine corrosion and scaling potential in rural water distribution network situated in different geographic locations of Urmia using the corrosion and scaling indices.

The water quality of studied villages conforms to the national and international standards. However, the waters of them have low hardness and alkalinity which can decrease scaling.

2. Materials and methods

In this descriptive cross-sectional study, corrosion and scaling potential in distribution network of four rural areas of Urmia, Iran, were evaluated using the RSI, the LSI, the PSI, the AI, and the LRI indices.

To examine the intended goals, 36 samples from water entering distribution networks of rural areas of Urmia such as Dizaj-e Siavosh, Dolama, Gogtapeh, and Band (Fig. 1) were taken and analyzed based on standard methods of water and wastewater examinations [15]. In order to evaluate the corrosion and scaling potential indices, such parameters as pH, total dissolved solids, sulfate, alkalinity, calcium hardness, and chloride were measured using standard methods. To increase the precision, all the experiments were repeated three times. After the analysis of samples, the mentioned indices were calculated using Excel software and then interpreted. Table 1 and subsequent descriptions provide the required information on indices.

2.1. The Langelier saturation index

The LSI is a measure of water's pH relative to its pH of saturation with $CaCO_3(s)$. A positive LSI value indicates a potential for scale formation that water is saturated with respect to $CaCO_3$ and is thus considered "noncorrosive". A protective layer of $CaCO_3$ is expected to form on the pipe wall [4,16]. A water with the LSI value more negative than −0.5 is described as aggressive. An aggressive water will not deposit a protective layer of calcium carbonate [22].

2.2. The Ryznar stability index

The RSI is similar to the Langelier index as it uses a water's tendency to precipitate $CaCO_3$. Typically, an RSI value between 5.0 and 7.0 is desirable. Heavy scale is expected to form when the RSI is below 5.0–5.5. Significant corrosion is expected when the value is above 7.0. An increasing value for RSI indicates an increasing water corrosivity [4,16].

2.3. The Puckorius scaling index

The PSI is a variation of the RSI. As with the RSI, it is also an empirical relationship, but differs from the RSI by using a calculated pH, referred to as the equilibrium pH, instead of the measured pH. The PSI considers scaling as likely to occur if its value is <6 and as likely to dissolve scale if >7 [16,18].

2.4. The aggressiveness index

The aggressive index, originally developed for monitoring water in asbestos pipe, is sometimes substituted for the Langelier index as an indicator of water corrosivity. The AI is derived from the actual pH, calcium hardness, and total alkalinity. Where it is applicable, it is more convenient than the LSI. Because the AI does not include the effects of temperature or dissolved solids, it is less accurate as an analytical index than the LSI [23].

2.5. The Larson–Skold index

The LRI incorporates the effects of chloride, sulfate, and bicarbonate concentrations on the corrosivity of a water. The LR assumes that chloride and sulfate behave to enhance corrosion and that bicarbonate mitigates corrosion. Bicarbonate concentration is assumed to be equal to alkalinity for pH ranges of treated water (6.5–9) [4,18,21].

3. Results and discussion

Such parameters as pH, total dissolved solids, sulfate, alkalinity, calcium hardness, and chloride of

