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Evaluation of corrosion and scaling tendency indices in water distribution system: a case study of Torbat Heydariye, Iran

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ABSTRACT

Corrosion and scaling tendency of water is an etiology of economic and health concerns in the water supply systems. The aim of this study was to investigate the water stability in Torbat Heydariye drinking water distribution system. This cross-sectional study was done with cluster sampling schemes and 90 samples were collected by simple random sampling from 15 clusters. All samples were taken from water distribution network during 2014. Also, the water stability was determined using Langelier saturation index (LSI), Ryznar Stability index (RSI), Puckorius scaling index (PSI), Larson-Skold index (LS), and Aggressiveness index (AI). Physical and chemical analysis showed that the mean of pH, total dissolve solid, electrical conductivity, chloride concentration, sulfate, temperature, bicarbonate, total alkalinity, calcium hardness were 7.75, 896 mg/L, 1,254 μMoh/cm, 203 mg/L, 201 mg/L, 22.7˚C, 251 mg/L, 209 mg/L as $CaCO_3$, 11.6 mg/L as $CaCO_3$, respectively. The results illustrated that the average values of LSI, RSI, PSI, LS, and AI was 0.02 (±0.125), 7.71 (±0.2), 12.04 (±0.125), 7.55 (±0.3), and 1.7 (±0.456), respectively. Moreover, According to LSI, RSI, PSI, LS, and AI, corrosion tendency in the water network was 40, 100, 93.3, 94, and 33.3%, respectively. The severity of corrosion in different regions of Torbat Heydariye was displayed using Geographic Information System.

Keywords: Corrosion; Water stability; Scaling; Drinking water; Torbat Heydariye

1. Introduction

Corrosion, which is the process of dissolving materials into the solution, is an etiology of reducing the durability of tanks, reservoirs, pipe lines, valves, and pumps and the cause of water leakage, as well as reducing the chemical and microbial quality of drinking water. Sediment forming and the occurrence of metallic taste in the drinking water are also other

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consequences of the corrosion [1,2]. Iron (red-brown sediment and metallic taste), copper (blue sediment and metallic taste), and zinc (metallic taste) are the main corrosion by-products that pose adverse effects on water quality [3–6]. According to World Health Organization (WHO) guidelines, monitoring of water stability is an important requirement for providing safe drinking water. The economic and health aspects of corrosion, which may not be obvious without network observation, is a significant concern for water supply. Monitoring of water stability is an appropriate tool for preventing water leaks and decreasing the cost of replacing pipes, pumps, and equipment [7,8]. Physical, chemical, and microbial water characteristics affect the water stability. In addition, the corrosion rate depends on the nature of substances which is in contact with water. Physical corrosion (erosion and friction) occurs in high velocity and high temperature flows. Biological growth provides a suitable environment for physical and chemical reaction in the aqueous solutions. Simple and inexpensive tools in monitoring of the water supply networks are essential due to the variety of factors affecting the corrosive nature and scaling tendency of water. Water stability indices have been developed for such purpose [9–11]. For instance, Langelier Saturation index (LSI) that is the difference between pH and pH of calcium carbonate saturation, widely used as a scale prediction tool [12]. LSI has been considered as a worthwhile network monitoring parameter especially when $CaCo_3$ used as a protective layer. Ryznar developed similar index with a modification in the Langelier index formula [13]. Puckorius Scaling index (PSI) predicts the maximum quantity of sediments formed in the equilibrium, based on buffer capacity [14]. In addition, Larson-skold index (LS) determines the tendency of water to corrosion of the steel and cast iron pipes. American consulting engineers developed Aggressiveness index (AI) in order to select the asbestos cement pipes [15–17].

Leaching of the contaminants to the water pipes may be increased with corrosivity of water. Contaminants that are more likely to be presented in the drinking water depend on the type of pipe and materials present into the water distribution networks. Some contaminants like bismuth, iron, lead, zinc, arsenic, nickel, vinyl chloride, cadmium, copper, and tin can leach to the water. So, it is important to evaluate the corrosive tendency of the water and the amount of the contaminant concentrations in drinking water [18].

High concentrations of chloride and sulfate can accelerate the corrosion of metallic and cementitious materials. The high concentrations of chloride and sulfate ions could make the water less corrosive; also, high concentration of bicarbonate would be responsible for the more corrosive tendency of the water [19].

