Journal of Applied Research in Water and Wastewater

E-ISSN: 2476-6283

Journal homepage: https://arww.razi.ac.ir

Corrosion and scaling potentials of rural water distribution network in different climate zones of Kermanshah province, Iran

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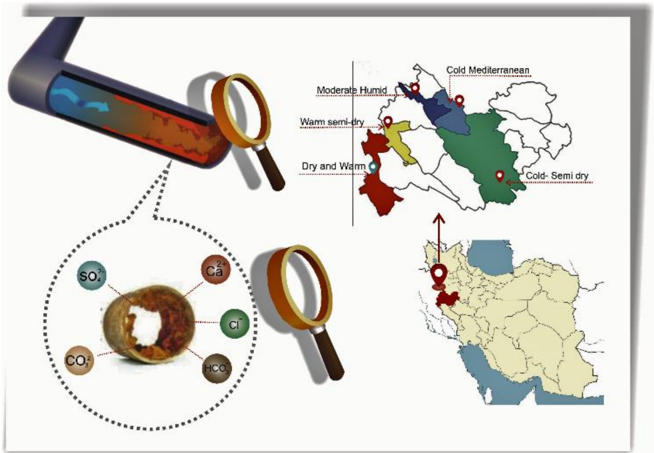
GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 19 June 2022
Reviewed 23 August 2022
Received in revised form 29 September 2022
Accepted 30 September 2022
Available online 3 November 2022

Keywords:
Aggressive index
Langelier saturation index
Larson–Skold index
Puckorius scaling index
Ryznar stability index

Article type: Research Article

ABSTRACT

Corrosion control is an important parameter to supply safe drinking water considered by the World Health Organization. This study is intended to determine the scaling and corrosion potentials of drinking water in rural distribution networks during 2009-2017 in different climate zones of Kermanshah province, Iran. The most commonly used corrosion indices, Langelier saturation index (LSI), Ryznar stability index (RSI), Puckorius scaling index (PSI), aggressive index (AI), and Larson–Skold index (L-SI), were calculated. Statistical analysis was executed to examine the significant differences in water corrosion and scaling indices between different climate zones. Statistical analysis showed significant differences in water chemical characteristics related to corrosion and scaling potentials between different climate zones (except temperature). Statistical analysis also indicated significant differences in water corrosion and scaling indices (P <0.001) between different climate zones. The lowest average amounts of LSI (0.06), AI (12.13), and L-SI (0.06), and the highest values of RSI (7.44) and PSI (7.11) were observed in moderate humid climate zone. Also, the highest values for LSI (0.39), and L-SI (0.15) were related to warm semi-arid climate zone. Based on water characteristics in various climate zones, LSI and RSI were chosen as good indices for corrosion or scaling of water corrosion potential in different climate zones. The results indicated that there is a weak tendency towards corrosion for warm semi-dry climate zones in contrast to the other climate zones that have higher corrosion potentials for Kermanshah Province under the conditions of this study, or maybe related to local water quality characteristics among climate zones.

1. Introduction

Safe and sanitary water is one of the most critical necessities for human life to provide a healthy community. The need for water from different aspects such as industrial, domestic, and agriculture use increases by population growth. By surpassing these demands beyond the water supply, water shortage, as well as the water quality decline, would occur (Heydariand Bidgoli. 2012). Water quality is affected by scaling and corrosion phenomena. Scaling and corrosion potentials are considered as one the most significant indices in water quality evaluation (Hoseinzadeh et al. 2013). Whenever a substance chemically reacts with its surroundings, corrosion occurs, and the

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How to cite: A. Fatemi, Z. Eskandari, M.B. Gholivand, M. Zarabi, Corrosion and scaling potentials of rural water distribution network in different climate zones of Kermanshah province, Iran, *Journal of Applied Research in Water and Wastewater*, 9 (2), 2022, 100-106.

properties of materials are consequently changed (Mirzabeygi et al. 2017). The global damage of corrosion is the intensive alteration of the infrastructure and equipment of countries. The enormous demands for maintenance, renovation, and replacement of various constitute and equipment result from corrosion. Also, more efforts are needed for excellent performance as the access, availability, and safety conditions of water decline. Moreover, more costs are spent examining these parameters (Thompson et al. 2005; Verma et al. 2018). The annual direct cost of corrosion in the USA was determined in 2001 as $ 276 billion—or 3.1% of the gross domestic product (GDP) (Schmitt. 2009). Recently, Li et al. (2018) reported a US$ 4 trillion financial loss per year worldwide due to corrosion. The indirect impact of corrosion could be considered as severe human beings and environmental risks (Verma et al. 2018).

