Scale Formation and Corrosion of Drinking Water Pipes: A Case Study of Drinking Water Distribution System of Shiraz City

Nima Tavanpour[1], Masoud Noshadi[1] & Navid Tavanpour[2]

[1] Department of Water Engineering, College of Agriculture, Shiraz University, Shiraz, Iran

[2] Department of Water Engineering, College of Agriculture, Shiraz Azad University, Shiraz, Iran

Correspondence: Masoud Noshadi, Department of Water Engineering, College of Agriculture, Shiraz University, Shiraz, Iran. E-mail: esfehani.mohamad3@gmail.com

Abstract

Due to increased consumption of drinking water in the world, there are attempts to apply new solutions for accessing sufficient amounts of water with proper quality. In addition, efficient usage of energy and finding a solution for reducing the scale-related problems in drinking water pipes are among major concerns of urban water supply. Annually, significant budgets are assigned for removing the scale of pipes as well as home and industrial devices. The present study endeavors to examine the scale-formation and corrosion potential of drinking water in drinking water distribution network of Shiraz City (south of Iran). This study is of descriptive type conducted through Langelier, Puckorius, Ryznar, Larson and aggressive indices and taking 144 samples of different sources and points of distribution network. The results showed that the mean values of LI, RI, LS and AI were 0.07 (slightly scale forming), 7.1 (non-scale forming), 1.2 (corrosive) and 14 (non-corrosive), respectively. The mean of scale formation rate value in Shiraz drinking water pipes was 0.26 mm/y. Accordingly, zones located in east, southeast and south of Shiraz have more problems of scale formation. Scale composition of 33 home pipe samples and 8 network pipe samples were analyzed by X-ray diffraction method. Results indicated that main compositions in scale samples were calcium carbonate, calcium sulfate, magnesium carbonate, magnesium sulfate, hematite, maghemite, magnetite, goethite, zinc oxide, gypsum, vivianite, dolomite, hydroxyapatite and troilite. Main elements in scale samples were magnesium, silicon, phosphorus, sulfur, zinc, copper and lead.

Keywords: scale-formation indices, corrosion, scale type, Shiraz

1. Introduction

In most of the cases, the mineral waters and springs used without typical treatment measures include mineral materials but they should lack mineral materials of external origins (3). Because of increased consumption of drinking water in all over the world, there are endeavors to find new solutions for accessing proper amounts of water with good quality. Depending on source, different seasons of the year and the lands over which they flow, these waters have highly varied compounds and diverse amounts of dissolved materials. Along with hardness-causing ions, water may include other cations such as iron, sodium, potassium and different levels of anions such as chloride, sulfate, nitrate, bicarbonate (5). Wherever natural water is used, settling of water scale is one of the major problems. The drinking waters are usually saturated with calcium carbonate (19). Annually, huge numbers are expended for removing the scale of pipes as well as home and industrial devices. Scale formation occurs when water includes large quantities of calcium carbonate which may form lumps on the surfaces. Excessive levels of scale-formation may be disruptive. Scale-formation may cause digestive problems too. In addition, scale formation may reduce the internal diameter of channels of distribution and transfer systems. As a result, the pipe may not have the capacity to transfer the expected amount of water. As a result, one should repair the distribution system or replaces it; both of these options impose high economic expenses (12).

In general, one could point to the following problems or scale formation:

- Water leakage in sliding tapes, generation of stains on external surface of pipes   (10)
- Pressure drop and reduced flow rate of water in pipes
- Bursting of pipes due to excessive pressure applied on them and reduced lifetime of water pipes

-    Clogging of filters and reduced efficiency of pumps

-    Reduced operating efficiency of heating and cooling devices (5)

Ghezavati et al., (2009) analyzed the qualitative parameters of water and corrosion potential of water supply sources for Bandar-Abbas City and Refinery. The results suggested that the parameters of chemical quality of water were in normal ranges with exception of total dissolved solids which was higher than average (7). To determine the corrosion and scale-forming potentials of Ilam City water distribution system, Avaz-pur et al., (2008) used significant scales such as Langelier saturation index, Ryznar stability index, and aggressive index. A comparison of Langelier saturation index and Ryznar stability index for the three rivers supplying dam reservoir water and the outpouring water of the dam to be used in Ilam City, suggests that the water supplied by dam reservoir-which enters the storage tanks and distribution networks for drinking and industrial usages is corrosive (2). Aghapur., et al (2009) examined the water corrosion and scale-forming levels in water transfer and distribution facilities of Urmia. The results suggested that scale formation is related to no. 1 treatment center and corrosiveness of water. It was also suggested that low levels of hardness and high levels of corrosion are associated with increased risk of solution of heavy metals such as lead, cadmium, copper and zinc (1). Hosseini, Shirmardi, Amini and Shafii (2009) examined the chemical and physical characteristics of waters in western and mountainous regions of Iran based on Langelier and Ryznar indices. The results suggest the corrosiveness of water. The Langelier index was in acceptable range and this signified water equilibrium and lack of need for modification of final pH (9). Derosa (1993) studied scale formation in drinking water distribution network of 17 regions of England. The results suggested a significant effect on settlement and accumulation of particles. More scale was found in main pipes with lower diameters that were located in downstream of distribution networks (4). Tang et al (2006) analyzed the internal scale of pipes made of polyvinyl chloride, covered ductile iron, iron-cast without cover and galvanized steel through XRD, RMS and XPS methods. The release of iron in coverless iron-cast pipes reduced as percentage of magnetite increased. It manifested a reduction as percentage of hematite declined. The transfer of dissolved iron and Siderite showed that as alkalinity and pH increased, the amount of iron increased too (25). Peng et al (2010) used x-ray diffraction method to examine the structural and elemental composition of solid materials and mobile scale that were separable from pipes of drinking water distribution networks. The results suggest that among the main elements, iron was the major one. A comparison of relative presence of these elements shows that hydraulic turbulences may impose relatively low effect on release of magnesium, aluminum and zinc but it influences the release of organic carbon, non-organic carbon and magnesium to a higher extent (17). Sarin (2002) analyzed corrosion scale of iron and steel pipes in their structure and composition. As a result, goethite, magnetite and lepidocrocite were identified as the main elements of dried samples. The corrosion scale included a broad shell-like layer that covered porous depots of iron oxide phases. The results of this study suggested that there was a major difference between corrosion scale found in the two different water supply networks (22). Kommineni et al (2008) set out to determine the reason of colored water and to develop strategies for reducing it. This evaluation included tests on iron pipes cut out of distribution network. They found out that alkalinity and acidity posed a significant effect on release on secondary products of corrosion. In addition, certain tests were done on examination of advantages of adding corrosion inhibitors. By addition of Dipotassium Orthophosphate and Tin (II) Chloride, the release of iron was reduced up to 40% (11).