In the study of evaluation of corrosion and scaling potential in Tabas, Iran, beside of five indices LSI, Ryznar stability index (RSI), PSI, LS, and Aggressive index (AI), Chloride, Sodium, Sulfate and Total, Dissolved Solids, has been studied for determining of water stability in rural drinking water distribution. The result of this study conducted that the water in studied area was mostly corrosive [8].

Torbat Heydariye, with a longitude of 58˚ 41´ to 60˚ 7´ E and latitude 34˚ 59´–35˚ 51´ N is located on Khorasan Razavi province (East part of Iran); its altitude is 1,333 m above sea level (Fig. 1). This city has 267,604 residents and covered an area of 62,220 km^2. Torbat Heydariye has four regions (Central, Jolgerokh, Kadkan, and Bayg), six cities, 11 districts, and 250 villages. The current study aimed to determine the stability of drinking water and map out the evaluation of the water stability in different areas of Torbat Heydariye city (East part of Iran).

2. Materials and methods

In the current cross-sectional study, sampling sites were distributed all over the city. A water sampling plan was prepared by dividing the city geographically into 15 clusters, (based on the aquifers, geographical location, geological structures, and population density) six samples were collected from each cluster, and 90 samples were totally taken in the whole study (one year monitoring (from March 2014 to February 2015)). The experiments were carried out to calculate the parameters and indices, including chloride ion, sulfate, temperature, Electrical Conductivity (EC), Total Dissolved Solids (TDS), pH, total alkalinity, bicarbonate ions, and calcium hardness according to standard methods for examination of water and wastewater. Then LSI, RSI, PSI, LS, and AI were used to evaluate the water stability. Fig. 1 shows the sampling locations and Table 1 presented the indexes, equation, and some definition and criteria for categorizing the stability of the water. In the definition of AI, as stated in the American Water Works Association (AWWA) standards, A is the total alkalinity (mg/l as CaCO3) and H is the calcium hardness (mg/l as $CaCO_3$).

Geographic Information System (GIS) version 9.3 and Excel software was used to display the severity of corrosion indifferent regions and analyze results, respectively.

