DOI: 10.17344/acsi.2022.7939 *Acta Chim. Slov.* **2023**, *70*, 173–183

Review article

A Critical Review on Corrosion and Fouling of Water in Water Distribution Networks and Their Control

Andi Muhammad Anshar[1], Bulkis Musa[1*], Muhammad Ayaz[2], Syahruddin Kasim[1], Indah Raya[1*], Andrés Alexis Ramírez-Coronel[3], Shakhawat Chowdhury[4], Rahman S. Zabibah[5], Rosario Mireya Romero-Parra[6], Luis Andres Barboza-Arenas[7], Yasser Fakri Mustafa[8] and Ali Hussein Demin Al-Khafaji[9]

[1] *Department of Chemistry, Faculty of Mathematics and Natural Science, Hasanuddin University Makassar 90245, Indonesia*

[2] *Sensor Networks and Cellular Systems (SNCS) research center, University of Tabuk, Tabuk, Saudi Arabia*

[3] *Research group in educational statistics, National University of Education (UNAE), Azogues, Ecuador*

[4] *Department of Civil and Environmental Engineering, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia*

[5] *Medical Laboratory Technology Department, College of Medical Technology, The Islamic University, Najaf, Iraq*

[6] *Universidad Continental, Lima, Perú*

[7] *Universidad Tecnológica del Perú. Lima, Perú*

[8] *Department of Pharmaceutical Chemistry, College of Pharmacy, University of Mosul, Mosul-41001, Iraq*

[9] *Department of Laboratories Techniques, Al-Mustaqbal University College, Babylon, Hillah, Iraq*

* *Corresponding author: E-mail: bulkismusa@unhas.ac.id & indahraya@unhas.ac.id*

Received: 12-10-2022

Abstract

Corrosion and scaling are among the problems that may arise when storing water in tanks. Several factors affect the corrosion and scaling of water, which include pH, temperature, alkalinity, Ca^{2+} hardness, TDS, concentrations of Cl^-, SO_4^{2-}, CO_3^{2-}, and HCO^{3-}. Also, several indices can be measured using these properties such as the Langelier saturation index, Ryznar index, Aggressive index, Larson, Scold index, water quality index, and Puckorius index. These indicators determine the degree of corrosiveness and sedimentation of water. The purpose of this review article was to study the impact of various factors on the corrosiveness and sedimentation of water. To this end, different sources of water in different countries were studied and the impact of physical and chemical parameters on their corrosiveness was investigated. Also, the reaction mechanism of water corrosion inside the pipe was studied. Finally, practical and constructive suggestions were presented to solve the problems of corrosion and sedimentation of desalination water.

Keywords: Corrosion, Fouling, Langelier Saturation Index, Ryznar Index, Inhibitors, Water

1. Introduction

Access to clean and unpolluted water resources is one of the basic human needs for a healthy and sustainable society.[1,2] Development of industrial and agricultural activities have led to the spread of environmental pollution.[3–6] The natural cycle of life on earth is menaced by the introduction of harmful chemicals. The water transmission and distribution network is responsible for storing and transporting water.[7–10] One of the problems that may arise when storing water in tanks is the corrosiveness of the water, resulting in corrosion of facilities (eg, pipes, tanks, etc.). Corrosion of drinking water transmission equipment is a global problem.[11,12] Corrosion is a physical-chemical reaction between a substance and its surroundings.[13] Determining water corrosion indices is one of the effective ways to manage drinking water resources. Corrosion of water can cause economic damage, reduce the useful life of water supply facilities, and illness in consumers.[14–16] Corrosion in water distribution networks not only destroys equipment, but also reduces the quality of drinking water because of chemical and biological reactions that occur in the water distribution system. Corrosion processes in drinking water pipes depend on the type of pipes, water quality and hydraulic conditions. Qualitative parameters related to water corrosion include pH, alkalinity, degree of buffering, dissolved oxygen, natural organic matter, microorganisms, temperature, inhibitors if used, etc.[17–20] Durowaye et al. (2014) surveyed the impact of water pH on the corrosion of mild steel and realized that the corrosion rate decreases with enhancing pH from 7.2 to 11.2.[21] Generally, pipe corrosion is prevented by controlling the chemical composition of water and using inhibitors. Due to its chemical properties, desalinated water is known as very corrosive water.[22,23]

Sedimentation is another fundamental problem in water distribution systems.[24] A thin layer of scaling is useful because it can prevent corrosion on the metal surface. However, if the thickness of the deposit on the pipe surface increases, it can cause a lot of damage, including pressure drop, reduced water flow, and reduced heat transfer rate, which leads to an increase in the energy required for pumping. This action reduces thermal conductivity and increases energy consumption.[25,26]

