Research Paper

Scaling and Corrosion Potential in Drinking Water Distribution Systems of Meshginshahr City, Iran Using Langelier Saturation Index and Ryznar Stability Index

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ABSTRACT

Background: Corrosion and scaling are major problems in the drinking water facilities causing problems such as water loss, recued life of facilities, pipe punctures, clogging of pipes, and pressure loss in drinking water distribution system. This study aims to determine the corrosion and scaling potential in drinking water distribution system of Meshginshahr, Ardebil, Iran.

Methods: This descriptive cross-sectional study was conducted during the two seasons (summer and winter) in 2019. A total of 20 water samples, which were obtained by averaging 100 samples, were analyzed to determine the corrosion and scaling potential using Langelier Saturation Index and Ryznar Stability Index.

Results: The results showed that the annual average of LSI and RSI were -1.34 and 10.03, respectively, indicating that the drinking water of Meshginshahr was corrosive and scale-forming.

Conclusion: Therefore, it is necessary to constantly evaluate the drinking water supply resources of this city and try to adjust the pH of water and control other factors affecting corrosion, including concentrations of chloride, dissolved oxygen, and sulfate.

1. Introduction

The issue of corrosion is one of the important problems in the drinking water industry, and can affect public health and the quality and cost of drinking water production [1]. According to the International Standard Organization (ISO) 8044, corrosion is a physicochemical interaction between a metallic material and its environment and causes changes in the properties of that material [2]. The rate of corrosion occurrence is affected by various physical, chemical, electrical factors including high carbon dioxide, alkalinity, temperature, and pH. Today, corrosion control in the

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drinking water industry is annually associated with a considerable cost [3].

Corrosion is a harmful process that causes many problems such as pipe punctures, reduced pipe life, destruction of transmission pipelines, pumping equipment, main lines and plumbing systems in houses; blockage of pipes, reduced life of facilities, land subsidence, and water loss [2, 4]. In addition to financial losses, some heavy metals may enter drinking water followed by corrosion of pipes. These metals include lead, cadmium, iron, zinc, copper, and manganese. Cadmium and lead are toxic elements, and iron, zinc, copper, and manganese cause drinking water aesthetic problems in terms of odor, taste, color, and stains in restrooms. Therefore, the standard limit for each of these metals in drinking water has been determined [5-7].

In the United States, the costs due to corrosion and scaling are estimated to be more than 300 billion annually, which is more than 4.5 percent of the country's gross national product [8]. Accurate statistics on corrosion and scaling damage are not available in Iran, but a study of urban wastewater losses shows that more than 31% of distributed water is wasted annually due to decay caused by corrosion of water transmission, and distribution pipes. This loss is in addition to the costs of replacing and repairing damaged pipes [9].

In addition to corrosion, scaling in the pipes can occur, which causes damage to the drinking water supply facilities. Scaling is a process in which divalent cations of calcium and magnesium react with other water-soluble substances and forms a hard layer on the inner wall of the pipe [10, 11]. Calcium carbonate is one of the major minerals in the water, which is known as the most important element responsible for sediment formation [12, 13].

Deposition of calcium carbonate formed in water is one of the most common methods of scale control in drinking water systems. If the scale formation occurs in pipes and in water with supersaturated calcium carbonate and its hardness values are high, it can lead to clogging of pipes and cause many problems in the house systems, including increased energy [12, 13]. Corrosion or scaling in pipes depends on the quality of urban supply sources and modification of these two issues, in addition to improving the quality and quantity of drinking water, and can reduce costs [2].

Due to spending millions of dollars annually to replace pipes, valves, tanks, meters, connections, etc., that have been damaged by corrosion, assessment of corrosion/scaling and corrosion control are the most important design factors for engineers [3]. Painting, proper coating of water transmission and distribution facilities, cathodic protection for metal structures, and continuous feeding in water transmission and distribution pipes are the most important tasks in drinking water treatment plants [14]. According to international standards such as EPA, drinking must not be corrosive [15].

One of the indirect methods of measuring and diagnosing corrosion and scaling is the use of corrosion indices including which show the quality characteristics of water. The accuracy of these indices is based on their ability to determine the state of undersaturation, saturation, or supersaturation of water in terms of calcium carbonate and to predict the capacity of water for calcium carbonate precipitation, decomposition or dissolution [16]; Langelier Saturation Index (LSI) and Ryznar Stability Index (RSI) are among these indices. The LSI shows the saturation level of calcium carbonate. It defines the concept of saturation through pH as a major variable. In other words, LSI is a change in pH required for water to reach equilibrium [17]. The RSI shows a quantitative correlation between calcium carbonate saturation and scale formation. In RSI, the pH value is determined by the actual pH, the concentration of calcium and bicarbonate ions, Total Soluble Solids (TDS), and temperature [18]. The two parameters show the difference between the actual pH and the pH at which calcium carbonate is saturated [19, 20].

