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Corrosion and Scaling Potential in Drinking Water Distribution System of Tabriz, Northwestern Iran

Hassan Taghipour[1], Mohammad Shakerkhatibi[1], *Mojtaba Pourakbar[2], Mehdi Belvasi[3]

[1] *Department of Environmental Health Engineering, Faculty of Health and Nutrition, Tabriz University of Medical Sciences, Tabriz, Iran*
[2. a.] *Student Research committee;* [b.] *Department of Environmental Health Engineering, Faculty of Health and Nutrition, Tabriz University of Medical Sciences, Tabriz, Iran*
[3] *M.A Student of Geographic Information Systems & Remote Sensing, Tabriz University, Tabriz, Iran*

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ABSTRACT

Background: This paper discusses the corrosion and scaling potential of Tabriz drinking water distribution system in Northwest of Iran. Internal corrosion of piping is a serious problem in drinking water industry. Corrosive water can cause intrusion of heavy metals especially lead in to water, therefore effecting public health. The aim of this study was to determine corrosion and scaling potential in potable water distribution system of Tabriz during the spring and summer in 2011.

Methods: This study was carried out using Langlier Saturation Index, Ryznar Stability Index, Puckorius Scaling Index, and Aggressiveness indices. Eighty samples were taken from all over the city within two seasons, spring, and summer. Related parameters including temperature, pH, total dissolved solids, calcium hardness, and total alkalinity in all samples were measured in laboratory according to standard method manual. For the statistical analysis of the results, SPSS software (version 11.5) was used

Results: The mean and standard deviation values of Langlier, Ryznar, Puckorius and Aggressiveness Indices were equal to -0.68 (±0.43), 8.43 (±0.55), 7.86 (±0.36) and 11.23 (±0.43), respectively. By survey of corrosion indices, it was found that Tabriz drinking water is corrosive.

Conclusion: In order to corrosion control, it is suggested that laboratorial study with regard to the distribution system condition be carried out to adjust effective parameters such as pH.

Keywords: Drinking water, Corrosion indices, Scaling, Corrosion potential, Iran

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Introduction

Safe water is one of the most important necessities to sustain life, and a satisfactory (adequate, safe, and accessible) supply must be available to all. Improving access to safe drinking water can result in tangible benefits to health. So every effort should be made to achieve a drinking water quality as safe as practicable [1]. It is argued that the water distribution system will be a key public health battlefield of the 21st century [2].

Tabriz drinking water is provided from two main resources, Nahand and Zarine rud

Corresponding Author: Mojtaba Pourakbar. Tel : +98 411 3357581, Fax : +98 411 3340634
Email: ppourakbar@yahoo.com

. In addition, there are some wells in south and southeast of the city, which inject low amounts of water to distribution system.

However, one of the major problems in water distribution systems is the corrosion. Corrosion is the "physicochemical interaction between a metal and its environment which results in changes in the properties of the metal". Internal corrosion of water distribution systems leads to two major problems for water utilities. The first is the failure of pipes in the water distribution systems, resulting in water leakage and loss of hydraulic capacity caused by the buildup of corrosion products. The second one is an unwanted change in water quality as the water is being transported through the distribution system [3].

When the water tended to be scaling, during the time creates thin layers in the internal parts of pipes then decrease internal diameter, at result the conveyed flow will diminish[4].The potential to form a protective layer containing a mixed precipitate of calcium carbonate and iron oxides depends on many different chemical and biological parameters such as pH, residual chlorine, hardness, temperature, total dissolved solids, alkalinity, acidity, dissolved salts, dissolved gases and microorganisms. In addition, corrosion tends to increase heavy metals concentration. In general, different water resources have different water characteristics and therefore their tendency to corrode the water pipes is different [5]. Corrosion products can shield microorganisms from disinfectants, causing many problems such as slimes, bad odor, and taste [6].