Generally, various factors affect water corrosion, including pH, CO_2 concentration, hardness, alkalinity, temperature, speed of water, TDS, dissolved oxygen, residual chlorine, fatigue, tension and other factors like cavitation.[23,27] Prevention of equipment corrosion is usually done by controlling the chemical composition of water and using inhibitors. Inhibitors are chemicals that, when added in low concentrations to a corrosive environment, decline or prevent the reaction between metals and the environment. Vinyl acetate-methacrylic acid and vinyl acetate-acrylic acid have shown high antifouling efficiency at lower pHs and temperatures.[28] The corrosion of equipment increases with enhancing water pH. High concentration of sodium and chlorine in water increases the water conductivity, resulting in an increase in water corrosion. According to WHO standards for drinking water, the permissible limit of calcium and TDS is 75 mg/L and 500 mg/L, respectively. Also, the standard value of pH is between 7–8.5. Moreover, the permissible limit of $CaCO_3$ alkalinity should be between 30-500 mg/L based on WHO standard.[25]

The Langelier index, along with the Ryznar and Puckorius indices, determines the corrosive or sedimentation status of water in the distribution network. The best case is when the water does not cause corrosion and deposits in the pipes of the water distribution network because both cases reduce the life of the pipes in the water transmission network and are costly. In distribution network management, by measuring the Langelier, Ryznar and Puckorius indices, they try to prevent the corrosion or clogging of the pipes by improving the water quality, which is called water stabilization. Water instability occurs when water quality characteristics such as hardness, alkalinity, temperature, TDS and pH are not balanced.[29,30] In general, physical, chemical and microbial factors are the three main causes of corrosion. Dissolved oxygen concentration, TDS, alkalinity, pH, CO_2 concentration and residual chlorine are chemical factors in corrosion. Also, temperature, fluid speed, and metal composition of pipes are physical factors[31] and biological factors include 1) iron bacteria such as Gallionella and Chronotropic[32] and 2) sulfate-reducing bacteria such as Desulfovibrio and De Sulfuric Ans.[33]

Therefore, considering the problems and damages caused by corrosion and sedimentation in the water transmission and distribution system, it is necessary to reduce its effects by monitoring and controlling the factors affecting this phenomenon. The purpose of this review paper is to investigate various factors on corrosion and fouling in water distribution networks. To this end, the chemical and physical features of water were studied. Then, effective factors on corrosion and fouling were fully investigated. Also, the corrosiveness and sedimentation of water for various water distribution systems were fully studied by several indices such as Langelier, Ryznar, Larson-Scold, Aggressive, and Puckorius. Finally, practical suggestions were presented to improve or fix these problems.

2. Effective Factors on Corrosion and Scaling

Sedimentation in water pipes occurs when divalent metal ions or hardness factors in water are combined with other ions dissolved in water and deposited on the inner wall of the pipe. The main forms of sediments consist of calcium sulfate, magnesium carbonate, calcium carbonate, and magnesium chloride. Based on previous studies, more than 60% of corrosion in pipes and water transmission networks is due to chemical factors, and 40% is caused by biological parameters. The rate of fouling enhances with increasing temperature and salt concentration.[34] Sedimentation reduces the amount of water flow inside pipes, reduces heat transfer, increases pressure drop and energy required for pumping, clogs pipes and increases the cost of operation and maintenance of water supply facilities. The effective factors in the occurrence of deposits and clogging of pipes are a function of temperature, pH and concentration of dissolved solids.[35,36] If the water is corrosive or sedimentary, it will cause many problems in the water transmission and distribution pipes and reduce the life of the facilities. The best pH value of water for preventing corrosion is 7. In fact, water with pH values below 6.5 or above 7.5 will be corrosive. Also, the corrosion rate triplicates with enhancing temperature from 15.55 to 60 °C.[37] Moreover, the presence of some gases such as H_2S can enhance the corrosion of metals. Water containing magnesium or calcium salts (hard water) is less likely to cause corrosion because the minerals coat the inside of the pipe and protect them. Soft water containing sodium salts doesn't cover the pipe and is therefore more corrosive.[25,27] Figure 1 illustrates various factors affecting the water corrosion and the appropriate amounts for preventing corrosion.

Figure 1. Effective factors and their conditions for preventing water corrosion and fouling

Corrosion is a physical-chemical reaction between a material and water, which changes the substance features. Excessive hardness of water causes corrosion and serious damage to facilities.[38] Stable water is water that does not cause corrosion in contact with metals and prevents sedimentation inside water pipes. Two important standards in the water supply network against corrosion are ISO1885 and EN12502.[39]

Corrosiveness and scaling of water can be determined by Langelier, Ryznar, Aggressive, and Puckorius indices. The Langelier index indicates the state of water in terms of corrosiveness and sedimentation, which depends on various factors such as water acidity, TDS, carbonate concentration, bicarbonate concentration, water temperature and alkalinity. The following relationship is utilized to measure the Langelier saturation index (LSI):

$$LSI = pH - pH_s \tag{1}$$

Where, pH_s is the saturation pH. There are different ways to calculate pH_s. In the first method, the pH_s can be determined through Figure 2. As shown, pHs can be easily determined by having the water temperature, calcium ion concentration and alkalinity by referring to the graph.[38]