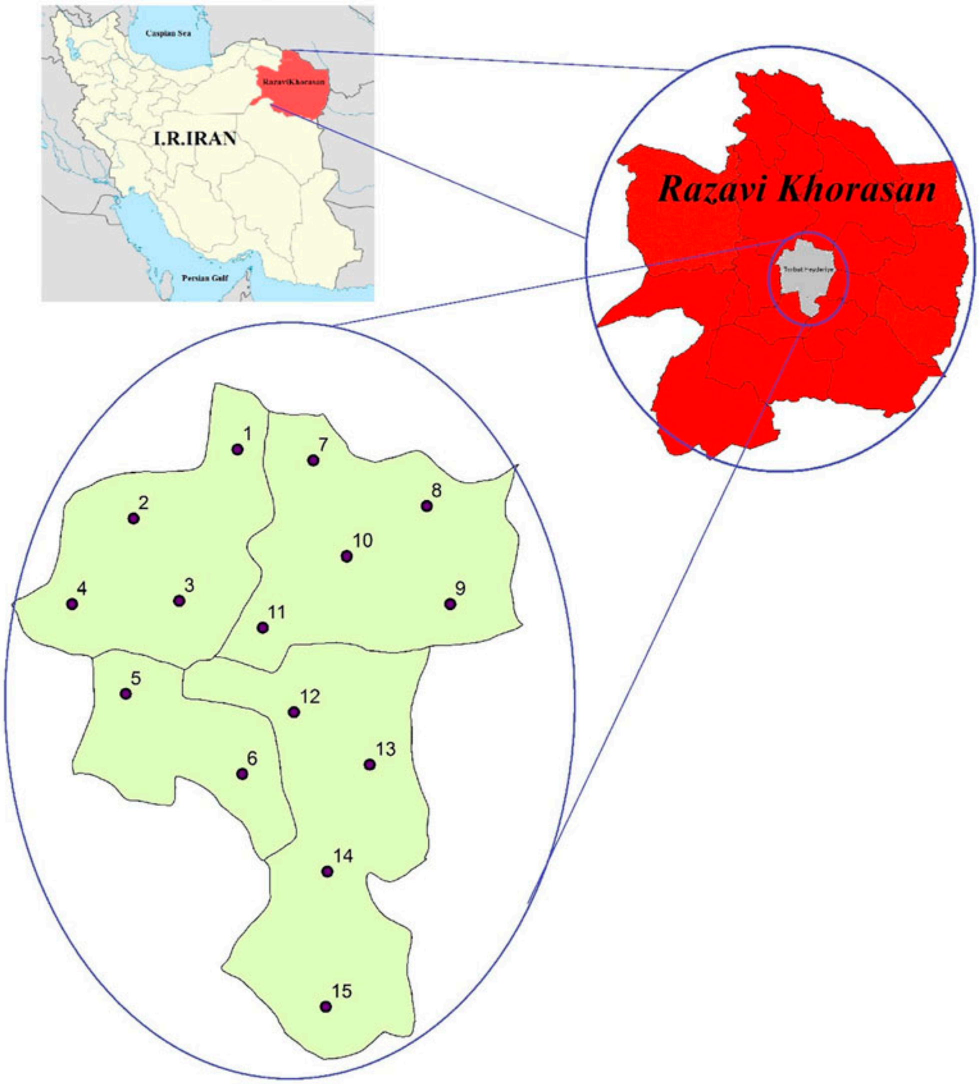

Fig. 1. Location of water sampling sites in Torbat Heydariye.
Source: Department of Geography, University of Mashhad, Mashhad, Iran.

3. Results

The chemical and physical properties of drinking water are presented in Table 2. Also, Table 3 shows the water stability indices in different parts of the region studied.

Based on some investigations, it was proved that the fluctuations of water temperature in distribution networks can affect corrosion rates [20–22]. So, the water stability indices were calculated as a function of temperature and the results of them are presented in Table 4.

As seen in Table 3, 40, 100, 33.3, 93.3, and 94% of water supplies of Torbat Heydariye were corrosive according to the obtained results from LSI, RSI, LS, PSI, and AI, respectively (Fig. 2).

Estimated corrosion indexes with GIS software are shown in Fig. 3.

4. Discussion

The current study showed that based on LSI, 40% of samples were slightly corrosive. The evaluation of water stability with the RSI showed that all samples were highly corrosive. While based on the PSI, 93.3% of samples were corrosive. Another Empirical index, LS is a modification of theory RSI, which is an indication of the water tendency to corrode steel and cast iron pipes showed that about 94% of the samples are corrosive. AI is used to predict the corrosion on Asbestos-cement pipes. The results obtained from AI indicated that the 33.3% of samples were corrosive.

Table 1
Corrosion and saturation indices, equation and criteria for categorizing the stability of the water used in the study [15,24,25]

Index	Equation	Index value	Water condition
Langelier saturation index (LSI)	LSI = pH – pHs	LSI > 0	Super saturated, tend to precipitate $CaCO_3$
	pHs = A + B – log (Ca^{2+}) – log (Alk) pH <= 9.3	LSI = 0	Saturated, $CaCO_3$ is in equilibrium
	pHs = (9.3 + A + B) – (C + D) (3) pH > 9.3	LSI < 0	Under saturated, tend to dissolve solid $CaCO_3$
Ryznar stability index (RSI)	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 dissolve solid$CaCO_3$
Puckorius scaling index (PSI)	PSI = 2 (pHeq) – pHs	PSI < 6	Scaling is unlikely to occur
	pH = 1.465 + log (T.ALK) + 4.54	PSI > 7	Likely to dissolve scale
	pHeq = 1.465 × log (T.ALK) + 4.54		
Larson-skold index (LS)	Ls = (Cl^- + SO_4^{2-})/(HCO_3^- + CO_3^{2-})	LS < 0.8	Chloride and sulfate are unlikely to interfere with the formation of protecting film
		0.8 < LS < 1.2	Corrosion rates may be higher than expected
		LS > 1.2	High rates of localized corrosion may be expected.
Aggressive index (AI)	AI = pH + log[(alk)(H)]	AI > 12	Non aggressive
		10 < AI < 12	Moderately aggressive
		AI < 10	Very aggressive

Table 2
Water quality characteristics associated with corrosion and scaling tendency