The overall costs of corrosion are astronomical. Unaccounted for water at utilities ranges from < 10% to 32% of the total production [7]. A study conducted by the Federal Highway Administration (2002) estimated that the direct cost of corrosion in public drinking water in U.S. represented $22 billion [8]. This is consistent with studies in Australia, Great Britain, Japan and other counties where it has been estimated that costs of corrosion are approximately 3-4% of the Gross National Product [2]. It is reported that average unaccounted water in Iran is about 30% [9]. Moreover, it is believed that a significant portion of this water is attributable to leaks due to corrosion [2].

The overriding corrosion concern today relates to public health, with an emphasis on the perceived threat generated by the release of metals (particularly lead) from the dissolution of the metallic surfaces. The association between chronic low-level lead exposure and adverse health effects is well documented for a variety of public health concerns [3].

So far, there has been no available and accurate data about corrosion and scaling potential, which describes various indices to assess the scale formation (protective layer), and corrosivity of water distribution system in Tabriz. Nevertheless, in the last few decades' rapid economic advancement, urbanization, development, population growth has resulted in an increase in the size of water distribution system in the city. There are concerns about the corrosion and scaling potential in drinking water distribution system of city.

The aim of this study was to determine corrosion and scaling potential of potable water of Tabriz in spring and summer 2011.

Materials and Methods

In this study, four indices including Langlier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI) and Aggressiveness Index (AI) were used to identify the corrosion and scaling potential. Despite the fact that some empirical evidences show no correlation between these indices and corrosive tendency of water, the LSI and RSI are still popularly used in helping to understand possible causes of corrosion [10, 11]. PSI has some advantages over these two indices, which only account for the driving force for calcium carbonate scale formation. They do not account for two other critical parameters: the buffering capacity of the water, and the maximum quantity of precipitate that can form in bringing water to equilibrium [12]. Aggressiveness Index is used for Asbestosis-cement pipelines [4], since Tabriz drinking water distribution system is an old one, there are some Asbestosis-cement pipes in some old parts of the city, therefore calculation if this index is justifiable.

In this study, eighty samples (40 in spring and 40 in summer) were taken from 40 same locations in 2011. The experiments were carried out to measure the parameters including temperature, pH, Total Dissolved Solids (TDS), calcium hardness, and total alkalinity according to standard methods manual [13].

Sampling sites were distributed all over the city and all samples were taken from health centers, which cover all the distribution system and population.

Langlier Saturation Index

The Langlier Saturation Index was developed by Dr. Langlier in 1936[14]. The LSI is a qualitative assessment of water potential to precipitate calcium carbonate [15]. It considers factors of water's tendency to be in equilibrium with calcium carbonate. Calcium carbonate is just one of many minerals found in water and is one of the most important elements responsible for forming calcareous deposits. The LSI considers the effects of calcium, total alkalinity, dissolved solids, and temperature to arrive at a computed pH shown as pHs in the formula. Once pHs is known you simply subtract it from the actual pH of water and, if the result is positive, the water will be scaling and conversely, if the number is negative, the water will tend to dissolve calcium carbonate [14]. After calculation of pHs, the value of LSI is defined as follows:

$LSI=pH-pHs$ (1)

Where, pH is actual pH of water and the pHs is the pH of water at calcium carbonate saturation condition [14].

pHs is calculated with following equation:

$pHs= \{(9.3+A+B)-(C+D)\}$ (2)

Values of A, B, C and D are determined according to Table 1[16]. Constant A is determined using the TDS table by taking the value that corresponds to the measured total filterable residue or the estimated TDS. Constant B takes into account the effect of temperature. Value C is obtained by the corresponding value to the calcium hardness (in mg/L $CaCO_3$) of the sample. Value D is obtained from the Hardness table by reading the measured value for total alkalinity (in mg/L $CaCO_3$) of the sample [4, 16].