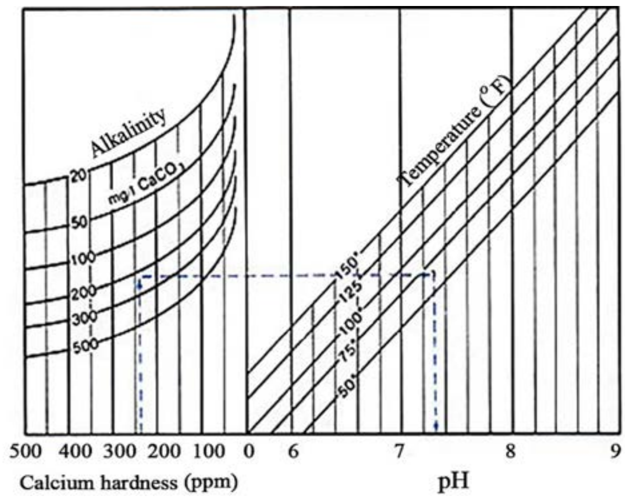

Figure 2. Determination of pHs in terms of Ca hardness, alkalinity, and pH parameters[38]

In the second method, the following relationship is utilized to calculate pHs:

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

$$A = (Log_{10}^{[TDS]} - 1)/(10 * \mathrm{TDS}) \tag{3}$$

$$B = -13.12 * Log_{10}^{T} - 34.55 \tag{4}$$

$$C = Log_{10}^{[Ca^{2+} as\ CaCO3]} - 0.5 \tag{5}$$

$$D = Log_{10}^{[Alkalinity\ as\ CaCO3]} \tag{6}$$

Where, TDS and T are in terms of mg/l, and kelvin, respectively. For LSI= 0, water is not corrosive or sedimentation. For LSI<0 and LSI>0, water tends to dissolve $CaCO_3$ and precipitate $CaCO_3$, respectively. When the index is negative, the water has corrosion potential.[40,41] Table 1 presents the different modes of the Langelier index and based on that, the desired suggestions are presented to fix them.

Also, the Ryznar index is used as a basis for measuring sediment thickness in urban water supply systems in order to predict the chemical influence of water. The Ryznar stability index (RSI) can be employed to compute the corrosiveness and sedimentation potential of water. The RSI value can be determined using Equation 7. At RSI>7 and RSI<6, water will be corrosive and precipitator, respectively. Also, for RSI between 6–7, the water will be stable.[42]

$$RSI = 2pH_s - pH \tag{7}$$

The table below presents the degrees of water sedimentation based on RSI values. As reported, an RSI value

Table 1. Different values of the Langelier index and desired suggestions

LSI value	Situation	Suggestion
−5	Intense corrosion	Needs purification
−4	Intense corrosion	Needs purification
−3	Moderate corrosion	Needs purification
−2	Moderate corrosion	Purification might be required
−1	Weak corrosion	Purification might be required
−0.5	Very weak corrosion	Maybe no need for purification
0	Stable	No need for purification
0.5	Weak sedimentation	Maybe no need for treatment
1	Gentle sedimentation	Purification might be required
2	Gentle to moderate sedimentation	Purification might be required
3	Moderate sedimentation	Purification is recommended
4	Intense sedimentation	Purification is recommended

between 6–7 is considered the best amount, so that water leads to little scale or corrosion. Also, Figure 3 indicates the RSI parameter in terms of temperature and pH. As shown, RSI at a certain amount of temperature declines with increasing pH. Also, at constant pH, the value of RSI decreases with enhancing temperature. Considering that the best value of RSI should be between 6 and 7, therefore water under high values of pH and temperature will form severe fouling. Also, water at very low pH and temperature will be corrosive.[43]

Table 2. RSI values and their interpretations[42]

RSI value	Case
4–5	Severe fouling
5–6	light fouling
6–7	Little fouling and corrosion
7–7.5	Moderate corrosion
7.5–9	Severe corrosion
>9	Unbearable corrosion

Moreover, the Puckorius index (PI) presents a relationship between scale formation and saturation state. High calcium concentration and low alkalinity of water result in a high level of calcite saturation. PI can be determined as follows:[24]

$$PI = 2pH_s - pH_{eq} \tag{8}$$

where, pH_s and pH_{eq} are the water pH at saturation state, and the water pH at equilibrium state, respectively. pH_{eq} can be calculated as follows:

$$pH_{eq} = 1.465 * \log(Alkalinity) + 4.54 \tag{9}$$

where, alkalinity is in terms of mg/L. If PI > 6 and PI < 6, the water tends to corrode and sediment, respectively.

