Spatial and Temporal Analysis of Corrosion and Scaling Trends in Zanjan Water Distribution Network Using GIS, Iran

Farhad Ghayurdoost[1], Javad Mohammadi[1], Ali Assadi[*1]

1) Department of Environmental Health Engineering, Zanjan University of Medical Sciences, Zanjan, Iran

[*]*Corresponding author:* assadi@zums.ac.ir

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ABSTRACT
Corrosion and scaling of piping are a main issue in the operation of the drinking water network. Corrosive water can cause the intrusion of heavy metals into water and can lead to affect public health. This study aims to present the corrosion and scaling potential of Zanjan drinking water network that is located in north west of Iran. This descriptive cross-sectional study was carried out using calculation of Langlier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI), and Aggressiveness index (AI). Thirty six samples were taken from all over the city within two seasons, summer and autumn in 2016. To reach this goal following parameters such as pH, total dissolved solids (TDS), alkalinity, calcium hardness, magnesium, total hardness, temperature and electrical conductivity (EC) in all samples were measured in the laboratory. The mean and standard deviation values of LSI, RSI, PSI and AI indices were equal to -0.62±0.18, 8.26±0.29, 8.04±0.51 and 11.5±0.24, respectively in summer and -0.83±0.12, 8.70±0.33, 8.00±0.29 and 11.15±0.25, respectively in autumn. According to all indices the results have shown that Zanjan drinking water is a mild corrosive. Finally, it is recommended that water authorities must be adjusted effective parameters such as pH of treated water at the beginning of the network in order to corrosion control.
Key words: Drinking Water Network, Saturation Indices, Corrosion, Scaling Potential

INTRODUCTION
Drinking water should be free of any harmful compounds which may be a threat to human health [1]. Inappropriate drinking water quality can be originated from physical, chemical and biological factors. The chemical aspects of water quality can be harmful from health and economic point of view [2]. Corrosion and scaling potential defined as chemical characteristics of water quality. Corrosion in water network includes the electrochemical or physicochemical interaction between a metal and its environment which leads to changes in the properties of the metal [3, 4]. Corrosion is most important issue which can affect water quality in drinking water distribution systems [5, 6]. Because of those tendency to increase the concentrations of some toxic agents such as lead, cadmium, nickel, copper, iron and zinc that cause staining of facilities or metallic taste, or both in tap water are considerable from public health and economic characteristics [5]. The scaled water tends to create a thin layer of deposits which can be used as a shield for microorganisms in water network and cause to low efficiency of disinfectants [4, 5, 7].

Several researches have been conducted for the determining of corrosion and scaling potential of drinking water in all of the world. Khorsandi *et al.*, investigate corrosion and scaling potential of 36 samples from four villages of Urmiya province in Iran. According their analysis three villages was corrosive and one was scaling [3]. The outcome of other study demonstrated seasonal variation can effect on corrosion and scaling potential [8]. Also, *Melidis et al.*, illustrated that potable water of Hrysoypolis in Greece is not corrosive and does not cause damage in the distribution system [5].

Variety of indicators have been used for estimation corrosion and scaling potential such as LSI, RSI, PSI, and AI. The LSI and RSI are most common indicators which shown $CaCO_3$ saturation [3, 9]. The mentioned indicators have shown water tendency to dissolve (under-saturated) or precipitate (supersaturated) $CaCO_3$ [9]. The AI belongs to pH, calcium concentration and alkalinity. For corrosion and scaling potential determination the range of this index is between 10-12. The PSI has shown the maximum quantity of scale that may form in bringing water to equilibrium. This index variation between 5-7 is shown water tendency to be corrosive or scaling [10]. Application of useful softwares such as Geographic Information System (GIS) can be one of the worth approaches in drinking water quality modeling and zoning [1]. This technology has received great attention and remarkable acceptance over the last decade as precious tool. Its ability in carrying out complex spatial operation and providing a link between spatial and descriptive information is landmark [11, 12]. The GIS is applicable in water quality modeling, predict nonpoint source pollution and managing site inventory [11, 13]. Furthermore, GIS can indicate spatial operation of corrosion and scaling potential. The aim of this study is an estimation of corrosion and scaling potential variations by different indicators in Zanjan city by GIS technology.

