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# Corrosion and scaling potential of the potable water in villages based on langelier saturation index, ryznar stability index, larson ratio, and saturation level

Mohammad Hashemifar[1], Mojtaba Davoudi[2], Sedigh Mohammadzadeh[3], Nazila Nilufari[4], Mohammad Khoshgoftar[1]

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1. Department of Environmental Health Engineering, School of Health, Lorestan University of Medical Sciences, Lorestan, Iran

2. **Correspondence to:** Department of Environmental Health Engineering, School of Health, Torbat Heydariyeh University of Medical Sciences, Torbat Heydariyeh, Iran

Email: davoudi85@gmail.com

3. Department of Engineering, School of Engineering, Islamic Azad University, Mahabad branch, Lorestan, Iran

4. Department of Environmental Health Engineering, School of Health, Urmia University of Medical Sciences, Urmia, Iran

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## Abstract

Corrosion and scaling are of the most important properties of potable water and can affect the public health and the economy of water industry. This study was conducted to evaluate the corrosion and scaling potential of potable water of villages covered by in Saqqez, city, Kurdistan province, Iran. In this descriptive study, 142 samples of water were collected from different parts of the distribution network of the village. The samples were analyzed in terms of certain physical and chemical parameters. The results were compared with the qualitative standards of potable water, and corrosion and scaling indices, including langelier saturation index (LSI), ryznar stability index (RSI), larson ratio (LR), and saturation level (SL) were calculated. All the measured parameters were in the range of national and international standards. Biennial mean of LSI, RSI, LR, and SL comprised 0.73, 6.51, .074, and 1.96, respectively. According to the results, the studied potable water was at the status of scaling in terms of LSI and SL, at the status of balanced in terms of RSI, and at the status of corrosion in terms of LR. Frequency distribution of these indices in the studied duration was also performed. In general, it could be argued that the village's potable water was at an acceptable level of corrosion and scaling. However, considering the significant annual changes in the indices, it is recommended to monitor the water every year in terms of corrosion and scaling.

**Keywords**: Chemical Water Pollution, Corrosion, Public Health

## Introduction

The accessibility to safe potable water is an essential factor for maintaining and promoting health of a society. There are different methods for determining the quality of potable water in the society. one of the most important actions for qualitative evaluation of water is to measure its corrosion and scaling properties [1]. The corrosive water damages the inner surface of pipes, transducers, pumps, valves, and other equipment that are in contact with the corrosive water during transmission [2]. This phenomenon not only causes considerable economical damages in the long time but also makes various health problems and undermines the functioning of the water treatment plant through dissolution of impurities in the equipment, such as heavy metals [3]. The most important determinants of the corrosion potential of water include the temperature, pH, dissolved gases, the concentration of sulfate, chloride, and chlorine residual [4]. Scaling is a phenomenon that occurs following the formation of insoluble deposits of divalent cations. The most common deposit in natural waters is calcium carbonate that usually occurs in waters with high hardness [5]. Scaling in transmission channels reduces the capacity of water supply and increases the pressure drop and costs of pumping in a way that the replacement of water transmission pipelines would be inevitable [6]. Therefore, the evaluation of corrosion and scaling properties may be one important action taken for qualitative monitoring of potable water.

Today, various indices are defined for defining the stability water. Langelier saturation index (LSI), Ryznar stability index (RSI), Larson ratio (LR), and saturation level (SL) are of the most important indices in this regard. LSI is defined in relation to the concentration of calcium carbonate. Determinants of LSI include pH, total dissolved solids (TDS), temperature, the concentration of calcium, and alkalinity. Positive values of LSI show that the water is supersaturated of calcium carbonate and tends to deposit. LSI is a qualitative index that only indicates that the sample in question tends to deposit or corrode. RSI was used to complement LSI and quantify the results [2]. Similar to LSI, RSI is determined through measuring pH of the water and calculating the saturation pH. LR is another index used for examining the stability of water. It is defined in relation to water corrosion in metal pipes and is determined using the concentration of sulfate, chloride, and bicarbonate. This index is important because most parts of water transmission and distribution networks are made of metals. In this respect, the corrosive water can solve some of the heavy metals in pipes, such as copper, lead, and cadmium, in itself and endanger the people using that water. SL is another index that is defined regarding the concentration and solubility of calcium carbonate in a water sample. Therefore, it can yield results that are comparable to results obtained from LSI.