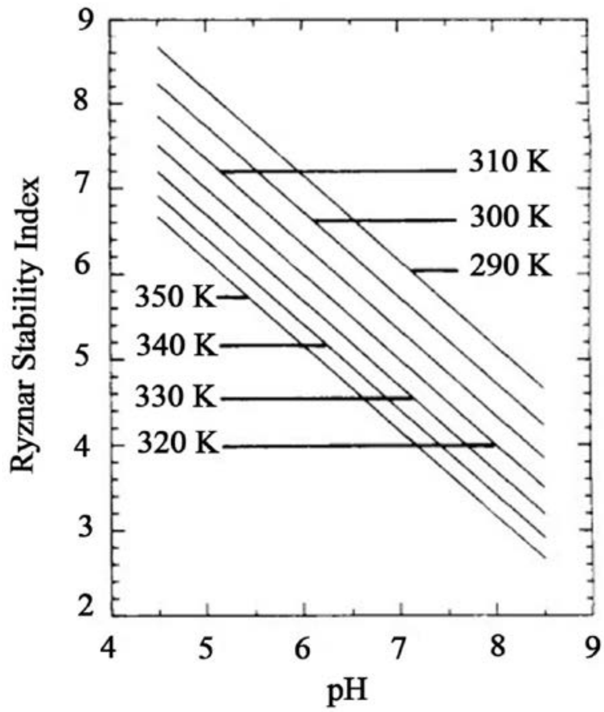

Figure 3. RSI versus pH and temperature[43]

Furthermore, Larson-Scold index (LRI) is used to show the degree of water corrosiveness for the steel metal surface. LRI is determined through the following equation:

$$LRI = \frac{C(Cl^-) + C(SO_4^{2-})}{C(HCO_3^-) + C(CO_3^{2-})} \tag{10}$$

where, C is the concentration of each ion (m_{eq}/L). If LRI<0.8, the water is not corrosive. Also, for 0.8<LRI<1.2, the water is corrosive and for LRI>1.2, the water will be very corrosive.[44]

Finally, the Aggressive index (AI) is used to monitor corrosion in asbestos pipes and can be used as an indicator of water corrosion. This index is calculated using the actual water pH, calcium hardness, and total alkalinity. In addition, this index is simpler and easier than the Langelier index because it is not affected by temperature or TDS. The following relationship is utilized to calculate AI:

$$AI = [pH + \log(A + H)] \tag{11}$$

where, A and H are alkalinity and total hardness, respectively. If the AI index is equal to or greater than 12, the water will be non-corrosive. It is worth noting that for AI smaller than 10, water is highly corrosive and in values between 10 and 12, it will be moderately corrosive.

Water quality index (WQI) is another significant parameter for determining water quality. WQI indicates the combined impact of various water quality variables. To calculate WQI, each physicochemical factor is assigned a weight (w_i). The value of w_i depends on the impact of each factor on health or its importance on the quality of water. Then, the relative weight (W_i) for n variables can be calculated as follows:

$$W_i = \frac{w_i}{\sum_{n=1}^{n} w_i} \quad (12)$$

Also, quality rating can be determined as follows:

$$q_i = \frac{C_i}{S_i} * 100 \quad (13)$$

Where, C_i and S_i are concentration of each chemical factor (mg/L) and the standard value for each factor except for pH (mg/L), respectively. Moreover, the sub-index of the i^{th} factor (SI_i) and WQI are calculated through Eqs. 14 and 15:[38]

$$SI_i = q_i * W_i \qquad WQI = \sum_{i=1}^{n} SI_i \quad (14)$$

Table 3 presents the water quality in various WQI amounts. As demonstrated, the WQI values below 100 are suitable for water quality.

Table 3. WQI values for drinking water and their cases[45]

WQI amount	Description
0–50	Great
50–100	Good
100–200	Poor
200–300	Very poor
>300	Improper

3. Reaction Mechanism

Iron is the most extensively used element in pipes in potable water distribution networks that are utilized to transport drinking water.[46,47] It is estimated that iron-based pipes make up a large portion of the drinking water distribution system around the world. For example, 67.2% of water distribution pipes in Italy, 56.6% in the US, 75.5% in China, 93% in Innsbruck (Austria), and 91% in Warsaw (Poland) are made of iron.[47] Corrosion and fouling easily occur in pipes, which involve complex reactions between the pipe surface and the passing water. In the corrosion process in water, iron and oxidants act as anode and cathode (electron acceptor), respectively. Chlorine, dissolved oxygen, hypochlorite ions, and hypochlorous acid are the most common oxidants in water distribution systems.[46–48] These oxidants can quickly react with zero-valent iron (Fe^0) inside the pipe's wall. Iron hydroxides (i.e., goethite, ferric hydroxide, maghemite) and iron oxides are the main corrosion products that can gently deposit on the pipe wall. The cumulation of corrosion on the pipes increases corrosion resistance and creates an obstacle between the transferred water and the metal pipe, leading to a decrease in the rate of corrosion. The following reactions can be occurred:[47]

