Evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water supply networks, Iran

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ABSTRACT

The aim of this study was to determine the corrosion and scaling potential of water supply sources in a province in eastern Iran. In this cross-sectional study, 879 samples were taken to evaluate the water quality characteristics during 12 months (2013–2014). Five indices, Langelier, Ryznar, Puckorius, Larson–Skold, and Aggressiveness, were programmed in Microsoft Excel. The results illustrated that the values of the Langelier saturation index, Ryznar stability index, Puckorius scaling index, Larson ratio, and Aggressiveness index were 0.33 (±0.17), 7.36 (±0.37), 7.4 (±0.6), 2.1 (±1.4), and 12.03 (±0.18), respectively. According to the Ryznar index (RSI), the index for the water resources of Torbat city was 6.99 and RSI for the central part of Gonabad was 6.4 (consolidation grade). The average pH in the studied water wells was 8.03. The amounts of turbidity, calcium, magnesium, nitrate, and fluoride in the study areas have favorable and acceptable conditions. However, the values of sulfate, total dissolved solids, and chloride in a few cities were higher than the standards. Comparison of five stability indices demonstrated that water in some parts of the study area is corrosive. Based on the results, selecting the best method to prevent the corrosion process is required.

Key words | corrosion and scaling, groundwater quality, Khorasan-e-Razavi, stability indices, water supply network

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INTRODUCTION

Sustainable development of social and economic conditions throughout the world depends on the availability of water resources. Water with appropriate quality and quantity is required for the development of industrial, agricultural, and household activities (Aslam *et al.* 2016; Mirzabeygi *et al.* 2016; Swan *et al.* 2016). As a major result of population growth, water demand for domestic as well as agricultural and industrial consumption is dramatically increasing. This has caused excessive use of groundwater resources as the main water supply (Nouri *et al.* 2006; 2008; Gharibi *et al.* 2012; Shirmardi *et al.* 2012). Since there is a possibility of heavy metal and organic pollution in groundwater, proper methods should be applied for removal of pollutants (Mahvi *et al.* 2008; Maleki *et al.* 2011; Bazrafshan *et al.* 2012). Chemical quality of groundwater depends on many factors, such as the composition of precipitation, the geological structure, the mineralogy of the watersheds and the aquifers. From hygienic and economic points of view, these factors play an important role in corrosion and scaling in water supply utilities (Smith *et al.* 1999; Hayes *et al.* 2016). Corrosion is a physicochemical process which occurs between a substance and its surroundings and results in

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changing the properties of materials (Long 1994). Pitting in pipes, reducing the lifetime of facilities, and loss of water are consequences of the corrosion characteristics of water (Wang *et al.* 2015). According to some studies, damage related to the corrosion process in countries such as Japan, America, Great Britain, Australia, and several other countries was several times higher than their gross domestic product. In addition, the most important health problems related to corrosion are the presence of heavy metals like lead, copper, zinc, and arsenic in drinking water (Edmunds *et al.* 2015). The most important factors which can effect the corrosion rate include pH, temperature, hardness, alkalinity, residual chlorine, total dissolved solids (TDS), gases, dissolved salts, and microorganisms in water. Scaling is a process in which divalent cations such as calcium and magnesium react with other water-soluble substances and form a thin layer in the inner walls of water pipe lines (Mirzabeygi *et al.* 2016; Sorlini *et al.* 2016). The most common scaling layers are made of calcium carbonate. The scaling process can cause problems such as blocked tubes, reduction of the water discharge and the water pressure in the distribution network as well as increasing the operation and maintenance costs (Sun *et al.* 2014).

Various indices have been used for determining calcium carbonate saturation. Langelier index, Ryznar, Aggressiveness, Puckorius, Larson–Skold, driving force, excess moment and the saturation level of index are the most common indicators used to determine the scaling or corrosiveness of water (Swan *et al.* 2016). Mathematical formulae for determining the potential sustainability of water have been developed. The first method for predicting the corrosion or deposition of water was conducted by Langelier (1936). The Ryznar index determines the severity of corrosion in water pipelines. According to the Ryznar index, when the value of the index is less than 7, calcium carbonate is deposited on the pipe wall and when the value of the index is higher than 7, there is no deposition on the wall (Ryznar 1944). The buffer capacity of water and the maximum amount of natural deposited water are generally ignored for calculation of the depositing and corrosiveness of water. The Puckorius index presents the relationship between the state of saturated water and scaling. The Larson–Skold index assesses the corrosiveness of water in the presence of steel pipes with low-carbon steel and cast-iron pipes (Larson & Skold 1958). The Invasion scale index is concerned with the water tendency to damage pipes. It was developed according to a request of American consulting engineers to choose a type of asbestos-cement pipe and ensuring the durable structural of pipes at temperatures between 4 and 27 °C (American Water Works Association 1995).