Cluster	Cl^- (mg/L)	SO_4^{2-} (mg/L)	Temp. (°C)	EC (µMoh/cm)	TDS (mg/L)	pH	Alk. (mg/L $CaCO_3$)	HCO_3 (mg/l)	CaH (mg/L $CaCO_3$)
1	241	286	22.6	1,495	1,068	7.96	205	231	96
2	276	202	23.9	1,462	1,044	7.94	247	301	84
3	139	162	22.0	901	643	7.89	207	252	89
4	199	190	22.7	1,156	826	7.87	202	247	145
5	223	218	21.9	1,370	979	7.82	169	206	109
6	180	172	22.6	1,177	841	7.80	213	244	55
7	131	166	23.0	973	695	7.80	198	222	100
8	144	144	23.5	718	513	7.80	220	268	73
9	280	195	23.0	1,277	912	7.78	204	248	108
10	220	320	22.4	1,876	1,340	7.74	162	214	161
11	282	274	23.0	1,795	1,282	7.71	250	282	101
12	171	147	23.4	1,037	741	7.70	169	203	94
13	225	189	22.8	1,354	967	7.63	251	306	160
14	165	177	21.8	1,057	755	7.54	228	278	118
15	169	173	21.8	1,168	834	7.39	216	264	180
Mean	203	201	22.7	1,254	896	7.76	209	251	112
Min	131	144	21.75	718	513	7.39	162	203	55
Max	282	320	23.92	1,876	1,340	7.96	251	306	180
St. dev.	50	51	0.62	306	219	0.14	27	31	34

Based on the result of the current study, physicochemical parameters of the drinking water of Torbat-Heydariye were below the permissible standards.

The EC is directly related to the amount of the dissolved salts in water, and therefore to the TDS [23]. The effect of dissolved solids on the corrosivity

Table 3
Drinking water stability of Torbat Heydariye water distribution networks

Index						Water stability				
Clusters	LSI	RSI	LS	PSI	AI	AI	PSI	LS	RSI	LSI
1	0.16	7.64	2.51	7.68	12.19	NA[a]	Ct[a]	Ct	Ct	St[a]
2	0.18	7.58	1.57	7.48	12.18	NA	Ct	Ct	Ct	St
3	0.09	7.71	1.23	7.69	12.12	NA	Ct	Ct	Ct	St
4	0.20	7.47	1.58	7.42	12.22	NA	Ct	Ct	Ct	St
5	−0.01	7.84	2.16	7.87	12.03	NA	Ct	Ct	Ct	Ct
6	−0.17	8.13	1.51	7.99	11.86	MA	Ct	Ct	Ct	Ct
7	0.06	7.68	1.46	7.58	12.07	NA	Ct	Ct	Ct	St
8	−0.05	7.91	1.14	7.75	11.94	MA	Ct	St	Ct	Ct
9	0.00	7.79	2.04	7.67	12.02	NA	Ct	Ct	Ct	Ct
10	0.02	7.70	2.65	7.67	12.07	NA	Ct	Ct	Ct	St
11	0.03	7.65	2.03	7.32	12.07	NA	Ct	Ct	Ct	St
12	−0.12	7.94	1.60	7.84	11.88	MA[a]	Ct	Ct	Ct	Ct
13	0.18	7.26	1.42	6.86	12.21	NA	Ct	Ct	Ct	St
14	−0.12	7.79	1.41	7.37	11.91	MA	Ct	Ct	Ct	Ct
15	−0.14	7.67	1.42	7.12	11.90	MA	Ct	Ct	Ct	Ct
Ct	40	100	94	93.3	33.3					
Stable	0	0	0	0	0					
St	60	0	6	6.7	66.7					

[a]St: scaling tendency; Ct: Corrosion tendency; NA: Non aggressive; MA: Moderately aggressive.

Table 4
Water Stability indices in the region studied as a function of temperature

