UMSHA Press

AJEHE
Avicenna Journal of Environmental Health Engineering
Avicenna J Environ Health Eng, 2024; 11(1):19-26. doi:10.34172/ajehe.5374
http://ajehe.umsha.ac.ir

Original Article

# Evaluating the Effects of Polyphosphate Cartridge at Point-of-Entry on Scaling and Corrosion Indices of Household Water

**Fatemeh Mortezazadeh[1], Fathollah Gholami-Borujeni[2*]**

[1]Student Research Committee, Faculty of Health, Mazandaran University of Medical Sciences, Sari, Iran
[2]Department of Environmental Health Engineering, Health Sciences Research Center, Mazandaran University of Medical Sciences, Sari, Iran

**Article history:**
**Received:** December 26, 2023
**Revised:** April 24, 2024
**Accepted:** May 3, 2024
**ePublished:** May 15, 2024

***Corresponding author:**
Fathollah Gholami-Borujeni,
Email: gholami_b_f@yahoo.com

**Abstract**
Scaling and corrosion are significant issues in water distribution systems that can lead to economic, aesthetic, and health concerns. This study aimed to investigate the effects of a point-of-entry (POE) polyphosphate cartridge on scaling and corrosion indices (Langelier Saturation Index [LSI], Ryznar Stability Index [RSI], Puckorius Scaling Index [PSI] and Aggressive Index [AI]), as well as the quality of water treated with household water treatment systems. In this study, a POE polyphosphate cartridge was directly connected to municipal water to adjust water stability and prevent scaling and corrosion. Parameters were tested in water samples before and after filtration with the POE polyphosphate cartridge. Spearman's correlation analysis was conducted to determine any monotonic relationship between the variables using SPSS. It was observed that water exhibited scaling properties at flow rates of 0.180, 0.252, and 0.522 L/min based on the LSI, while in other cases, it showed corrosion properties. Additionally, the results of the Spearman analysis indicated a strong positive correlation ($r$ = 0.74) between RSI and PSI and a strong negative correlation ($r$ = -0.64) between LSI and RSI in the outlet water from the POE polyphosphate cartridge. The results indicated that more precise control of key quality parameters for scaling and corrosion of water is essential. Significant adjustments must be implemented to prevent corrosion of facilities and valves when utilizing a POE polyphosphate cartridge in household water systems. Moreover, due to the fluctuations in household water consumption, the use of inline POE polyphosphate cartridges may not ensure water stability in the household water supply system.
**Keywords:** Point-of-entry, Polyphosphate filter, Corrosion, Scaling, Water stability

**Please cite this article as follows:** Mortezazadeh F, Gholami-Borujeni F. Evaluating the effects of polyphosphate cartridge at point-of-entry on scaling and corrosion indices of household water. Avicenna J Environ Health Eng. 2024; 11(1):19-26. doi:10.34172/ajehe.5374

## 1. Introduction

Access to safe drinking water is a key factor in maintaining and promoting community health. One of the most important measures for assessing water quality is to determine scaling and corrosion indices (1-3). According to the World Health Organization (WHO) guidelines, drinking water must be free of organisms and chemicals that pose a risk to human health. Waterborne diseases are among the most common infectious diseases and are considered one of the greatest health threats worldwide, accounting for 70% to 80% of health problems in developing countries. Additionally, more than 80% of infectious diseases worldwide are caused by contaminated drinking water (4-6). Point-of-entry (POE) and Point-of-use (POU) household water treatment systems are utilized to enhance the safety and quality of drinking water. However, the use of these devices depends on the quality of raw water, the availability of materials or equipment, and the education level of individuals (4, 7). Improper use and operation of these water treatment devices at the point of use can result in issues such as biofilm formation or decline in water quality (8). Scaling and corrosion are major problems in water distribution systems that can lead to economic, aesthetic, health, and hydraulic problems. Corrosive water can react with household plumbing fixtures and metal appliances, causing damage to pipes. Consuming water with high levels of toxic metals, such as lead and copper, has been associated with both acute and chronic health problems. Additionally, the taste and smell of water can also be negatively affected (9). Corrosion is an electrochemical interaction process between water and pipeline walls that gradually deteriorates the inner surfaces of metal pipes, eventually dissolving minerals and metals from corroding pipes (10). Corrosion occurs as a result of physical and chemical reactions between materials and their environment, leading to changes in material properties (11, 12). One of the effects of corrosion, which has been mainly considered in domestic and industrial fields, is the damage to water devices and distribution networks. The use of groundwater treated with improper methods increases the effects of scaling and corrosion, posing a threat to the supply of safe drinking water (10). There has been an increase in secondary pollutants in drinking water, such as increased concentrations of iron, zinc, copper, and manganese, which exceed the standards for drinking water (13). Indicators used in water supply networks include the Ryznar Stability Index (RSI), Langelier Saturation Index (LSI), Aggressive Index (AI(, Larson–Skold (LS), Puckorius Scaling Index (PSI), and Chloride Sulfate Mass Ratio (CSMR) (14). The corrosion of water distribution systems can lead to significant annual resource costs for system repairs, replacements, and maintenance. Pipes with corrosion defects are prone to microbial contamination and increased concentrations of water metals such as iron, zinc, copper, manganese, lead, selenium, and arsenic, which can lead to consumer complaints due to odor and taste in addition to endangering human health (15). Furthermore, the scaling process can result in issues such as pipe clogging, decreased water drainage, and pressure within distribution networks, as well as high operating and maintenance costs (16). The study of water distribution networks in Iran shows that approximately 30% of water is wasted due to leakage caused by corrosion. In countries such as Australia and Japan, the annual cost of corrosion is estimated to be 3% to 4% of the gross domestic product (GDP). A study conducted by the Federal Highway Administration (FHWA) reported that the cost of corrosion in US public water systems is $22 billion per year, which includes 3.1% of GDP (17). Scaling plays an important role in the development of gastrointestinal diseases. Studies have shown that corrosion by-products from the inner surface of pipes can accumulate or deposit in distribution networks, thereby protecting microorganisms from the effects of disinfectants (13). Various research studies have been conducted on water scaling and corrosion potential. Egbueri (18) noted that although values of Ca, Cl, $HCO_3^-$, $SO_4$, total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), and Zn were below their respective maximum allowable limits for drinking water, and contamination with Fe and Pb was observed in some samples. Moreover, CSMR, Revelle index, LS, RSI, LSI, AI, and PSI showed low to insignificant scaling potentials in the majority of the samples. In another study, Egbueri et al (19) stated that the industrial water quality assessment indicated that natural waters have a greater tendency towards corrosion than towards scaling. The corrosion and scaling indices revealed that natural waters are highly corrosive, posing a risk of damage to domestic, irrigation, and industrial water distribution systems. Derakhshannia et al (20) stated that river water has a negative LSI and a high RSI during a specific period, indicating high acidity that can lead to damage and decay in marine structures, particularly in areas with low pH levels. Yousefi et al (13) stated that the water resources in Ilam city were corrosive, emphasizing the need for water quality management and the replacement of distribution pipes in the water network. Kurdi et al (11) also investigated the chemical quality and sensitivity of corrosion indices in the Qareh Sou basin. They stated that, according to LSI, RSI, and PSI values, the Qareh Sou basin could be considered corrosive. It is possible to effectively disinfect and limit bacteria regrowth in the distribution system through effective corrosion control along with high organic matter removal during water treatment (21). Polyphosphates form stable complexes with many metals and are useful in preventing scaling caused by the oxidation of iron and calcium carbonate (22). However, phosphate species can also support the growth of bacteria, facilitating the accumulation of biofilm biomass (23). Polyphosphates are effective in the separation of iron, manganese, and alkaline earth metals like calcium and magnesium. They can dissolve mineral deposits already present in water, increasing the carrying capacity of the water system, softening the water, and reducing detergent consumption (24). Installing a POE water treatment system on the water supply lines ahead of water taps can be a solution to deal with water quality degradation that may occur in the distribution system (25, 26). Therefore, considering the characteristics of healthy water from physical, chemical, and biological aspects is important for maintaining human health and sustainable development. Therefore, this study aimed to investigate the effect of POE polyphosphate cartridge on scaling and corrosion indices (LSI, RSI, PSI, and AI) and the quality of water treated with household water treatment systems.