$$Fe - 2e^- \rightarrow Fe^{2+} \quad (15)$$

$$2H_2O + O_2 + 4e^- \rightarrow 4OH^- \quad (16)$$

$$HClO + H^+ + 2e^- \leftrightarrow Cl^- + H_2O \quad (17)$$

$$ClO^- + H_2O + 2e^- \leftrightarrow Cl^- + 2OH^- \quad (18)$$

The corrosion process may occur non-uniformly in different locations. Pit corrosion, galvanic, and crevice corrosion are common types of non-uniform corrosion. With the beginning of corrosion in a pipe, corrosion products are produced and accumulate on the pipe surface, which gradually lead to the formation of scales. Figure 4 shows the impact of various factors on the formation of corrosion on the pipe wall.

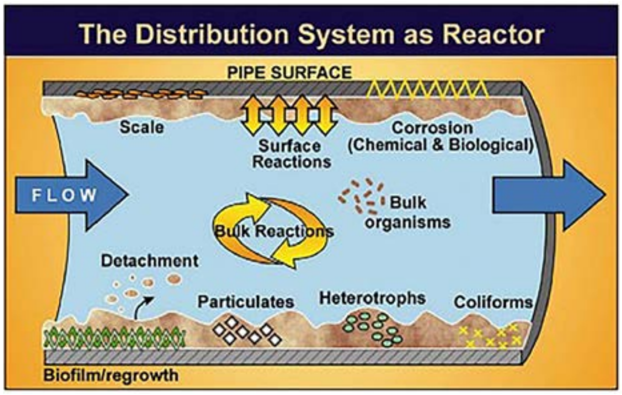

Figure 4. Different factors affecting the formation of corrosion on the pipe wall

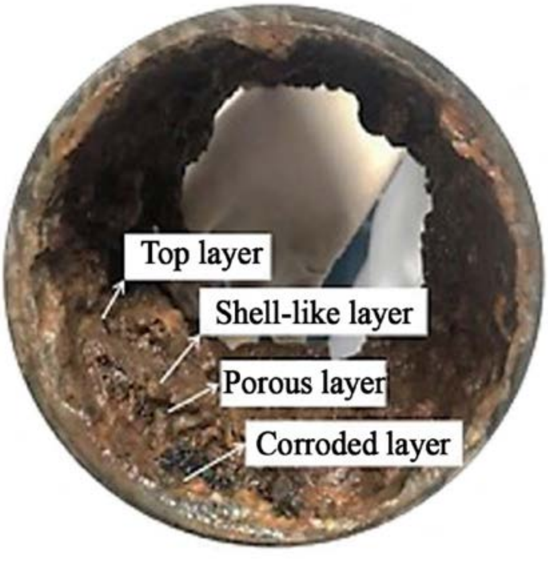

Figure 5. Schematic of corrosion and different layers inside the pipe

Also, the following figure illustrates different layers inside the pipe. As shown, there are 4 layers in iron pipes, which include corroded layer, porous layer, shell-like layer, and top layer. The corroded layer contains zero-valent iron. Also, the porous layer is composed of iron components like ferric hydroxide ($Fe(OH)_3$), ferrous hydroxide ($Fe(OH_2)$), goethite (α-FeOOH), siderite, hematite (Fe_2O_3), and lepidocrocite (γ-FeOOH). Moreover, the shell-like layer contains the porous core and finally, the top layer is a heterogeneous layer containing silicates, carbonates, phosphates, goethite, iron hydroxide, and lepidocrocite. The corrosion composition depends on various variables like the quality of water, the operation time, and pipe material.[47]

4. Previous Studies

Corrosion is a physical-chemical reaction between a material and its surrounding, which leads to changing the properties of that material. By attacking the inner wall of the pipe, the corrosive water dissolves the materials of the pipes and causes many problems. Economic losses, the formation of by-products, problems with taste, smell, color, staining and increasing turbidity are among the most important problems related to corrosiveness. Langelier, Ryznar, and Puckorius indices are important factors for determining the corrosiveness of water. Many studies have been done on the water's corrosiveness, which are reported in Table 4.