Ryznar Stability Index

First, John Ryznar developed a modification of the LSI in 1944 upon realizing that it was possible for both low and high hardness waters to have the same LSI [1]. By reversing the placement of pH and pHs in the formula the result of RSI always will be a positive number. The pHs for the RSI is determined via the actual pH as well as the concentration of the calcium and bicarbonate ions, TDS and temperature. A RSI less than 5 should be scaling whereas a RSI above 7 will produce little if any scale [14].The value of RSI is evaluated as follows:

$RSI=2pHs-pH$ (3)

Puckorius Scaling Index

The next improvement of the scaling index was developed by Paul Puckorius. The PSI is also called the Practical Scaling Index. The PSI accounts for two additional variables that the indices do not –the buffering capacity of water and the maximum quantity of precipitate that brings water to equilibrium. Therefore, the PSI uses an equilibrium pH rather than the actual pH to account for the buffering effect [14]. The equilibrium pH is determined as:

$pHeq = 1.465+ \log (T.ALK) + 4.54$ (4)

The numbers resulting from the equation 4 are the same as the RSI index so a value less than 5 will be scaling and a number greater than 7 will result in little if any scaling. PSI is calculated as follows [4]:

$PSI=2pHs-pHeq$ (5)

Aggressiveness Index

The AI was developed for Asbestos-cement pipes with water temperatures ranging from 4 to 27°C (40 to 80°F). The AI is calculated as a function of pH, calcium concentration, and alkalinity. Waters with AI less than 10 are considered highly aggressive; AI between 10 and 12 are considered mildly aggressive; and AI greater than 12 are considered noncorrosive and depositing[14]. Aggressiveness index is calculated as follows [4]:

AI= pH + log[(A)(H) (6)

Where, A is the total alkalinity in mg/l as CaCO3 and H is the calcium hardness (in mg/l CaCO3).

Statistical analysis

For the statistical analysis of the results, SPSS software (version 11.5) was used. Data were summarized with mean and standard deviation. To assess the normality of the variables in spring and summer seasons, KS-test was used and confirmed. For the comparison of the mean values of the indices, independent t-test was used. $P<0.05$ was considered significant.

Results

The location of sampling sites was distributed uniformly all over the city, which covers all the city and water distribution system. According to the results of analysis of the samples, values of A, B, C and D in equation 2 determined according to Table 1.

Maximum, minimum, average values and SD of the analyzed parameters are shown in Table 2. The values of calculated indices are shown, both spring and summer, in Table 3. The calculated results showed that the mean and SD of LSI, RSI, PSI and AI in spring and summer were equal to -0.68 (±0.43), 8.43 (±0.55), 7.86 (±0.36) and 11.23 (±0.43), respectively.

For Langlier, Ryznar and Puckorius indices, there was a significant difference between two seasons ($P<0.05$), and P-values are 0.019, 0.004 and 0.000, respectively. For Aggressiveness index the difference was not significant ($P=0.138$).

By comparing measured parameters with the Environmental Protection Agency (EPA) guidelines and Iran standards (standard No 1053), we found that water pH was 6.30-7.70 which is in accepted range except in one case that is less than 6.50, the values of TDS was ranged between 186-551 which is less than the EPA and Iran guidelines, and also calcium concentration was from 25.6 up to 65.6 that is less than the allowable maximum in Iran guidelines.

In order to see the severity of corrosion in different parts of the city, Geographic Information System (GIS) based maps have been developed for the calculated indices in spring and summer (Fig. 1-8).

Table 1: Values of A, B, C, and D

TDS (mg/L)	A	Ca Hardness (mg/L CaCO3)	C	Alkalinity (mg/L CaCO3)	D
50-300	0.1	10-11	0.6	10-11	1.0
400-1000	0.2	12-13	0.7	12-13	1.1
Temperature	B	14-17	0.8	14-17	1.2
0-1	2.6	18-22	0.9	18-22	1.3
2-6	2.5	23-27	1.0	23-27	1.4
7-9	2.4	28-34	1.1	28-35	1.5
10-13	2.3	35-43	1.2	36-44	1.6
14-17	2.2	44-55	1.3	45-55	1.7
18-21	2.1	56-69	1.4	56-69	1.8
22-27	2.0	70-87	1.5	70-88	1.9
28-31	1.9	88-110	1.6	89-110	2.0
32-37	1.8	111-138	1.7	111-139	2.1
38-43	1.7	139-174	1.8	140-176	2.2
44-50	1.6	175-220	1.9	177-220	2.3
51-55	1.5	230-270	2.0	220-270	2.4
56-64	1.4	280-340	2.1	280-350	2.5
65-71	1.3	350-430	2.2	360-440	2.6
72-81	1.2	440-550	2.3	450-550	2.7
		560-690	2.4	560-690	2.8
		700-870	2.5	700-880	2.9
		880-1000	2.6	890-1000	3.0