Considering the problems caused by scale-formation in drinking water pipes and lack of relevant studies on drinking water distribution network of Shiraz City, the significance of present study is evident. This research Objectives are: 1- Measurement of scale-formation rate in water pipes of different zones of Shiraz Cityand 2- Analysis of type of scale forming in old water pipes of different zones of Shiraz City.

Indices of Corrosion and Scale-forming Potential of Water

The commonly accepted indices for corrosion and scale-forming are: the Langelier saturation index (LSI), Ryznar stability index (RSI), aggressive index, Puckorius scaling index (PSI), Larson-Skold index (LR), and Aggressive index (AI). The existence of numerous indices show that there is no single and explicit solution for determining the water corrosion and scale-forming. The corrosive tendency of water is a complicated phenomenon the extent of which is not only a function of physical and chemical characteristics of water but also of the water transfer system (14).

Langelier Index

$$LI = pH - pHs \tag{1}$$

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

$$A = (\log[TDS]-1)/10 \tag{3}$$

$$B = -13.12 * (\log(C+273)+34.55) \tag{4}$$

$$C = \log[Ca^{2+} \text{ as } CaCO_3] - 0.4 \tag{5}$$

$$D = \log[\text{Alk as } CaCO_3] \tag{6}$$

Where pHs is the pH of water saturated with calcium carbonate. A is total dissolved solids (mg/L), B refers to temperature (^{o}C), C represents the calcium hardness (mg/L as calcium carbonate), and D is total alkalinity (mg/L as calcium carbonate).

Table 1. Interpretation of Langelier Index

Index Value	Interpretation	Index Value	Interpretation
-5	Severe Corrosion	0	Balanced
-4	Mild Corrosion	0.5	Low Scale-forming
-3	Mild Corrosion	1	Moderate Scale-forming
-2	Mild Corrosion	2	Moderate Scale-forming
-1	Low Corrosion	3	Mean Scale-forming
-0.5	Low Corrosion	4	Severe Scale-forming

The Langelier index only shows the tendency of water to form scale and it cannot be used as a qualitative indicator (14). This index is only conducive to control the calcium carbonate index in systems with low total dissolved solids in not much high temperature ranges. The Langelier index could be more efficiently used in systems with low current speed of water.

Ryznar Stability Index (RI)

Based on the report of scale-forming and corrosion result in urban water distribution network, the Ryznar stability index (RI) could be defined in the following manner:

$$RI = 2\,pH_s - pH \tag{7}$$

Table 2. Interpretation of Ryznar Stability Index

Index Value	Interpretation
RI<5.5	Highly scale-forming
5.5<RI<6.2	Relatively scale-forming and corrosive
6.2<RI<6.8	Balanced
RI>8.5	Corrosive

The Langelier index is more reliable for application on still waters (e.g. water inside tanks and filters) while Ryznar index is experimental and it could only be used for (water inside pipeline) with velocity of about 0.6 m/sec. The obtained results of Ryznar index show that this index is not suitable for the case of water saturation (18).

Larson-Skold Index (LR)

This index was developed by Larson and Skold (1958) for examining the extent of corrosion by water which is exposed to steel pipe lines with light carbonic structure and cast-iron pipes. The equation and interpretation of the index is as follow:

$$LS = \frac{C_{Cl^-} + C_{SO_4^{2-}}}{C_{HCO_3^-} + C_{CO_3^{2-}}}$$ (8)

Where C refers to the concentration of each elements (in mg/L of calcium carbonate).