Hasani et al. (2021) suggested that pH, Cl^- concentration, dissolved oxygen, and sulfate should be continuously checked and controlled to prevent water corrosion.[50] Also, Bouderbala (2021) measured different properties of water such as pH, EC, Cl^-, TDS, COD, BOD, Na^+, K^+, Mg^{2+}, SO_4^{2-}, Ca^{2+}, HCO_3^-, NH_4^+, NO_3^-, NO_2^-, and PO_4^{3-} to determine water quality for irrigation and industrial applications. The outcomes indicated that the WQI is in the range of 50–100, which shows the proper quality of water for irrigation.[51] In other studies, other characteristics such as pH, water temperature, hardness, TDS, electrical conductivity, alkalinity, HCO_3^-, CO_3^{2-}, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, and SO_4^{2-} were calculated to determine the rate of corrosion and fouling.[44, 52] In addition to these variables, García-Ávila et al. measured other factors such as sulfate, phosphate, and nitrite to predict and control corrosion.[55] Eslami et al. (2020) showed that the concentration of Cl^- and SO_4^{2-} has a greater effect on the corrosion and fouling potential of water than other parameters. They proposed that the water pH must be controlled to avoid water corrosion and scaling.[52]

The morphology and composition of sediments are strongly related to the electrochemical features of water, and with the increase in corrosion and sedimentation, the corrosion current density decreases continuously. By adding sodium hypochlorite disinfection to the groundwater, the water pH increases and results in the formation of calcium carbonate. Calcium carbonate strongly affects the corrosion potential.[62] Also, controlling water quality before entering the water distribution network is an effective way to prevent corrosion and fouling.[36]

Shahmohammadi et al. (2018) surveyed the corrosion and sedimentation potential of 46 water supply sources in Sarvabad County (Iran). The Langelier index in some water sources indicated that water tends to dissolve calcium carbonate and in other areas, water tends to form calcium carbonate scale. According to the Ryznar index, the tendency of water to corrode steel pipes increases. The Aggressive index (11.6) showed that the corrosion potential of water is moderate. The corrosion potential of water was also detected by the Puckorius index (7.03).[56] Therefore, several indicators simultaneously indicate the corrosiveness of water. Furthermore, Maeng et al. surveyed the corrosion potential of river water in Korea. The amount of LSI (–2.97), RSI (12.8), and AI (9.26) showed severe corrosiveness of river water. Also, their results indicated that pH and alkalinity reduce in the rainy season, while calcium hardness has little change throughout the year.[58] Davoudi et al. (2016) suggested that stabilization of water before entering the distribution network can prevent water corrosiveness.[63] According to the study done by Akter et al. in Bangladesh, the water quality index in some cities such as Kurigram Sadar and Rangabali was lower than 50, which indicates the water has excellent quality. However, some cities such as Anwara and Kamalganj had WQI values above 250, indicating very poor water quality. These results indicate that the WQI amount of water below 100 can be suitable for drinking.[45]

Hoseinzadeh et al. (2013) studied the water corrosion and fouling in the water treatment network in Takab city during ten months. According to their results, the amount of LSI was 0.22, which indicates that the water was slightly scale-forming and corrosive. Also, the amount of RSI (7.6) showed that the water is corrosive. Moreover, the AI value (12.63) indicated that the water is non-aggressive. They suggested that corrosion and fouling can be controlled by adjusting the pH and temperature of the water.[59] Moreover, the LSI value in water sources of Tafila (Jordan) was in the range of –0.39 and –1.5, and the RSI value was in the range of 8.7 and 9.8, which indicates that the water is corrosive. Also, microbiological experiments indicated that three water samples were contaminated with faecal coliform bacteria.[61]

In general, it can be concluded that RSI, PI, AI, LSI, and WQI are critical indices for determining water corrosiveness and fouling, which have been widely utilized in previous researches.

Table 4. Characterization of different water sources, problems, and suggestions for solving their problems