## 2. Materials and Methods

### *2.1. POE Polyphosphate Cartridge*

Scaling causes several problems for household water supply system installations. A commonly used commercial method for scaling control is the addition of chemical additives at very low concentrations (0.5 to 20 ppm). Many additive formulations are commercially available. Commonly used antiscalants include condensed polyphosphates, organophosphates, and polyelectrolytes. One of the most common methods of controlling water scaling in household water supply systems is the use of POE polyphosphate cartridges. In this study, a widely used POE polyphosphate cartridge was utilized (Fig. 1).

**Fig. 1.** The Most Commonly Used POE Polyphosphate Cartridge

This water filter was made by Atlas Filtri, Italy. The filter housings were made of polyethylene terephthalate (PET), with a head/ring nut made of reinforced polypropylene. The maximum working pressure was 8 bar (116 psi), the maximum working temperature was 35 °C (95 °F), and the minimum working temperature was 4 °C (39.2 °F) (27). The mechanism of these filters was to prevent the formation of calcium and magnesium deposits by dissolving a small amount of polyphosphate crystals in water. The volume of this filter was 154 mL and the diameter of its inlet and outlet was 0.5 inches. It was installed on the urban water supply system, as shown in Fig. 2. The quality parameters of water from the inlet and outlet of the filter were investigated at different flow rates.

### 2.2. Experimental Methods

In this experimental study, a POE polyphosphate cartridge was directly connected to the Sari (the capital of Mazandaran province) municipal water system to balance the quality parameters of drinking water, including calcium and bicarbonate ($HCO_3^-$) concentration, TDS, total alkalinity (TA), pH, turbidity, and EC. These selected parameters provide insight into the quality, purity, and physicochemical characteristics of the water.

Temperature, pH, EC, and turbidity were measured at the sampling site using the following instruments: digital thermometer (AQUALUTIC SensoDirect con 200), pH meter (EUTECH Instruments PH 5500), EC meter (AQUALUTIC SensoDirect con 200), and turbidity meter (HACH 2100P Turbidimeter).

TDS (2540 C. Total Dissolved Solids Dried at 180 °C), total phosphorus (4500-P D Stannous Chloride Method), TH (2340 C. EDTA Titrimetric Method), calcium hardness (CH) (3500-Ca B. EDTA Titrimetric Method), and TA (2320 B. Titration Method) were measured following the standard methods for the examination of water and wastewater (28).

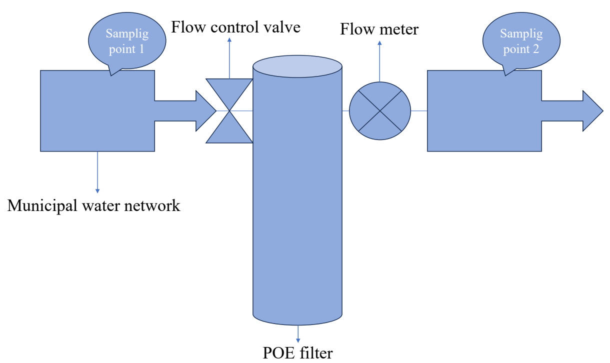


**Fig. 2.** POE Polyphosphate Cartridge and the Sampling Points

### 2.3. Determination of Water Quality

The scaling and corrosion indices (Table 1) were investigated by examining the impact of various parameters such as flow rate and retention time.