Table 3. Interpretation of Larson Index

Index Value	Interpretation
LS<0.8	Formation of protective membrane without meditation of chloride and phosphate ions
0.8<LS<1.2	Formation of protective membrane with meditation of chloride and phosphate ions (in cases of high steel corrosion levels)
LS>1.2	Local corrosion

Aggressive Index (AI)

The aggressive index (AI) was developed to contribute to selection of proper pipeline for transfer of water in transfer lines of distribution networks. It is based on water acidity and solubility of calcium carbonate (27). This index is calculated as follow (20).

$$AI = pH + \log[(A)(H)]$$ (9)

Where A is total alkalinity (mg/L as calcium carbonate) and H refers to calcium hardness (mg/L as calcium carbonate).

Table 4. Interpretation of Aggressive Index

Index Value	Interpretation
AI<10	High water corrosion
AI=10-12	Moderate water corrosion
AI>12	Lack of water corrosion

2. Materials and Method

Shiraz City (capital of Fars province in south of Iran) with mean altitude of 1540 m above mean sea level and total area of 10531 km^2 is in the central part of the province. The mean altitude of the city is 1540 m above the sea level. Shiraz lacks permanent road and only a number of dried-up flood channels exist which direct all surficial waters towards Maharloo Lake during raining seasons. About 70 to 80% of the city's demand for water is satisfied through deep wells located in the city and its surrounding highlands and the rest are supplied by DoroodZan Dam.

Sampling of Waters

To examine the condition of corrosion and scale-forming in water-distribution network of Shiraz, 25 samples of water resources and 42 samples of houses in different points of Shiraz were taken. The sampling of waters was done on three occasions during winter, spring and summer of 2010-2011. The sampling of waters was done on three occasions during winter, spring and summer of 2010-2011. Shiraz was divided to 17 zones according to areas covered by each resource (Figure 1).
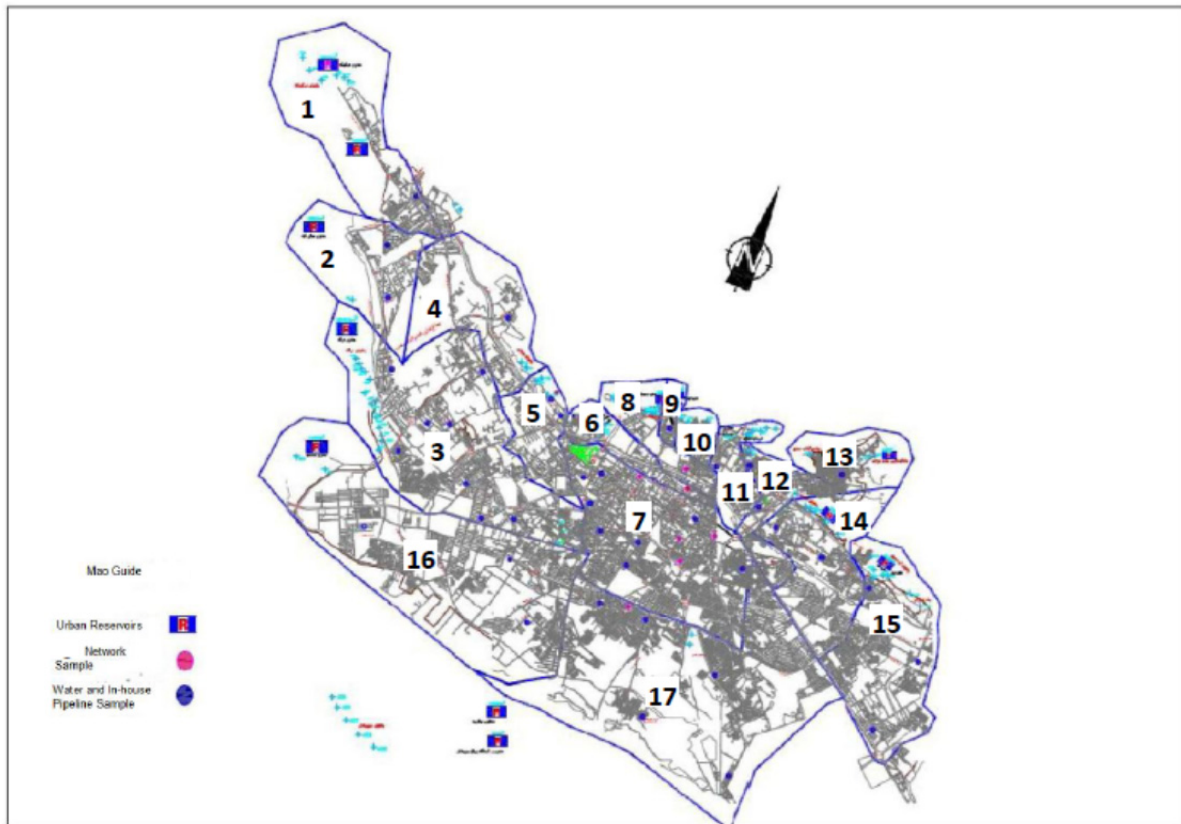
Figure 1. Zoning map of water reservoirs of Shiraz City and Sampling Points

Analysis of Waters

The parameters of acidity (pH meter), temperature (Thermometer; HM Digital, USA), total dissolved solids (TDS meter), and electrical conductivity (EC Meter) were measured in sampling site. In addition, the parameters of total alkalinity, total hardness and concentrations of anions including carbonate, bicarbonate, chloride and sulfate as well as concentrations of cations such as calcium, magnesium, sodium, potassium and iron were measured based on standard methods. It should be noted that the parameter of total dissolved solids was measured in the intended site by portable machine and in the laboratory by determining the remaining dry weight after evaporation). The mean values of these parameters, associated with sampling points in each area, were defined as parameters of each zone. With the help of measured parameters, the Langelier, Ryznar, Larson, Puckorius, and aggressive indices were determined for evaluation of corrosion or water scale-forming.