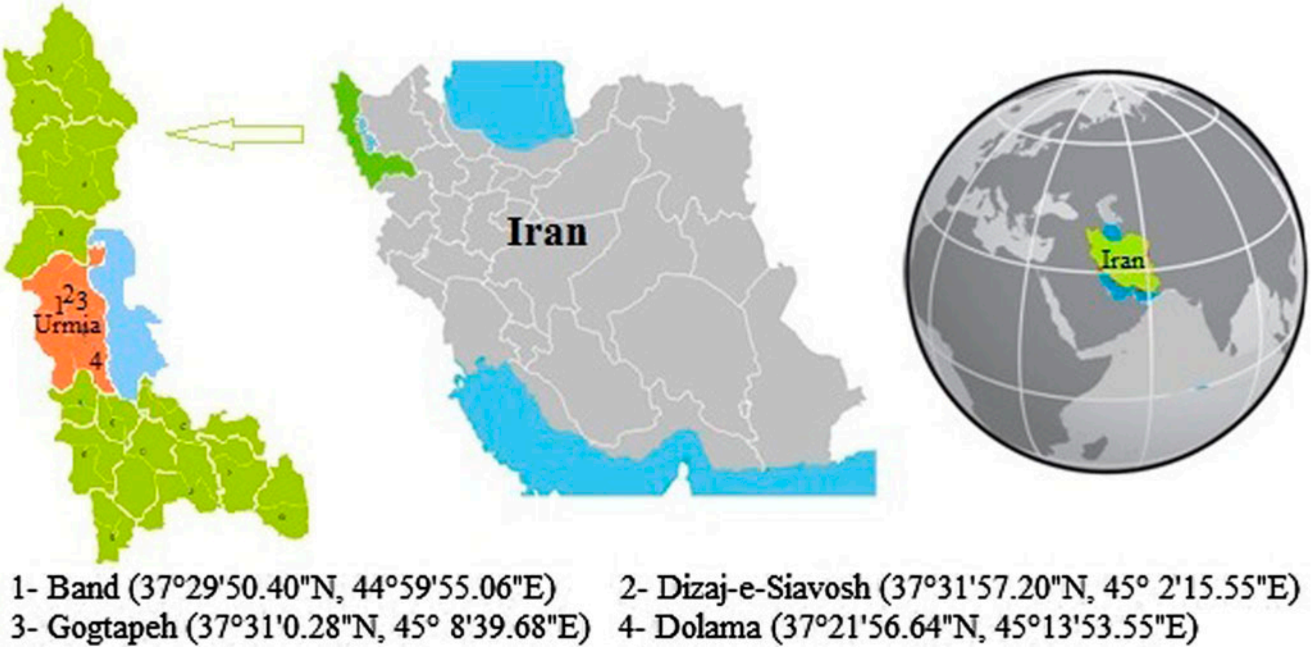

Fig. 1. Geographical coordinates and location of villages studied, Urmia, Iran.

Table 1
Water corrosion and scaling indices

Index	Equation	Interpretation		References
Langelier saturation index (LSI)	pH–pHs*	$LSI < -2$	High corrosion	[4,16–19]
		$-2 < LSI < -0.5$	Serious corrorion	
		$-0.5 < LSI < 0$	Slight corrosion	
		$LSI = 0$	Balance	
		$0 < LSI < 0.5$	Slight scaling	
		$0.5 < LSI < 2$	High scaling	
Ryznar stability index (RSI)	2pHs–pH	$RSI < 6$	Scaling	[1,4,7,18,19]
		$7 < RSI < 8$	Low corrosion	
		$RSI > 8$	High corrosion	
Puckorius scaling index (PSI)	2pHs–pH_{eq}**	$PSI < 5.5$	High scaling	[16,18]
		$5.5 < PSI < 6.5$	Low scaling	
		$6.5 < PSI < 7.5$	Low scaling or	
		$7.5 < PSI < 8.5$	Corrosion	
		$PSI > 8.5$	Significant corrosion	
Aggressiveness index (AI)	pH + log (Alk.) (H)	$AI < 10$	High corrosion	[18,20,21]
		$10 < AI < 12$	Significant corrosion	
		$AI > 12$	Scaling	
Larson–Skold index (LRI)	$LR = \frac{2[SO_4^{2-}]+[Cl^-]}{[HCO_3^-]}$	$LR < 0.8$	Scaling	[4,5]
		$0.8 < LR < 1.2$	Relative corrosion	
		$LR > 1.2$	Pitting corrosion	

Notes: Alk. = Total alkalinity (mg/L as $CaCO_3$) and H = Calcium hardness.

*$pH_s = (9.3 + A + B) - (C + D)$, $A = (\log [TDS] - 1)/10$, $B = -13.12 \times \log [°C + 273] + 34.55$, $C = \log [Ca^{2+}$ as $CaCO_3] - 0.4$, $D = \log$ [alkalinity as $CaCO_3$].