MATERIALS AND METHODS

Area of study

Zanjan city which is the center of Zanjan province is located in the North West of Iran at altitude of 36˚ 30' 30.95'' and longitude of 48˚ 23' 45.63''. According to demographic information of Iranian Statistics Agency in 2011, the Zanjan city has 486495 population. The water requirement of this city is supplied by two sources: Taham dam (about 60%); the wells which located in the eastern part of the city (about 40%). According to investigations, the water requirement of this city till the year of 2031 would equal to 1910L/s. Sometimes at peak consumption (special warm seasons), in many parts of the city (special altitude zones) occur cut off the water flow.

Procedure

In this descriptive cross-sectional study thirty six samples were collected during two seasons (summer and autumn) in 500 mL polyethylene bottles in 2016. The sampling locations were determined by the sign of A1, A2, and A18 on the map. The experiments were carried out to measure the parameters including pH, total dissolved solids (TDS), alkalinity, calcium hardness, magnesium, total hardness, temperature and electrical conductivity (EC) were measured by different indices to determine corrosion and scaling potential in water distribution system according to standard methods [14]. According to Table 1, all samples were analyzed and interpreted by different indices as a following:

The LSI and RSI were calculated using Equations 1 and 2:

$$\textbf{LSI=pH- pHs} \quad (1)$$

$$\textbf{RI=2pHs-pH} \quad (2)$$

Where pH: is the actual pH of water samples, pHs: is saturated ($CaCO_3$) pH which calculated by equation 3:

$$\textbf{pHs= \{(9.3+A+B)-(C+D)\}} \quad (3)$$

A: TDS (mg/l), B: Temperature °C, C: Calcium Hardness (mg/L as $CaCO_3$), D: Alkalinity (mg/L as $CaCO_3$) [10]

The PSI was determined by equation 4:

$$\textbf{PSI=2pHs-pHeq} \quad (4)$$

Where pHs: is saturated ($CaCO_3$), peak: is the pH of water at the equilibrium condition that computed by using equation 5:

$$\textbf{pHeq = 1.465+ log (T.ALK) + 4.54} \quad (5)$$

T.ALK: is Total alkalinity

The AI was determined by equation 6:

$$\textbf{AI= \{pH + log [(A) × (H)]\}} \quad (6)$$

Where pH: is the actual pH of water samples, A: is Total alkalinity (mg/L as $CaCO_3$), H: is Calcium hardness (mg/L as $CaCO_3$)

Table 1: Water corrosion and scaling indices [15-17]

Index	Index Value	Interpretation
Langlier Saturation Index	LSI<0 LSI=0 LSI>0	Under saturated, High corrosion Balance High scaling, Super saturated
Ryznar Stability Index	RSI<6 6<RSI<7 RSI>7	Scaling Low corrosion High corrosion
Pockurius Scaling Index	PSI<5 5<PSI<7 PSI>7	High scaling Little scaling or corrosion Corrosion
Aggressiveness Index	AI < 10 10 < AI < 12 AI > 12	Very aggressive Moderately aggressive Non aggressive

RESULTS AND DISCUTIONS

To investigate of corrosion and scaling potential in Zanjan water distribution system different chemical water quality parameters such as pH, temperature, alkalinity, total hardness, calcium, magnesium, total dissolve solid, turbidity, and EC, were measured. The maximum, minimum, mean and standard deviation of parameters in the summer and autumn have been shown in Tables 2 and 3. Then, indexes include LSI, PSI, RSI, AI, were calculated by using equations which mentioned in materials and methods.