Scale-formation Rate and Type of Scale

From different regions of Shiraz city, 41 water pipes made of galvanized iron (from homes) and 8 pipes of urban water distribution network were collected to evaluate the thickness and type of scales. To determine the scale-formation rate (a), the following equation was used:

$$\varepsilon = \varepsilon_0 + \alpha.t \tag{10}$$

where ε is secondary diameter of pipe, ε_0 is primary diameter of pipe, a is scale-formation rate and t is time. The lifetime of each sample of home pipe was determined by asking house owners. To analyze the type of scale, the scale of each sample of pipe was removed by grindstone to be turned into powder by a pounder. Then, x-ray diffraction method was used to determine the chemical composition of scale. The x-ray diffraction pattern was analyzed by Xpert Software. The model of x-ray diffraction system used in the present study was D8 Advanced. The x-ray diffraction source in this model was Cu. Furthremore, the intensity of wave was 40 map/40 kv and its wavelength was 1.54 angstrom.

3. Results and Discussion

The values of water of chemical analysis for each zone and the spatial variation of parameters in different zones

were determined by the analysis of variance (ANOVA) (table 5). The statistical analysis showed that the local variations of parameters across different zones were significant at 5% probability level.

Table 5. Values of water chemical analysis of Waters in different Zone

Zone number	Acidity (pH)	Total dissolved solids	Calcium	Magnesium	Sulfate	Chloride	Hardness (as CaCO$_3$)	Alkalinity (as CaCO$_3$)
		………… ……..… mg/L ……………………………………………………………						
1	7.4	375	77	22	49	19	282	220
2	7.7	460	97	26	128	24	355	194
3	7.4	472	95	30	120	25	356	204
4	7.4	520	103	34	146	28	389	221
5	7.3	600	114	39	186	32	440	222
6	7.5	527	108	31	156	28	400	212
7	7.1	706	131	43	223	55	500	223
8	7.2	491	94	33	115	25	370	225
9	7.5	626	107	49	203	39	471	222
10	6.9	719	120	58	216	65	537	260
11	7.1	681	135	40	221	46	501	228
12	7.2	713	134	48	242	65	442	223
13	7.6	437	82	29	96	23	327	206
14	7.05	843	150	51	290	82	586	228
15	7.2	834	145	53	281	88	580	227
16	7.7	440	81	32	107	23	333	198
17	7.3	756	136	48	264	65	538	196
Mean	7.3	600	112	39	179	43	436	218
Max	7.7	843	150	58	290	88	586	260
Min	6.9	375	77	22	49	19	283	194
Standard deviation	0.26	167.1	26.4	11.6	79.5	28.6	107.7	18
P-value	0.004	0	0	0	0	0	0	0
Interpretation	Significant	Significant	Significant	Significant	Significant	Significant	Significant	Significant

Table 6. National Standards of Drinking Water

Parameter	Maximum of Desired Value (mg/L)	Minimum of Desired Value (mg/L)
Total Dissolved Solids	2000	500
Total Hardness (as CaCO3)	500	-
Calcium	200	75
Magnesium	150	-
Zinc	15	5
Chloride	400	200
Sulfate	400	250
Acidity (pH)	6.5-9.2	7-8.5

Chemical parameters

Total Dissolved Solids. The mean total solids dissolved in different zones was between 375 to 843 mg/L. The total amount of dissolved solids in 65% of the zones (i.e. Zones no. 4, 5, 6, 7, 9, 10, 11, 12, 14, 15, 17) is higher than maximum value of desirable level (but less than maximum desirable value). These zones are often located in eastern, southeastern and southern regions of Shiraz.

Acidity (pH). The mean values of water acidity in different zones ranged between 6.9 and 7.1. Maximum and minimum pH values were in zone no.2 and zone no.10 respectively. The values of acidity in all zones were in

desirable and permitted range. Acidity values except zone no.10, were within the acidity range of 7-9.

Alkalinity. The mean value of alkalinity in different zones was between 194 to 228 mg/L. The least alkalinity was associated with zone 2 and the highest was in zone of Central zone 11 and zone 14. Due to the fact that the acidity values in the samples were less than 8, the alkalinity was in the form of bicarbonate. The alkalinity value of less than 30 mg/L, in the form of calcium carbonate, causes water corrosion. If the alkalinity level of higher than 65 mg/L is maintained as calcium carbonate, the extent of corrosion and release of iron decrease. In addition, high alkalinity causes buffer property in water. In other words, acidity changes to a lesser extent. Therefore, the values of alkalinity in drinking water of different parts of Shiraz are high which increases the corrosion inside of water pipes. Indeed, the alkalinity values of higher than 100 mg/L in water samples leads to creation of calcium carbonate which may negatively influence the water taste.

