Original Article

Corrosion and scaling potential of drinking water resources of Sarayan County, Iran

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(Received: 23 Jan. 2018; Revised: 28 Apr. 2018; Accepted: 18 Jul. 2018)

Abstract

Background and purpose: In the area of water quality issues, much attention has been paid to water corrosivity and scaling potential since the water tendency to each of them can impose huge financial losses and many health problems.

Materials and Methods: In this descriptive cross-sectional study, 38 water samples were collected from 19 sampling sites including wells and aqueducts of Sarayan, Iran, in spring and autumn seasons of 2015, and analyzed for total dissolved solids (TDS), calcium hardness, total alkalinity, water temperature, pH, Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Aggressive Index (AI), and Puckorius Index (PI). The results were analyzed by Excel and water stability analyzer Software and were compared with standard limits.

Results*:* It was found that TDS, temperature, pH, alkalinity, and hardness of water were lower than the maximum allowed limits, but calcium hardness was also lower than the optimum value for drinking water. The average value of LSI, RSI, AI, and PI in spring was 0.437±0.264, 7.25±0.368, 12.33±0.273, and 7.37±0.432, while the average values of these indices in autumn were 0.501±0.229, 7.231±0.359, 12.55±0.225, and 7.33±0.503, respectively.

Conclusion*:* According to corrosion indices, drinking water of Sarayan County was relative scaling. Considering the negative effects of scale-forming water on pipe diameter, and flow rate and probable economic damages, control measures must be taken to prevent scaling in water resources.

Keywords: Corrosion and Scaling potential; Corrosion indices; Drinking Water Distribution System

Citation: Momeni H, Nekounam H, **Rahmanpour Salmani E***, Corrosion and scaling potential of drinking water resources of Sarayan County, Iran. Iran J Health Sci. 2018; 6 (3): 36-44.

1. Introduction

The quality and health of drinking water has a vital importance in terms of human health, and economic and aesthetic aspects. Corrosion and scaling are considered as important indictors regarding the chemical quality of drinking water supply sources (1,2). The occurrence of corrosion and scaling phenomena, can adversely affect the economy of the treatment industry, and the transmission and distribution of water. The entry of compounds separated from the body of the pipes into drinking water, the occurrence of health problems, and the reduced lifetime of pipes and fittings are some of the other adverse effects of corrosion. Scaling also reduces the flow of pipes and efficiency of valves and fittings (2). As a result, it can be said that corrosion and scaling problems currently account for a significant percentage of per capita income in different countries (1).

Temperature, alkalinity, pH, ions, in particular, chloride and sulfate, and pipe material are considered as factors that affect corrosion. In low alkaline water, in the presence of residual chlorine concentration of 0.4 mg/l and more, the corrosion rate increases. Corrosion leads to the dissolution of metals from the pipes and fittings into the water, some of which are harmful to human health, such as lead, arsenic, cadmium, copper, and selenium (3-6). Apart from health effects, this phenomenon can also have aesthetic effects, such as the appearance of some stains on the surfaces of restrooms and clothes; for example, copper leaves blue-green stains on plumbing fixtures, iron imparts a red color to water, and manganese is generator of black color. Moreover, corrosion causes leakage and loss of water, creates negative pressure, and increases the entry of pollutants into the pipelines by creating cavities in the pipes and distribution system (7). Corrosion imposes astronomical costs to the water utilities. It is responsible for 10-32% of the total costs of production in utilities. According to a study conducted by the Federal Highway Administration (2002), the direct cost of corrosion in public drinking water in U.S. represented $22 billion. A same trend can be observed in studies conducted in other countries, such as Australia, Great Britain, Japan, and where costs of corrosion was estimated to be approximately 3-4% of the Gross National Product. It is reported that the average unaccounted water in Iran is about 30%. Moreover, it is believed that a significant portion of this water is attributable to leaks due to corrosion (8). Scaling is another qualitative factor of water. During the scaling process, the bivalent cations react with other dissolved compounds in water and are scaled in the form of a layer in the inner wall of the pipe. This layer that is constituted due to the saturation of dissolved solids in water is called sediment (9,10). The main sediments that disrupt the water distribution system include calcium carbonate, magnesium carbonate, calcium sulfate, and magnesium chloride. In addition, these sediments lead to clogging pipes, reduce the inner diameter of the pipe, increase transferring and pumping costs, and cause environmental problems as a result of emission of pollutants (8,11,12). To reduce water corrosion and scaling, as one of the modifying actions, it must be stabilized before entering to water distribution network (13).