According to Tables 4 and 5 the mean of LSI during the summer and autumn were -0.62 and -0.83 respectively, which shows that water was far corrosive during autumn than summer. Similarly, the results of other study in Zanjan drinking water network in 2006 have shown that 53.51 percent of the samples were corrosive [18]. Also, the comparison between minimum and maximum values of this index shows that minimum value during two seasons were same, but maximum value for autumn was higher than summer. In order to show the intensity of corrosion in different parts of the city, GIS based maps have been prepared for the calculated indices in summer and autumn (Fig. 1-4). As can be seen from Fig. 1, the water quality was more corrosive during autumn than summer and its intensity is more than summer according to LSI index.

Table 2: The statistical values of measured parameters in summer

Parameter	n	Minimum	Maximum	Mean	SDR	SD
pH	18	6.80	7.50	7.1500	.05731	.24314
Temperature (°C)	18	25.00	29.00	27.0000	.30250	1.28338
Turbidity (NTU)	18	.50	.91	.6344	.02877	.12205
Total hardness (mg/L)	18	164.00	348.00	2.3111E2	12.37140	52.48741
Mg^{+2} (mg/L)	18	32.00	148.00	59.3333	6.12079	25.96831
Ca^{+2} (mg/L)	18	120.00	276.00	1.7467E2	11.82442	50.16678
TDS (mg/L)	18	340.00	1112.00	6.7983E2	49.97138	212.01061
Alkalinity (mg/L)	18	104.00	142.00	1.2544E2	2.64108	11.20516
EC (µs/cm)	18	566.60	1853.30	1.1330E3	83.28755	353.35913

Table3: The statistical values of measured parameters in autumn

Parameter	n	Minimum	Maximum	Mean	SDR	SD
pH	18	6.30	7.10	6.7389	.05058	.21458
Temperature (°C)	18	18.00	22.00	20.1111	.27876	1.18266
Turbidity (NTU)	18	.23	.56	.3556	.01876	.07957
Total hardness (mg/L)	18	164.00	376.00	2.3622E2	15.46312	65.60448
Mg^{+2} (mg/L)	18	24.00	84.00	49.7778	4.13146	17.52832
Ca^{+2} (mg/L)	18	124.00	292.00	1.8556E2	11.89118	50.45000
TDS (mg/L)	18	274.00	626.00	4.2822E2	24.43299	103.66039
Alkalinity (mg/L)	18	104.00	148.00	1.2672E2	3.14654	13.34962
EC (µs/cm)	18	456.60	1043.30	7.1359E2	40.73435	172.82122

Table4: The statistical values of corrosion and scaling indices in summer

Index	n	Minimum	Maximum	Mean	SDR	SD
LSI	18	-.99	-.36	-.6239	.04250	.18030
RSI	18	7.80	8.80	8.2667	.07048	.29902
PSI	18	7.60	9.90	8.0444	.12160	.51589
AI	18	11.00	11.90	11.5000	.05774	.24495

Table5: The statistical values of corrosion and scaling indices in autumn

Index	n	Minimum	Maximum	Mean	SDR	SD
LSI	18	-.99	-.58	-.8383	.02852	.12099
RSI	18	8.10	9.30	8.7278	.07995	.33921
PSI	18	7.40	8.40	8.0056	.06977	.29600
AI	18	10.70	11.70	11.1556	.06008	.25489