City/Country	Effective factors	Description	Their suggestions	Ref.
Thanjavur/India	LSI = 0.13, AI = 12.09, RSI = 7.92, PI = 8.02, LRI = 1.08	Scaling and corrosiveness		30
Bangladesh	WQI for Sadar = 11.79 WQI for Rangabali = 40.05	Excellent quality of water	–	45
Bangladesh	WQI for Alfadanga = 169, WQI for Kendua = 142.5, WQI for Shajahanpur = 135.6, WQI for Debhata = 113, WQI for Bijoynagar = 111.8	Poor quality of water	–	45
Bangladesh	WQI for Rupsha = 92.14 WQI for Patharghata = 75.35	Good quality of water	–	45
Bangladesh	WQI for Anwara = 253.29 WQI for Kamalganj = 258.36	Very poor quality	–	45
Bangladesh	WQI for Shibchar = 371.5	Unsuitable for drinking	–	45
Juja/Kenya	WQI = 131–151	The water quality is very poor	–	49
Ardebil/Iran	LSI = –1.34 RSI = 10.03	Water is corrosive and has a high fouling capability	Water pH, Cl^-, dissolved oxygen and sulfate should be monitored.	50
Oued Fodda dam/ Algeria	WQI = 50–100	Desirable suitable water quality	–	51
Oued Fodda dam/ Algeria	RSI>7.5 from November to June	Heavy corrosion	–	51
Oued Fodda dam/ Algeria	RSI<7.5 from July to October	Little corrosion and sedimentation	–	51
Kerman/Iran	LSI<0, RSI>7.5, PI> 6, and 10<AI<12	Water is corrosive	Controlling pH	52
Iranshahr/Iran	–1.53<LSI<–0.96, 9.63<RSI<10.54, 9.05<PI<10.8, 12.04<AI<12.91	moderate corrosiveness	–	53
Rudsar/Iran In summer	LSI = –1.05, RSI = 10.04, LRI = 0.19, PI = 10.18, AI = 11.92	Corrosive	–	54
Amlash/Iran In winter	LSI = –1.31, RSI = 9.73, LRI = 0.24, PI = 9.74, AI = 11.5	Corrosive	–	54
Amlash/Iran In summer	LSI = –1.51, RSI = 10.71, LRI = 0.25, PI = 10.72, AI = 11.36	Corrosive	–	54
Rudsar/Iran In winter	LSI = –1.12, RSI = 9.69, LRI = 0.16, PI = 9.19, AI = 11.33	Corrosive	–	54
Azogues/Ecuador	RSI = 6.76, LSI = 0.5, LRI = 6.5	Slightly corrosive	–	55
Sarvabad/Iran	LSI = 0.23, RSI = 7.12, AI = 11.6, PI = 7.03	Moderate corrosion	–	56
Jolfa/Iran For 30 water wells	LSI = 1.15, RSI = 6.92, AI = 12.79, LRI = 0.85, PI = 6.42	Corrosive	–	57
Han, Geum, Nakdong, and Yeongsan in Korea	LSI = –2.97, RSI = 12.8, AI = 9.26	Strong corrosiveness	Controlling pH	58
Takab city/Iran	LSI = 0.22, RSI = 7.6, AI = 12.63	Slightly scale forming and corrosive, non-aggressive	pH and temperature Control	59
Tabriz/Iran In spring and summer	LSI = –0.68, PI = 7.86, AI = 11.23, RSI = 8.43	Corrosive	Adjusting pH	60
Tafila/Jordan	RSI = 8.7 – 9.8 LSI = –0.39 – –1.5	Corrosive	Evaporation of water	61

5. Suggestions for Preventing Corrosion and Fouling

To prevent water corrosion, the saturation index must be bigger than zero to ensure that not only corrosion doesn't take place, but also a thin layer of scale is formed. Therefore, maintaining LSI in the range of 0.6–1 is necessary to control corrosion. In practice, the best way to prevent corrosion is to create a uniform calcium carbonate deposit layer, but some factors that prevent this deposit from forming must be eliminated.[64,65] Table 5 reports various suggestions to prevent water corrosion and fouling by previous researchers. Corrosion inhibitors are anti-corrosion chemicals. Sodium silicate prevents corrosion by forming a layer on the internal surfaces of metal pipes in the anodic region. Sodium silicate is an effective, economical, and environmentally friendly material that has been used for more than 70 years as a metal protector against the corrosive effects of water.[66,67] One of the ways to prevent the formation of sediment is to identify the type of sediments in the pipes of the water transmission network. Another effective method to prevent water corrosion is to clean the pipes before installation. This will remove any debris and remarkably increase the life of the pipelines. Adding a cleaning agent to the plumbing will extend its life.[68,69]

Also, adjusting the water pH or alkalinity can effectively prevent water corrosion in the water distribution network. Acid rain as well as minerals in the walls of the tanks can change the water's pH. Also, the addition of chemicals to water for preventing corrosion can change the pH.[58]

Moreover, microbiological contamination can cause water corrosion. The addition of chlorine to water keeps the water safe and prevents corrosion, resulting in further problems in the municipal supply network. Chlorination in water treatment should be done by professionals because if it is done incorrectly, it can increase corrosion.[70,71]

Phosphates can be also utilized to prevent water corrosion. These chemicals act as corrosion inhibitors and prevent the separation of metals from copper and lead pipes. By adding phosphates to the water source, a protective fouling layer is formed inside the pipes, which protects the pipelines from corrosion. The amount of phosphate added to the water source is very small in comparison to the adult diet.[72] In one study, Karthiga et al. used henna leaf extract as an inhibitor to reduce the corrosiveness potential of soft steel in well water, and after adding 10 mL of henna leaf extract to water, the inhibition efficiency declined by 96%, which indicates the remarkable ability of the aforementioned substance.[79]

Passivators are chemicals utilized to directly interact with minerals in water in the water refinement process. For instance, chlorine dioxide directly prevents manganese and iron to react with copper, lead, and steel pipes.[73] Chlorine dioxide, ultraviolet light, chlorine gas, ozone, and hypochlorite are some important passive inhibitors. Each passive inhibitor has advantages and disadvantages. Some of them are more environmentally friendly, but their prices are high. According to the Environmental Protection Agency, the highest concentration of chlorine dioxide and chlorite must be 0.8 and 0.1 mg/L, respectively. Others have corrosive effects on an extensive range of minerals but inhibit corrosion to a lesser extent. Others are very efficient but generate large amounts of waste.[74]