A large part of drinking water in Meshginshahr, Ardebil, Iran is supplied from groundwater sources according to geographical and rainfall conditions. Due to poor and different quality of drinking water in this city and its effects on public health, it seemed necessary to study the drinking water resources of this region. Therefore, this study aims to investigate the corrosion and scaling potential in drinking water distribution system in Meshginshahr City using LSI and RSI.

2. Materials and Methods

In this cross-sectional study, a total of 10 sampling stations was considered for drinking water supply sources of Meshginshahr City during summer and winter (two stages of sampling). Five drinking water samples were selected from each sampling station in each season separately, and the average of five samples were calculated for each station. A total of 100 samples were selected from 10 sampling stations during summer and winter and finally, 20 samples were selected for analysis. The volume of each sample was 0.5 liter. The samples were collected by plastic sampling containers washed with distilled water and transferred to the Chemistry and Microbiology Laboratory of Ardabil School of Health on the same day.

Electrical Conductivity (EC) parameters, pH, and temperature were measured at the sampling site. Total soluble solids (TDS), alkalinity, and calcium hardness of the samples were measured and analyzed in accordance with standard methods in the laboratory. After analyzing the samples and obtaining quantitative values of the parameters, the Langelier and Ryznar indices were calculated using a water stability analyzer software. The Langelier Index is an indicator for qualitative evaluation of the water potential in the formation of calcium carbonate sediment. Calcium carbonate is one of the major minerals in the water, which is known as the most important element responsible for sediment formation [21].

The LSI was calculated according to Table 1 [22], where pH values represent the pH of water saturated by calcium carbonate, A is the TDS of water (mg/L), B is the temperature of water (°C), C is the calcium hardness (mg/L $CaCO_3$), and D is the alkalinity of water (mg/L $CaCO_3$). The RSI, unlike LSI, has positive values [23]. It is calculated using Equation 1 and interpreted according to Table 2.

(1) $RSI=2pHs - pH$

3. Results and Discussion

The chemical analysis results of water samples during the two stages of sampling are presented in Tables 3 and 4. The values of most of tested parameters were greater than the standard values (national and WHO standards), and due to chemical imbalance in water quality in all samples, the quality of drinking water in the study stations had corrosive or scaling properties. The values of LSI and RSI during the two sampling stages presented in Tables 3 and 4 showed that all stations with LSI< 0 had corrosion potential. The average LSI was -1.32 in the first stage and -1.42 in the second stage. The results for RSI showed that in both stages of sampling in all study stations, drinking water had a significant scaling. The average RSI was 9.99 in the first stage and 10.12 in the second stage.

Table 1. LSI indications and equations

LSI	Indications	Equations
0 >LSI	Water is corrosive due to lack of scale formation and dissolution of calcium carbonate.	LSI= pH – pHs pHs= (9.3 + A + B) - (C + D)
0 =LSI	Water is neither corrosive nor scale-forming (neutral state)	A= (Log10 [TDS] - 1) / 10 B= -13.12 × Log10 (C + 273) + 34.55
0 <LSI	Water is scale-forming (calcium carbonate sediment)	C= Log10 [Ca^{2}+ as $CaCO_3$] - 0.4 D= Log10 [alkalinity as $CaCO_3$]

Table 2. RSI indications

RSI	Indications
<4	Water is heavily scale-forming
5-6	Water is relatively scale-forming and slightly corrosive.
6-6.5	Water is neither corrosive nor scale-forming
6.5-7	Water is corrosive and its scaling-forming is low
>8	Water is highly corrosive

Table 3. Results of chemical analysis of drinking water in Meshginshahr City (first stage of sampling in the Summer)