MATERIAL AND METHODS

Study area

Khorasan-e-Razavi province with an area of 118,854 square kilometers, is located in the northeastern part of Iran. Khorasan-e-Razavi has a population of over 5,994,402 inhabitants and consists of 28 cities, 46 districts, and 156 villages. This province is located between longitude of 33° 52′ to 37° 42′ N and latitude 56° 16′ to 61° 16′ E. The province is characterized by a semi-arid climate, average rainfall of 210 mm, and an annual average temperature of 15.6 °C. Regarding the geographical, geological situation and low rainfall in the region, the main source of water in this area is underground water and the major part of the water is provided through deep and semi-deep wells. The aim of this study is to investigate the physical and chemical characteristics of the water and examine the corrosiveness or scaling tendency of water in rural areas of Khorasan-e-Razavi province, according to Langelier, Ryznar, Puckorius, Larson–Skold, and Aggressiveness indices.

Materials and methods

In this cross-sectional study, 879 rural drinking water sources in Khorasan-e-Razavi were analyzed during 12 months (2013–2014) according to physical and chemical parameters. Figure 1 shows the studied area and sampling locations in this study. Samples were collected in polythene bottles (1 L) and then transported to the central laboratory of the water and wastewater company. Groundwater samples were transported to the laboratory on the same day and kept at 4 °C. All water samples were analyzed according to *Standard Methods for the Examination of Water and Wastewater* (Rice *et al.* 2012). Temporary and

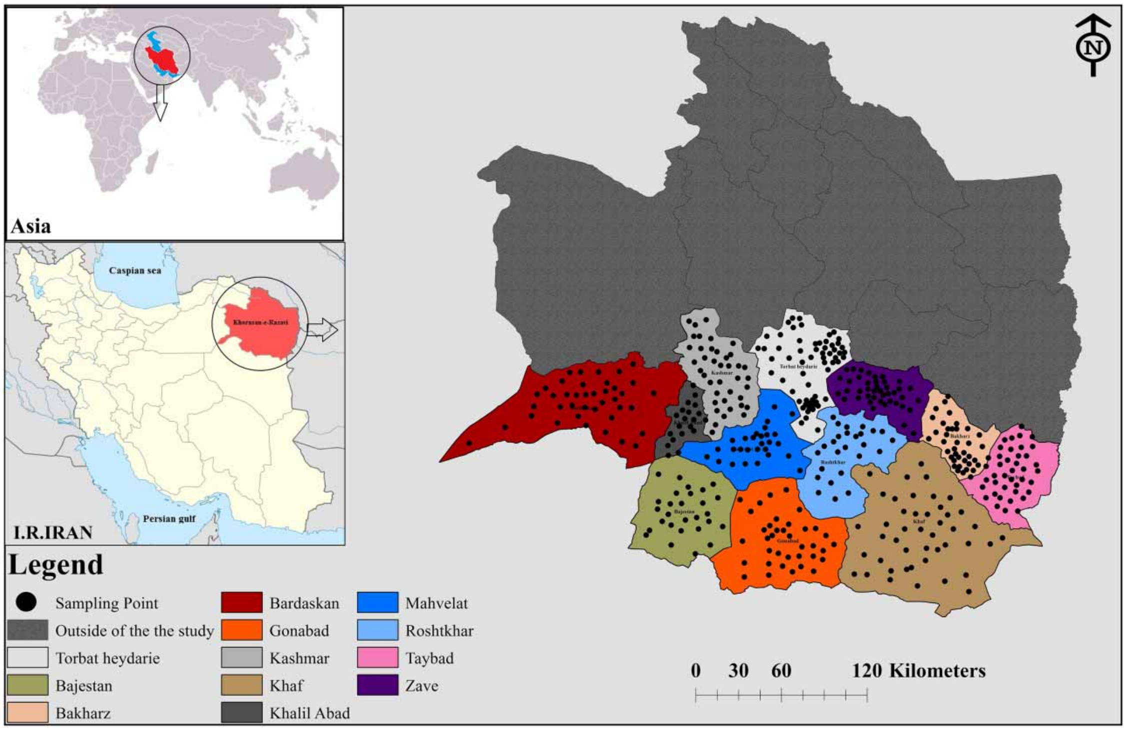

Figure 1 | Location of studied area in the IR. Iran and Khorasan-e-Razavi province.

permanent hardness, magnesium, calcium, and chloride were measured by titration method. The hydrogen ion concentration (pH) and electrical conductivity and opacity were analyzed with pH meter (model wtw, Esimetrwb) and turbidity meter (model Hach 50161/co 150 model P2100Hach, USA), respectively. Also, fluoride, nitrate, and sulfate were determined with Hach DR5000 spectrophotometer and compared with internal standards. Then, the Langelier saturation index (LSI), Ryznar saturation index (RSI), Aggressiveness index (AI), Larson–Skold index, and Puckorius scaling index (PSI) were calculated and the results divided into three categories: depositing, stabilized, and corrosive. Table 1 presents the indices, equations and some definitions and criteria for categorizing the stability of the water. Finally, the severity of corrosion in different water supply systems of Khorasan-e-Razavi province was displayed using a geographic information system (GIS). All analyses were done using Excel 2010 and Arc GIS 10.3 software. In addition, according to the results, a Piper triangular diagram for the water samples in the study area was plotted to assess the hydrochemistry of the groundwater.