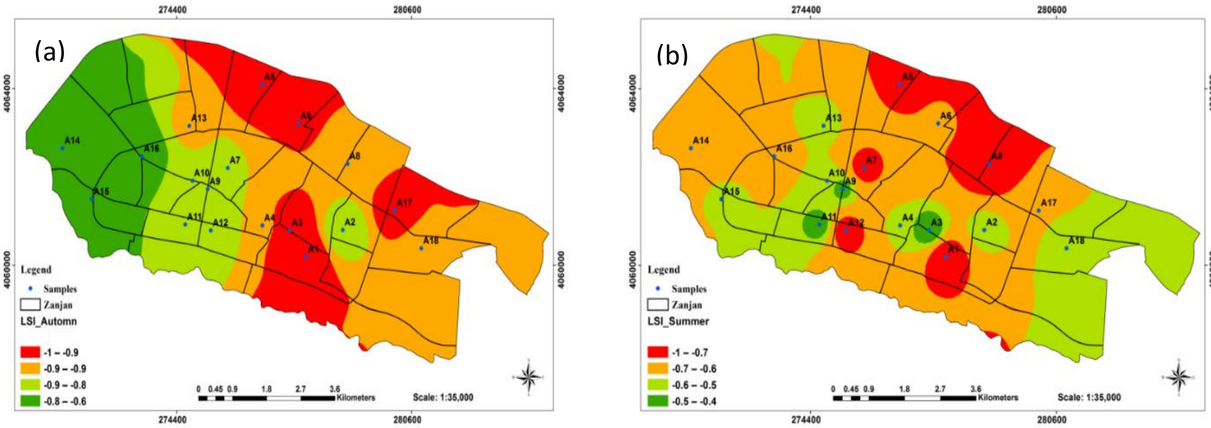

Fig.1: Spatial variations of water based on LSI: (a) autumn and (b) summer

On the other hand, results indicated that the mean value for the RSI in summer and autumn was 8.26 and 8.72 respectively, which prove that in autumn water is more corrosive in comparison with summer. According the Fig.2, water quality in majority points of city during summer was High corrosive.

Meanwhile, the quality in the North West of the city was low corrosive and in the autumn was highly corrosive in the central part of the city and that was low corrosive in east and west. The findings of another work presented that based on RI water condition in Miyaneh (closest city to Zanjan) was corrosive during autumn [19].

According to PSI calculations from tables 4 and 5, the mean values in summer and autumn were 8.04 and 8.00 respectively, which illustrates the water quality was corrosive in both. The Fig.3 clearly illustrated that the water quality during summer in east part of the city was highly corrosive while in the west part was little scaling or corrosion and water quality during autumn season was highly corrosive in the west and partly of the east.

As well, AI results displayed that this value was barely same during two seasons, which proves water quality was moderately aggressive. According to Fig.4, during autumn distributed water in whole across the city was moderately aggressive while most part of the city were aggressive during the summer.