Calcium. The mean values of calcium in water of the zones were between 77 to 150 mg/L. The least and highest values of calcium were associated with zone 1 and zone 15, respectively. The values of calcium in the zones range between maximum extent of desirable value and minimum extent of permissible value. The main origin of calcium in waters is limestone.

Magnesium. The mean values of magnesium in water of the zones were between 22 to 53mg/L. The minimum and maximum values of magnesium were associated with zone 1 and zone 10, respectively. The values of magnesium in the zones were within permitted range. The high concentration of magnesium was undesirable due to scale-forming inside of pipelines. The main origin of magnesium in waters is Dolomite.

Hardness. The mean values of water hardness in the zones were between 282 to 586 mg/L. Therefore, the waters of all zones are categorized in the group of highly hard waters. The least and highest values of hardness were associated with zone 1 and zone 14, respectively. The values of hardness in 35% of the zones (i.e. zones no. 7, 10, 11, 14, 15, and 17) were higher than maximum permissible level. The main factor of water hardness in Shiraz is the water originating from Karst regions. The most frequent type of hardness of water in Shiraz is the temporary or carbonate hardness. It seems that the proper combination of groundwater resources with surface water resources (DoroodZan Dam), with less hardness level, is influential on modification of hardness of water. The high hardness contributes to formation of protective layer of calcium carbonate and inhibits the corrosion of pipes. The excessive hardness increases the extent of scale-formation in pipes and frequency of blockages. As a result, the current transfer potential decreases. The highest level of hardness of water in Shiraz city is temporary or carbonate type (Tootoonchi, A., N. Naseri., and R. Sarkhoshiyan, 2003).

Sulfate. The mean values of sulfate in different zones were between 49 to 290 mg/L. The minimum and maximum of sulfate concentration were associated with zone 1 and zone 14, respectively. The values of sulfate in zones 14, 15, and 17 were higher than maximum desirable value. These zones are located in eastern, southeastern and southern areas of Shiraz City.

Chloride. The mean values of chloride in different zones were between 19-88 mg/L. The least and highest values of chloride were associated with zone 1 and zone 15, respectively. The values of chloride in all zones were in permissible and desirable range. Chloride is the most active and corrosive ion.

Corrosion and scale-forming indices. Considering the values of measured above parameters for different zones, the indices of corrosion and scale-formation were calculated and spatial variations of indices values in different zones were determined the analysis of variance (ANOVA) (Table 7). The statistical analysis showed that variation of all indices except Ryznar index were not significant across different zones at 5% level of probability.

Table 7. Values of Langelier, Ryznar, Larson and Aggressive Indices of different Zones

Zone number	Langelier index value	Langelier index Interpretation	Ryznar index value	Ryznar index Interpretation	Larson index value	Larson index Interpretation	Aggressive index value	Aggressive index Interpretation
1	0.12	Low Scale-forming	7.4	Lack of Scale-forming	0.27	Scale-former	13.94	Non-corrosive
2	0.42	Low Scale-forming	6.9	Lack of Scale-forming	0.83	Probable Corrosion	14.27	Non-corrosive
3	0.05	Low Scale-forming	7.33	Lack of Scale-forming	0.76	Scale-former	13.97	Non-corrosive
4	0.24	Low Scale-forming	6.93	Lack of Scale-forming	1.03	Probable Corrosion	14.06	Non-corrosive
5	0.18	Low	6.95	Lack of	1.03	Probable	14.01	Non-corrosive

		Scale-forming		Scale-forming		Corrosion		
6	0.17	Low Scale-forming	7.2	Lack of Scale-forming	0.96	Probable Corrosion	14.05	Non-corrosive
7	-0.07	Low Corrosion	7.2	Lack of Scale-forming	1.39	Corrosive	13.82	Non-corrosive
8	-0.08	Low Corrosion	7.4	Lack of Scale-forming	0.7	Scale-former	13.84	Non-corrosive
9	0.24	Low Scale-forming	6.97	Lack of Scale-forming	1.20	Corrosive	14.18	Non-corrosive
10	-0.27	Low Corrosion	7.45	Lack of Scale-forming	1.15	Corrosive	13.73	Non-corrosive
11	-0.1	Low Corrosion	7.3	Lack of Scale-forming	1.28	Corrosive	13.87	Non-corrosive
12	0.04	Low Scale-forming	7.08	Lack of Scale-forming	1.54	Corrosive	13.97	Non-corrosive
13	0.27	Low Scale-forming	7.02	Lack of Scale-forming	0.68	Scale-forming	14.05	Non-corrosive
14	-0.06	Low Corrosion	7.16	Lack of Scale-forming	1.82	Corrosive	13.88	Non-corrosive
15	0.06	Low Scale-forming	7.15	Lack of Scale-forming	1.77	Corrosive	13.95	Non-corrosive
16	0.24	Low Scale-forming	7.18	Lack of Scale-forming	0.67	Scale-former	14.17	Non-corrosive
17	0.2	Low Scale-forming	6.92	Lack of Scale-forming	1.66	Corrosive	14.1	Non-corrosive
Mean	0.08	-	7.15	-	1.1	-	14	-
Max	0.42	-	7.45	-	1.82	-	14.27	-
Min	-0.27	-	6.9	-	0.27	-	13.73	
Standard deviation	0.2	-	0.26	-	0.49	-	0.17	-
P-value	0.504	Insignificant	0.447	Insignificant	0	significant	0.477	Insignificant