RESULTS

The results of physicochemical parameters of water are presented in Tables 2 and 3. The average concentrations of calcium, magnesium, and fluoride are 53 ($\pm$22.7), 22.7 ($\pm$13.6), and 0.57 ($\pm$0.23) mg/L, respectively, which are in the range of acceptable levels. According to these values, Langelier, Ryznar, Aggressive, Larson–Skold, and Puckorius indices for the water resources situation in the villages of Khorasan-e-Razavi province were determined. Table 4 illustrates the calculations related to these indices. According to the results obtained, most of the water resources were corrosive and the values of LSI, RSI, PSI, Larson ratio, and AI were 0.33 ($\pm$0.17), 7.36 ($\pm$0.37), 7.4 ($\pm$0.6), 2.1 ($\pm$1.4), and 12.03 ($\pm$0.18), respectively.

The severity of corrosion in different village waters of Khorasan-e-Razavi province that was displayed using a GIS is shown in Figure 2. According to the results, water sources were less corrosive based on RSI, LSI, and PSI. However, according to the AI and Langelier index, water sources presented low scaling and intermediate scaling,

Table 1 | Indicators used in the study for Khorasan-e-Razavi province (eastern Iran)

Index	Equation	Index value	Water condition
Langelier saturation index (LSI)	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 dissolve solid $CaCO_3$
Ryznar stability index (RSI)	RSI = pHs2 − 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 < 0.08	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
Aggressiveness index (AI)	AI = pH + log[(alk) (H)]	AI > 12	Non-aggressive
		10 > AI < 12	Moderately aggressive
		AI < 10	Very aggressive

respectively. Also, a Piper triangular diagram for the water type in the study area is shown in Figure 3. According to these results, the amounts of sulfate and chloride, calcium and magnesium are high.

DISCUSSION

Due to the health effects of corrosiveness and the high population in this area (537,920 inhabitants), ground water monitoring in this area is crucial. According to Table 3, the average pH in the studied water wells was 8.03; in comparison with the internal standard, the average of pH was within the standard limit. In addition, TDS, apart from in the central city of Gonabad, the Sangan, Zozen plain of Khaf, and forestry sector of the Roshtkhar, where they are higher than the standard limit, were at a desirable level. High levels of TDS can lead to such problems as scaling in pipes and changing the taste of water. Opacity was within the allowable range except in the central part of the Mahvelat and in Khaf of Gonabad city. The color in all areas was in the standard range. The average hardness of the water sources in many parts of Khorasan-e-Razavi province was more than the desirable range, but in the central city of Gonabad it exceeded the permitted limit. High amounts of hardness (carbonate and bicarbonate hardness) may cause clogging in pipes as well as disruption in some household appliances like water heaters. Also, comparing the hardness of water in the villages of Khorasan-e-Razavi province with internal and external standards, it was found that the water sources are in the range of hard water class (WHO 2004). According to Table 2, the average concentration of calcium, magnesium, and fluoride were in the acceptable range, but the concentration of sodium in many parts was higher than the standard. In most parts of the studied area, the amounts of chloride and sulfate exceeded permitted limits. High levels of chloride and sulfate in water can accelerate corrosiveness in the distribution networks. In addition, the presence of high sulfate can create an undesirable flavor, as well as reducing the quality of water. Nitrate concentration in all areas was less than