Different studies have been performed to determine the stability of water in different parts of Iran. Zazuli et al. examined the corrosion and scaling potential of potable water in Yasouj, Iran. They showed that the potable water tended to corrode a little [7]. In their study on potable water of the distribution network in Khorramabad, Iran, Piri Elm et al. concluded that there was a little tendency to corrode in that water [5]. Mazlumi et al. examined the potable water in Shiraz, Iran in terms of different indices, including LSI and RSI. They showed that most of water samples had the potential of scaling and found few cases of low corrosion [8]. Rabbani et al. determined the corrosion and scaling indices of the water of villages covered by ABFAR Company in Kashan, Iran. They proved the corrosiveness of that water in all seasons [3].

The present study was conducted to determine the corrosion and scaling potential of potable water of villages covered by ABFAR Company in Saqqez city, Kurdistan province, Iran in terms of LSI, RSI, LR, and SL.

## Method

This cross-sectional study was performed in the region under the cover of ABFAR Company in Saqqez in 2011 and 2012. There were 275 villages in that region of which 145 villages with over 41 thousand people were covered by ABFAR Company in Saqqez. The water supplied through 86 springs and 59 wells. About 94 participants were collected in 2011, and 48 participants were collected in 2012 from different parts of the distribution network. The participants were analyzed in terms of the parameters, including temperature, pH, calcium, alkalinity, sulfate, chloride, bicarbonate, and TDS. The relevant tests were performed according to the book of standard methods for water and wastewater examination [9]. LSI, RSI, LR, and SL values were calculated using the results of tests. Equation 1 was used to calculate LSI:

$$LSI=pH-pHs \quad (1)$$

In the above equation, pHs represents water saturation pH that was calculated by the following equation:

$pH_s$=(9.3+A+B)-(C+D) (2)

Where, A, B, C, and D are respectively coefficients of TDS, temperature, calcium hardness, and alkalinity. In this study, samples with LSI lower than -0.3, higher than +.03, and between these two values were classified as corrosive water, scaling water, and balanced water, respectively. RSI was determined using Equation 3:

RSI=2$pH_2$-pH (3)

According to the above equation, samples with RSI lower than 6, higher than 7, and between these two values were classified as scaling water, corrosive water, and balanced water, respectively. LR was calculated using molar concentration of chloride, sulfate and b to Equation 4:

$$LR = \frac{[Cl^-]+2[SO_4^{2-}]}{[HCO_3^-]} \quad (4)$$

The LR lower than 0.5, 0.5-1, and higher than 1 were considered as low water corrosion, moderate water corrosion, and high water corrosion, respectively. The SL index was calculated using the concentration of calcium and bicarbonate based on Equation 5:

$$SL = \frac{[Ca^{2+}][CO_3^{2-}]}{K_{sp}} \quad (5)$$

Ksp represents the solubility of calcium carbonate in actual conditions of water. According to this index, the SL lower than 1, higher than 1, and near 1 showed the unsaturated corrosive water, scaling water, and balanced water, respectively. The descriptive presentation and analysis of the data were performed in Excel and SPSS-19.

## Results

This study was conducted to determine the corrosion and scaling potential of potable water of villages covered by ABFAR Company in Saqqez through determining LSI, RSI, LR, and SL. To do so, parameters, including temperature, pH, and concentration of calcium, alkalinity, sulfate, chloride, bicarbonate, and TDS were measured. Minimum, maximum, mean, and standard deviation (SD) of the parameters were determined and provided in tables 1 and 2 for the years 2011 and 2012, separately. The comparison of these two tables reveals annual variations of examined physicochemical parameters. Among them, the variations of pH, temperature and Ca concentration were significant (p-value=0.000). Table 3 shows the comparison of biennial mean of the mentioned parameters with available values of national and international standards for drinking water. As can be seen, the supplied water in rural areas of Saqqez had excellent quality in terms of dissolved solids.

**Table 1** *Physicochemical parameters of potable water in 2011*

| Parameter | Min | Max | Mean | SD |
|---|---|---|---|---|
| Temperature | 14.20 | 31.00 | 23.95 | 3.31 |
| PH | 7.00 | 8.6 | - | - |
| Calcium | 38.00 | 137.00 | 79.44 | 13.45 |
| Alkalinity | 109.60 | 312.00 | 219.57 | 43.72 |
| Sulfate | 49.00 | 117.00 | 62.60 | 9.90 |
| Chloride | 2.81 | 60.20 | 10.75 | 9.30 |
| Bicarbonate | 109.60 | 312.00 | 219.63 | 43.73 |
| TDS | 123.30 | 569.40 | 274.11 | 67.67 |