### 2.4. Samples Collection

Water samples were collected from a municipal water distribution network (Payambar Azam Academic Complex at Mazandaran University of Medical Sciences, Sari, Iran), which was supplied from groundwater. Before each sampling, the tap was wiped with a cloth to remove any possible dirt. The tap was then turned on to let the water run at the maximum flow rate for one minute. After washing the sample collection bottle twice with the collected water, samples were gathered in 500 mL sterile plastic bottles for doing the experiments mentioned above and were tested within 30 minutes of sampling. All parameters in the water samples were tested both before and after filtration with the POE polyphosphate cartridge at 5 different flow rates (Fig. 2). The samples were tested in triplicate at various flow rates, and the mean values of the test results were recorded. Fig. 2 displays the POE polyphosphate cartridge and the sampling valves, both before and after filtration.

### 2.5. Statistical Analysis

Descriptive parameters including minimum, maximum,

**Table 1.** Water Stability Indices for Scaling and Corrosion Potential

| Index | Index formula | Water condition based on index value |
|---|---|---|
| LSI | $LSI = pH^a - pH_s^b$<br>$pHs = (9.3 + A + B) - (C + D)$<br>$A = (Log10\ (TDS) - 1)/10$<br>$B = -13.12 \times Log_{10}(T + 273) + 34.55$<br>$C = Log_{10}\ (Ca^{2+c})\ -0.4$<br>$D = Log_{10}\ (Alk^d)$ | LI < 0: Water is not saturated and has a tendency to corrode.<br>LI = 0: Water is stable and does not tend to be scaling.<br>LI > 0: Water is fully saturated and has a scaling effect. |
| RSI | $RI = 2pH_s - pH$ | RI < 5.5: Water has a strong scaling ability.<br>5.5 < RI < 6.2: Water has scaling propensity.<br>6.2 < RI < 6.8: Water is safe and does not tend to be scaling or corrosive.<br>6.8 < RI < 8.5: Water has a corrosive propensity.<br>RI > 8.5: Water has a high corrosive tendency. |
| PSI | $PI = 2pH_s - pH_{eq}^e$<br>$pH_{eq} = 1.465 \times Log_{10}(Alk) + 4.54$ | PI < 6: Water has scaling tendency.<br>6 < PI < 7: Water has less scaling and corrosive tendency.<br>PI > 7: Water has a greater corrosive capability. |
| AI | $AI = pH + Log_{10}\ (Alk \times Ca^{2+})$ | AI < 10: Water has a corrosion potential.<br>10 ≤ AI ≤ 12: Water is moderately corrosive.<br>AI > 12: Water has scaling potential and is non-aggressive. |

[a] = actual pH of water; [b] = pH at saturation state of $CaCO_3$; [c] = CH (mg/L as $CaCO_3$); [d] = alkalinity (mg/L as $CaCO_3$); [e] = pH at equilibrium.

mean, and standard deviation (SD) were used to describe the data. The calculations for indices were conducted in Microsoft Excel (2010). Spearman's correlation analysis was used to measure the strength and direction of a monotonic relationship between the two variables in SPSS version 24.0 (IBM SPSS Statistics for Windows). All statistical tests were performed at 95% and 99% confidence intervals. This correlation test evaluated the interrelationships between quality parameters, ionic complexes, and similarities within the indices for corrosion and scaling abilities of water.

## 3. Results and Discussion

### 3.1. Water Quality Analysis

This study aimed to assess the impact of a POE polyphosphate cartridge on scaling and corrosion indices in household water by analyzing LSI, RSI, PSI, and AI. Since water quality significantly influences drinking water consumption, parameters such as temperature, pH, TDS, calcium concentration, TA, and other relevant water quality parameters were measured both before and after filtration with the POE polyphosphate cartridge.

The minimum, maximum, mean, and SD values of the physicochemical properties of the inlet and outlet water (at 5 different flow rates) of the POE polyphosphate cartridge were measured and are presented separately in Table 2. The mean temperature was 24 °C in the inlet water and 23.27 °C in the outlet water. Additionally, the pH, turbidity, and hardness decreased in the outlet water. The remaining parameters are shown in Table 2.

Physicochemical parameters such as pH, total dissolved solids, temperature, and EC play crucial roles in determining the acceptability and usability of drinking water for recreational and domestic purposes (29). Fluctuations in water temperature within distribution networks can impact water stability (30). Temperature is an essential parameter for drinking water as it can impact the taste, odor, color, and so on. According to Table 3, the mean temperature before filtration with the POE polyphosphate cartridge decreased from 24 ± 1.80 ˚C to 23.27 ± 2 ˚C. The results showed that as the water temperature increased, the tendency towards scaling also accelerated, which is consistent with the results of studies conducted by Mirzabeygi et al (30) and Shams et al (31). In their research, they observed an increase in LSI and RSI, as well as a decrease in PSI.

Although minor variations in pH have little or no direct impact on water consumers, it is one of the most important operational parameters (32). Table 3 shows the recorded pH values before and after the POE polyphosphate cartridge, following the WHO guidelines for drinking water (33). This indicates that the POE polyphosphate cartridge does not significantly alter the pH values of the water. Turbidity, a measure of the ability of water to absorb or scatter light, is caused by the presence of particulate matter in water such as clay, silt, colloidal particles, plankton, and other microscopic organisms (34). The turbidity of the sample after filtration with the POE polyphosphate cartridge was measured to be 0.92 ± 0.15 NTU, which was in accordance with WHO guidelines for drinking water. The TA of water, determined by the levels of $CO_3^{2-}$, $HCO_3^-$, and hydroxide, is a measure of the acid-neutralizing ability of water (29, 35). The values of TA in the outlet water ranged from 274 to 306 mg/L $CaCO_3$, with a mean value of 289.86 ± 34.11 as shown in Table 2, which met the WHO guidelines range (33). TH, known as the ability of water to form insoluble complexes with calcium and magnesium ions in water, is the sum of carbonate