Corrosion is influenced by various factors related to (i) water chemistry and hydraulic flow properties, (ii) climate conditions, and (iii) the composition of pipe scale. The water's chemical properties that contributed to corrosion are pH, alkalinity, dissolved oxygen content, and total dissolved solids (TDS). The hydraulic flow properties include temperature, flow, and velocity of water (Benson. 2009). Scaling is a multi-phased process that occurs when water is saturated by divalent cations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) (Mirzabeygi et al. 2017). Alkalinity, temperature, pH, and some anions such as phosphates and sulfates, as well as the presence of some trace metals, impact the saturation point of water (Rezaei Kalantari et al. 2013). In this study, we investigate water chemistry characteristics that influence water corrosion and scaling. Some functional indices to evaluate of saturation point (i.e., corrosion and scaling potential) of water include Langelier saturation index (LSI), Ryznar stability index (RSI), Puckorius scaling index (PSI), aggressive index (AI), and Larson–Skold index (L-SI) (Table 1).

On a global scale, the corrosion of metals in arid climates is less than in moist ones (Kibblewhite et al. 2015). The average annual atmospheric precipitation directly impacts the corrosion of buried ferrous objects in various soils, as evidenced by the US NBS study for corrosion of buried objects (Melchers et al. 2019). Although large-scale weather systems have the same influence on different parts of Kermanshah province, this province experiences various local climates, too. The city of Kermanshah is located in the west of Iran. It has different climate zones, including moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm. However, so far, a comprehensive study has not been done on corrosion and scaling potentials of drinking water distribution systems in Kermanshah province, Iran. The assumptions for this study were (*i*) there are differences between chemical parameters attributing to corrosion and scaling potentials of water between different climate zones, and (*ii*) there are differences between corrosion and scaling potential of water in different climate zones. This study aimed at investigating the chemical characteristics of the water-related to corrosion and scaling potentials. The corrosiveness or scaling tendency of the water in rural areas of Kermanshah province, located in different climate zones, was examined according to LSI, RSI, PSI, L-SI, and AI.

2. Materials and Methods

2.1. Study area

The present study area is situated in Kermanshah province, west of Iran. It is located between 33° 40′ and 35° 18′ N latitude and 45° 24′ and 48° 07′ E longitude (Fig. 1). This region with, an area of about 25045 km^2, has a variety of climatic zones. Based on meteorological data, there are six types of climate in Kermanshah province using the revised Embereger (Fig. 1). The temperature is an essential parameter because it influences water temperature. Besides, the LSI water corrosion equation calculates corrosion and scaling potentials for water by considering the water temperature (Table 1). According to the long-term meteorological data, the average annual temperature in different climate zones ranged from 12.8 to 22.0 °C, and the annual rainfall is about 290–756 mm (Table 2).

2.2. Datasets

Considering the different climatic zones of Kermanshah province (Fig. 1), 32 sampling datasets from stations located in five cities were obtained from the city's Hydraulic Works. The datasets included results for a corrosion characteristic (alkalinity, pH, calcium hardness, temperature, TDS) (Singley et al. 1984), as well as anions (Cl^-, CO_3^{2-}, HCO_3^- and SO_4^{2-}), monitored over nine years from 2009 to 2017. The monitoring stations cities include Javanrood, Ravansar, Kermanshah, Sarpol-e-Zahab, and Qasr-e-Shireen, which contributed to moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones, respectively. The analyzed parameters, according to standard methods, are presented in Table 2. The values of pH and temperature were measured by pH meter and thermometer, respectively. Calcium hardness, alkalinity, TDS, Ca^{2+} were measured in the laboratory using the standard methods (ISIRI. 2010).

The corrosion indices, including LSI, RSI, PSI, AI, and L-SI, were employed, and water classification was performed (Table1). Table 1 presents the indices, equations, and some definitions and criteria for categorizing the stability of the water (Aghazadeh et al. 2017; Rossumand Merrill. 1983; Singley et al. 1984; Zia et al. 2008).

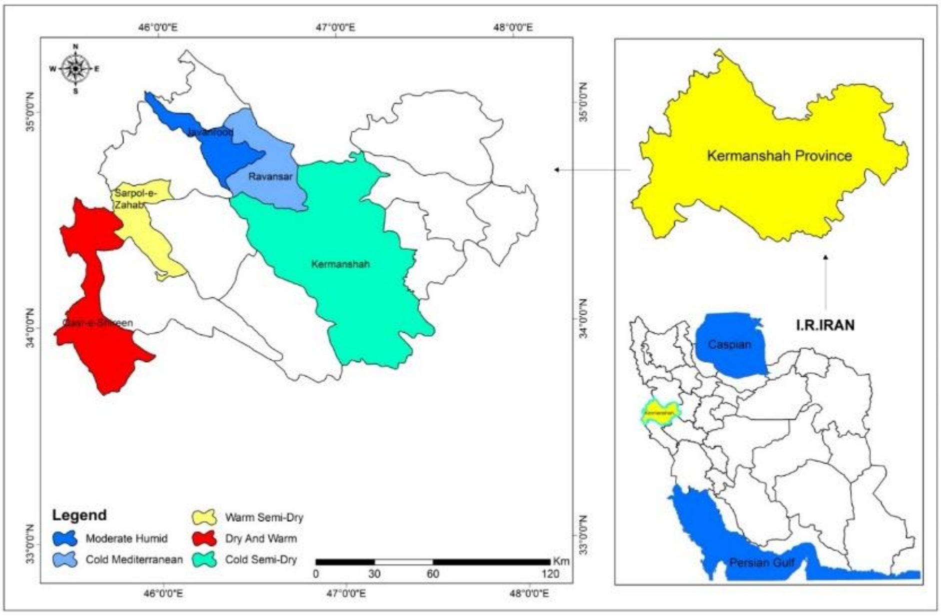


Fig. 1. Location of the study area in Kermanshah province, Iran.