Role of Indices in Zones of Shiraz

Langelier and Ryznar Indices. The Langelier index values in all zones ranged between -0.27 to 0.42. In this regard the least amount obtained (most corrosive) is related to Babakoohi wells (Zone 10) while the highest value obtained (most scale-forming) is related to Maali-Abad reservoir (Zone 2). The Ryznar index values in all zones were in the range of 6.9 to 7.45. The least (most scale-forming) and highest values of this index were associated with Maali-Abad reservoir and Babakoohi wells (Zone 10). The Langelier index was close to equilibrium in all zones. The Ryznar index for all zones showed lack of scale-forming. Considering the fact that the Langelier index only represents the tendency of water to form scale or to corrosion, it cannot be used as an index for quantitative measurement of corrosion or scale-forming. On the other hand, this index is preferably used for still waters and for controlling formation of calcium carbonate scale in waters with low level of total dissolved solids (TDS) and in this study, TDS is not in low level range. Therefore, it is recommended that Langelier and Ryznar indices should be simultaneously used for more precise prediction and decision-making. Because the value of Ryzner index for all water resources was not more than 6, the waters tend towards corrosion and the thin layer does not form or cannot protect the internal wall of the tubes. On the

Larson Index. The Larson index values in all zones ranged from 0.27 to 1.82. The minimum value of the index (i.e. most scale-forming) was related to Dokoohak wells (Zone 1) and the maximum value (i.e. most corrosive) belonged to Sorsore reservoir (Zone 14). This index is associated with corrosion of steel and iron-cast pipes. Based on the index, there is a tendency toward corrosion in most of the zones.

Aggressive Index. The mean values of aggressive index in all zones ranged from 13.73 to 14.27. The minimum and maximum values of the index were related to Babakoohi wells (Zone 10) and Maali Abad Reservoir (Zone 2), respectively. The aggressive index is specific to asbestos-cement pipes which are used in some parts of distribution network pipes. Based on this index, the waters were not corrosive to asbestos-cement pipes in all zones.

Table 8. Rates of Scale-formation of Zones

Number of Zone	Source	Mean Rate of Scale-forming (mm/year)
1	Do-Kohak wells	0.18
2	Maali-Abad reservoir	0.17
3	Derak reservoir	0.13
4	Chamran wells	0.19
5	Chamran and Chogia wells	0.3
6	Abivardi reservoir	0.19
7	Namazi treatment plant	0.28
8	Dare-Chenari reservoir	0.28
9	Sheikh Agha reservoir	0.34
10	Baba-Koohi wells	-
11	Central storage (Anbar Markazi) reservoir	0.29
12	Haft-Tanan wells	0.3
13	Kharame reservoir	0.25
14	Sorsore reservoir	0.38
15	Golha reservoir and wells of Nasr Boulevard	0.41
16	Mohammadieh reservoir	0.26
17	Sabz-Poshan reservoir	0.34
Mean	---	0.26
Max	---	0.41
Min	---	0.13

Analysis of Scale-forming Rate in Zones

The most significant factors affecting the scale-forming rate are hardness, acidity, alkalinity, pressure and values of chloride and sulfate. The increase in the extent of hardness, acidity, alkalinity and pressure leads to increase in the rate of scale-forming. The anions of chloride and sulfate are corrosive and their increased amounts in water leads to decreased rate of scale-forming. The least rate of scale-forming is associated with Derak reservoir (Zone 3) and the highest value of scale-forming rate was observed in Golha reservoir and wells of Nasr boulevard (Zone 15). It should be noted that the zone of Dokoohak wells (Zone 1) had mean scale-forming rate despite of lowest level of hardness. This is probably due to high water pressure as well as high corrosion rate. As a result, more corrosion products were found in the zone. Probably, the main factor underlying the highest scale-forming rate of Golha reservoir (Zone 3) is significantly high level of hardness in this zone. In general, the rate of scale-formation in drinking water pipes of the houses in Shiraz is 0.26 mm per year
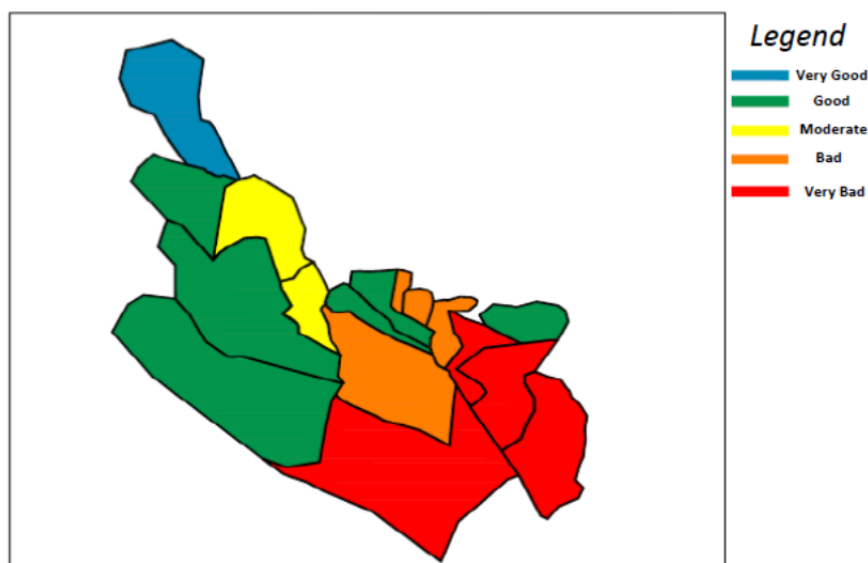