One of the indirect methods for the measurement and determination of corrosivity and the tendency of water to precipitate is application of corrosive indices. The assessment of corrosive indices is based on their ability in determining the under-saturation and the over-saturation mode of water in terms of calcium carbonate and the prediction of water capacity in maintaining, generating or dissolving calcium carbonate sediment. These indexes are Langelier Index, Corrosivity Index, and Puckorius Index (14).

The Langelier Index indicates the degree of saturation of calcium carbonate in water, which presents the concept of saturation using pH as the main variable. Ryznar Index expresses the relationship between experimental data with thickness of observed cortex in urban water system to chemistry of water that is based on saturation level. Indices of Langelier and Ryznar express the difference between real pH of water and pH of water saturated with calcium carbonate. Index of Puckorius is based on buffer capacity of water, and shows the maximum rate of required sediment for creating balance in water. So, for this index, balance pH is used more than real pH (15, 16).

Considering the importance of providing safe potable water for human consumption and with respect to the role of corrosion control in maintaining the quality of water and pipes and fittings, this study was conducted to predict the potential of scale formation and corrosivity in the tap water resources of Sarayan using corrosion indices.

2. *Materials and Methods*

This descriptive cross-sectional study was conducted in Sarayan County in spring and autumn of 2015. 38 water samples were totally taken through grab sampling from 19 wells and aqueducts in Sarayan in two seasons. To achieve the study goal, the indicators determining water corrosivity and scaling potentials including LSI, RSI, AI, and PI, and factors affecting the physicochemical quality of water including TDS, total hardness, calcium hardness, calcium concentration, sulphate concentration, alkalinity, pH, and temperature were measured in the samples of water taken from different points of Sarayan drinking water resources. All sampling and analytical procedures were conducted according to the standard method for the examination of water and wastewater book (17). Accordingly, sterile glass bottles were used to collect samples. Prior to sampling, water samples were tested for remained chlorine. In the presence of chlorine in water, before collecting water, bottles containing enough sodium thiosulfate were used to neutralize chlorine of water. pH was then measured in the sampling site using a portable pH-meter. Hardness was determined through complexometric method using standard solution of EDTA, ErioChrome Black T and Murexide. Alkalinity was also measured through titration using HCl. Table 1 provides methods of calculation for corrosiveness indices based on the measured parameters. Table 2 provides water behavior under different values of corrosion indices. After calculating the corrosion indices, the obtained results were analyzed using Excel and water stability analyzer Software and studied according to water national and international standards. (Ethical Code: IR.BUMS.REC.1395.261)

Table 1. Calculation of corrosiveness indices based on measured parameters (18)

Langelier Saturation Index (LSI)	**LI = pH – pHs** **pHs= 9.3 +A +B – C – D** **A= (log10TDS -1) / 10** **B = −13.12 log10 (T°C+273)+34.55** **C = log10 [Ca^{2+} as CaCO3 mg/L]** **D= log10 [Alkalinity as CaCO3 mg/L]**
Ryznar Saturation Index (RSI)	RI = 2 (pHs) – pH
Aggressiveness Index (AI)	AI =pH - Log (A.H)
Puckorius Saturation Index (PSI)	PI = 2 pHs – pHeq 54.465 Log (T - AIK) + 4.pHeq = 1

Table 2. Equality of different values of corrosion indices with water behavior (18)

Water status	**Intolerable corrosion**	**High corrosion**	**slight corrosion – but non- scale forming**	**Neither scale-forming nor scale removing**	**slightly scale forming**	**scale forming**
LSI	LSI<-2	-2<LSI<-0.5	-0.5<LSI<0	LSI=0	0<LSI<0.5	0.5<LSI<2
Water status	High scaling	Slight scaling	Equilibrium	Slightly Corrosive	Highly Corrosive	Intolerably corrosive
RSI	4-5	5-6	6-7	7-7.5	7.5-9	>9
Water status	non-corrosive		moderately corrosive		highly corrosive	
AI	AI>12		10<AI<12		AI<10	
Water status	Scale-forming water		Inactive		Corrosive water	
PSI	PSI<6		PSI=6		PSI>6	

3. Results

To estimate the corrosive action of Sarayan drinking water, at first, the qualitative parameters of water including temperature, calcium hardness, total hardness, total alkalinity, pH, and TDS were measured. The results related to descriptive analysis of these physico-chemical parameters including minimum, maximum, mean, and standard deviation are displayed in Table 3. Then, scaling and stability indexes were calculated and expressed in terms of RSI, LSI, PI, and AI in Table 4.