Table 1. Water corrosion and scaling indices' definition and criteria.

Index	Equation	Index value	Water condition	Reference
Langelier saturation index (LSI)	$LSI = pH - pH_s^{*}$	2.0	Scale forming but non-corrosive	(Zia et al. 2008)
		0.5	Slightly scale forming and corrosive	
		0.02	Balanced but pitting corrosion is possible	
		-0.5	Slightly corrosive but non-scale forming	
		-2.0	Serious corrosion	
Ryznar stability index (RSI)	$RSI = 2pH_s - pH$	<6.5	Scaling	(Singley et al. 1984)
		6.5-7.0	Low corrosive	
		>7.0	High corrosive	
Puckorius scaling index(PSI)	$PSI = 2pH_s - pH_{eq}^{**}$	4.5-5.5	Heavy and serious scale	(Zia et al. 2008)
		5.5-6.5	Light scale prediction	
		6.5-7.5	Little scale or corrosion	
		7.5-8.0	Corrosion significant	
		8.0-9.0	Heavy and serious corrosion	
		>9.0	Crossion intolerable	
Aggressive index (AI)	$^{***}AI = pH + log\left(Alk \times H\right)$	<10	Highly aggressive	(Rossumand Merrill. 1983)
		10-12	Moderately aggressive	
		>12	Not aggressive	
Larson–Skold index (L-SI)	$L-SI = \frac{\left(SO_4^{2-} + Cl^-\right)}{\left(HCO_3^- + CO_3^{2-}\right)}$	<0.8	Chloride and sulfate are unlikely to interfere with the formation of protecting film	(Aghazadeh et al. 2017)
		0.8-1.2	Corrosion rates may be higher than expected	
		<1.2	High rates of localized corrosion may be expected	

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

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

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

2.3. Statistical analysis

The Kolmogorov-Smirnov test evaluates the normality of distributions of data. For data with normal distribution, statistical analysis was performed by ANOVA (F-test). Significant differences between means at the 95% level of probability were done by Duncan's multiple range test. For data that are not normally distributed, first of all, Box-Cox transformation was applied. Box-Cox transformation proposed a parametric power transformation technique to reduce non-normality and heteroscedasticity (Sakia. 1992). Johnson transformation method was also tested (by Minitab software version 20.3.0.0) for data that were not normalized by the Box-Cox technique. For data that did not transform, the nonparametric Kruskal-Wallis test was executed. The Kruskal-Wallis test uses variation among ranked sample means (Chanand Walmsley. 1997). The post-hoc Dunn-Bonferroni method was applied following a significant Kruskal-Wallis test. All statistical analyses were performed by SPSS software (version 26).

3. Results and Discussion

3.1. Water's chemical characteristics in different climate zones

The amounts of chemical characteristics of water attributed to corrosion and scaling potential of water in different climate zones were reported in Table 2. The average of EC for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones was 362.4, 429.3, 319.0, 589.0, and 476.2 µmhos cm^{-1}, respectively. The average of Ca^{2+} varied from 61.3, 61.9, 46.5, 67.7, and 64.9 mg/L for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones, respectively. The range of the average CO_3^{2-} was from 0.01 to 0.02 mg/L for different climate zones. The average of HCO_3^-ranged from 3.2 to 4.3 mg/L related to moderate humid and warm semi-dry climate zones, respectively. Cl^- and SO_4^{2-} ranged from 0.1 to 0.3 mg/L on average in different climate zones. pH ranged from 7.6 to 7.7 on average for different climate zones. The temperature ranged from 19.3 to 22.6 °C. However, the average of TDS, hardness, and total alkalinity changed widely between different climate zones. The range of the average of TDS was 221.4, 268.1, 228.7, 368.2, and 295.6 mg/L for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones, respectively. The hardness ranged from 199.9 to 305.1 mg/L on average related to moderate humid and warm and dry climate zones, respectively. The total alkalinity also showed a similar trend. Besides, the lowest amount of total alkalinity (i.e., 196.5 mg/L) was observed for the moderate humid climate zone. The highest amount of total alkalinity was 272.0 mg/L related to the warm and dry climate zone. Taheri Tizro et al. (2014) reported a variation of TDS from about 150 to 300 mg/L for the Hor Rood River at Kakareza station, Kuhdasht region, West of Iran. Fatemi. (2015) reported that TDS values varied from 225.7 to 346.8 mg/L for the Gharasoo River, Kermanshah city. Roholamin Kasmaei et al. (2017) reported that the range of TDS was from 233 to 435 mg/L and the total hardness varied from 211 to 372 mg/L for groundwater resources of the Zawar village, Tonekabon city.