**$pH_{eq} = 1.465 \times \log (T - Alk) + 4.54$, $T - Alk$: Total alkalinity (mg/L as $CaCO_3$).

Table 2
Chemical quality of drinking water in the village of Dolama

Sampling month		SO_4^- (mg/L)	Cl^- (mg/L)	Alkalinity (mg/L $CaCO_3$)	Ca^{2+} (mg/L $CaCO_3$)	TDS (mg/L)	pH	Temperature (℃)
May	First time	11	20	185	73	328	7.7	18.4
	Second time	11	20.5	180	68	325	8	18.4
	Third time	11	20	184	80	327	8.1	18.4
June	First time	11	21.5	185	80	325	8.3	14.5
	Second time	11	22.5	185	85	326	8.3	14.7
	Third time	11	21.5	190	84	326	8.3	16.2
July	First time	10	20.5	156	82	331	8.2	17.3
	Second time	10	21	162	80	329	8	17.9
	Third time	10	21.5	164	80	329	8.2	18.2
	Average	10.67 ± 0.5	21 ± 0.63	176.78 ± 12.52	79.11 ± 5.37	327.3 ± 2.06	8.12 ± 0.2	17.1 ± 1.59

Table 3
Chemical quality of drinking water in the village of Gogtapeh

Sampling month		SO_4^- (mg/L)	Cl^- (mg/L)	Alkalinity (mg/L $CaCO_3$)	Ca^{2+} (mg/L $CaCO_3$)	TDS (mg/L)	pH	Temperature (℃)
May	First time	60	31	246	92	429	7.6	17.3
	Second time	60	31	250	95	428	8.2	18.3
	Third time	60	31	256	98	428	8.3	18.4
June	First time	57	30.5	246	105	427	8.2	13.5
	Second time	57	30	250	100	427	8.2	15
	Third time	57	31	240	105	428	8.2	16.5
July	First time	58	30	226	95	432	8.4	14.6
	Second time	58	30.5	225	104	430	8.2	17
	Third time	58	30	224	95	430	8.2	17.2
	Average	58.3 ± 1.3	30.56 ± 0.46	240.3 ± 12.27	98.78 ± 4.94	428.78 ± 1.64	8.17 ± 0.2	16.42 ± 1.7

water entering the distribution network of intended rural areas were studied and examined in three months to calculate Langelier, Ryznar, Aggressive, Puckorius, and Larson–Skold indices. The results of chemical analysis of drinking water in the villages of Dolama, Gogtapeh, Dizaj-e Siavosh, and Band are presented in Tables 2–5, respectively. As one regards, the values of examined parameters in these villages are within the guidelines of World Health Organization. In the villages of Dolama, Band, and Gogtapeh, the values of such parameters as hardness, alkalinity, and bicarbonate are high due to the use of groundwater resources. However, the same parameters are rather low in the village of Dizaj-e Siavosh due to the use of surface water supply.

Based on Tables 1 and 6, the LSI index values in the villages of Gogtapeh, Dizaj-e Siavosh, Band, and Dolama are −1.94, −2.22, −2.03, and −2.09. The RSI index values are 12.05, 12.72, 12.10, and 12.3. The values of AI index are also 12.54, 11.82, 12.37, and 12.26. The PSI index shows the values of 12.20, 13.6, 12.06, and 12.59. The LRI values are also 0.68, 0.4, 0.30, and 0.29, respectively.

The AI, originally developed for monitoring water in asbestos pipes, is sometimes substituted for the LSI as an indicator of water corrosivity. As mentioned, because the AI does not include the effects of temperature or dissolved solids, it is less accurate as an analytical index than the LSI [23]. Since asbestos pipe has not been used in the villages studied, the corrosion and scaling potential were not evaluated in Table 6.