**Table 2.** Evaluation of Water Quality Parameters (before and after Filtration)

| Parameters | Before Filtration (n = 30) | | | | After Filtration (n = 30) | | | |
|---|---|---|---|---|---|---|---|---|
| | Min[a] | Max[b] | Mean | SD | Min | Max | Mean | SD |
| Temperature (°C) | 22 | 26 | 24 | 1.80 | 18.70 | 26.40 | 23.27 | 2 |
| pH | 7.40 | 7.65 | 7.50 | 0.10 | 7.04 | 7.59 | 7.30 | 0.18 |
| EC (μs/cm) | 685 | 714 | 694 | 13.70 | 689 | 822 | 768.86 | 34.11 |
| Turbidity (NTU) | 3.33 | 3.49 | 3.40 | 0.06 | 0.85 | 1.44 | 0.92 | 0.15 |
| TA (mg/L $CaCO_3$) | 290 | 310 | 300 | 9.90 | 274 | 306 | 289.86 | 6.40 |
| Carbonate hardness (mg/L $CaCO_3$) | 310 | 330 | 320 | 8.16 | 94 | 392 | 282.26 | 57.50 |
| Noncarbonate hardness (mg/L $CaCO_3$) | 190 | 210 | 200 | 11.50 | 84 | 346 | 145.80 | 53.10 |
| TH (mg/L $CaCO_3$) | 500 | 540 | 520 | 18.20 | 344 | 504 | 428 | 30.50 |

[a] = Minimim; [b] = Maximum

**Table 3.** Corrosion and Scaling Indices (before and after Treatment)

| Index | Water Stability Before Treatment | | Water Stability After Treatment | |
|---|---|---|---|---|
| | Mean ± SD | Interpretation | Mean ± SD | Interpretation |
| LSI | 1.05 ± 0.28 | Water is fully saturated and has a scaling effect. | 0.03 ± 0.31 | Water is stable and does not tend to be scaling. |
| RSI | 5.44 ± 0.57 | Water is safe and does not tend to be scaling or corrosive. | 7.23 ± 0.52 | Water has a corrosive propensity. |
| PSI | 8.7 ± 0.15 | Water has a greater corrosive capability. | 8.91 ± 0.18 | Water has a greater corrosive capability. |
| AI | 10.3 ± 0.09 | Water is moderately corrosive. | 9.92 ± 0.18 | Water has a corrosion potential. |

hardness ($CaCO_3$, $MgCO_3$, $Ca(HCO_3)_2$, $Mg(HCO_3)_2$) and noncarbonate hardness ($CaCl_2$, $MgCl_2$, $CaSO_4$, $MgSO_4$) (35). One of the properties of hard water is the high rate of scale formation; in addition, high levels of hardness cause the formation of scum when using soaps (10, 35). It has been observed that TH levels are reduced after filtration with a POE polyphosphate cartridge. McNeill and Edwards (36) stated that alkalinity has a negative effect on the corrosion rate, and the corrosion rate decreases in alkalinity above 60 ppm.

### 3.2. Stability Indices

Based on the data presented in Table 3, the mean (±SD) values of scaling and corrosion indices of household water before and after filtration with the POE polyphosphate cartridge were calculated in terms of LSI, RSI, PSI, and AI and were reported based on the formulas in Table 1. The results show that the drinking water before filtration with the POE polyphosphate cartridge has a scaling tendency based on the LSI, it is safe in terms of the RSI, and it is corrosive based on the PSI and AI. Additionally, drinking water after filtration with the POE polyphosphate cartridge is stable in terms of the LSI and corrosive in terms of other indices. Taghipour et al (37) reported that Tabriz drinking water distribution system was corrosive because the values of the LSI, RSI, PSI, and AI were equal to -0.68, 8.43, 7.86, and 11.23, respectively. In a study by Hashemifar et al (1), the two-year average values of LSI (0.73), RSI (6.51), and LS (0.74) were calculated to assess the corrosion and scaling potential of potable water in villages covered by Saqqez city. The results indicated that the drinking water in the studied areas was categorized as scaling based on LSI, stable based on RSI, and corrosive based on LS.

Moreover, stability indices after filtration show that the chemical quality of water has the potential to corrode the water system and other facilities. Even if the water meets drinking water standards, it may not be associated with chemical composition and water stability (15). Based on the LSI, RSI, PSI, and AI values presented in Tables 2 and 3, the water before filtration with the POE polyphosphate cartridge was determined to be scaling, safe, corrosive, and moderately corrosive, respectively, and after filtration with the POE polyphosphate cartridge, it tended to be more corrosive.

Similar to the present study, Fazlzadeh Davil et al (38) investigated the corrosion potential of water produced in Ilam water treatment plant. Despite meeting the standards for $Ca^{2+}$, $SO_4^{2-}$, $Cl^-$, TDS, hardness, and pH set by water regulations in Iran and the Environmental Protection Agency, the study found that the water tended to be corrosive.

Corrosion is mainly caused by factors such as pH, alkalinity, temperature, water velocity, carbon dioxide, hardness, soluble solids, dissolved oxygen, and residual chlorine (39). Temperature and water age have not been given due importance in evaluating the indices. However, Volk et al (40) reported that corrosion rates in distribution systems were strongly correlated with seasons and water temperatures and that temperature changes can cause changes in the chemical and physical properties of water and corrosion. Besides, in a study on water stability indices at Urmia water treatment plant, Mohammadi and Aghapour (41) suggested that pH adjustment can control corrosion issues.

For a more detailed study, water stability indices were calculated at 5 different flow rates. Table 4 shows scaling and corrosion indices at different water flow rates. It is observed that only at 3 flow rates (0.180, 0.252, 0.522 L/min) does water exhibit scaling properties according to the LSI, while in other cases, corrosion properties are present. The highest values for LSI, RSI, PSI, and AI were found at flow rates of 0.252, 2.610, 3.528, and 0.252 L/min, respectively. In addition, the lowest values for LSI, RSI, PSI, and AI were observed at flow rates of 3.528, 0.252, 0.252, and 3.528 L/min, respectively.