The Kolmogorov-Smirnov test showed that water's chemical characteristics did not have a normal distribution. The results of the Box-Cox transformation showed that pH, temperature, hardness, total alkalinity, and CO_3^2 could not be transformed. Johnson transformation method also could not transform these parameters. The ANOVA results indicated that the differences in the water's chemical characteristics between climate zones were significant. EC, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, and TDS were significantly different between different climate zones (*P* <0.001). The Kruskal-Wallis test indicated that differences of pH (Chi-square =10.98, *P*= 0.03, df=4), hardness (Chi-square =96.33, *P*= 0.000, df=4), and total alkalinity (Chi-square =75.10, *P*= 0.000, df=4), and CO_3^{2-} (Chi-square =15.24, *P*= 0.000, df=4) between different climate zones. However, the temperature difference was not significant (Chi-square =7.02, *P*= 0.14, df=4).

Pairwise comparisons using the Dunn-Bonferroni test indicated that pH (P = 0.051), hardness (P = 0.000), total alkalinity (P = 0.001), and CO_3^2 (P = 0.006) scores in dry and warm, and moderate humid climate zones were observed to be significantly different from those of other climate zones. The scores of hardness (P = 0.000), total alkalinity (P = 0.000), and CO_3^2 (P = 0.032) of warm semi-dry and moderate humid climate zones were significantly different. The significant differences were observed for the hardness (P = 0.000), and total alkalinity (P = 0.000) scores in cold semi-dry, and moderate humid climate zones. Also, the results indicated that the differences of hardness (P = 0.000), and total alkalinity (P = 0.000) scores in cold semi-dry and warm semi-dry climate zones were significant. Likewise, the hardness (P = 0.000), and total alkalinity (P = 0.000) scores in warm semi-dry and moderate humid climate zones showed significant differences. The total alkalinity scores in dry and warm and Mediterranean climate zones were significantly different (P = 0.031). There were significant differences in CO_3^2 scores between cold semi-dry and moderate humid climate zones (P = 0.032). No other differences were statistically significant.

3.2. Water corrosion and scaling indices

LSI, RSI, PSI, AI, and L-SI were determined for drinking water in the villages of Kermanshah province located in different climate zones

(Table 3). The minimum, maximum, and mean of each index for different climate zones were reported in Table 3. The Kolmogorov-Smirnov test showed that all water corrosion and scaling indices have a normal distribution except AI and L-SI, which they normalized by the Box-Cox technique. The statistical analysis showed that most of the chemical characteristics related to water corrosion and scaling potentials were significantly different between different climate zones. Therefore, it was expected that water corrosion and scaling indices were also different between different climate zones. The ANOVA indicated that LSI, RSI, PSI, AI, and L-SI were significantly different (*P* <0.001) between different climate zones. The LSI, RSI, PSI, AI, and L-SI are discussed for each climate zone henceforward.

Table 2. The mean values of cations and anions in the water samples (mg/L) and chemical quality of drinking water in different climate zones of Kermanshah province.

Climate zones		EC	Ca^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	pH	Temperature	TDS*	Hardness**	T.Alk***
		µmhos cm^{-1}	mg/L						^{0}C	mg/L		
Moderate humid	Min	305.00	49.70	0.01	1.89	0.06	0.04	7.30	16.20	198.40	174.00	116.00
	Max	435.00	75.50	0.23	5.23	0.21	0.21	7.50	27.80	269.70	252.00	320.00
	Mean	362.40 a	61.34 a	0.01	3.20 a	0.10 a	0.08 a	7.55	22.08	221.43 a	199.90	196.50
	SD	43.51	8.86	0.01	0.67	0.03	0.03	0.15	4.12	26.74	24.93	41.01
Cold Mediterranean	Min	350.00	47.50	0.01	2.64	0.07	0.03	7.40	13.50	217.00	174.00	150.00
	Max	541.00	79.60	0.03	4.05	0.61	2.80	8.00	27.90	432.10	304.00	248.00
	Mean	429.25 b	61.88b	0.01	3.43 b	0.27c	0.15 a	7.65	22.59	268.11 b	222.00	210.97
	SD	71.29	8.12	0.01	0.36	0.27	0.38	0.18	4.35	40.04	25.45	22.09
Cold semi-dry	Min	348.00	41.80	0.00	2.96	0.01	0.05	7.00	17.00	220.00	168.00	178.00
	Max	371.00	65.70	0.05	4.08	0.94	0.16	8.30	25.40	228.74	204.00	206.00
	Mean	319.00 a	46.47c	0.02	3.27 ab	0.15b	0.13 a	7.70	22.62	228.68 a	202.90	199.48
	SD	115.00	4.53	0.01	0.25	0.16	0.03	0.29	2.04	25.98	25.43	15.26
Warm semi-dry	Min	499.00	20.10	0.00	2.20	0.15	0.21	7.20	12.70	288.30	208.00	140.00
	Max	712.00	121.81	0.14	6.09	0.71	0.61	8.10	27.90	441.30	384.00	323.00
	Mean	588.97 d	67.65cd	0.01	4.34 c	0.27 d	0.33 c	7.59	21.24	368.19 d	305.10	271.97
	SD	55.78	28.61	0.02	1.04	0.13	0.12	0.18	4.52	39.75	40.18	40.25
Dry and warm	Min	467.00	55.30	0.01	3.50	0.10	0.15	7.60	12.50	289.40	238.00	220.00
	Max	483.00	68.10	0.03	4.60	0.61	0.22	7.80	27.10	305.40	282.00	284.00
	Mean	476.16 c	64.86 d	0.02	4.02 c	0.17 bc	0.19 b	7.70	19.28	295.63 c	264.83	247.16
	SD	5.44	4.37	0.01	0.32	0.14	0.02	0.09	5.77	4.40	16.36	19.73