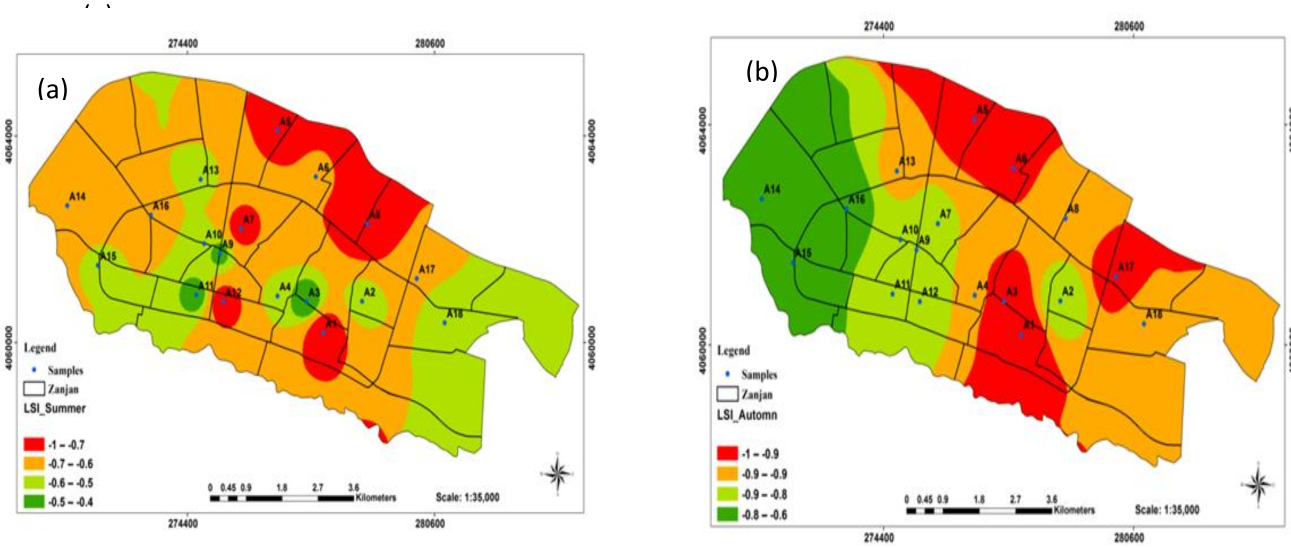

Fig. 2: Spatial variations of water based on RSI: (a) autumn and (b) summ

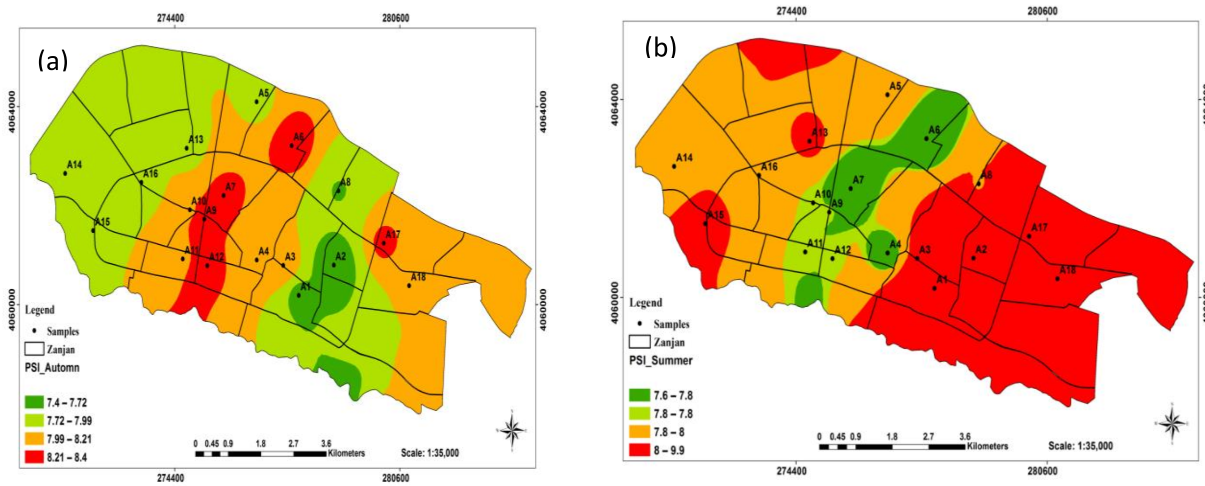

Fig. 3: Spatial variations of water based on PSI: (a) autumn and (b) summe

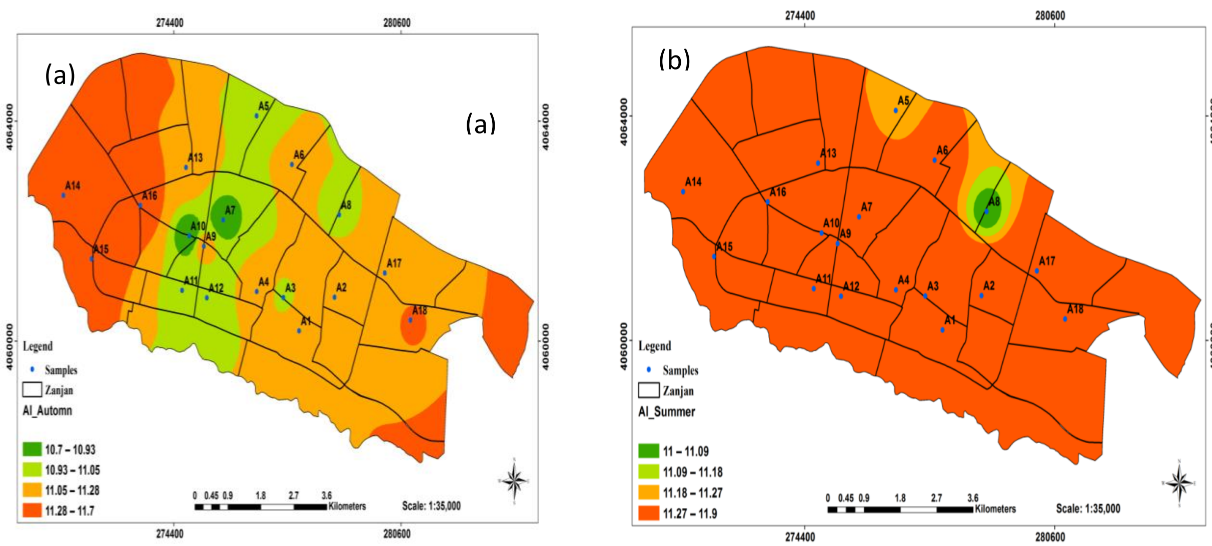

Fig. 4: Spatial variations of water based on AI: (a) autumn and (b) summer

Due to the possible different interpretations of various water stability indices, finding the most appropriate index would be helpful in managing water distribution systems to maintain safe drinking water quality [20].

A study of the potential for scale formation and corrosion of drinking water in South Jordan, showed that based on LSI and RSI values, water samples were slightly corrosive and confirming the results of the present work [21]. Similarly, corrosion and scaling indexes for water supply sources of villages of Qom province based on Langelier, Ryznar, aggressive and Puckorius indexes are -1.62, 10.5, 12.03 and 9.92, respectively indicating that the water is corrosive in the studied regions [22].

The corrosion and scaling potential of Tabriz drinking water network based on the values of Langelier, Ryznar, aggressive and Puckorius indexes were determined as -0.79, 8.16, 11.16 and 8, respectively indicating that Tabriz water is corrosive [4]. The water corrosion values of above mentioned works in terms of all studied indexes are also slightly more than compared with the present study.

CONCLUSION