Index	LSI	RSI	PSI	LSI				RSI				PSI			
TEM	T	T	T	T − 10	T − 5	T + 5	T + 10	T − 10	T − 5	T + 5	T + 10	T − 10	T − 5	T + 5	T + 10
1	0.160	7.681	7.638	−0.036	0.063	0.256	0.350	8.030	7.833	7.447	7.259	8.073	7.875	7.490	7.302
2	0.177	7.481	7.580	−0.018	0.081	0.273	0.366	7.971	7.774	7.390	7.203	7.872	7.675	7.291	7.104
3	0.091	7.687	7.712	−0.106	−0.007	0.186	0.281	8.105	7.907	7.520	7.332	8.080	7.881	7.495	7.307
4	0.201	7.423	7.465	0.005	0.103	0.296	0.390	7.857	7.660	7.274	7.086	7.815	7.618	7.232	7.044
5	−0.013	7.872	7.842	−0.210	−0.111	0.082	0.177	8.235	8.037	7.650	7.462	8.265	8.067	7.680	7.492
6	−0.167	7.993	8.133	−0.363	−0.264	−0.071	0.023	8.526	8.328	7.942	7.754	8.386	8.188	7.802	7.614
7	0.061	7.583	7.678	−0.135	−0.036	0.157	0.250	8.069	7.872	7.487	7.299	7.975	7.777	7.392	7.204
8	−0.054	7.747	7.907	−0.249	−0.150	0.042	0.136	8.298	8.101	7.716	7.529	8.138	7.941	7.556	7.369
9	−0.002	7.666	7.787	−0.198	−0.099	0.093	0.187	8.179	7.982	7.597	7.409	8.058	7.860	7.475	7.288
10	0.020	7.665	7.696	−0.176	−0.077	0.116	0.210	8.088	7.890	7.505	7.317	8.058	7.860	7.474	7.286
11	0.031	7.324	7.647	−0.165	−0.066	0.127	0.221	8.039	7.841	7.456	7.269	7.716	7.518	7.133	6.945
12	−0.121	7.843	7.942	−0.317	−0.218	−0.026	0.068	8.333	8.136	7.751	7.564	8.235	8.037	7.653	7.465
13	0.184	6.861	7.265	−0.012	0.087	0.280	0.374	7.657	7.459	7.074	6.886	7.253	7.055	6.670	6.482
14	−0.123	7.374	7.790	−0.320	−0.221	−0.028	0.067	8.183	7.985	7.598	7.410	7.767	7.569	7.182	6.994
15	−0.140	7.124	7.670	−0.337	−0.238	−0.044	0.050	8.064	7.865	7.479	7.290	7.517	7.319	6.932	6.744
Corrosion	40	100	100	93.3	73.3	26.6	0	100	100	100	93.3	100	100	86.6	73.3
Stable	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scaling	60	0	0	6.7	26.7	73.4	100	0	0	0	6.7	0	0	13.4	26.7
Mean	0.020	7.555	7.717	−0.176	−0.077	0.116	0.210	8.109	7.911	7.526	7.338	7.947	7.749	7.364	7.176
Min	−0.167	6.861	7.265	−0.363	−0.264	−0.071	0.023	7.657	7.459	7.074	6.886	7.253	7.055	6.670	6.482
Max	0.201	7.993	8.133	0.005	0.103	0.296	0.390	8.526	8.328	7.942	7.754	8.386	8.188	7.802	7.614
St. dev.	0.121	0.288	0.198	0.121	0.121	0.121	0.121	0.198	0.198	0.198	0.198	0.288	0.288	0.288	0.121