**Table 2** *Physicochemical parameters of potable water in 2012*

| Parameter | Min | Max | Mean | SD |
|---|---|---|---|---|
| Temperature | 16.40 | 23.50 | 19.87 | 2.32 |
| PH | 7.33 | 8.33 | - | - |
| Calcium | 44.00 | 134.42 | 90.48 | 21.4 |
| Alkalinity | 60.40 | 743.00 | 239.73 | 110.11 |
| Sulfate | 39.00 | 75.00 | 59.64 | 7.69 |
| Chloride | 3.00 | 53.40 | 12.54 | 11.04 |
| Bicarbonate | 60.40 | 743.00 | 239.10 | 110.24 |
| TDS | 76.00 | 467.40 | 256.15 | 84.32 |

**Table 3** *Comparison of biennial mean of physicochemical parameters of potable water with national and international standards*

| Parameter | Mean | SD | WHO | EPA | Iran | |
|---|---|---|---|---|---|---|
| | | | | | favorable | allowable |
| Temperature | 22.57 | 3.58 | - | - | - | - |
| PH | 7.00-8.60 | - | 6.5-8.5 | 6.5-8.5 | 7.0-8.5 | 6.5-9.0 |
| Calcium | 83.18 | 17.30 | - | - | 75 | 200 |
| Alkalinity | 226.38 | 73.44 | - | - | - | - |
| Sulfate | 61.60 | 9.29 | 250 | 250 | 200 | 600 |
| Chloride | 11.35 | 9.91 | 250 | 250 | 200 | 400 |
| Bicarbonate | 226.20 | 73.47 | - | - | - | - |
| TDS | 268.04 | 73.92 | 1000 | 500 | 500 | 1500 |

Based on the data provided in tables 1 to 3, the corrosion and scaling potential of potable water of villages covered by ABFAR Company in Saqqez were calculated and reported in terms of LSI, RSI, LR, and SL. Table 4 provides the minimum, maximum, mean, standard deviation, and interpretation of these indices respectively for 2011 and 2012. As shown in the tables, the potential of corrosion and scaling did not change in terms of the studied parameters from 2011 to 2012. However, the independent t test showed a significant difference between 2011 and 2012 in terms of mean LSI and RSI ($p=0.000$). The significant difference was also observed for SL ($p=0.003$). However, LR did not show any significant difference between 2011 and 2012 ($p=0.712$).

Table 5 provides the biennial mean of the indices and a general interpretation. In this regard, it could be concluded that the potable water of villages in Saqqez was at the scaling status in terms of LSI and SL, slightly corrosive in terms of LR, and balanced in terms of RSI.

Figure 1 shows the frequency distribution of corrosion and scaling status of the studied samples. As shown in Figure 1-A, over 93% of the samples had a high level of scaling in terms of LSI (LSI>+.03), whilst, 56.2% of the samples collected in 2012 were scaling. About 41.7% of the samples collected in 2012 had a slight corrosion and scaling potential and were at a balanced status (LSI=±0.3). In general, LSI showed that 81% of all the samples had a high scaling potential; 17.6% of them were almost balanced; and only 1.4% of them had a high corrosion potential.

Figure 1-B shows the frequency distribution of the samples in terms of RSI. According to the figure, 84% of the samples collected in 2011 and 54.2% of the samples collected in 2012 were balanced in terms of corrosion and scaling (RSI=6-7). About 40% of the samples collected in 2012 had a high corrosion potential in terms of RSI (RSI>7). The analysis of all samples collected in 2011 and 2012 revealed that 74% of the samples were at a balanced status, 19% of them were corrosive, and only 7% of them were at a scaling status.

**Table 4** *Annual mean of corrosion and scaling indices in 2011 and 2012*

| Studied year | Index | Min | Max | Mean | SD | Interpretation |
|---|---|---|---|---|---|---|
| 2011 | Langelier | -0.41 | 2.06 | 0.73 | 0.40 | Scaling |
| | Ryznar | 3.54 | 8.03 | 6.51 | 0.65 | Balanced |
| | Larson | 0.45 | 1.52 | 0.74 | 0.18 | Slightly Corrosive |
| | Saturation Level | 0.14 | 8.27 | 1.96 | 1.49 | Scaling |
| 2012 | Langelier | -0.35 | 1.40 | 0.39 | 0.33 | Scaling |
| | Ryznar | 5.52 | 8.10 | 6.93 | 0.55 | Balanced |
| | Larson | 0.18 | 2.01 | 0.72 | 0.32 | Slightly Corrosive |
| | Saturation Level | 0.17 | 9.54 | 1.14 | 1.53 | Scaling |