The outcome of this research indicated that Zanjan drinking water has a mild corrosion potential according to all calculated indices. Drinking water in the Zanjan network can become less corrosive by adjusting its pH, alkalinity or by appending corrosion inhibitors. Pilot studies should be conducted to determine the effectiveness of the corrosion control method selected for the particular conditions dominant in the network. Also, other important parameters such as material properties of water mains, water age in the pipes, dissolved oxygen concentration, free chlorine residual, and dissolved solids could affect the corrosion level in the water, and have not investigated in this study.

ETHICAL ISSUES

The ethical issues were considered during the conduct of this study.

CONFLICT OF INTEREST

We confirm that this article is the original work of the authors and have no conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors were participating in all stages of the research.

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REFERENCES

[1] Dehghani P, Shahmoradi B, Amini A, Sabeti MS. Determining suitable model for zoning drinking water distribution network based on corrosion potential in Sanandaj City, Iran. Journal of Advances in Environmental Health Research. 2014;2(2):72-80.

[2] Kafia M, Slaiman G, Nazanin M. Physical and chemical status of drinking water from water treatment plants on Greater Zab river. Journal of Applied Sciences and Environmental Management. 2009;13(3):89-92.

[3] Khorsandi H, Mohammadi A, Karimzadeh S, Khorsandi J. Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran. Desalination and Water Treatment. 2016;57(23):10585-92.