Table 2 | The mean values of cations and anions in the water samples

City	Region	$HCO3^-$	$NO3^-$	$SO4^{2-}$	Cl^-	F^-	K^+	Na^+	Mg^{2+}	Ca^{2+}
Bakharz	Balavelait	288 ± 127	23 ± 21	232 ± 162	123 ± 127	0.4 ± 0.2	1.6 ± 0.8	214 ± 130	30 ± 21	66 ± 29
	Malin	312 ± 71	21 ± 4	499 ± 142	174 ± 70	0.7 ± 0.2	3.5 ± 0.9	311 ± 15	47 ± 11	97 ± 43
	Markazi	285 ± 45	23 ± 19	298 ± 399	136 ± 205	0.5 ± 0.3	2.5 ± 2	269 ± 9	41 ± 34	82 ± 41
Bajestan	Markazi	217 ± 40	28 ± 15	405 ± 271	417 ± 480	0.8 ± 0.6	1.5 ± 0.6	454 ± 370	17 ± 13	64 ± 37
	Yonsei	208 ± 26	27 ± 3	415 ± 32	874 ± 590	0.8 ± 0.08	1.7 ± 0.3	770 ± 320	19 ± 10	66 ± 30
Bardaskan	Markazi	287 ± 100	18 ± 11	105 ± 41	59 ± 29	0.5 ± 0.1	1.1 ± 0.5	119 ± 38	17 ± 8	43 ± 22
	Shahrabad	194 ± 40	7 ± 2	177 ± 46	91 ± 17	0.6 ± 0.1	1.4 ± 0.2	428 ± 640	11 ± 3	14 ± 2
	Anabd	279 ± 88	21 ± 22	302 ± 181	265 ± 218	0.6 ± 0.2	2.1 ± 1.4	336 ± 196	30 ± 28	43 ± 32
Taibad	Markazi	226 ± 25	18 ± 7	247 ± 226	154 ± 154	0.7 ± 0.4	2.2 ± 1	189 ± 199	24 ± 10	70 ± 25
	Mian velait	232 ± 49	25 ± 13	260 ± 207	175 ± 202	0.6 ± 0.3	2.5 ± 1	200 ± 166	31 ± 20	85 ± 36
Torbat Heydariye	Markazi	244 ± 69	17 ± 11	179 ± 152	319 ± 285	0.5 ± 0.2	3.6 ± 3.5	286 ± 236	24 ± 25	59 ± 37
	Jolge rokh	208 ± 66	16 ± 6	223 ± 134	184 ± 120	0.4 ± 0.1	1.4 ± 0.9	203 ± 87	37 ± 25	26 ± 13
	Bayg	346 ± 77	21 ± 24	79 ± 64	67 ± 58	0.3 ± 0.1	1.3 ± 0.6	86 ± 61	26 ± 8	84 ± 41
	Kadkan	228 ± 90	9 ± 5	218 ± 135	147 ± 124	0.4 ± 0.2	1.6 ± 1.6	171 ± 145	28 ± 17	54 ± 43
Khalil Abad	Sheshteraz	147 ± 26	6 ± 1.3	125 ± 28	70 ± 47	0.5 ± 0.1	1.4 ± 0.9	116 ± 38	7 ± 3	17 ± 7
	Markazi	149 ± 19	6 ± 2	137 ± 21	77 ± 65	0.6 ± 0.1	1.2 ± 0.3	140 ± 20	6 ± 2	21 ± 15
Khaf	Markazi	259 ± 50	15 ± 6	442 ± 360	240 ± 158	0.8 ± 0.7	1.9 ± 0.9	361 ± 229	32 ± 23	51 ± 32
	Salami	212 ± 41	7 ± 6	144 ± 75	48 ± 32	0.3 ± 0.1	1.9 ± 0.6	75 ± 43	26 ± 13	56 ± 26
	Sangan	209 ± 17	12 ± 2	377 ± 158	458 ± 226	1 ± 0.4	1.5 ± 0.4	484 ± 221	21 ± 6	34 ± 8
	Jolge zozan	267 ± 77	35 ± 18	706 ± 895	492 ± 395	1.4 ± 1	1.5 ± 0.8	556 ± 306	14 ± 9	56 ± 50
Roshtkhar	Markazi	267 ± 77	17 ± 11	219 ± 75	190 ± 96	0.6 ± 0.2	2.1 ± 0.8	281 ± 80	18 ± 13	37 ± 17
	Jangal	351 ± 52	13 ± 3	392 ± 152	422 ± 246	0.6 ± 0.1	3.5 ± 0.5	462 ± 185	53 ± 9	39 ± 13
Zaveh	Markazi	280 ± 58	12 ± 1.5	210 ± 152	113 ± 151	0.4 ± 0.1	1.1 ± 0.6	150 ± 141	47 ± 18	37 ± 20
	Jolge zaveh	263 ± 95	20 ± 15	138 ± 150	95 ± 107	0.3 ± 0.2	1.2 ± 0.8	123 ± 110	30 ± 19	48 ± 26
Kashmar	Markazi	187 ± 35	14 ± 8	121 ± 62	73 ± 87	0.5 ± 0.1	1.4 ± 0.5	96 ± 79	14 ± 6	51 ± 24
	Kohsorkh	293 ± 104	17 ± 19	152 ± 143	95 ± 111	0.3 ± 0.1	1.1 ± 0.6	151 ± 107	23 ± 15	56 ± 38
Gonabad	Markazi	320 ± 109	31 ± 17	614 ± 439	501 ± 303	0.6 ± 0.2	2.6 ± 1.2	515 ± 284	60 ± 35	108 ± 66
	Kakhk	265 ± 76	22 ± 17	258 ± 211	260 ± 257	0.5 ± 0.3	2.1 ± 1.4	237 ± 207	46 ± 52	51 ± 20
Mahvelat	Markazi	176 ± 14	20 ± 4	373 ± 138	280 ± 60	0.6 ± 0.1	1.5 ± 0.5	342 ± 50	25 ± 5	40 ± 10
	Shadmehr	204 ± 49	18 ± 7	170 ± 135	79 ± 84	0.4 ± 0.1	1.3 ± 0.4	149 ± 97	13 ± 8	36 ± 22

the allowed maximum and the color and carbonate were zero. According to Table 4, the Langelier index illustrates that water has a scaling grade. Also, according to the RSI, the water resources of Torbat city had a stabilization grade and the index for this region was 6.99. RSI for the central part of Gonabad was 6.4 (consolidation grade). However, RSI for other parts of the study area was in the range of corrosive. According to the Aggressive index, many parts of the studied regions are in the range of scaling and some parts of the studied area are in the range of corrosive. Based on the LSI, water in the central part of Bardeskan city and Baieg of Torbat city has been precipitated without the interference of chloride and sulfate ions; however, in other parts of the area, a protective film interference with chloride ions and sulfate was formed. Based on the PSI, all areas have a corrosive grade. It is essential to note that PSI for areas with pH less than 8 is not a good indicator for scaling and corrosion

Table 3 | The mean, desirable, and permissible limits of the measured parameters in the water of Khorasan-e-Razavi villages