Table 2: Maximum, minimum, average values and standard deviation of analyzed parameters

Season		**N**	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**	**EPA* standard**	**Iran standard**
Spring	pH	40	6.43	7.77	7.027	0.34547	6.5-8.5	6.5-8.5
	Temperature	40	14	20	17.7125	1.48448		
	Calcium hardness (mg/l)CaCO3	40	64	164	107.15	25.87895		
	Alkalinity (mg/l)CaCO3	40	100	160	132.45	14.50367		
	TDS (mg/l)	40	200	530	295.1075	96.27146	500	1500
	Calcium concentration (mg/l)	40	25.6	65.6	42.86	10.35158		250
Summer	pH	40	6.3	7.7	7.126	0.321	6.5-8.5	6.5-8.5
	Temperature	40	16	24.5	21.3125	1.92715		
	Calcium hardness (mg/l)CaCO3	40	70	150	114.3	21.1832		
	Alkalinity (mg/l)CaCO3	40	110	162	137.1	15.184		
	TDS (mg/l)	40	186	551	334.45	97.8345	500	1500
	Calcium concentration (mg/l)	40	28	60	45.72	8.47328		250

Table3: Values of calculated indices in two seasons

Season		N	Minimum	Maximum	Mean	Std. Deviation
Spring	Langlier	40	-1.77	0.09	-0.7932	0.44803
	Ryznar	40	7.51	9.97	8.6130	0.56271
	Puckorius	40	7.45	8.87	8.0005	0.32341
	Aggressiveness	40	10.27	12.16	11.1593	0.47385
	Valid N (listwise)	**40**				
Summer	Langlier	40	-1.60	0.00	-0.5685	0.39296
	Ryznar	40	7.59	9.50	8.2590	0.50090
	Puckorius	40	7.23	8.67	7.7230	0.35079
	Aggressiveness	40	10.25	11.91	11.3053	0.39289
	Valid N (listwise)	40				