Figure 2. Atlas of water quality in different zones of Shieaz city

Interpretation of Scale Type Analyses

The presence of goethite and magnetite in most of the formed scale represent a shell-like layer in them. The phases of iron-oxide, calcium carbonate and magnesium carbonate were found in most of the formed scale and lepidocrocite was found in some of them. In addition, the presence of goethite, magnetite and magnemite in most of the formed scale imply the presence of oxygen in waters. Alongside, Siderite was found in a limited number of samples.

Iron

As a result of scale analysis, iron was rarely found in the samples in its elemental form. It was often present in oxide, hydroxide and complex forms such as goethite, magnetite, and magnemite among many others.

Calcium. The presence of calcium in scale samples was due to its natural inclusion in regional water. It was the result of deposition and decomposition of calcite, dolomite, hydroxyapatite and gypsum ($CaSO_4.2H_2O$). These mineral materials were present in most of the samples.

Manganese. The presence of manganese in scale samples is probably due to their natural inclusion in waters and settlement of oxide and magnesium hydroxide in water.

Magnesium. It seems that presence of magnesium in scale samples is due to formation and decomposition of mineral materials such as dolomite ($CaMg(CO_3)_2$). This compound was found in most of the samples.

Calcium Carbonate. In all of the samples, calcium carbonate was present because these waters are excessively hard and rich with calcium and bicarbonate. Among these phases, calcium is thermodynamically the most suitable phase in temperature and pressure of the environment. During settlement from pure calcium bicarbonate, it is the dominant phase. Aragonite and vaterite are kinesthetically similar and they may appear as the first forms. They also may turn into calcite as time passes. Calcite usually deposits in room temperature and in most of the samples, one could find calcite phase. In majority of samples, vaterite phase also existed. Because aragonite often deposits when temperature is higher than 65 °C, this type of phase was not identified in the sample.

Type of Hardness. In most of the water samples, the concentration of bicarbonate ion was higher than sulfate and chloride ions. In addition, the analysis of scale samples through x-ray diffraction method showed that carbonate compounds of calcium and magnesium ions are more than their non-carbonate compounds. Therefore, the most frequent type of hardness in waters of Shiraz city is temporary one.

Phosphorus. The presence of phosphorus in scale samples may be associated with formation of hydroxyapatite, accumulation of phosphate in biofilm and cellular materials. The accumulation of phosphorus in scale-forms demands the presence of phosphorus in treated water.

Sulfur. The presence of sulfur in scale samples is probably due to existence of troilite which is a typical component in iron corrosion deposit sub-layer. The results of x-ray diffraction analysis refer to presence of this compound in the samples.

Silica. Silica was present in almost all of the scale samples.

Aluminum. The detection of aluminum in scale samples could be attributed to its natural presence in water, deposition of alumina and aluminum hydroxide along with formation of aluminosilicates. In addition, aluminum may have entered the cement coatings through separation.

Zinc. The underlying reason for presence of zinc in samples may be their natural presence in source water and corrosion of galvanized iron pipes.

Lead. Lead was present in most of the scale samples. The detection of lead in scale samples might be due to its natural presence in source water or corrosion of brass fittings of water piping systems.

Cadmium and Arsenic. The source of cadmium and arsenic is their natural presence in water sources or corrosion of galvanized pipes.

4. Conclusion

The showed that the mean value of Langelier, Ryznar, Puckorius, Larson, and aggressive indices in water distribution network of Shiraz city were respectively 0.07 (low scale-formation), 7.12 (lack of scale-formation), 6.67 (corrosive), 1.2 (corrosive) and 13.96 (non-corrosive). Based on Langelier index, 71% of waters in studied zones were scale-forming. Based on Ryzner index, all of the zones lacked the characteristic of scale-formation. Based on Larson index for iron-cast and steel pipes, 29% of zones are scale-forming, 23% are probably corrosive and 48% of them are corrosive. Based on aggressive index, none of the zones are corrosive for asbestos-cement pipes. The highest rate of scale-formation was associated with Zone 15 (Golha reservoir) and

the least value of the index belonged to Zone 3 (Derak reservoir). In general, the rate of scale-formation in drinking water pipes of the houses in Shiraz is 0.26 mm per year. The zones located in eastern, south-eastern and southern zones of water distribution network have more problems in regard to scale-formation while northern and northwestern zones had the best conditions in regard to scale-formation. In general, certain arrangements should be made to put the water resources in relatively balanced conditions and to create a proper membrane of calcium carbonate on the interior layer of pipes for protecting them against corrosion. On the other hand, the conditions should be modified in a way that excessive scale-formation of waters and consequent reduction of transportation capacity are prevented. Results indicated that main compositions in scale samples were calcium carbonate, calcium sulfate, magnesium carbonate, magnesium sulfate, hematite, maghemite, magnetite, goethite, zinc oxide, gypsum, vivianite, dolomite, hydroxyapatite and troilite. Main elements in scale samples were magnesium, silicon, phosphorus, sulfur, zinc, copper and lead.