City	Region	T. Alk	Total hardness	EC	TDS	pH	Temp	Turbidity
Bakharz	Balavelait	288 ± 127	286 ± 119	1,337 ± 786	1,006 ± 813	7.8 ± 0.2	21.4 ± 3	1.2 ± 1.4
	Malin	312 ± 71	436 ± 150	2,048 ± 412	1,270 ± 256	7.9 ± 0.1	19.8 ± 0.1	0.8 ± 0.9
	Markazi	285 ± 45	373 ± 243	1,478 ± 1,419	916 ± 880	7.5 ± 0.3	22.7 ± 0.05	1.6 ± 1.6
Bajestan	Markazi	217 ± 40	229 ± 143	2,429 ± 1,704	837 ± 578	8.0 ± 0.3	21.0 ± 0.5	0.7 ± 0.7
	Yonsei	208 ± 26	244 ± 116	3,830 ± 1,654	1,196 ± 918	8.0 ± 0.1	20.7 ± 0.2	0.2 ± 0.06
Bardaskan	Markazi	287 ± 100	175 ± 83	845 ± 212	533 ± 133	8.0 ± 0.2	25.0 ± 1.5	0.4 ± 0.3
	Shahrabad	194 ± 39	78 ± 16	975 ± 109	614 ± 69	8.3 ± 0.1	22.4 ± 0.4	1.4 ± 1.7
	Anabd	279 ± 88	231 ± 175	1,890 ± 925	1,191 ± 583	8.1 ± 0.1	20.6 ± 2.4	0.7 ± 1.5
Taibad	Markazi	226 ± 25	273 ± 84	1,324 ± 895	844 ± 575	7.9 ± 0.1	21.6 ± 1	1.4 ± 3.5
	Mian velait	232 ± 49	341 ± 169	1,510 ± 934	997 ± 649	7.8 ± 0.1	21.1 ± 1.2	0.5 ± 0.5
Torbat Heydariye	Markazi	244 ± 69	245 ± 167	1,818 ± 1,232	1,136 ± 770	7.8 ± 0.3	22.2 ± 2.8	0.5 ± 0.4
	Jolg rokh	209 ± 66	221 ± 114	1,339 ± 507	837 ± 317	8.2 ± 0.1	20.7 ± 2.6	2.8 ± 5.5
	Bayg	346 ± 77	316 ± 127	948 ± 409	593 ± 256	7.6 ± 0.3	18.2 ± 1.7	1.3 ± 1.8
	Kadkan	228 ± 90	252 ± 141	1,228 ± 425	767 ± 425	8.0 ± 0.2	22.7 ± 1.3	0.5 ± 0.3
Khalil Abad	Sheshteraz	147 ± 26	71 ± 29	734 ± 201	460 ± 122	8.3 ± 0.3	23.6 ± 0.5	0.5 ± 0.2
	Markazi	142 ± 19	76 ± 49	776 ± 236	483 ± 149	8.3 ± 0.2	23.3 ± 1	2.1 ± 2.5
Khaf	Markazi	259 ± 50	257 ± 172	2,032 ± 1,087	1,321 ± 706	8.0 ± 0.2	21.2 ± 0.9	0.3 ± 0.2
	Salami	212 ± 41	246 ± 117	794 ± 247	516 ± 161	8.5 ± 0.2	21.6 ± 0.8	0.7 ± 0.7
	Sangan	209 ± 17	170 ± 45	2,529 ± 976	1,664 ± 634	8.1 ± 0.1	21.2 ± 0.8	0.3 ± 0.1
	Jolge zozan	267 ± 77	199 ± 154	2,815 ± 1,595	1,830 ± 1,037	8.0 ± 0.3	21.4 ± 0.7	1.2 ± 2.5
Roshtkhar	Markazi	265 ± 86	167 ± 64	1,492 ± 493	970 ± 321	7.9 ± 0.1	19.1 ± 2	0.5 ± 0.8
	Jangal	351 ± 53	317 ± 69	2,647 ± 976	1,721 ± 634	8.1 ± 0.1	21.2 ± 0.1	0.3 ± 0.1
Zaveh	Markazi	280 ± 59	286 ± 123	1,172 ± 715	762 ± 465	8.2 ± 0.1	17.4 ± 5.3	0.4 ± 0.4
	Jolge zaveh	263 ± 95	242 ± 120	1,007 ± 633	654 ± 411	8.0 ± 0.3	23.1 ± 1.7	2.2 ± 10
Kashmar	Markazi	187 ± 135	155 ± 54	822 ± 461	510 ± 286	8.2 ± 0.1	20.2 ± 2.6	0.7 ± 1.3
	Kohsorkh	293 ± 104	232 ± 146	1,067 ± 648	662 ± 402	8.1 ± 0.3	22.3 ± 1.8	2.6 ± 6.9
Gonabad	Markazi	320 ± 109	516 ± 292	3,223 ± 1,600	2,095 ± 1,040	8.0 ± 0.2	22.6 ± 0.7	0.8 ± 0.8
	Kakhk	265 ± 76	318 ± 240	1,672 ± 1,196	1,087 ± 77	8.1 ± 0.2	22.7 ± 0.2	5.1 ± 9.4
Mahvelat	Markazi	176 ± 14	203 ± 46	1,956 ± 291	1,272 ± 189	8.0 ± 0.1	21.8 ± 0.1	5.5 ± 5.9
	Shadmehr	204 ± 49	144 ± 83	947 ± 484	615 ± 315	8.1 ± 0.2	22.3 ± 1.2	0.8 ± 1.4