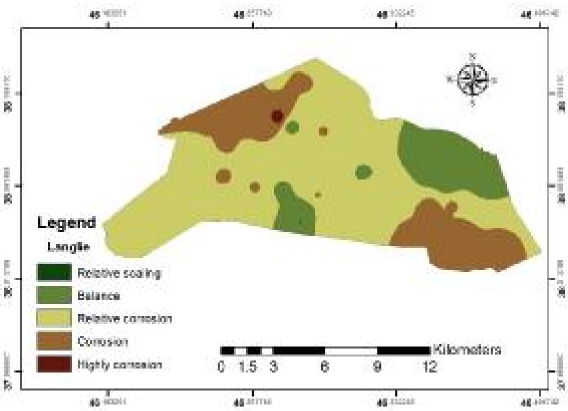

Fig. 1: Langlier saturation index in spring

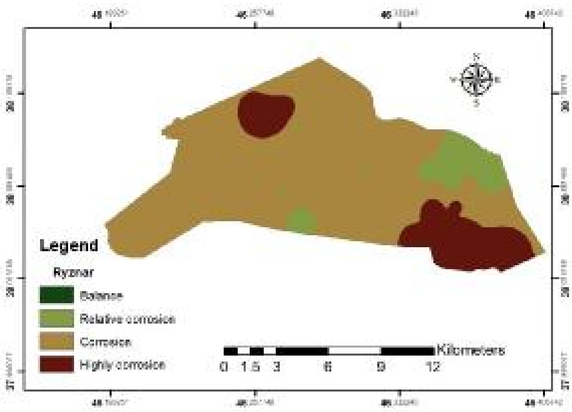

Fig. 2: Ryznar stability index in spring

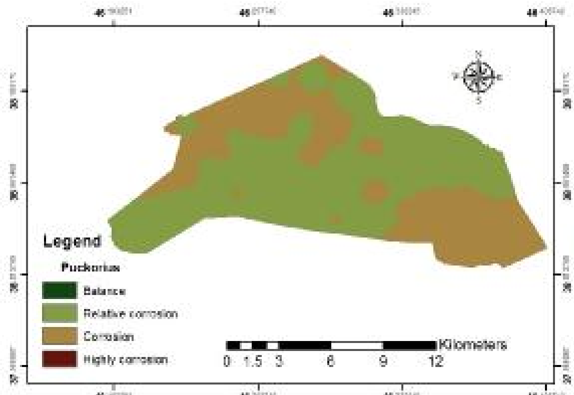

Fig. 3: Puckorius scaling index in spring

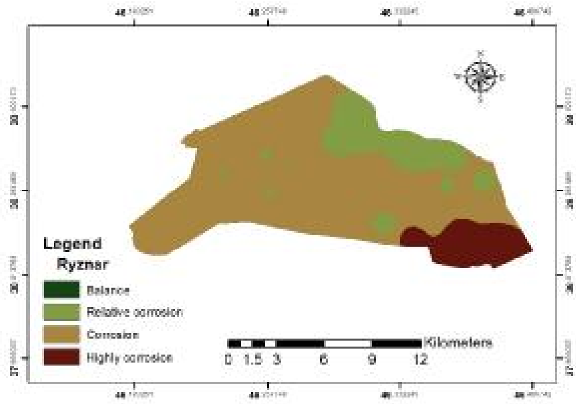

Fig. 6: Ryznar stability index in summer

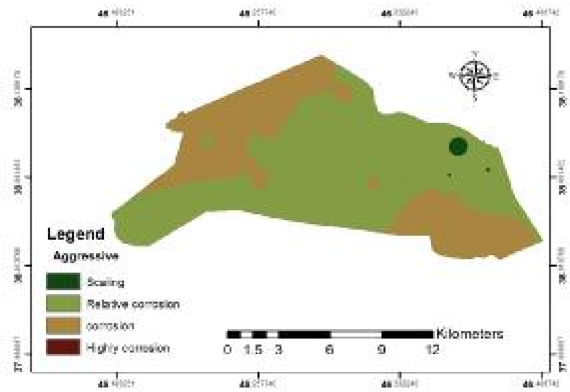

Fig. 4: Aggressiveness index in spring

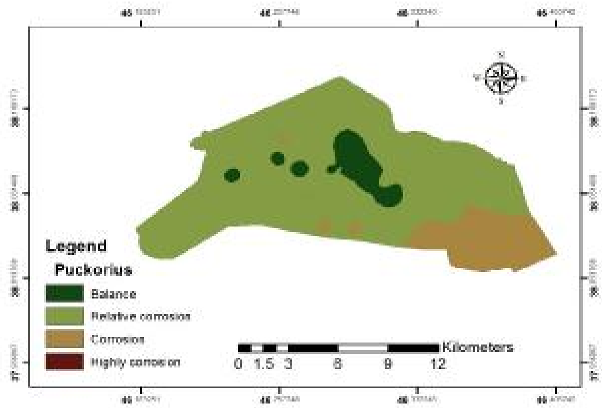

Fig. 7: Puckorius scaling index in summer

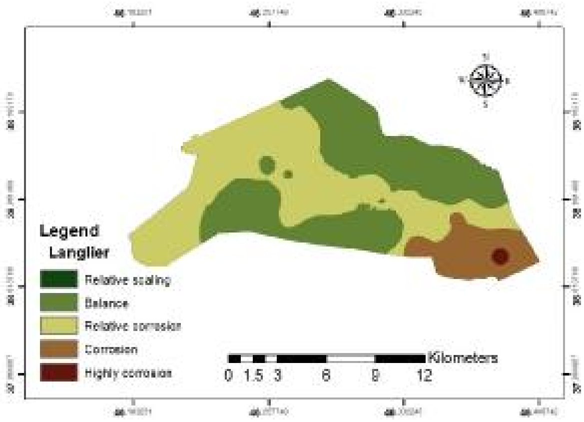

Fig. 5: Langlier saturation index in summer

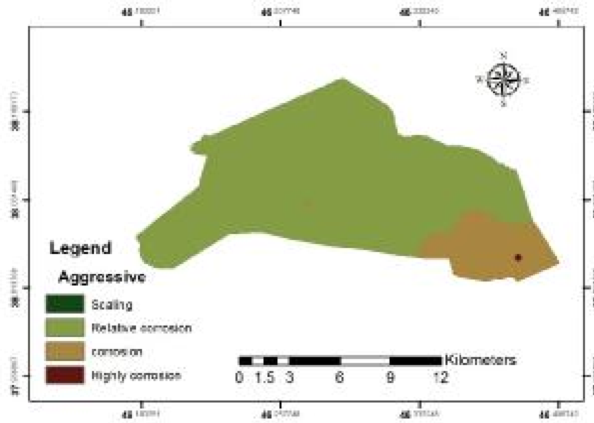

Fig. 8: Aggressiveness index in summer

Discussion

By survey of corrosion indices, it was found that Tabriz drinking water has corrosion potential in both spring and summer seasons. As shown in figures, corrosion potential varies in different parts of the city. In spring season, although drinking water is corrosive, the severity of corrosion is more obvious in north-west and south-east of the city (Fig. 1-4), it is the same for summer season except that only south-east of the city has highly corrosive water (Fig. 5-8).

According to the studies of Al-Rawajfeh and Al-Shamaileh on Tafila province, south Jordan, tap water recourses, LSI values were negative and ranged from -0.39 to -1.55 and RSI values ranged from 8.7 to 9.8, which shows that Tafila's water is corrosive[17]. RSI and LSI values of their findings are similar to our findings and both of them indicate the same problem related to drinking water of these two cities.

Another similar study was done by Christian Agatemor and Patrick O. Okolo in the distribution system of university of Benin, Nigeria. Three corrosion indices - Langelier Index, Ryznar Index, and Larson–Skold Index have been used to assess the corrosion and scaling potential. The Langelier Index ranged from -5.569 to -3.684, Ryznar Index was between 13.340 and 16.418 while the Larson–Skold Index was between 1.191 and 31.750[10]. The results of their study, although indicate that distribution system in Benin university carries corrosive, is significantly different from ours. This may be because of the fact that their drinking water pH is extremely low.