Stations	Temperature (°C)	Electrical conductivity (µS/cm)	TDS (mg/L)	Alkalinity (mg/L.$CaCO_3$)	Calcium hardness (mg/L.$CaCO_3$)	pH	pHs	LSI	RSI
S1	15.9	235	140.5	32.2	39	7.2	8.62	-1.42	10.04
S2	16.1	238	149.94	38	38	7.3	8.56	-1.26	9.82
S3	14.5	234	147.42	30.4	40	7.15	8.67	-1.52	10.19
S4	14.9	240	151.2	34.4	36	7.4	8.65	-1.25	9.90
S5	15.1	247	155.6	37.8	38	7.2	8.58	-1.38	9.97
S6	16.7	238	149.9	34.4	48	7.32	8.49	-1.17	9.65
S7	13.2	271	170.7	30.8	38	7.25	8.73	-1.48	10.21
S8	14.8	241	151.8	39.4	36	7.45	8.6	-1.15	9.74
S9	12.4	237	149.31	35	37.4	7.33	8.69	-1.36	10.05
S10	14.1	244	151.72	27.4	38	7.5	8.75	-1.25	10
Average	14.7	242.5	151.8	34	38.8	7.31	8.63	-1.32	9.99

Table 4. Results of chemical analysis of drinking water in Meshginshahr City (second stage of sampling in the Winter)

Stations	Temperature (°C)	Electrical Conductivity (µS/cm)	TDS, mg/L	Alkalinity (mg/L.$CaCO_3$)	Calcium Hardness, (mg/L. $CaCO_3$)	pH	pHs	LSI	RSI
S1	10.2	248	156.24	36.2	44.3	7.27	8.66	-1.39	10.06
S2	11.7	248	157.13	33.1	46.5	7.13	8.64	-1.51	10.16
S3	8.5	259	163.17	30.7	50.2	7.25	8.73	-1.48	10.21
S4	6.2	257	161.91	35.8	40.8	7.4	8.81	-1.41	10.22
S5	9	246	154.98	39.5	49.6	7.36	8.61	-1.25	9.85
S6	11	247	155.61	40.2	51.4	7.17	8.53	-1.36	9.90
S7	6.1	268	168.84	29.8	50.9	7.2	8.8	-1.60	10.40
S8	5.65	263	165.69	32.62	46.7	7.48	8.81	-1.33	10.14
S9	5.2	262	165.08	38.28	45.25	7.23	8.77	-1.54	10.30
S10	5	260	163.80	37.1	60	7.31	8.66	-1.35	10.01
Average	7.85	255.8	161.24	35.23	48.56	7.28	8.71	-1.42	10.12

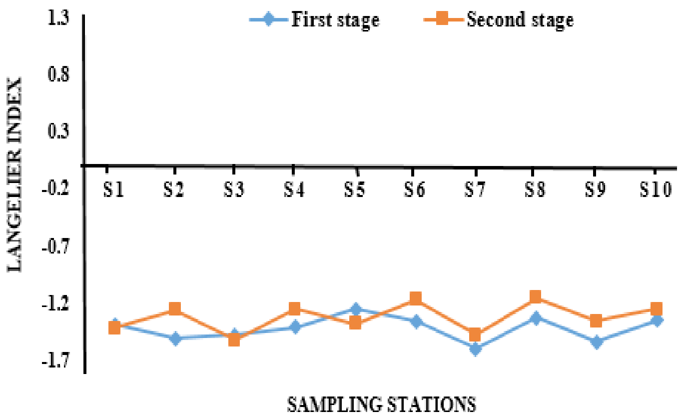

Figure 1. Comparison of LSI values for Meshginshahr's drinking water distribution system

The LSI and RSI values are compared in Figures 1 and 2 for ten different stations in two sampling stages, respectively. As can be seen in Figure 1, except for three stations S1, S3, and S5, the values of LSI in the first stage was less than that in the second stage of sampling, indicating that the rate of corrosion in Meshginshahr's drinking water distribution system in the first stage of sampling was less in than the second stage. Regarding the RSI, the amount of scaling in the second stage of sampling was somewhat higher than in the first stage (Figure 2).

Corrosion and scaling of water are the most important issues that should be considered in drinking water distribution systems. In addition to physical damage and water loss, they can disturb the chemical balance of water; lack of attention to the chemical quality of water leads to health and economic problems [24, 25]. The LSI in both summer (-1.32) and winter (-1.42) for drinking water supply sources showed that the drinking water in Meshginshahr City had corrosion. This corrosion can be a reason for failure in transmission and distribution pipelines or entering many pollutants into the drinking water and causing health problems; therefore, provision of measures to control corrosion in drinking water of Meshginshahr City seems to be necessary.