Refrences

Aghapur, A. A., & Mohamadi Boini, A. (2009). The study of corrosion and scale-formation of output water of no.1 treatment center of Urmia City. *Twelfth National Conference of Environmental Safety,* 16.

Avaz-pur, M., Gholami, M., & Ali, R. (2008). The study of corrosion and scale-formation potential or drinking water resources of Ilam Town, Zahedan, Sistan and Baluchesta. *Eleventh National Conference of Environmental Health*, 10-15.

Badlians Gholi Kandi, G. (2003). *Chemistry of water.* Tehran, Tehran: Norpardazan Press, 1(1-21; 191-215).

Derosa, S. (1993). Loose deposits in water mains. Department of the Environment, London. Drinking Water Inspectorate, Report No. DoE 3118-/2, WRc plc, Swindon.

Dobersek, D., & Goricanec, D. (2007). Influence of water scale on thermal flow losses of domestic appliances. *International journal of mathematical models and methods in applied sciences, 1*(2), 55-61

Dobersek, D., Goricanec., D., & Krope, J. (2005). Economic analysis of energy savings by using rotary heat regenerator in ventilating systems. *IASME Trans,* (4), 1640-1647.

Ghezavati, M., Noshadi, M., & Marandi, R. (2009). The study of chemical quality and corrosion potential of drinking waters produced in Bandar Abbas Refinery. *Second National Conference of Environmental Health in Iran*. Shahid Beheshti University of Medial Sciences, 735-753.

Greenberg, A. E., Clesceri, L. S., & Eaton, A. D. (2005). Standard methods for the examination of water and wastewater (20th ed.). APHA, Washington, DC, pp.180-266.

Hosseini, H., Shirmardi, M., Amini, J., & Shafii, S. (2009). The study of corrosion and scale-formation indices of drinking water of western regions of country: A case study of Javanrood Town. *National Conference of Environmental Health*, 789-795.

Kemmer, E. (1979). The NALCO water handbook. McGraw-Hill, New York, pp.13-14.

Kommineni, S., Mishra, D., & Macphee, M. (2008). Colored water cauces and control strategies-pilot test experiences of a U.S water provider. *Water practice & technology, 3*(3), 1-7.

Legrand, L., & Larvi, P. (1999). *Inhibition of corrosion and formation of hard scale in water supply networks*. In Horfar, A (Trans). Tehran University Press, 1-312.

Lippmann, F. (1973). Sedimentary Carbonate Minerals. Springer, New York, pp.62-85.

McNeill, L. S., & Edwards, M. (2001). Review of iron pipe corrosion in drinking water distribution systems. *Journal of AWWA, 93*(7), 88-100.

Nikpur, B. (2006). *The study of quality of drinking water of Behshahr City from perspective of corrosion and scale formation.* M. sc. Dissertation of Technical-Engineering Department. Azad University of Bandar Abbas, 116.

Peng, C., Korshin, G. V., & Valentine, R. L. (2010). Characterization of elemental and structural composition of corrosion scales and deposits formed in drinking water distribution systems. *Water research, 44,* 4570-4580.

Pishmazi, A. (1999). *The role of water and corrosion control in industries through analysis of corrosion samples.* Isfahan, Isfahan: Arkan Publication, 1(480-516).

Prisyazhniuk, A. V. (2007). Prognosticating scale-forming properties of water. *Applied thermal engineering, 27*(8), 1637-1641.

Reddy, M. M., & Nancollas, G. H. (1971). Crystalization of calcium carbonate, Isotopic exchange and kinetics.

Journal of colloid and interface science, *36*(2), 166-172

Rossum, J. R. (1980). Fundamentals of metallic corrosion in fresh water. Report prepared for Roscoe moss compony, Los Angeles, CA: 1-12.

Rossum, J. R., & Merrill, D. T. (1983). An evaluation of the calcium carbonate saturation index. *Journal of AWWA, 75*(2), 95-100.

Sarin, P. (2002). Iron release from corrosion scales in old iron/steel/drinking water distribution pipes. PHD thesis. The graduate college of the university of Illinois at Urbana-champaign, p.158.

Seyyed Razi, M. (1996). Corrosion Control in Industries.Corrosion Association of Iran, pp.46-78.

Singley, J. E., Beaudet, B. A., & Markey, P. H. (1984). Corrosion manual for internal corrosion of water distribution systems. Environmetal sience and engineering.Inc, pp.1-67.

Tang, Z., Hong, S., Xiao, W., & Taylo, J. (2006). Characteristics of iron corrosion scales established under blending of ground, surface and saline waters and their impacts on iron release in the pipe distribution system. *Corrosion science, 48*, 322-342.

Tootoonchi, A., Naseri, N., & Sarkhoshiyan, R. (2003). Shiraz water supply and wastewater collection and disposal. Report of Iranab consulting engineering corporation, 1-37.

Von Huben, H. (1995). Water treatment principles & practices of water supply operations. Second Edition. AWWA, pp.36-72.

Copyrights