In another study, corrosion and scaling potential in produced water from water treatment plant was studied by Mehdi Fazlzadeh Davil et al in Ilam, Iran. The mean and standard deviation values of Langlier Saturation Index, Ryznar Stability Index, Aggressiveness Index and Puckorius Scaling Index were equal to 0.29 (±0.5), 7.45(±0.17), 12.44 (±0.16), 7.99 (±0.14) and 0.77(±0.1), respectively. By survey of these indices, it is reported that produced water in Ilam is moderately corrosive[4]. According to these values, the severity of corrosion in Tabriz is more than Ilam.

Corrosion may cause the leaching of contaminants that would be a concern for the health of people. The materials present in the distribution system determine which contaminants are most likely to be found at the tap. The principal contaminants of concern that can leach from materials in drinking water distribution systems are aluminum, antimony, arsenic, bismuth, cadmium, copper, iron, lead, nickel, organolead, organotin, selenium, tin, vinyl chloride and zinc. It is important to assess whether these contaminants will be present at concentrations that exceed those considered safe for human consumption [18].

Since Tabriz water distribution system is an old one and there are different types of pipes and fittings in the distribution system, it is likely to have the above-mentioned contaminants in tap water, so it is reasonable to examine water about this case n this city.

Drinking water in the Tabriz City distribution system can be made less corrosive by adjusting its pH or alkalinity or by introducing corrosion inhibitors. Of course, corrosion inhibitors and pH or alkalinity adjustments to control lead, copper or iron levels in drinking water should be employed with caution. Pilot studies should be conducted to determine the effectiveness of the corrosion control method chosen for the particular conditions prevailing in the distribution system.

Our study had some limitations. Some other factors such as material properties of water mains, water age in the pipes, dissolved oxygen concentration, free chlorine residual, sulphate, chloride, etc could affect the corrosion level in water, and this paper could be a hint to initiate more investigation about this case in this city.

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