According to the average levels of physico-chemical parameters presented in Table 3, in both seasons, TDS was not only lower than permitted level of standard but also very close to the optimum value. pH was also in the optimum range, and alkalinity was less than the relevant standard. Calcium hardness was less than the national standard; however, it was also lower than the optimum level of calcium hardness in water. According to the data presented in Table 4, LSI in all water samples was greater than zero, so water had scaling potential and was not corrosive. Moreover, AI in all of the samples was equal to or greater than 12, so the water was not corrosive. Based on RSI values, 32% and 73.68% of water samples in spring and autumn had, respectively, weak to severe levels of corrosion. PSI value was higher than 6 in all samples that showed corrosive water.

Table 3. Results of descriptive analysis of physico-chemical quality of drinking water of Sarayan and their comparison with standard limits

Season	Measured parameters	Minimum	Maximum	Average ±standard deviation	Standard of Iran		EPA* standard
					Favorable value/range	Allowed value	
Spring	Temperature (^0C)	28.2	33.1	30.87±2.16	-	-	-
	TDS (mg/l)	169.41	800.46	416.22±177.287	500	1500	500
	PH	7.84	8.32	8.09±0.13	7-8.5	6.5-9.2	6.5-8.5
	Total alkalinity (mg/l $CaCO_3$)	110.67	367.71	258.08±62.231	-	500	-
	Calcium hardness (mg/l $CaCO_3$)	55.83	126.03	87.35±22.77	150	500	-
Autumn	Temperature (^0C)	19.8	21.6	20.65±0.89	15	23	-
	TDS (mg/l)	329.46	778.6	543.588±139.31	500	1500	500
	PH	7.96	8.52	8.229±0.14	7-8.5	6.5-9.2	6.5-8.5
	Total alkalinity (mg/l)	279.95	327.25	307.956±33.89	-	500	-
	Calcium hardness (mg/l $CaCO_3$)	50.33	107.75	72.671±17.92	150	500	-

* Environmental Protection Agency of United States

Table 4. Calculation of corrosion indices of drinking water resources in Sarayan

Sampling Site	LSI		RSI		AI		PSI	
	Spring	Autumn	Spring	Autumn	Spring	Autumn	Spring	Autumn
No.1	0.19	0.09	7.4	7.7	12.1	12.1	7.1	7.5
No.2	0.6	0.27	6.9	7.5	12.4	12.3	7	7.3
No.3	0.2	0.32	7.4	7.4	12.1	12.3	6.9	7.3
No.4	0.48	0.19	6.8	7.6	12.2	12.2	6.6	7.5
No.5	0.15	0.67	7.8	7	12	12.7	8.4	7.2
No.6	0.54	0.8	6.8	6.8	12.4	12.8	6.6	7.1
No.7	0.82	0.54	6.6	7	12.7	12.5	6.7	6.9
No.8	0.88	0.77	6.5	6.9	12.7	12.8	6.6	7.2
No.9	0.52	0.7	6.9	6.9	12.3	12.7	7	7.1
No.10	0.55	0.43	6.8	7	12.3	12.4	6.8	6.9
No.11	0.67	0.68	6.8	7	12.5	12.7	6.8	7.1
No.12	0.64	0.34	6.7	7.4	12.5	12.4	6.6	7.4
No.13	0.29	0.72	7.3	6.9	12.2	12.7	6.9	7.1
No.14	0.5	0.61	6.9	6.9	12.3	12.6	7	6.9
No.15	0.3	0.55	7.6	7.2	12.1	12.5	8.4	7.4
No.16	0.27	0.04	7.3	8.2	12.2	12	7	8.9
No.17	0.77	0.6	6.6	7.1	12.6	12.6	6.4	7.5
No.18	0.53	0.58	6.8	7	12.3	12.6	6.7	7.2
No.19	0.71	0.54	6.7	7	12.5	12.6	7	7.1

4. Discussion

Researches show that, the amount of water loss in some countries, such as Iran is more than 20% of the total produced water. With respect to this fact that Iran suffers from water shortage, continuous monitoring of the physico-chemical quality of water which can lead to long-lasting use of pipes and fittings in the distribution network, and consequently reduced water loss, has a vital importance (7,16).