In various studies, by examining the relationship between the type of soil layers and the chemical quality of water, it was shown that the calcareous layers of land around water sources increase the hardness and scaling of water. These conditions are predictable in some areas and cause small differences in the results of various studies compared to our results [26, 27]. The results of Davil et al. on corrosion and scaling potential of water in Ilam, Iran showed that the water of this city had scaling properties (LSI= 0.29) [13]. Due to the fact that the drinking water status in terms of corrosion or scaling is affected by parameters such as pH, temperature, calcium hardness, alkalinity, and TDS,

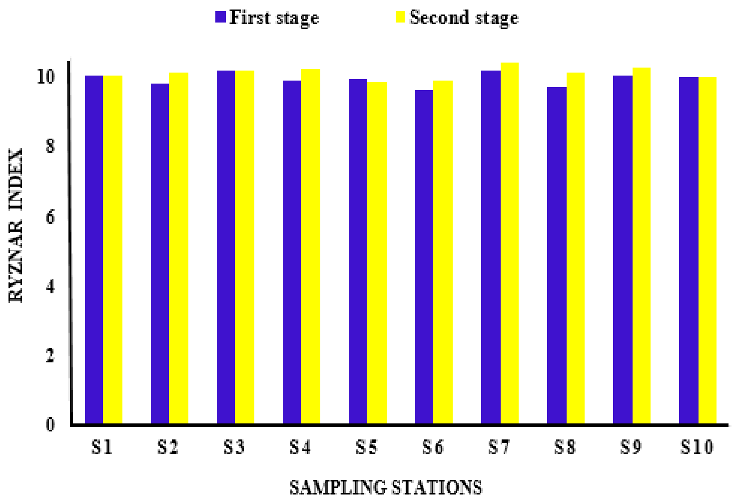

Figure 2. Comparison of RSI values for Meshginshahr's drinking water distribution system

the difference in the values of each of these parameters can change the water status in terms of stability. Therefore, the difference in drinking water resources of Ilam and Meshginshahr cities as well as the difference in their water status can be the main reasons for the difference in the values of mentioned parameters in these two cities. Findings of Taghipour et al. on corrosion and scaling of drinking water in Tabriz, Iran showed that the value of LSI water was -0.79, indicating that the drinking water in this city was corrosive; however, its corrosion rate was much lower than that in the present study [28].

The corrosion in drinking water distribution systems causes the entry of harmful and dangerous pollutants such as arsenic, cadmium, lead, copper, tin, nickel, iron, zinc, and vinyl chloride, which have side effects such as carcinogenicity [29-31]. Therefore, periodical monitoring, analysis, and comparison of the concentrations of these pollutants in drinking water resources with standard values are necessary. In Davil et al.'s study, the findings showed that the values of Ca^{2+}, SO^{2-}_4, Cl^-, TDS, hardness, and pH were within the national and EPA standard levels, but water was corrosive in terms of stability [13].

The average value of RSI for two seasons of summer and winter in drinking water of Meshginshahr City was 10.05, which indicates the severe corrosion level of drinking water. Davil et al. and Taghipour et al. on drinking water resources of Ilam and Tabriz reported an RSI values of 7.54 and 8.16, respectively [13, 28], which is somewhat less than that in our study. Kalantari et al., by examining the quality and stability of drinking water resources in the villages of Qom, Iran using RSI and LSI, concluded that the drinking water in the study areas was in the corrosive range [2]. Shams et al. in a study on corrosion and scaling of drinking water in rural water supply networks of Tabas city showed that the percentages of LSI and RSI for corrosion were 29% and 90%, respectively [32]. The process of corrosion and scaling considerably affects the quality of drinking water; therefore, appropriate steps should be taken by measuring effective parameters in this field.

4. Conclusion

The drinking water of Meshginshahr City is corrosive based on RSI and LSI values. Therefore, controlling the corrosion process in the drinking water resources of Meshginshahr is essential. For this purpose, methods such as painting the pipes, use of durable polyethylene pipes instead of metal and asbestos-cement pipes, covering the pipes, proper maintenance, applying cathodic protection for metal pipes, adjusting the pH, and injecting inhibitors into the distribution systems should be utilized. The selection of an appropriate method to prevent the corrosion process depends on the chemical properties of the water, the effect of selected process on other processes, and on water quality. The above methods should be used with caution and under certain conditions to control the amounts of lead, copper, and iron in the water. Pilot studies are recommended to determine an effective method for corrosion control under specific conditions.

Ethical Considerations

Compliance with ethical guidelines

This study was approved by the Ethics Committee of the Ardabil University of Medical Sciences (Code: IR.ARUMS.REC.1399.307).

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Authors' contributions

All authors equally contributed to preparing this article.

Conflict of interest

The authors declared no conflict of interest.

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