*Total Dissolved Solids; ** Hardness as $CaCO_3$; *** T.ALK = Total Alkalinity as $CaCO_3$

The means with a common letter indicate that they are not significantly different (P <0.05).

The ANOVA results indicated that EC, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}, and TDS were significantly different between different climate zones (*P* <0.001). The Kruskal-Wallis test indicated significant differences of pH (Chi square =10.98, *P*= 0.03, df=4), hardness (Chi square =96.33, *P*= 0.000, df=4), and total alkalinity (Chi square =75.10, *P*= 0.000, df=4), and CO_3^{2-} (Chi square =15.24, *P*= 0.000, df=4) between different climate zones.

3.2.1. Moderate humid climate zone

For the moderate humid climate zone, the range of LSI was from -0.40 to 0.66, with an average of 0.06. The average RSI was 7.44, with a range from 6.58 to 8.10. However, PSI changed from 6.25 to 7.98, with an average of 7.11. The range of AI also was 11.79 to 12.64, with an average of 12.13. Moreover, L-SI also ranged from 0.03 to 0.14 (the average= 0.06). According to Table 2, the AI was in the scaling range (>12), and water tends to be non-aggressive. Since the average of L-SI for different climate zones was lower than 0.8 indicated that chloride and sulfate are unlikely to interfere with the formation of protecting film (Table 2). The ANOVA results showed that the lowest amounts of LSI, AI, and L-SI also the highest amounts of RSI and PSI were observed for moderate humid climate zone among different climate zones (Table 3). The LSI data showed that water is corrosive with the probability of occurrence of 60.0% and slightly corrosive as 35.0 % (Fig. 2a). Besides, the probability of occurrence of serious corrosive conditions based on RSI was 90.0% and slightly corrosive conditions as 10.0% (Fig. 2b). Furthermore, PSI data showed that only 15.0 % of water fell in the serious corrosive category. However, corrosive conditions would be as 80.0 % and non-corrosive conditions as 5.0 % (Fig. 2c).

3.2.2. Cold Mediterranean climate zone

For the cold Mediterranean climate zone, LSI ranged from -0.17 to 0.72, with an average of 0.24. However, the minimum, maximum, and average of RSI were 6.63, 7.73, and 7.18, respectively. Also, the average PSI was 6.89, with a range of 6.44-7.47. Moreover, AI changed from 11.93 to 12.75 (average =12.32). The amounts of L-SI also altered from 0.03 to 0.90, with an average of 0.12. According to the ANOVA, there were no significant differences in LSI, RSI, AI, and L-SI between the cold Mediterranean and cold semi-dry climate zones. Moreover, no significant differences were observed for L-SI for moderate humid and cold semi-dry climate zones (Table 3).

AI and L-SI showed that water is in scaling conditions. Therefore, the potential of the corrosivity of water regarding other indices was calculated (Fig. 2). LSI estimated the potential of corrosive conditions of water as 88.9%, and non-corrosion conditions as 11.1% (Fig. 2a). While, according to PSI, the possibility of occurrence of serious corrosive conditions was 72.2%. Moreover, the probability of the corrosive conditions of the water was about 27.8% (Fig. 2b). RSI also estimated corrosive and non-corrosive conditions as 94.4% and 5.6%, respectively (Fig. 2c).

3.2.3. Cold semi-dry climate zone

For the cold semi-dry climate zone, LSI was in the range of -0.63 to 0.85, with an average of 0.23. RSI ranged from 6.60-8.25, with an average of 7.23. The magnitude of PSI changed from 6.41 to 7.35 (mean=7.03). The minimum, maximum, and average of AI also were 11.54, 12.87, and 12.30, respectively. Besides, the amounts of minimum, maximum, and average L-SI were 0.03, 0.27, and 0.08, respectively. The results indicated that there were no significant differences in PSI between moderate humid and cold semi-dry climate zones (Table 3). The potential of corrosion and scaling conditions of water in percentages considering LSI, RSI, and PSI was calculated and presented in Fig. 2. According to LSI, the data showed that in cold semi-dry climate zone water is 3.2% high corrosive, 71.0% corrosive, 9.7% slightly corrosive, and 12.8% non-corrosive (Fig. 2a). While the possibility of occurrence of serious corrosive and slightly corrosive conditions based on RSI was 80.6% and 19.4%, respectively (Fig. 2b). PSI resulted in a 100 percent probability of corrosive conditions for water (Fig. 2c). Like moderate humid and cold Mediterranean climate zones, AI and L-SI, were in non-aggressive and non-interference conditions.