[4] Taghipour H, Shakerkhatibi M, Pourakbar M, Belvasi M. Corrosion and scaling potential in drinking water distribution system of Tabriz, northwestern Iran. Health promotion perspectives. 2012;2(1):103-11.

[5] Melidis P, Sanozidou M, Mandusa A, Ouzounis K. Corrosion control by using indirect methods. Desalination. 2007;213(1):152-58.

[6] Peng C-Y, Korshin GV, Valentine RL, Hill AS, Friedman MJ, Reiber SH. Characterization of elemental and structural composition of corrosion scales and deposits formed in drinking water distribution systems. water research. 2010;44(15):4570-80.

[7] Gungor A, Arslan H. Assessment of water quality in drainage canals of Carsamba plain, Turkey, through water quality indexes and graphical methods. Global Nest Journal. 2016;18(1):67-78.

[8] Dehghani M, Tex F, Zamanian Z. Assessment of the potential of scale formation and corrosivity of tap water resources and the network distribution system in Shiraz, South Iran. Pakistan Journal of Biological Sciences. 2010;13(2):88-92.

[9] Al-Rawajfeh AE, Al-Shamaileh EM. Assessment of tap water resources quality and its potential of scale formation and corrosivity in Tafila Province, South Jordan. Desalination. 2007;206(1-3):322-32.

[10] Davil MF, Mahvi AH, Norouzi M, Mazloomi S, Amarluie A, Tardast A, et al. Survey of corrosion and scaling potential produced water from Ilam water treatment plant. World Appl Sci J. 2009;7(11):11-24.

[11] Wong KM, Strecker EW, Stenstrom MK. GIS to estimate storm-water pollutant mass loadings. Journal of Environmental Engineering. 1997;123(8):737-45.

[12] Elhag M, Al-Ghamdi A, Bahrawi J, Hegazy A. Olive Mill Waste Water Risk Assessment Based on GIS Techniques in Crete, Greece. Global Nest Journal. 2017;19(1):82-93.

[13] Nas B, Berktay A. Groundwater quality mapping in urban groundwater using GIS. Environmental monitoring and assessment. 2010;160(1-4):215-27.

[14] APHA. Standard Methods for the Examination of Water and Wastewater 15ed: APHA American Public Health Association; 2005.

[15] Benson AS. Evaluation of iron corrosion release models for water distribution systems (Doctoral dissertation). Virginia Tech, Blackasburg, VA. Retrieved from https://vtechworks.lib.vt.edu/handle/10919/32271. 2009.

[16] Silbert M. W-INDEX (Water INDEX calculations), Toronto, Available from: <http://www.silbert.org/W-index-Spreadsheet.pdf>. 2006.

[17] Singley J, Beaudet B, Markey P. Corrosion manual for internal corrosion of water distribution systems. Environmental Science and Engineering, Inc., Gainesville, FL (USA), 1984.

[18] Mahvi A, Eslami A. Corrosion and scaling analysis of water supply and distribution system in Zanjan. Journal of Environmental Science and Technology. 2006;8(1):90-95.

[19] Heibati B, Mazloomi S, Fazlzadeh M, Shervin D, Noruzi M. Survey of Corrosion and Scaling Potential Myaneh city drinking water in 2008. Proceeding of 12 th National Congress of Environmental Health, Tehran, Iran. 2008.

[20] Alipour V, Dindarloo K, Mahvi AH, Rezaei L. Evaluation of corrosion and scaling tendency indices in a drinking water distribution system: a case study of Bandar Abbas city, Iran. Journal of water and health. 2015;13(1):203-09.
[21] Rezaei Kalantari R, Yari AR, Ahmadi E, Azari A, Tahmasbi Zade M, Gharagazlo F. Survey of corrosion and scaling potential in drinking water resources of the villages in Qom province by use of four stability indexes (With Quantitative and qualitative analysis. Archives of Hygiene Sciences. 2013;2(4):127-34.