Figure 3 shows the variations in phosphate concentration at different flow rates. This figure shows that as water flow increases, the phosphate concentration in the outlet water decreases. This is a result of a reduced contact time of polyphosphate crystals with water as it flows through a POE polyphosphate cartridge.

At all studied flow rates, the phosphate concentration in the outlet water was higher than the limit allowed by the United States Environmental Protection Agency (USEPA) (less than 0.03 mg/L) (42). Phosphate is considered a pollutant if its concentration exceeds the permissible limit in water. Maintaining a permissible concentration of phosphate is crucial for human health, as exceeding this limit may lead to kidney damage and osteoporosis (43).

On the other hand, the presence of lead (Pb) in drinking water, which may be due to corrosion of household piping (44, 45), can be controlled by the solubility of lead carbonate or hydroxide-carbonate deposits. Besides, the concentration of lead in drinking water can be minimized by adjusting pH and alkalinity. One water treatment measure that may inadvertently increase lead solubility is the addition of polyphosphate-containing products to drinking water (46, 47). In addition, several studies have reported higher lead concentrations in water treated with polyphosphate than in water treated with orthophosphate. Cantor et al (47) reported that effluent lead concentrations from lead pipe loops in contact with water treated with polyphosphate ranged between 190 and 810 μg/L. They

**Table 4.** Scaling and Corrosion Indices at Different Water Flow Rates (after Treatment)

| Q (L/min) | Sample Size (N) | LSI | RSI | PSI | AI |
|---|---|---|---|---|---|
| 0.180 | 6 | 0.159 [b] | 7.093 [d] | 8.814 [e] | 10.027 [d] |
| 0.252 | 6 | 0.222 [b] | 7.040 [d] | 8.735 [e] | 10.102 [d] |
| 0.522 | 6 | 0.187 [b] | 7.056 [d] | 8.799 [e] | 10.058 [d] |
| 2.610 | 6 | -0.192 [d] | 7.512 [d] | 9.071 [e] | 9.733 [e] |
| 3.528 | 6 | -0.205 [d] | 7.493 [d] | 9.149 [e] | 9.697 [e] |

[a] = very scaling; [b] = scaling; [c] = stable; [d] = corrosive; [e] = very corrosive.

also found that the concentration of lead in this purified water was four times higher than the concentration of lead in the control loop in untreated water. Trueman et al (22) stated that orthophosphate was associated with an overall reduction in lead emissions in POU water samples, while polyphosphate sequestered lead as an aqueous complex. Replacing silicates, in addition to solving problems related to the solubility of lead, copper, and iron, can also be controlled in small water systems (48).

### 3.3. *Statistical Relationship between Physicochemical Parameters and Water Stability Indices*

In Table 5, the results of the physicochemical parameters and water stability indices were analyzed in the outlet water from the POE polyphosphate cartridge to study the relationships among variables using Spearman's correlation. The correlation coefficients in Table 5 show that some parameters are correlated. Bold numbers in Table 5 indicate all strong correlations in this study.

EC has a strong positive correlation with TDS (r = 0.681), $HCO_3^-$ (r = 0.653), $Ca^{2+}$ (r = 0.754), $Mg^{2+}$ (r = 0.635), and AI (r = 0.645), which is consistent with the study of Tyagi and Sarma (10) on qualitative assessment and corrosion-scaling potential of groundwater resources in India. In their study, EC was strongly and positively correlated with TDS (r = 0.706) and $Ca^{2+}$ (r = 0.570). On the other hand,

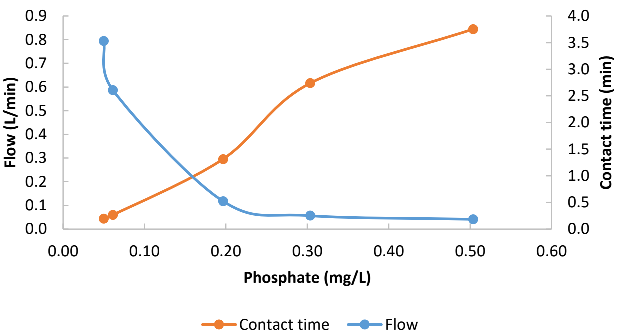


**Fig. 3.** Changes in Phosphate Concentration at Different Flow Rates and Contact Times of Outlet Water

$Ca^{2+}$ showed a significant negative correlation with PSI (r = -0.643) and RSI (r = -0.72) but it showed a significant positive correlation with $Mg^{2+}$ (r = 0.612). Additionally, TDS had a strong positive correlation with TH (r = 0.640) and $Ca^{2+}$ (r = 0.675). There was also a strong positive correlation (r = 0.740) between RSI and PSI in the outlet water from the POE polyphosphate cartridge. However, the correlation between LSI and RSI was strongly negative.

To face their applicability for corrosion and scaling potential, water stability indices are correlated with parameters and themselves (10). The sign of the Spearman's correlation coefficient indicates the direction of the relationship between the analyzed variables (49). The correlation coefficient varies between -1 and 1. A negative correlation indicates the decrease of one variable with the increase of another variable and a positive correlation indicates the increase of one variable with the increase of one unit of the independent variable. A zero value indicates no correlation. The strength of the correlation increases from 0 to 1, as well as from 0 to -1 (50, 51). According to Table 5, there is a significant correlation between EC and TDS. High TDS levels can make the water very aggressive and influence the formation of protective films against corrosion (52). TDS is strongly associated with $Ca^{2+}$, as this ion is one of the major contributors to TDS formation (53).