(Colin 2008). It was found that the Langelier, Ryznar, Aggressive, and Puckorius indices in the Tabriz water distribution network (northwest Iran) were −0.79, 8.16, 8, and 11.16, respectively, and show the corrosive condition of Tabriz water (Taghipour *et al.* 2012). Also, a study of the rural water distribution network of Urmia city (northwest Iran), that used the Langelier, Ryznar, and Puckorius indices, indicated corrosive water in some of the investigated regions (Khorsandi *et al.* 2016). In a study done for monitoring scaling and corrosion of the water in Ilam using the Langelier, Ryznar, Larson–Skold, Puckorius, and Aggressive indices found that water in Ilam city (west Iran) tended to be corrosive (Davil *et al.* 2009). According to the Langelier index, Ryznar index, and calcium carbonate precipitation potential, assessment of tap water sources in Tafila province showed the corrosion and scale formation (Al-Rawajfeh & Al-Shamaileh 2007).

Table 4 | Korasan-e-Razavi water properties based on corrosion and scaling indices

City	Region	Aggressive index	Larson–Skold index	Puckorius index	Ryznar index	Langelier index
Bakharz	Balavelait	12.06 ± 0.2	1.3 ± 1.2	6.8 ± 0.8	7.1 ± 0.4	0.37 ± 0.2
	Malin	12.4 ± 0.2	2.2 ± 0.8	6.5 ± 0.6	6.7 ± 0.4	0.60 ± 0.2
	Markazi	11.9 ± 0.2	1.3 ± 1.7	6.5 ± 0.4	7.1 ± 0.2	0.24 ± 0.2
Bajestan	Markazi	12.1 ± 0.2	4.2 ± 4.1	7.4 ± 0.4	7.3 ± 0.3	0.38 ± 0.2
	Yonsei	12.1 ± 0.1	6.5 ± 4	7.6 ± 0.08	7.5 ± 0.08	0.30 ± 0.1
Bardaskan	Markazi	12.0 ± 0.2	0.62 ± 0.3	7.06 ± 1	7.16 ± 0.7	0.42 ± 0.3
	Shahrabad	11.7 ± 0.06	1.4 ± 0.4	8.5 ± 0.2	8.12 ± 0.1	0.10 ± 0.05
	Anabd	12.05 ± 0.2	2.4 ± 2.1	7.5 ± 0.8	7.5 ± 0.5	0.29 ± 0.2
Taibad	Markazi	12.08 ± 0.2	1.7 ± 1.5	7.01 ± 0.3	7.1 ± 0.3	0.40 ± 0.2
	Mianvelait	12.09 ± 0.2	2.2 ± 2.2	6.9 ± 0.4	7.1 ± 0.3	0.38 ± 0.2
Torbat Heydariye	Markazi	11.9 ± 0.3	2.2 ± 2.7	7.2 ± 0.6	7.4 ± 0.5	0.23 ± 0.3
	Jolg rokh	11.9 ± 0.2	2.09 ± 1.2	8.1 ± 0.4	7.8 ± 0.4	0.20 ± 0.2
	Bayg	12.07 ± 0.3	0.39 ± 0.2	6.4 ± 0.8	6.9 ± 0.5	0.34 ± 0.2
	Kadkan	11.9 ± 0.3	1.7 ± 0.8	7.4 ± 0.9	7.3 ± 0.6	0.34 ± 0.3
Khalil Abad	Sheshteraz	11.6 ± 0.2	1.3 ± 0.4	8.7 ± 0.5	8.1 ± 0.3	0.07 ± 0.2
	Markazi	11.7 ± 0.2	1.5 ± 0.4	8.7 ± 0.8	8.0 ± 0.5	0.12 ± 0.2
Khaf	Markazi	12.1 ± 0.3	2.6 ± 1.9	7.3 ± 0.6	7.3 ± 0.6	0.37 ± 0.3
	Salami	12.0 ± 0.3	0.9 ± 0.4	7.3 ± 0.6	7.2 ± 0.4	0.39 ± 0.3
	Sangan	11.9 ± 0.1	3.98 ± 1.7	8.0 ± 0.2	7.7 ± 0.2	0.20 ± 0.1
	Jolgezozan	12.0 ± 0.3	4.9 ± 4.4	7.4 ± 0.4	7.5 ± 0.4	0.28 ± 0.3
Roshtkhar	Markazi	11.9 ± 0.1	1.6 ± 0.6	7.6 ± 0.4	7.7 ± 0.3	0.10 ± 0.2
	Jangal	12.2 ± 0.1	2.4 ± 1.4	7.1 ± 0.1	7.2 ± 0.1	0.40 ± 0.1
Zaveh	Markazi	12.1 ± 0.3	1.1 ± 0.9	7.5 ± 0.5	7.4 ± 0.5	0.38 ± 0.2
	Jolgezaveh	12.1 ± 0.3	0.9 ± 1	7.1 ± 0.7	7.1 ± 0.6	0.48 ± 0.3
Kashmar	Markazi	12.1 ± 0.3	1.1 ± 0.5	7.6 ± 0.5	7.3 ± 0.4	0.40 ± 0.2
	Kohsorkh	12.2 ± 0.3	0.8 ± 0.7	7.05 ± 1	7.0 ± 0.7	0.50 ± 0.3
Gonabad	Markazi	12.4 ± 0.3	4.3 ± 4.7	6.5 ± 0.7	6.7 ± 0.4	0.66 ± 0.2
	Kakhk	12.2 ± 0.3	1.9 ± 1.7	7.1 ± 0.7	7.0 ± 0.5	0.50 ± 0.3
Mahvelat	Markazi	11.9 ± 0.1	3.7 ± 0.5	8.0 ± 0.2	7.7 ± 0.2	0.20 ± 0.1
	Shadmehr	11.9 ± 0.2	1.3 ± 1.3	7.8 ± 0.8	7.6 ± 0.5	0.27 ± 0.2