The LRI is used to incorporate the effects of chloride, sulfate, and bicarbonate concentrations on the water corrosivity in steel pipes [4,18,21]. Due to the usage of steel pipes in Gogtapeh distribution network, application of the LRI is much more appropriate for

Table 4
Chemical quality of drinking water in the village of Dizaj-e-Siavosh

Sampling month		SO_4^- (mg/L)	Cl^-(mg/L)	Alkalinity (mg/L $CaCO_3$)	Ca^{2+} (mg/L $CaCO_3$)	TDS (mg/L)	pH	Temperature (°C)
May	First time	16	5	92	40	147	8.2	17.6
	Second time	16	7	98	41	146	8.5	18.5
	Third time	16	6.5	95	44	146	8.4	18.5
June	First time	15	5	98	37.5	145	8.4	12.3
	Second time	15	5	96	39	146	8.2	14.8
	Third time	15	5	97	41	147	8.3	15
July	First time	11	5.5	76	33	151	8.25	13.8
	Second time	11	6	82	34	150	8.2	13.9
	Third time	11	5	82	33	151	8.2	14.7
	Average	14 ± 2.29	5.56 ± 0.77	90.67 ± 8.38	38 ± 3.96	147.7 ± 2.35	8.29 ± 0.1	15.46 ± 2.2

Table 5
Chemical quality of drinking water in the village of Band

Sampling month		SO_4^- (mg/L)	Cl^-(mg/L)	Alkalinity (mg/L $CaCO_3$)	Ca^{2+} (mg/L $CaCO_3$)	TDS (mg/L)	pH	Temperature (°C)
May	First time	29	11.5	280	92	386	8	18.4
	Second time	29	11	290	91	383	8.2	18.5
	Third time	29	11	286	89	380	8.2	18.5
June	First time	30	11.5	280	90	382	8.1	17
	Second time	30	11.5	290	91	383	8.1	17
	Third time	30	11.5	286	86	384	8.3	16.7
July	First time	32	11.5	205	75	379	7.8	18.2
	Second time	32	11	210	73	381	7.8	18.7
	Third time	32	11.5	200	72	383	7.9	19
	Average	30.3 ± 1.32	11.33 ± 0.25	258.55 ± 40.4	84.33 ± 8.46	382.3 ± 2.12	8 ± 0.18	17.9 ± 0.87

the village. Hence, the water entering Gogtapeh distribution system has a tendency to scaling. With regard to the LRI value [18], chloride and sulfate in Gogtapeh distribution network are unlikely to interfere with the formation of a natural film.

The water supply in Dizaj-e Siavosh village is the surface water, and therefore its water, according to Table 4, has no tendency to calcium carbonate scaling due to low alkalinity and hardness. Thus, it is highly corrosive based on the LSI, RSI, and PSI.

Although the water supplies in the villages of Dolma and Band are groundwater, their water is also classified as highly corrosive based on the LSI, the RSI, and the PSI. However, their corrosion rate is less than that of Dizaj-e Siavosh village because of their higher hardness and alkalinity compared to that of Dizaj-e Siavosh village. Waters containing low alkalinity and hardness are more corrosive than those of high alkalinity and hardness primarily due to their participation in the formation of calcium carbonate precipitate coatings.

A large budget is allocated to run the rural drinking water distribution networks every year. Therefore, all the scientific and technical principles should be taken into consideration so as not to cause damage. Various methods can be used to diagnose, evaluate, and control corrosion problems. Techniques for controlling it include distribution and plumbing system design considerations, water quality modifications, corrosion inhibitors, cathodic protection, and coatings and linings [24,25].

Operators can promote the formation of a protective calcium carbonate scaling on the metal surface of plumbing by adjusting pH, alkalinity, and calcium levels. Calcium carbonate scaling occurs when water is oversaturated with it. It is important to note that pH levels well suited for corrosion control may not be optimal for other water treatment processes, such as coagulation and disinfection. To avoid this conflict, the pH level should be adjusted for corrosion control immediately prior to water distribution, and after the other water treatment requirements have been satisfied [24,25]. Lime softening affects metal solubility by changing the water's pH and carbonate levels. Hydroxide ions are then present and they decrease metal solubility by promoting the formation of solid basic carbonates that protect the surface of the pipe [24,25].