Chemicals react with minerals in the water, while cathodic inhibitors interact with infrastructure piping.[75,76] Cathodic inhibitors greatly decrease corrosion by creating a protective coating inside metal pipes, such as zinc or calcium. Zinc salts, silicates, calcium carbonate, and polyphosphates are important cathodic inhibitors for controlling water corrosion.[77,78] In a research done by Lee et al. (2012), the influence of two important inhibitors (e.g., phosphate, silicate, and their mixtures) for controlling

Table 5. Different water sources, their problems, and solutions

Sample	Problem	Solution and result	Ref.
Green water problem and copper pipes	Corrosion	Using silicate inhibitor (10 mg/l) to control corrosion.	48
River water	Strong corrosiveness	Controlling pH in the standard range to prevent corrosion.	58
Water supply source	Corrosiveness and scaling	Adjusting pH is the best way to control corrosion.	60
Water	Corrosion	Microbiological contamination causes water corrosion, and adding chlorine to water prevents corrosion.	70
Copper pipes in household drinking water in Florida	Corrosion	The effect of adding phosphate to water indicated that phosphorus is more concentrated in the areas of corrosion attack and has a good effect on removing copper pipe corrosion.	72
Soft steel in well water	Corrosion	The inhibition efficiency declined by 96% by adding 10 mL of henna leaf extract.	79
Simulated cooling water	Scale	Adding 30 ppb of $CaCO_3$ inhibitor for reducing sedimentation.	80
Mild steel in seawater	Corrosion	Adding *Azadirachta indica L.* extracts led to 98% inhibition efficiency.	81

copper pipe corrosion was investigated. Their results showed that silicate-based inhibitors were the most effective between them to control the pipe corrosion.[48]

6. Conclusions and Practical Suggestions

6. 1. Conclusions

Corrosion of water can cause economic damage, reduce the useful life of water supply facilities, and also reduce the quality of drinking water due to chemical and biological reactions and as a result, illness in consumers. Among the economic effects caused by fouling, we can also mention the reduction of water flow inside the pipes, which results in a pressure drop and an increase in the energy required for pumping. Therefore, the water quality must be controlled chemically or physically before entering the water distribution network. In this review article, the physicochemical properties of water such as pH, temperature, hardness, TDS, electrical conductivity, alkalinity, and concentration of HCO_3^-, CO_3^{2-}, Ca^{2+}, Mg^{2+}, Na^+, Cl^-, and SO_4^{2-} for different water sources around the world were studied to determine the potential of corrosion and fouling. Various indices such as LSI, RSI, PI, AI, LRI, and WQI were also used to evaluate water quality. According to previous studies, LSI value close to zero, RSI between 6 and 7, PI value close to 6, LRI less than 0.8, and AI greater than 12 indicate that the water is not corrosive and does not form sediment. Also, a WQI value less than 100 demonstrates that the quality of water is good for drinking.

6.2. Practical suggestions

In previous studies, various practical suggestions have been presented to eliminate corrosion and water fouling. Accordingly, the adjustment of pH and temperature, the addition of anti-corrosion such as sodium silicate and phosphates, the addition of inhibitors such as chlorine dioxide, ultraviolet light, chlorine gas, ozone, hypochlorite, zinc salts, silicates, calcium carbonate, polyphosphates, and clean the pipes before installation are important ways for preventing corrosion and scaling.

Conflict of Interests Statement

There are no conflicts of interest to declare.

7. References

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Povzetek

Pri shranjevanju vode v rezervoarjih se lahko pojavijo težave, med katerimi sta najpogostejši korozija in nastajanje vodnega kamna. Na procese korozije in nabiranja vodnega kamna vpliva več dejavnikov, kot so pH, temperatura, alkalnost, trdota Ca^{2+}, TDS, ter koncentracije Cl^-, SO_4^{2-}, CO_3^{2-} in HCO_3^-. Z uporabo teh parametrov je mogoče izmeriti različne indekse, med katerimi so Langelierjev indeks nasičenosti, Ryznarjev indeks, Agresivni indeks, Larsonov indeks, Scoldov indeks, indeks kakovosti vode in Puckoriusov indeks. Ti indikatorji nam omogočajo določiti stopnjo korozivnosti in sedimentacije vode, kar je tudi namen tega preglednega članka. Proučevani so bili različni vodni viri v različnih državah, raziskano je bilo, kako fizikalni in kemijski parametri vplivajo na jedkost vode. Prav tako so bili preučeni reakcijski mehanizmi vodne korozije znotraj cevi. Na koncu so predstavljeni praktični in konstruktivni predlogi za reševanje problemov korozije in sedimentacije razsoljene vode.