CONCLUSION

In this study, it was found that the physical and chemical parameters, cations and anions of water in most villages located in Khorasan-e-Razavi were desirable, only the parameters of hardness, alkalinity, sulfate, chloride, sodium, and TDS exceeded the standard level in sectors such as central villages of Gonabad city, central villages of Bajestan city, central villages of Sangan and Zozen plain of Khaf city. The main reason for this could be the existence of minerals and ions in these areas. Based on these results, the following conclusions can be drawn:

- According to the Langelier index, water in all regions has a tendency to sedimentation.
- Based on the Ryznar index, in all regions, there is a poor tendency towards corrosion.

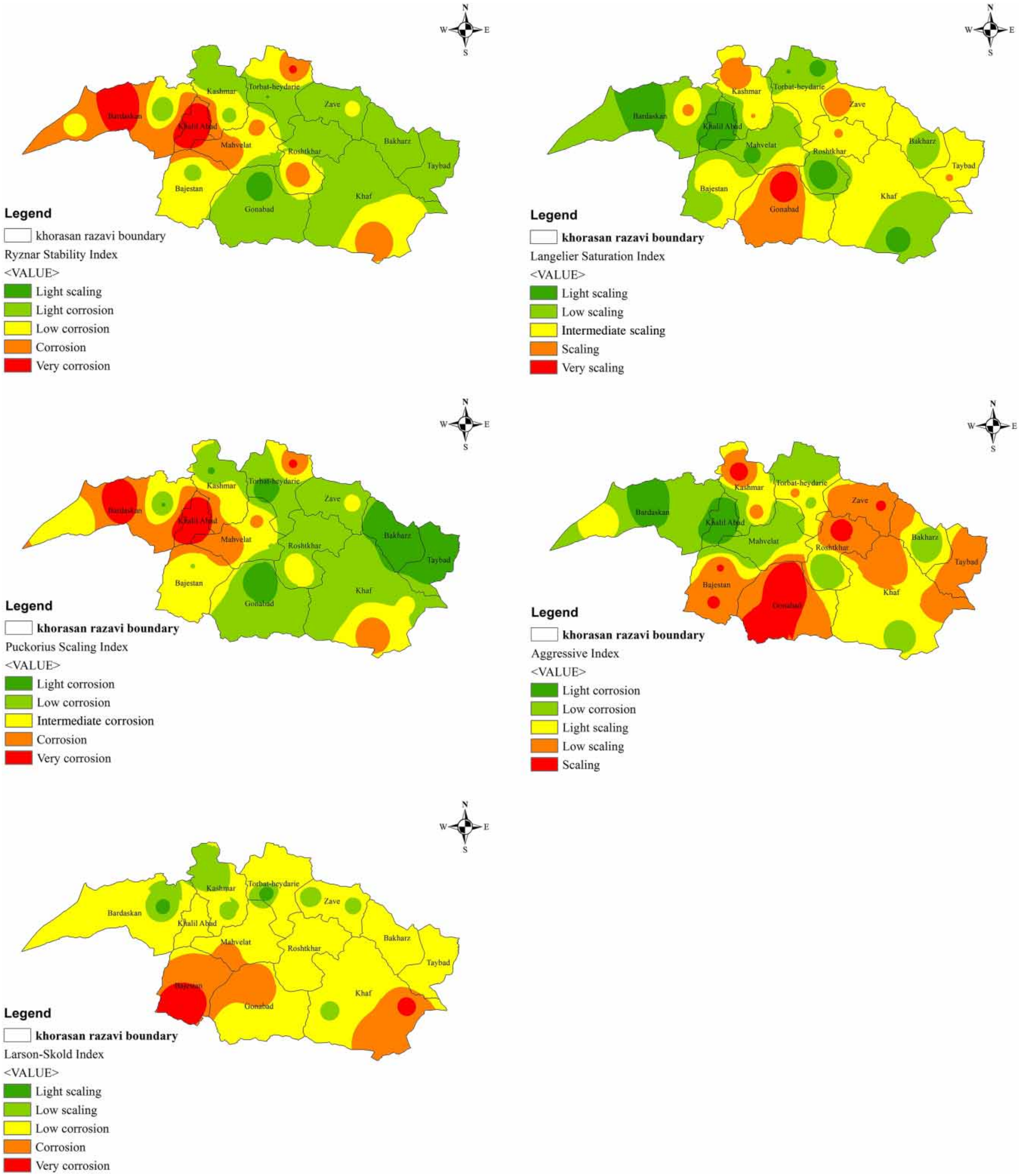

Figure 2 | Spatial distribution of RSI, LSI, PSI, AI, and LS in the study area.