Table 3. Summary statistics of corrosion and scaling indices. Different letters indicate that LSI, RSI, PSI, AI, and L-SI differed in statistical tests (one-way ANOVA, *P* <0.001) between different climate zones.

Climate zones		LSI	RSI	PSI	AI	L-SI
Moderate humid	Min	-0.40	6.58	6.25	11.79	0.03
	Max	0.66	8.10	7.98	12.64	0.14
	Mean	0.06 a	7.44 d	7.11 d	12.13 a	0.06 a
	SD	0.25	0.39	0.43	0.20	0.02
Cold Mediterranean	Min	-0.17	6.63	6.44	11.93	0.03
	Max	0.72	7.73	7.47	12.75	0.90
	Mean	0.24 b	7.18 b	6.89 c	12.32 b	0.12 b
	SD	0.21	0.28	0.26	0.21	0.15
Cold semi-dry	Min	-0.63	6.60	6.41	11.54	0.03
	Max	0.85	8.25	7.35	12.87	0.27
	Mean	0.23 b	7.23 b	7.03 d	12.30 b	0.08 ab
	SD	0.31	0.34	0.16	0.28	0.04
Warm semi-dry	Min	-0.20	6.32	5.80	12.02	0.08
	Max	0.78	7.49	7.34	12.93	0.27
	Mean	0.39 c	6.82 a	6.32 a	12.51 c	0.15 d
	SD	0.24	0.34	0.36	0.22	0.05
Dry and warm	Min	0.29	6.77	6.40	12.34	0.06
	Max	0.49	7.09	6.81	12.66	0.20
	Mean	0.38 bc	6.96 a	6.62 b	12.52 c	0.09 b
	SD	0.06	0.11	0.13	0.11	0.04

The means with a common letter indicate that they are not significantly different (P <0.05).

3.2.4. Warm semi-dry climate zone

For the warm semi-dry climate zone, the range of LSI was -0.20 to 0.78 (average of 0.39). While for RSI, the minimum, maximum, and average were 6.32, 7.49, and 6.82, respectively, the PSI ranged from 5.80 to 7.34, with an average of 6.32. However, AI varied from 12.02 to 12.93, with an average of 12.51. For L-SI, the minimum amount was 0.08, while the maximum value was 0.27, and the average was 0.15 (Table 3).

Like the cold semi-dry climate zone, the AI>12 and L-SI< 0.8 indicated that water is in the range of scaling. Therefore, no interference of chloride and sulfate with the formation of protecting film is anticipated. The probability of corrosive conditions for water based on LSI, RSI, and PSI is shown in Fig. 2. Based on LSI, the possibility of water is corrosively estimated at 51.3%, slightly corrosive at 7.7%, and non-corrosive at 41.0% (Fig. 2a). According to RSI, the possibility of occurrence of serious corrosive conditions of water is 33.3%, slightly corrosive conditions as 48.7%, and non-corrosive conditions as 18.0% (Fig. 2b). Moreover, PSI showed the probably corrosive conditions of water estimated at 23.1% and for non-corrosive conditions, about 76.9% (Fig. 2c).

3.2.5. Dry and warm climate zone

For the dry and warm climate zone, LSI was ranged from 0.29 to 0.49, and the average is 0.38. Furthermore, RSI changed from 6.77 to 7.09, with an average of 6.96. PSI magnitudes also were 6.40 as the minimum, 6.81 as the maximum, and 6.62 as the average. In addition, the minimum, maximum, and average of AI varied as 12.34, 12.66, and 12.52, respectively. However, the L-SI range was from 0.06 to 0.20, with an average of 0.09. The ANOVA indicated that there were no significant differences of LSI, RSI, and AI between warm semi-dry and dry and warm climate zones (Table 3).