The presence of excessive dissolved oxygen increases water's corrosive activity. The optimal level of dissolved oxygen for corrosion control is 0.5–2.0 ppm. The most reasonable strategies for minimizing the presence of oxygen are to exclude the aeration process in the treatment of groundwater, to increase lime softening, and to extend the detention periods for treated water in reservoirs [24,25]. Corrosion inhibitors, cathodic protection, and lining the pipe walls are not practical or effective for rural distribution systems.

In rural water distribution systems, we can promote the formation of a protective calcium carbonate coating on the metal surface of plumbing by adjusting pH, alkalinity, and calcium levels. Calcium carbonate scaling occurs when water is oversaturated with calcium carbonate. The saturation point of any particular water source depends on the concentration of calcium ions, alkalinity, temperature, and pH, and the presence of other dissolved materials, such as phosphates, sulfates, and some trace metals. It is important to note that pH levels well suited for corrosion control may not be optimal for other water treatment processes, such as coagulation and disinfection. To avoid this conflict, the pH level should be adjusted for corrosion control immediately prior to water distribution, and after the other water treatment requirements have been satisfied [19,22,23,25].

Table 6
The condition of water in terms of scaling and corrosion rates in the villages studied

		Langelier saturation index		Ryznar stability index		Puckorius scaling index		Larson–Skold index	
Village	Water supply	Class	Value	Class	Value	Class	Value	Class	Value
Gogtapeh	Groundwater	Inapplicable index		Inapplicable index		Inapplicable index		Scaling (0.68)	
Dizaj-e-Siavosh	Surface water	Highly corrosive	−2.22	Highly corrosive	12.72	Highly corrosive	13.60	Inapplicable index	
Band	Groundwater	Highly corrosive	−2.03	Highly corrosive	12.10	Highly corrosive	12.06	Inapplicable index	
Dolama	Groundwater	Highly corrosive	−2.09	Highly corrosive	12.30	Highly corrosive	12.59	Inapplicable index	

4. Conclusions

The concordance between the analysis of chemical water quality and national standards could not be sufficient to confirm the water quality balance. According to the results of this study, although the values of temperature, total dissolved solids, sulfate, alkalinity, calcium hardness, and chloride were admissible, the water entering Gogtapeh distribution system has a tendency to scaling based on the LRI as an only appropriate index for the corrosion and scaling potential in this village, and water entering Dizaj-e Siavosh, Dolama, and Band distribution networks are highly corrosive based on the LSI, RSI, and PSI indices.

It is clearly evident that the stabilization of water before entering the distribution networks is an important factor in control and prevention of corrosion potential which needs to be performed well in water supply and treatment systems.

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References

[1] B.S. Shankar, Determination of scaling and corrosion tendencies of water through the use of Langelier and Ryznar Indices, Sch. J. Eng. Tech. 2A (2014) 123–127.

[2] P. Sarin, V.L. Snoeyink, J. Bebee, K.K. Jim, M.A. Beckett, W.M. Kriven, J.A. Clement, Iron release from corroded iron pipes in drinking water distribution systems: Effect of dissolved oxygen, Water Res. 38 (2004) 1259–1269.

[3] P. Sarin, V.L. Snoeyink, D.A. Lytle, W.M. Kriven, Iron corrosion scales: Model for scale growth, iron release, and colored water formation, J. Environ. Eng. © ASCE. 130(4) (2004) 364–373.

[4] A.S. Benson, Evaluation of Iron Corrosion Release Models for Water Distribution Systems, Thesis for Master of Science in Environmental Sciences & Engineering, The Virginia Polytechnic Institute and State University, Blacksburg, VA, 2009.

[5] Y. Zhang, Relative Effects of Water Chemistry on Aspects of Iron Corrosion, Thesis for Master of Science in Environmental Sciences & Engineering, The Virginia Polytechnic Institute and State University, Blacksburg, VA, 2005.

[6] HDR Engineering Inc., Handbook of Public Water Systems, second ed., Wiley, New York, NY, 2001.