- The Puckorius index showed that water resources in all parts of study tended to be corrosive.
- Based on the Larson–Skold index, water resources in Kashmar and Zaveh cities tended to be deposition and in other studied cities in the range of corrosive.
- The water resources in Roshtkhar city tended to be corrosive and in other regions was in the range of corrosive (based on water invasion).
- Some factors, such as high levels of chloride, total dissolved solids, and sulfate result in aggravating the

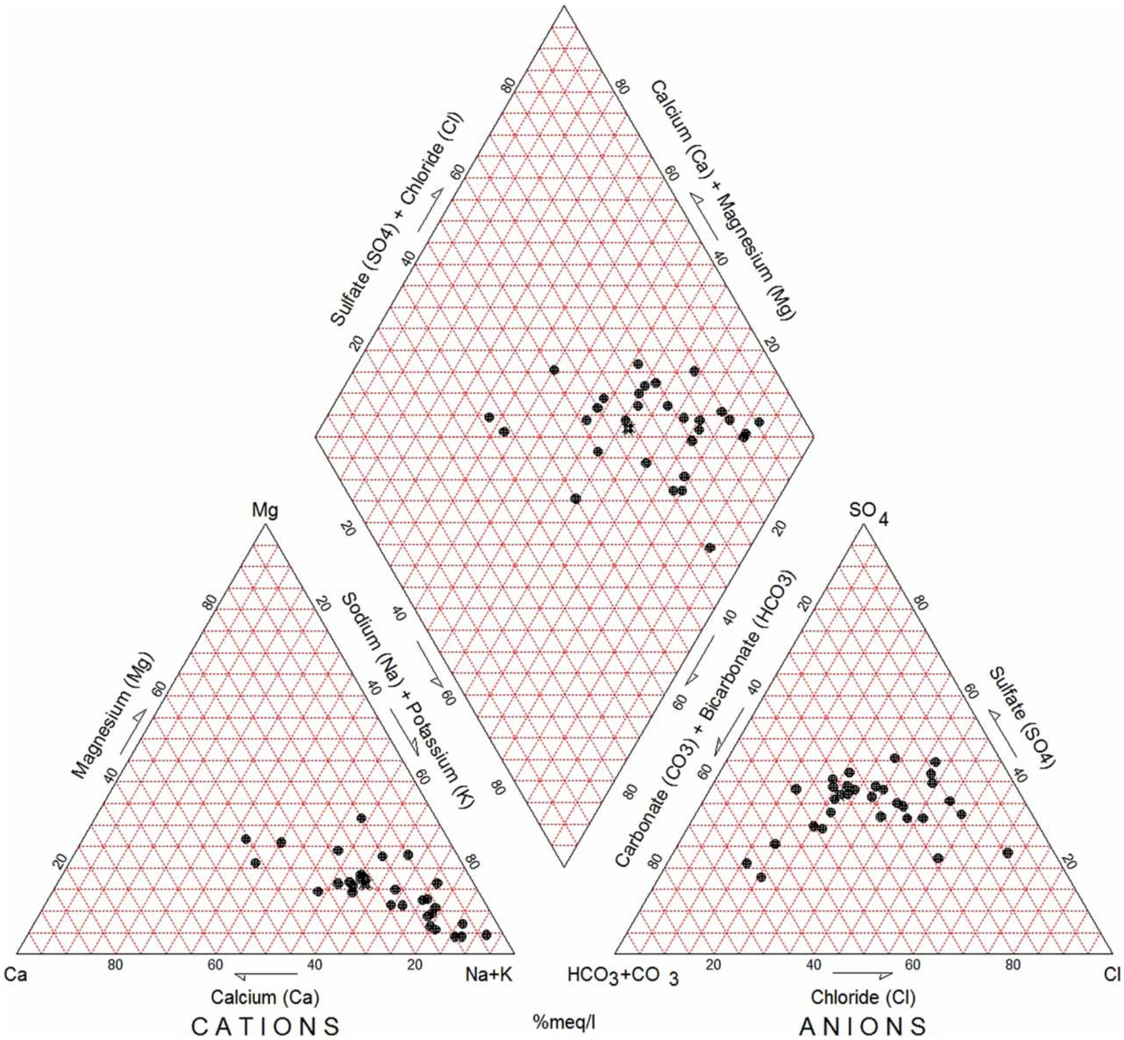

Figure 3 | Piper triangular diagram for the water samples in the study area.

corrosion process in some areas. Therefore, it is necessary to control the corrosion process. In order to control this difficult and expensive process, some methods, such as painting the pipes, using polyethylene pipes instead of metal pipes and asbestos-cement materials, covering plumbing, maintenance, implementation of cathodic protection for metal pipes, pH adjustment and inject inhibitors have been used in the distribution system. Selecting the best method to prevent the corrosion process depends on chemical properties of water. Using lime as a pH adjustment is the most common method for control of the corrosion process.

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