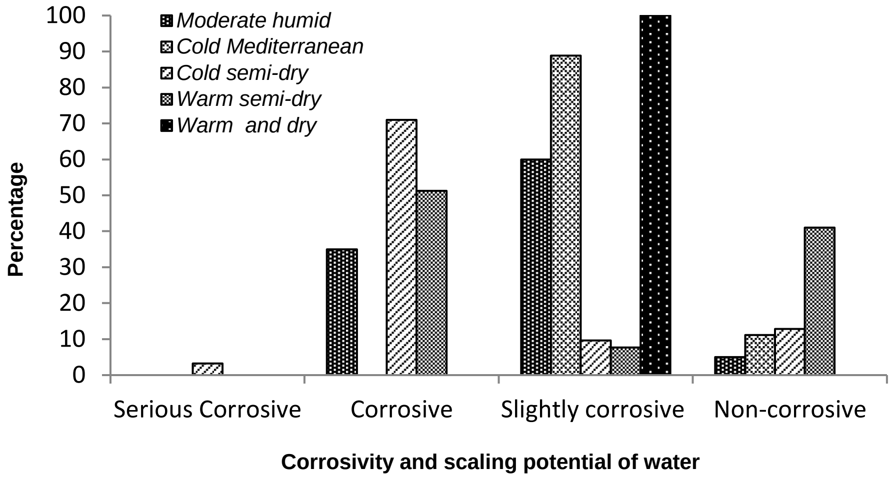
Like the climate zones mentioned above, AI and L-SI were in non-aggressive and non-interference conditions. With the knowledge that AI and L-SI were in the non-corrosion conditions, the estimated corrosive conditions for water, considering LSI, RSI, and PSI are presented in Fig. 2. According to LSI, the probability of water is corrosive as 100% (Fig. 2a), while RSI showed the possibility of occurrence of serious corrosive and corrosive conditions for water equally (Fig. 2b). Based on the PSI, corrosive and non-corrosive conditions of water were estimated at 83.3% and 16.7%, respectively (Fig. 2c).

3.3. Selection of the best index to indicate corrosion or scaling potential of water in different climate zones

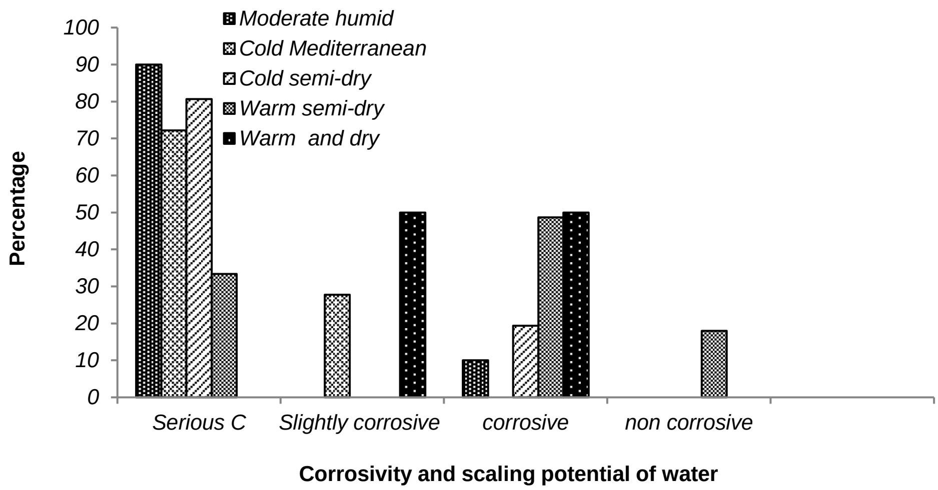
The comparison of various corrosion indices in different climate zones indicated that LSI in different climate zones showed a variety range. The average (and the standard deviation) of LSI for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones was 0.06 (±0.25), 0.24 (±0.21), 0.23 (±0.31), 0.39 (±0.24), and 0.38 (±0.06), respectively. Based on the average of calculated RSI for each climate zone, it seems that the difference between climate zones is not as wide-ranging as LSI. The average amounts of RSI were 7.44, 7.18, 7.23, 6.82, and 6.96 for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones, respectively. Average magnitudes of PSI for different climate zones were 7.11, 6.89, 7.03, 6.32, and 6.62 for moderate humid, cold Mediterranean, cold semi-dry, warm semi-dry, and dry and warm climate zones, respectively.

The amounts of the average AI for different climate zones were similar and did not show a varied range. The lowest average of AI was 12.1 for the moderate humid climate zone, and the highest was 12.5 for the dry and warm climate zone. The average amounts of L-SI show the same trend for various climate zones. Moreover, according to L-SI criteria (Table 2), since the average of L-SI for different climate zones was lower than 0.8, chloride and sulfate are unlikely to interfere with the formation of protecting film. On the other hand, water in different climate zones is not in the corrosive conditions based on L-SI. In a study on monitoring scaling and corrosion of the water in Ilam city (west of Iran), the mean and standard deviation values of LSI, RSI, AI, and PSI were reported as 0.29 (±0.5), 7.45 (±0.17), 12.44 (±0.16), and 7.99 (±0.14), respectively which indicated that water in Ilam tended to be corrosive (Davil et al. 2009). Taghipour et al. (2012) reported the means (standard deviation) values of LSI, RSI, PSI, and AI as -0.68 (±0.43), 8.43 (±0.55), 7.86 (±0.36), and 11.23 (±0.43), respectively. They considering these results, reported that Tabriz drinking water is corrosive.