## 4. Conclusion

In the present study, the scaling and corrosion potentials of household water using a POE polyphosphate cartridge were estimated. The tendency of water to scale and corrode is influenced by its physical, chemical, and microbial properties. Therefore, factors such as pH, TDS, EC, $HCO_3^-$, TA, CH, and temperature were measured in this study. Scaling and corrosion are common indicators of water quality that can lead to economic and health issues. Based on the results, the water treated with the POE polyphosphate cartridge was stable according to the LSI (0.03 ± 0.31). However, it exhibited corrosive

**Table 5.** Spearman's Correlation Matrix for Physicochemical Parameters and Water Stability Indices (n = 403)

| | Temp | pH | EC | TDS | TH | $HCO_3^-$ | $Ca^{2+}$ | $Mg^{2+}$ | LSI | RSI | PSI | AI |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Temp | 1 | | | | | | | | | | | |
| pH | 0.023 | 1 | | | | | | | | | | |
| EC | 0.125 | 0.076 | 1 | | | | | | | | | |
| TDS | 0.087 | 0.143 | **0.681**[a] | 1 | | | | | | | | |
| TH | 0.065 | 0.231 | 0.543[a] | **0.64**[b] | 1 | | | | | | | |
| $HCO_3^-$ | 0.095 | 0.092 | **0.653**[a] | 0.452 | **0.852**[b] | 1 | | | | | | |
| $Ca^{2+}$ | 0.143 | 0.127 | **0.754**[b] | **0.675**[a] | 0.562[a] | 0.534[b] | 1 | | | | | |
| $Mg^{2+}$ | 0.056 | 0.324 | **0.635**[a] | 0.458 | 0.534[a] | 0.420 | **0.612**[b] | 1 | | | | |
| LSI | 0.074 | 0.263 | -0.450 | 0.436 | 0.452 | 0.153 | 0.423[a] | -0.43[a] | 1 | | | |
| RSI | 0.165 | 0.345[a] | -0.431[a] | -0.540[b] | -0.320 | -0.113 | **-0.720** | -0.160[a] | **-0.64$_0$**[b] | 1 | | |
| PSI | 0.170 | 0.176 | -0.342 | **-0.631** | -0.320 | -0.240 | **-0.643**[b] | 0.234[a] | -0.540[b] | **0.740a** | 1 | |
| AI | 0.093 | 0.237[a] | **0.645**[b] | **0.643**[a] | 0.231 | -0.124[a] | 0.346[b] | 0.324 | 0.243 | -0.430[b] | -0.230[a] | 1 |

a = Correlation is significant at 0.05 level (2-tailed). Bold: r > 0.60 Strong correlation, b = Correlation is significant at 0.01 level (2-tailed).

properties in terms of the RSI (7.23 ± 0.52), PSI (8.91 ± 0.18), and AI (9.92 ± 0.18). The stability indices showed a tendency towards corrosion. Statistical analysis also revealed a significant relationship between certain physicochemical parameters and water stability indices. Therefore, it is necessary to have more accurate control over effective quality parameters in water to prevent scaling and corrosion. When using a POE polyphosphate cartridge in household water treatment, it is important to make appropriate adjustments to prevent corrosion of facilities and valves, as well as any negative impact on water quality. The flow rate passing through the POE polyphosphate cartridge in conditions where household water consumption is variable will lead to a decrease in the efficiency of this filtration system to control the corrosion and scaling.


### Acknowledgments
The authors would like to express their gratitude to the Student Research Committee and the Deputy of Research and Technology of Mazandaran University of Medical Sciences for their financial support (IR.MAZUMS.REC.1400.582).


### Authors' Contribution
**Conceptualization:** Fathollah Gholami-Borujeni.
**Data curation:** Fatemeh Mortezazadeh.
**Formal analysis:** Fathollah Gholami-Borujeni.
**Funding acquisition:** Fatemeh Mortezazadeh.
**Investigation:** Fathollah Gholami-Borujeni.
**Methodology:** Fathollah Gholami-Borujeni.
**Project administration:** Fatemeh Mortezazadeh.
**Resources:** Fatemeh Mortezazadeh.
**Supervision:** Fathollah Gholami-Borujeni.
**Validation:** Fathollah Gholami-Borujeni.
**Visualization:** Fathollah Gholami-Borujeni.
**Writing–original draft:** Fatemeh Mortezazadeh.
**Writing–review & editing:** Fathollah Gholami-Borujeni.

### Competing Interests
No competing interest was reported by the authors.

### Ethical Approval
This study was approved by Student Research Committee of Mazandaran University of Medical Sciences. (Code: IR.MAZUMS.REC.1400.582).