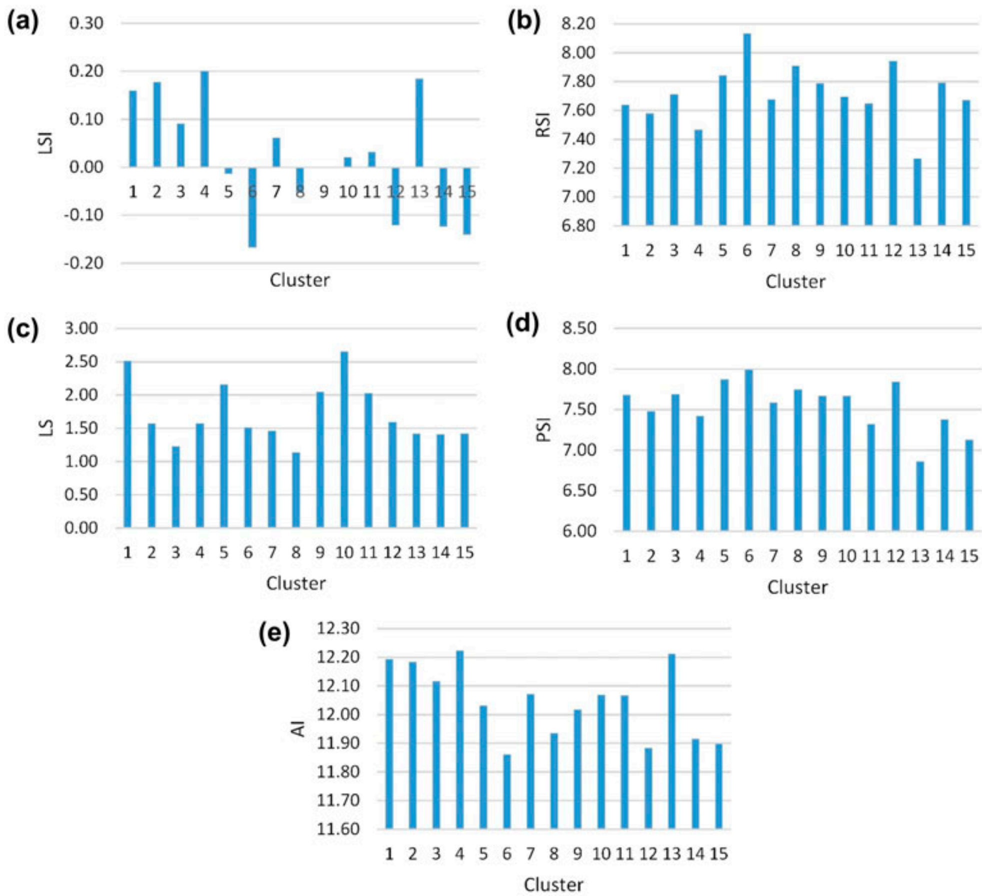

Fig. 2. (a) LSI, (b) RSI, (c) LS and Ratio, (d) PSI, and (e) AI in studied clusters area.

depends on the nature of the dissolved solids. As sulfate and chloride are anionic contributors for TDS, the corrosive tendency of the water is increased, but when the bicarbonate anion is an anionic contributor for TDS, the corrosive tendency of the water is declined. In this study, the concentration of sulfate and chloride in the water is high, so, the corrosive tendency of the water is also high [19].

In a case study of water stability in Bandar Abbas, the authors concluded that the nature of water based on RSI, PSI, and AI was slightly scale forming [15].

Taghipour et al. evaluated the water stability indices in Tabriz, Iran using different corrosion indices. They found that the water resources mostly tended to be corrosive [18].

In a survey on the corrosion tendency of drinking water in the distribution system at the University of Benin, the authors revealed that water was corrosive based on LSI, RSI, and LS [19].

A study of Evaluation of corrosion and scaling potential in rural water distribution network of four villages located in Urmia, Iran reveal that based on the LSI, RSI, and PSI values, water samples in the three of villages were highly corrosive, however for one of these villages, LRI as a suitable index showed that the water of distribution network has tendency to scaling [9].

As mentioned above, LS has been modified for determining of water tendency corrosion in the steel and cast iron pipes (pH 6.6–8.8). according to Fig. 3 LS, choosing appropriate pipe is necessary due to the corrosiveness of water in most part of the area (94% of water samples) which can cause the corrosivity in the distribution networks [16,17].

Also, the AI was calculated for evaluation of water stability for asbestos-Cement pipes. This index shows that 33.3% of the samples are corrosive, so prevention of releasing asbestos fibers into the water is required (Fig. 3) AI. WHO hasn't established guidelines for asbestos due to there being no evidence related to adverse effects of asbestos in the drinking water. Nevertheless, according to the AI index, AWWA classified asbestos-cement pipes based on their utilization and level of water corrosive tendency [16].