According to the measurements of present research, the average value of pH in the drinking water of Sarayan was 8.16, that is in the acceptable range of Iran (6.5-9.2) and EPA standards (6.5-8.5). The average amount of temperature, calcium concentration, sulphate concentration and TDS were 25.7 ^{o} C, 30.13 mg/l, 72.45 mg/l, and 479 mg/l, respectively, all of which less than EPA and national standard levels (12,19).

The average LSI values were also documented to be 0.437±0.264 and 0.501±0.229 in spring and autumn seasons, respectively, which suggested that the Sarayan water supplies were scaling. In the present research, based on Langelier Index, 100% of water samples were scaling when studied. Similarly, Dehghani et al. (20) showed that 95% of drinking water samples tested in Shiraz had scaling potential. Average values of AI were 12.33±0.273 and 12.55±0.225 in spring and autumn, respectively that indicated the non-corrosive property of

Sarayan water. In the study performed in Juybar city, based on the aggressive index, drinking water had tendency to scaling as the water samples in summer and autumn were 12.65 and 12.59, respectively (21). RSI mean levels were also observed to be 7.25±0.368 and 7.231±0.359 in spring and autumn, respectively. Based on half of the samples, water of Sarayan was slightly corrosive. This difference between the results provided by LSI and RSI was due to the high pH level of water samples in the present study. Water has buffer property in pH values higher than 8, and under this condition, there would not be a proper relationship with alkalinity. Hence, Ryznar Index will lose its credit to predict the corrosion status of water in the current study (22). According to RSI, water tendency to scaling in spring was higher than autumn. With respect to Table 3, water temperature and calcium content in spring was higher than autumn which is consistent with the results reported in the study of Motesaddi et al. (23). The average amount of PI was found to be 7.33±0.503 in spring and 7.37±0.432 in autumn which appears to indicate corrosive water, but it should also be considered that Puckorius Index is scaling index and is used when water is high in calcium, but low in alkalinity (22). While according to data presented in Table 3, water of Sarayan was low in calcium and high in alkalinity. So, Puckorious Index was not a useful index to calculate water corrosion status in the present research. Similar to the findings of present study, in the study conducted in Manujan city by Ahmadpour et al. (24), the values of RSI and PSI had different behavior compared to LSI values.

Totally, based on this study, water resources of Sarayan were scaling. Scaling is a process in which divalent cations such as calcium and magnesium react with other soluble elements in water and are deposited in the form of a layer in the inner wall of the pipes (25). The most common created layer of scale is from calcium carbonate. Scaling can cause problems including blocked pipes, reduced flow and increased pressure drop in the network that will increase operational costs of water facilities (26, 27).

5. *Conclusion*

According to the obtained results, water of wells and aqueducts in Sarayan was relatively scaling. With respect to the pH level of water, Ryznar and Puckorious Indices were not suitable measures to decide about the corrosion status of water. Considering the negative effects of scale-forming water on pipe diameter, flow rate, and probable economic damages, control measures must be taken to prevent scaling in water resources.

Acknowledgments

Authors appreciate Dr. Parinaz PourSafa, and Dr. HamidReza PourZamani for their guidance and assistance in conducting the research.

Conflicts of interest: none.