[7] S. Ibrahim-Korfali, Total and speciated metals and metal scales in domestic water: Impact of metallic water distribution system, J. Environ. Sci. Eng. 1 (2012) 732–749.

[8] H. Tan, W. He, H. Han, Y. Lu, N. Zhang, Speciation of iron and development of iron corrosion scales in drinking water distribution systems, Desalin. Water Treat. (2014) 1–9, doi: 10.1080/19443994.2014.941303.

[9] C.Y. Hu, J. Zhang, B. Xu, Y.L. Lin, T.Y. Zhang, F.X. Tian, Effect of pipe corrosion product-goethite-on the formation of disinfection by-products during chlorination, Desalin. Water Treat. (2014) 1–9, doi: 10.1080/19443994.2014.971877.

[10] U.S. Departement of Transportation Federal Highway Administration, Corrosion Costs and Preventive Strategies in the United States, FHWA-RD-01-156, NACE International, Lanham, MD, 2002.

[11] H. Taghipour, M. Shakerkhatibi, M. Pourakbar, M. Belvasi, Corrosion and scaling potential in drinking water distribution system of Tabriz, northwestern Iran, Health Promot. Perspect. 1 (2012) 103–111.

[12] N.V. Lakshmi, S. Karthikeyan, P.A. Jeeva, M. Paramasivam, S. Narayanan, The influence of an eco-friendly antibiotic as anti-scalant and inhibitor for steel in gypsum solution and brine water, Desalin. Water Treat. (2014) 1–9, doi: 10.1080/19443994.2014.942702.

[13] A.A. Alshehri, S.J. Duranceau, J.S. Taylor, E.D. Stone, Investigating iron release in distribution systems with blend variations of source waters and phosphate inhibitors, Desalin. Water Treat. 8(1–3) (2009) 211–220.

[14] M.S. Rahman, G.A. Gagnon, Bench-scale evaluation of ferrous iron oxidation kinetics in drinking water: Effect of corrosion control and dissolved organic matter, J. Environ. Sci. Health A Tox. Hazard Subst. Environ. Eng. 1 (2014) 1–9.

[15] APHA, AWWA, WPCF, Standard Methods for the Examination of Water and Wastewater, twenty-first ed., APHA, AWWA, WPCF, Washington, DC, 2005.

[16] K.M. Zia, H. Bhatti, I.A. Bahatti, R. Nawaz, A pHs equation for calcium carbonate scale prediction in cooling water system, J. Chem. Soc. Pak. 2 (2008) 182–185.

[17] M. Hernández-Suáraz, Guidline for the Remineralization of the Salinated Waters, Acuamed, Madrid, Spain, 2010.

[18] M. Silbert, W-INDEX (Water INDEX calculations), Toronto, 2006. Available from: <http://www.silbert.org/W-index-Spreadsheet.pdf>.

[19] A. Postwa, C. Hoyes, Best Practice Guide on the Control of Iron and Manganese in Water Supply, IWA Puplishing, London, 2013.

[20] J.L. Barringer, G.R. Kish, A.J. Velnich, Corrosiveness of Ground Water in the Kirkwood-Cohansey Aquifer System of the New Jersey Coastal Plain, New Jersey Department of Environmental Protection and Energy, West Trenton, NJ, 1993.

[21] Z. Ahmad, Principal of Corrosion Engineering and Corrosion Control, first ed., Elsevier, Oxford, 2006.

[22] F. Leitz, K. Guerra, Water Chemistry Analysis for Water Conveyance, Storage, and Desalination Projects, U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, CO, 2013.

[23] Safe Drinking Water Committee, National Research Council, Drinking water and Health, vol. 4, The National Academies Press, Washington, DC, 1982.

[24] J.H. Lehr, J. Keeley, J. Lehr, Water Encyclopedia: Domestic, Municipal, and Industrial Water Supply and Waste Disposa, vol. 1, Wiley, Hoboken, NJ, 2005.

[25] R.W. Revie, H.H. Uhlig, Corrosion and Corrosion Control: An Introduction to Corrosion Science and Engineering, fourth ed., Wiley, Hoboken, NJ, 2008.