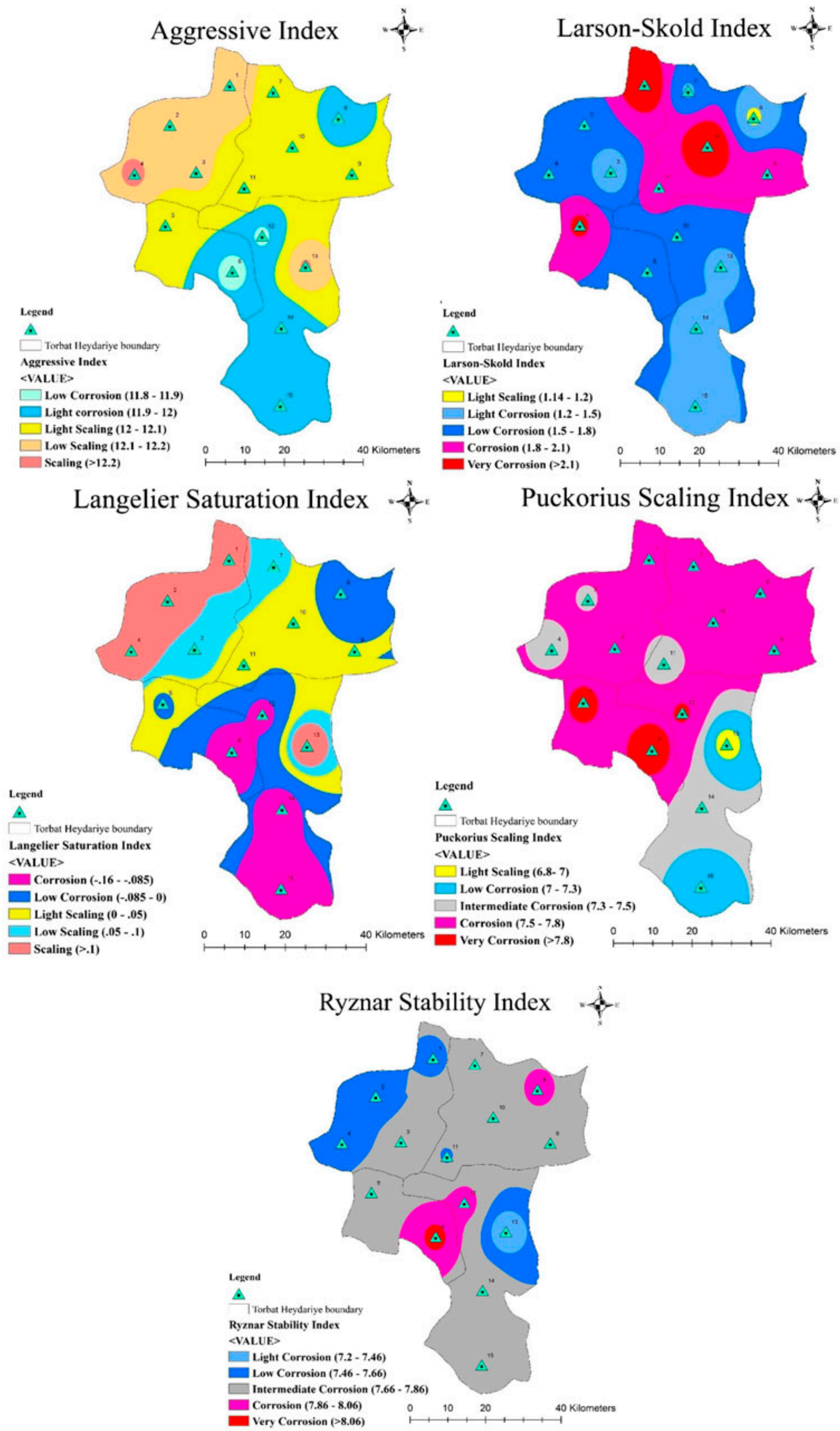

Fig. 3. Spatial distribution of AI, LS, LSI, PSI, and RSI in region studied.

Variation in water temperature during the year in distribution networks can be affected on the water stability. In order to evaluate the effect of water temperature on water stability, Water Stability indices have been calculated at T – 10℃, T – 5℃, T + 5℃, and T + 10℃. According to obtained results, as water temperature increased, LSI, RSI increased, but PSI decreased. This means that the tendency of water toward scaling has been accelerated by increasing the water temperature. The previous study has confirmed these results [8].

5. Conclusion

In the current study, scaling potential and corrosiveness of water have been estimated through the investigation of drinking water resources of Torbat Heydariye. Corrosive tendency of water has been influenced by physical, chemical, and microbial water characteristics. As the representative of these factors, pH, total dissolve solid, EC, chloride concentration, sulfate, bicarbonate, total alkalinity, calcium hardness, and temperature have been measured in this research. Although these calculated parameters met the permissible standards level, the results revealed that the high TDS level related to the concentrations of sulfate and chloride anions has a significant role in increasing corrosive tendency of water. Also, it has been observed that the water tendency toward scaling has been increased by water temperature.

According to The RSI, 40% of samples were slightly corrosive. The langelier scaling index has classified all the samples into Aggressive category. Based on the PSI, 93.3% of samples were corrosive. Another Empirical index (Larson Scale (LS)), 94% of the samples were corrosive. The results obtained from AI indicated that 33.3% of samples were corrosive. These five indices confirmed that the drinking water of Torbat Heydariye in most conditions is corrosive. According to the obtained result of this study, control of sulfate, chloride anions, and water temperature as important parameters of corrosive tendency of water has been recommended.

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