Reference

1. Crittenden JC, Trussell RR, Hand DW, Howe KJ, Tchobanoglous G. MWH's water treatment: principles and design: John Wiley & Sons; 2012.
2. Kirmeyer GJ, Logsdon GS. Principles of internal corrosion and corrosion monitoring. U.S. Environmental Protection Agency, Washington, D.C., EPA/600/J-83/355(NTIS PB87115655)
3. WHO. Guidelines for drinking-water quality: World Health Organization; 2004.
4. Casey T. Water stabilisation and corrosion control. 2009.
5. Jafari M, Fallah F, Hassani A. Investigating the Hygiene of Anzali drinking water resources for corrosion and precipitation potentials using corrosion indexes. Journal of Guilan University of Medical Sciences. 2011;20(79):90-6.
6. Mahvi A, Dindarlou K, Ali Jamali H, Alipour V. Corrosion and scaling in Bandar Abbas Pipe water network. Bimonthly Journal of Hormozgan University of Medical Sciences. 2011;14(4):335-40.
7. 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.
8. 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):103-111.doi: 10.5681/hpp.2012.013.eCollection2012.
9. Torres-Lozada P, Bueno-Zabala K, Delgado-Cabrera L, Barba-Ho L, Cruz-Vélez C. Corrosion control using hydroxide and bicarbonate alkalising agents in water drinking processes. Drinking Water Engineering & Science Discussions. 2015;8(1): 53-76.doi: 10.5194/dwesd-8-53-2015.
10. Pirialam, Shams KGA, Shah MM, Farzadkia M. Determination of corrosion and scaling potential in drinking water distribution system of Khorramabad city by corrosion indices and weight loss method. Yafteh. 2008; 10(3): 79-86.
11. Murray WB. A corrosion inhibitor process for domestic water. Journal (American Water Works Association). 1970:659-62.https://doi.org/10.1002/j.1551-8833.1970.tb03986.x
12. Ghaneian M, Ehrampoush M, Ghanizadeh G, Amrollahi M. Survey of corrosion and precipitation potential in dual water distribution system in kharanagh district of yazd province. The Journal of Toloo-e-behdasht. 2008; 7(3):65-72.
13. Shams M, Mohamadi A, Sajadi SA. Evaluation of corrosion and scaling potential of water in rural water supply distribution networks of Tabas, Iran. World Applied Sciences Journal. 2012;17(11):1484-89.
14. 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.
15. 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.
16. Mokhtari S, Aalighadri M, Hazrati S, Sadeghi H, Gharari N, Ghorbani L. Evaluation of corrosion and precipitation potential in Ardebil drinking water distribution system by using Langelier & Ryznar indexes. Journal of health. 2010;1(1):14-23.
17. Federation WE, Association APH. Standard methods for the examination of water and wastewater. American Public Health Association (APHA): Washington, DC, USA. 2005.

18. Amouei A, Fallah H, Asgharnia H, Bour R, Mehdinia M. Evaluation of corrosion and scaling potential of drinking water resources in Noor city (Iran) by using stability indices. Koomesh. 2016; 18(3): 326-33.
19. EPA U. Edition of the drinking water standards and health advisories. US Environmental Protection Agency, Washington, DC, epa. 2006.
20. Dehghani M, Tabatabaii S H: Survey of precipitation and corrosion in water resource and distribution system in shiraz city in 2007, 11 th National Environmental Health Conference, 2008 (Persian).
21. Amouei A, Asgharnia H, Fallah H, Miri S, Momeni H. Evaluating corrosion and scaling potential of drinking water supplies in Juybar, North of Iran. Iranian Journal of Health Sciences. 2017; 5(2): 11-18.
22. Yazdani V, Banejad H, Mirzaee M. Evaluation of groundwater resources of Hamadan Bahar plain in terms of scaling and corrosion. Water Engineering Journal. 2009; 2: 57-68 (Persian).
23. Motesaddi Zarandi S, Paseban A, Atamaleki A, Ahmadabadi M, Yanegh OA, Ghorbanpoor R, Torkanloo H. Corrosion and scaling potential of Bojnurd drinking water. Journal of North Khorasan University. 2014; 6(4): 913-924.
24. Ahmadpur A, Zazooli M, ghaneian M. The survey on potential of corrosion and sedimentation in drinking water distribution network of Manujan city and and its effective factor. Fourteenth National Conference on Environmental Health; Yazd 2012(Persian).
25. Mudali, U.K. and B. Raj, Corrosion Science and Technology: Mechanism, Mitigation and Monitoring. 2008: Alpha Science International.
26. Dąbrowski, W., et al., Calcium carbonate equilibria in water supply systems. Environment Protection Engineering. 2010; 36(2): 75-94.
27. Liang, J., et al., Impact of elevated Ca(2+)/Mg(2+) concentrations of reverse osmosis membrane desalinated seawater on the stability of water pipe materials. Journal of Water Health. 2014; 12(1): 24-33.