*Table 5. Biennial mean of corrosion and scaling indices*

| | Langelier | Ryznar | Larson | Saturation Level |
|---|---|---|---|---|
| Mean | 0.61±0.41 | 6.65±0.65 | o.73±0.24 | 1.68±1.55 |
| Interpretation | Scaling | Balanced | Slightly corrosive | Scaling |

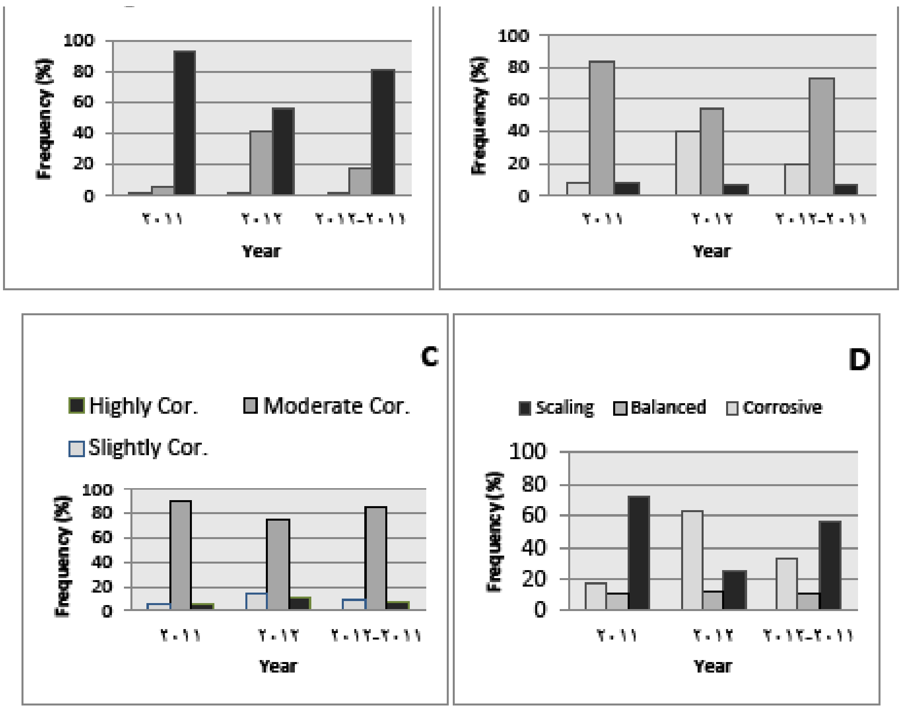


**Figure 1** *Frequency distribution of corrosion and scaling status of the potable water of villages covered by ABFAR company in saqqez in terms of: A) LSI; B) RSI; C) LR; and D) SL*

Figure 1 shows the frequency distribution of corrosion and scaling status of the studied samples. As shown in Figure 1-A, over 93% of the samples had a high level of scaling in terms of LSI (LSI>+.03), whilst, 56.2% of the samples collected in 2012 were scaling. About 41.7% of the samples collected in 2012 had a slight corrosion and scaling potential and were at a balanced status (LSI=±0.3). In general, LSI showed that 81% of all the samples had a high scaling potential; 17.6% of them were almost balanced; and only 1.4% of them had a high corrosion potential.

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Figure 1-C shows the corrosion and scaling status of the potable water of villages covered by ABFAR Company in Saqqez in terms of LR. According to LR, 90% of the samples collected in 2011, 75% of the samples collected in 2012, and generally, 85% of the samples collected in 2011-2012 showed moderate corrosion (LR=0.5-1). Maximum frequency of corrosion in terms of LR was observed in 2012 as 10.4% (LR>1). At the same year, 15% of the samples showed a slight corrosion (LR<0.5).

Figure 1-D shows the frequency distribution of the samples in terms of SL. Maximum frequency in terms of SL was observed in 2011 as 72.3% and was related to the samples with scaling potential (SL>1.1). However, only 25% of the samples in 2012 had the scaling potential. In the same year, 62.5% of the samples were corrosive (SL<0.9). In general, 56.3% of the studied samples were scaling.

## Discussion

The potable water supplied in rural areas of Saqqez city, Kurdistan province, was examined for some physicochemical parameters. According to data presented in Table 1 and 2, the total alkalinity in the samples was due to the presence of HCO3—, and there was no carbonate alkalinity. A study conducted on potable water in Ardebil, Iran by Sadeghi and Roohollahi (2007) indicated that 94% of the samples did not contain carbonate, and mean concentration of bicarbonate was obtained as 310 mg/l [10].