### Funding
This study was supported by Student Research Committee of Mazandaran University of Medical Sciences.


### References

1. Hashemifar M, Davoudi M, Mohammadzadeh S, Nilufari N, Khoshgoftar M. Corrosion and scaling potential of the potable water in villages based on Langelier Saturation Index, Ryznar Stability Index, Larson ratio, and saturation level. Journal of Research and Health. 2016;5(4):45-52.
2. Mosaferi M, Shakerkhatibi M, Dastgiri S, Asghari Jafarabadi M, Khataee A, Sheykholeslami S. Natural arsenic pollution and hydrochemistry of drinking water of an urban part of Iran. Avicenna J Environ Health Eng. 2014;1(1):7-16. doi: 10.5812/ajehe.164.
3. Mahmoodnia A, Mousavi M, Golbabaei Kootenaei F, Asadi-Ghalhari M. The performance of several current interpolation methods for variability of cations in groundwater in Esfarayen plain, Iran: a case study. Avicenna J Environ Health Eng. 2022;9(2):75-84. doi: 10.34172/ajehe.2022.4206.
4. Badeenezhad A, Abbasi F, Shahsavani S. Performance of household water desalinations devices and health risks assessment of fluorides (F−) and nitrate (NO3−) in input and output water of the devices in Behbahan city southwest Iran. Hum Ecol Risk Assess. 2019;25(1-2):217-29. doi: 10.1080/10807039.2019.1568858.
5. Baloïtcha GMP, Mayabi AO, Home PG. Evaluation of water quality and potential scaling of corrosion in the water supply using water quality and stability indices: a case study of Juja water distribution network, Kenya. Heliyon. 2022;8(3):e09141. doi: 10.1016/j.heliyon.2022.e09141.
6. Aali R, Kishipour A. Risk assessment of drinking water supply system of Talesh based on world health organization water safety plan in 2021: a case study. Avicenna J Environ Health Eng. 2022;9(1):54-61. doi: 10.34172/ajehe.2022.07.
7. Abd Rahim NS, Othman N. Home water purification system in Malaysia: qualitative and quantitative study. IOP Conf Ser Mater Sci Eng. 2019;601(1):012011. doi: 10.1088/1757-899x/601/1/012011.
8. Gholami-Borujeni F, Rahimi H, Eslamifar M, Yazdani Charati J. Heterotrophic bacteria count index in drinking water and possibility of biofilm formation in household drinking water treatment devices in Sari, Iran. J Mazandaran Univ Med Sci. 2021;30(192):118-25. [Persian].
9. 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. J Water Health. 2015;13(1):203-9. doi: 10.2166/wh.2014.157.
10. Tyagi S, Sarma K. Qualitative assessment, geochemical characterization and corrosion-scaling potential of groundwater resources in Ghaziabad district of Uttar Pradesh, India. Groundw Sustain Dev. 2020;10:100370. doi: 10.1016/j.gsd.2020.100370.
11. Kurdi M, Shahi Ferdows M, Maghsoudi A. Sensitivity of corrosion and scaling indices based on ions; case study Iran. Water Qual Expo Health. 2015;7(3):363-72. doi: 10.1007/s12403-015-0156-8.
12. Myers-O'Farrell S, Duranceau SJ. Addressing corrosion control and valve tuberculation in a water distribution system supplied by a silica-laden groundwater. Urban Water J. 2018;15(1):39-45. doi: 10.1080/1573062x.2017.1364776.
13. Yousefi Z, Kazemi F, Ali Mohammadpour R. Assessment of scale formation and corrosion of drinking water supplies in Ilam city (Iran). Environ Health Eng Manag. 2016;3(2):75-80. doi: 10.15171/ehemj.2016.04.
14. Ahmed S, Sultan MW, Alam M, Hussain A, Qureshi F, Khurshid S. Evaluation of corrosive behaviour and scaling potential of shallow water aquifer using corrosion indices and geospatial approaches in regions of the Yamuna river basin. J King Saud Univ Sci. 2021;33(1):101237. doi: 10.1016/j.jksus.2020.101237.
15. Asghari FB, Jaafari J, Yousefi M, Mohammadi AA, Dehghanzadeh R. Evaluation of water corrosion, scaling extent and heterotrophic plate count bacteria in asbestos and polyethylene pipes in drinking water distribution system. Hum Ecol Risk Assess. 2018;24(4):1138-49. doi: 10.1080/10807039.2017.1407632.
16. Mirzabeygi M, Yousefi N, Abbasnia A, Youzi H, Alikhani M, Mahvi AH. Evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water supply networks, Iran. J Water Supply Res Technol Aqua. 2017;66(6):416-25. doi: 10.2166/aqua.2017.128.
17. Mokhtari Z, Yousefzadeh S, Safari M, Binesh Brahmand M, Soleimani H, Yaghmaeian K. Assessment of the drinking water quality of a rural distribution network in the north of Iran by corrosion and scaling indices. Desalin Water Treat. 2020;206:27-33. doi: 10.5004/dwt.2020.26203.