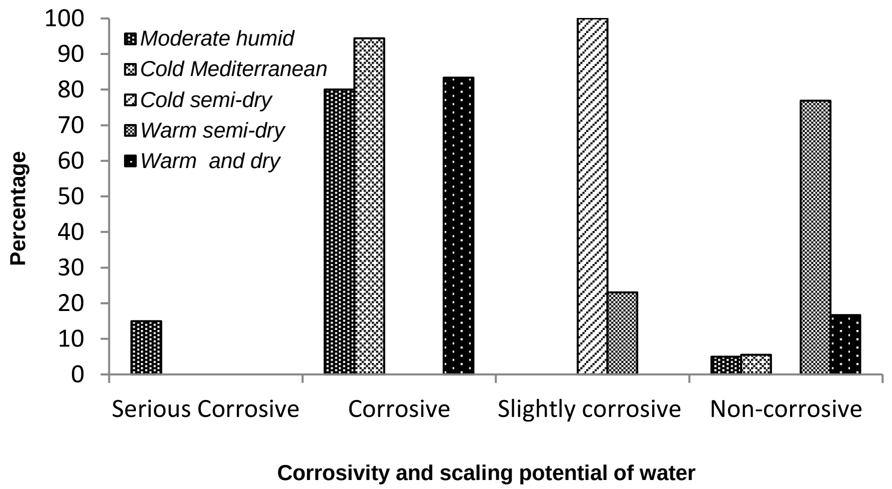
Rezaei Kalantari et al. (2013) compared the corrosion rate of Qom water in terms of all studied indices with Tabriz water. They concluded that the water of Qom is less corrosive, which could be due to high levels of TDS and high temperature in the groundwater of the villages of Qom province. Asgari et al. (2015), in a study on corrosion and scaling potential of Bushehr drinking water, reported the values of LSI, RSI, AI, and PSI as 0.28, 7.24, 12.02, and 9.92, respectively. Khorsandi et al. (2016) reported the value of L-SI as 0.68 for water distribution networks of four villages of Urmia, northwest of Iran.



(a)



(b)



(c)

Fig. 2. Water corrosivity and scaling status of water in different climate zones according to a) LSI, b) RSI, and c) PSI

Low chloride and sulfate concentrations explained the reason. According to Mirzabeygi et al. (2017) study, most of the water resources in the villages of Khorasan-e-Razavi province were corrosive, and the values of LSI, RSI, PSI, and AI were 0.33 (±0.17), 7.36 (±0.37), 7.4 (±0.6), and 12.03 (±0.18), respectively. Taghavi et al. (2019) reported that LSI ranged from −1.53 to −0.96, RSI from 9.63–10.54, PSI from 9.05–10.68, and AI from 12.04 and 12.91, for drinking water resources of Iranshahr.

As mentioned in the previous sections, under different climate zones, the AI was in the range of scaling (>12), and water tended to be non-aggressive. AI, originally developed for monitoring water in the asbestos pipe, is sometimes substituted for the LSI as an indicator of water corrosivity. Khorsandi et al. (2016) explained that AI is derived from the actual pH, calcium hardness, and total alkalinity. However, the effects of temperature or dissolved solids are not considered. For this reason, it is less accurate than LSI. The L-SI is used to incorporate the effects of chloride, sulfate, and bicarbonate concentrations on the water corrosivity in steel pipes (Benson. 2009).

To select which index among LSI, RSI, and PSI might indicate corrosion or scaling potential of water in different climate zones of Kermanshah province, further explanation is provided. Generally, RSI, similarly to LSI, uses water's tendency to precipitate in $CaCO_3$

(Khorsandi et al. 2016). PSI considers the buffering capacity and the maximum quantity of precipitation that can form in water to equilibrium (Davil et al. 2009). PSI uses an equilibrium pH rather than the actual system pH to account for the buffering effects (Zia et al. 2008). However, whenever the pH of water is lower than 8, PSI is not considered a useful index for corrosion or scaling of water (Mirzabeygi et al. 2017). The pH of water in most of the studied villages is lower than 8 (Table 2). Therefore, PSI is not considered as a useful index for corrosion or scaling of water to compare the results between different climate zones. Opportunely, PSI is calculated like the RSI, and the numbering systems and general interpretation of PSI and RSI are the same (Zia et al. 2008).

4. Conclusions

After investigating various corrosion and scaling indices, we selected LSI and RSI to study the potential of corrosion and scaling of water in different climate zones of Kermanshah province. According to the classification of corrosion and scaling indices for water supply sources of different climate zones, based on LSI, the percentages of the probability of water would be corrosively estimated at 65.0, 70.4, 74.2, and 53.8% for moderate humid, cold Mediterranean, cold semi-dry, and warm semi-dry climate zones, respectively. Based on RSI, there are possibilities of water that would be highly corrosive at 95.0, 74.1, 87.1, and 51.3 for moderate humid, cold Mediterranean, cold semi-dry, and warm semi-dry climate zones, respectively. Based on the criteria of LSI and RSI, there is a weak tendency towards corrosion for the warm semi-dry climate zones. Still, higher corrosion potential for the other climate zones is reported for Kermanshah province under the conditions of this study or may be related to local water quality characteristics among climate zones.

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