As shown in the table 3, the potable water of villages in Saqqez in 2011 and 2012 was in the range of standards of WHO and EPA and was favorable in terms of the studied parameters, except calcium hardness, in comparison to the standard 1053 of the Institute of Standards and Industrial Research of Iran. In Heibati et al.'s study, the potable water of Miyaneh, Iran in 2008 had a favorable concentration of sulfate and chloride according to Iran standards and was classified in the allowable limit in terms of TDS [11].

The measured parameters were used to evaluate corrosion and scaling potential of the distributed water in terms of Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Larson Ratio (LR), and Saturation Level (SL). The SLI value was higher in 2011 compared to 2012. This might be due to the different temperature of the samples. As expected, an increase in temperature results in an increase in the amount of LSI [12]. To examine the hypothesis, the independent t test was performed for the temperature recorded in 2011 and that recorded in 2012. The results of t test showed the temperature of the water samples collected in 2011 was significantly higher than that of the water samples collected in 2012 (P=0.000). Therefore, the higher temperature of water samples in 2011 might be a cause of higher mean LSI in that year than that in 2012. Another reason might be the higher pH of the samples collected in 2011. Regarding the equation provided for calculation of RSI, changes in temperature and pH of the water might be the main reasons of the significant increase in RSI in 2012.

It should be noted that LSI and SL are defined in relation to the concentration of calcium carbonate. Tables 4 and 5 showed that LSI and SL always conformed to each other and denoted the scaling status of the potable water. The regression analysis of these two indices also showed the coefficient of determination as 0.8028. Therefore, it seems that future studies can focus only on one of these two indices.

The use of LSI is usually recommended when there are bicarbonate alkalinity, normal pH, low ionic strength (TDS<1000 mg/L), and water velocity lower than 0.6 m/s [13]. All these conditions existed in this study except that the water velocity in network is usually higher than the favorable rate for LSI. In such a situation, it is recommended to use RSI. RSI works appropriately if pH is lower than 8, otherwise, other indices, such as Puchorius index, should be used [4]. In this study, 59% and 90% of the samples respectively in 2011 and 2012 had a pH lower than 8. Therefore, it could be argued that RSI is more efficient for interpretation of corrosion and scaling properties of the potable water in villages covered by ABFAR Company in Saqqez. However, Puchorius index could be also used to determine the corrosion and scaling potential of water in 2011.

LR is a rather newer index showing the corrosiveness of water for metal pipes. The index is important because metal pipes are used in most of distribution networks, and some heavy metals, such as copper, lead, and cadmium, are also used in those pipes. The present study showed that the potable water of the studied villages was corrosive to some extent, and this was rather constant during the two years. The corrosiveness of the potable water in terms of LR has been also reported in other Iran's cities, including Elam and Miyaneh [11,14].

## Conclusion

The quality of the potable water in villages covered by ABFAR Company in Saqqez was in the permissible limit in terms of the studied parameters. The analysis of the potable water in terms of the four indices of corrosion and scaling did not show any changes in the water in this regard from 2011 to 2012. Biennial mean of LSI, RSI, LR, and SL comprised 0.73, 6.51, .074, and 1.96, respectively. According to these results, the studied potable water was at the status of scaling in terms of LSI and SL, at the status of balanced in terms of RSI, and at the status of corrosive in terms of LR. The regression analysis with coefficient of determination as 0.8028 showed a favorable conformity between LSI and SL. Therefore, future studies can focus only on one of these two indices. The frequency distribution showed that 81% of the samples were scaling in terms of LSI; and 74% of the samples were balanced in terms of RSI. However, LR showed the tendency of water to corrode the metal pipes, as 85% of the samples had moderate corrosion. In general, regarding the properties of the studied samples and indices, it seems that RSI is the best index for determining the corrosion and scaling potential. In terms of RSI, most of the samples of the potable water in villages covered by ABFAR Company in Saqqez did not tend to corrode and deposit. However, considering that the annual mean of three indices significantly differed from one another, it is recommended to monitor the corrosion and scaling potential of the water in the studied villages every year in order to take necessary controlling actions in case of any unfavorable changes in the water's quality.

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## Contributions

Study design: SM, MH
Data collection and analysis: NF, MKh, MD
Manuscript preparation: MD, MH

## Conflict of interest

"The authors declare that they have no competing interests."

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