18. Egbueri JC. Signatures of contamination, corrosivity and scaling in natural waters from a fast-developing suburb (Nigeria): insights into their suitability for industrial purposes. Environ Dev Sustain. 2021;23(1):591-609. doi: 10.1007/s10668-020-00597-1.
19. Egbueri JC, Mgbenu CN, Digwo DC, Nnyigide CS. A multi-criteria water quality evaluation for human consumption, irrigation and industrial purposes in Umunya area, southeastern Nigeria. Int J Environ Anal Chem. 2023;103(14):3351-75. doi: 10.1080/03067319.2021.1907360.
20. Derakhshannia M, Dalvand S, Asakereh B, Ostad-Ali-Askari K. Corrosion and deposition in Karoon River, Iran, based on hydrometric stations. Int J Hydrol Sci Technol. 2020;10(4):334-45. doi: 10.1504/ijhst.2020.108264.
21. Melidis P, Sanozidou M, Mandusa A, Ouzounis K. Corrosion control by using indirect methods. Desalination. 2007;213(1):152-8. doi: 10.1016/j.desal.2006.03.606.
22. Trueman BF, Krkošek WH, Gagnon GA. Effects of ortho-and polyphosphates on lead speciation in drinking water. Environ Sci Water Res Technol. 2018;4(4):505-12. doi: 10.1039/c7ew00521k.
23. Shen Y, Huang PC, Huang C, Sun P, Monroy GL, Wu W, et al. Effect of divalent ions and a polyphosphate on composition, structure, and stiffness of simulated drinking water biofilms. NPJ Biofilms Microbiomes. 2018;4:15. doi: 10.1038/s41522-018-0058-1.
24. Kulakovskaya TV, Vagabov VM, Kulaev IS. Inorganic polyphosphate in industry, agriculture and medicine: modern state and outlook. Process Biochem. 2012;47(1):1-10. doi: 10.1016/j.procbio.2011.10.028.
25. Wu J, Cao M, Tong D, Finkelstein Z, Hoek EM. A critical review of point-of-use drinking water treatment in the United States. NPJ Clean Water. 2021;4(1):40. doi: 10.1038/s41545-021-00128-z.
26. Wang D, Chen Y, Jarin M, Xie X. Increasingly frequent extreme weather events urge the development of point-of-use water treatment systems. NPJ Clean Water. 2022;5(1):36. doi: 10.1038/s41545-022-00182-1.
27. Atlas Filtri. https://filterkala.com/catalog/atlas-catalog.pdf. Accessed December 20, 2022.
28. Baird R, Eaton A, Rice E, Bridgewater L. Standard Methods for the Examination of Water and Wastewater. Washington, DC: American Public Health Association; 2017.
29. Chinedu SN, Nwinyi OC, Oluwadamisi AY, Eze VN. Assessment of water quality in Canaanland, Ota, southwest Nigeria. ABJNA. 2011;2(4):577-83. doi: 10.5251/abjna.2011.2.4.577.583.
30. Mirzabeygi M, Naji M, Yousefi N, Shams M, Biglari H, Mahvi AH. Evaluation of corrosion and scaling tendency indices in water distribution system: a case study of Torbat Heydariye, Iran. Desalin Water Treat. 2016;57(54):25918-26. doi: 10.1080/19443994.2016.1162206.
31. Shams M, Mohamadi A, Sajadi SA. Evaluation of corrosion and scaling potential of water in rural water supply distribution networks of Tabas, Iran. World Appl Sci J. 2012;17(11):1484-89.
32. Ong C, Ibrahim S, Sen Gupta B. A survey of tap water quality in Kuala Lumpur. Urban Water J. 2007;4(1):29-41. doi: 10.1080/15730620601145923.
33. Gorchev HG, Ozolins G. WHO guidelines for drinking-water quality. WHO Chron. 1984;38(3):104-8.
34. Katz EL. The stability of turbidity in raw water and its relationship to chlorine demand. J Am Water Works Assoc. 1986;78(2):72-5. doi: 10.1002/j.551-8833.1986.tb05697.x.
35. Khatri N, Tyagi S, Rawtani D, Tharmavaram M. Assessment of river water quality through application of indices: a case study River Sabarmati, Gujarat, India. Sustain Water Resour Manag. 2020;6(6):101. doi: 10.1007/s40899-020-00459-8.
36. McNeill LS, Edwards M. The importance of temperature in assessing iron pipe corrosion in water distribution systems. Environ Monit Assess. 2002;77(3):229-42. doi: 10.1023/A:1016021815596.
37. Taghipour H, Shakerkhatibi M, Pourakbar M, Belvasi M. Corrosion and scaling potential in drinking water distribution system of Tabriz, northwestern Iran. Health Promot Perspect. 2012;2(1):103-11. doi: 10.5681/hpp.2012.013.
38. Fazlzadeh Davil M, 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.
39. Geldreich EE. Microbial Quality of Water Supply in Distribution Systems. CRC Press; 2020.
40. Volk C, Dundore E, Schiermann J, LeChevallier M. Practical evaluation of iron corrosion control in a drinking water distribution system. Water Res. 2000;34(6):1967-74. doi: 10.1016/s0043-1354(99)00342-5.
41. Mohammadi A, Aghapour AA. Investigation the Corrosiveness and Scaling on Outlet Urmia Water Treatment Plant No. 1 in 2009. 12th National Conference on Environmental Health; 2010; Tehran, Iran.
42. Mohebbi MR. Study of Drinking Water Quality in Village of Tehran Weakness and Options to Improve it [dissertation]. Tehran: Tehran University of Medical Sciences; 2007.
43. Singh AL. Nitrate and phosphate contamination in water and possible remedial measures. In: Dwivedi N, ed. Environmental Problems and Plant Edition. Heidelberg, Germany: Springer Verlag GmbH; 2013. p. 44-56.
44. Edwards M, Dudi A. Role of chlorine and chloramine in corrosion of lead-bearing plumbing materials. J Am Water Works Assoc. 2004;96(10):69-81. doi: 10.1002/j.1551-8833.2004.tb10724.x.
45. Wang W, Li CQ, Shi W. Degradation of mechanical property of corroded water pipes after long service. Urban Water J. 2019;16(7):494-504. doi: 10.1080/1573062x.2019.1687744.
46. Holm TR, Shock MR. Potential effects of polyphosphate products on lead solubility in plumbing systems. J Am Water Works Assoc. 1991;83(7):76-82. doi: 10.1002/j.1551-8833.1991.tb07182.x.
47. Cantor AF, Denig-Chakroff D, Vela RR, Oleinik MG, Lynch DL. Use of polyphosphate in corrosion control. J Am Water Works Assoc. 2000;92(2):95-102. doi: 10.1002/j.1551-8833.2000.tb08820.x.
48. Schock MR, Lytle DA, Sandvig AM, Clement J, Harmon SM. Replacing polyphosphate with silicate to solve lead, copper, and source water iron problems. J Am Water Works Assoc. 2005;97(11):84-93. doi: 10.1002/j.1551-8833.2005.tb07521.x.
49. Lobo M, Guntur RD. Spearman's rank correlation analysis on public perception toward health partnership projects between Indonesia and Australia in East Nusa Tenggara province. J Phys Conf Ser. 2018;1116(2):022020. doi: 10.1088/1742-6596/1116/2/022020.
50. Wozniak PJ. Applied nonparametric statistics (2nd ed.). Technometrics. 1991;33(3):364-5. doi: 10.1080/00401706.1991.10484849.
51. Akoglu H. User's guide to correlation coefficients. Turk J Emerg Med. 2018;18(3):91-3. doi: 10.1016/j.tjem.2018.08.001.
52. Egbueri JC, Ezugwu CK, Unigwe CO, Onwuka OS, Onyemesili OC, Mgbenu CN. Multidimensional analysis of the contamination status, corrosivity and hydrogeochemistry of groundwater from parts of the Anambra basin, Nigeria. Anal Lett. 2021;54(13):2126-56. doi: 10.1080/00032719.2020.1843049.
53. Rehman S, Hussain Z, Zafar S, Ullah H, Badshah S, Ahmad SS, et al. Assessment of ground water quality of Dera Ismail Khan, Pakistan, using multivariate statistical approach. Sci Technol Dev. 2018;37(4):173-83. doi: 10.3923/std.2018.173.183.