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Assessing the Corrosion and Scaling Potential of Drinking Water in Morocco Using Water Stability Indices

Hind El Baroudi[1], Chadia Ouazzani[1*], Abdellah Moustaghfir[1,2], Azzeddine Er-Ramly[2], Youssef El Baroudi[1], Abdallah Dami[1], Lhousaine Balouch[1]

[1] Laboratory of Biochemistry and Molecular Biology, Faculty of Medicine and Pharmacy, Mohammed V University in Rabat, Morocco

[2] Laboratory of Research Odontological, Biomaterials and Nanotechnology, Department of Fundamental Sciences, Faculty of Dental Medicine, Mohammed V University in Rabat, Morocco

* Corresponding author's e-mail: ouazcom@yahoo.fr

ABSTRACT

Corrosion and scaling occur in water distribution systems. However, not much data is available concerning this issue in Morocco. This study aimed to evaluate the corrosive and scaling potential of drinking water in the water distribution systems of several cities in Morocco using water stability indices and other physicochemical parameters. For this purpose, 100 samples were collected, mainly from the cities in the Rabat-Salé-Kenitra region of Morocco. The results of the physicochemical analysis of 100 collected samples show that the means of the pH, total alkalinity, calcium hardness, chloride, temperature, and total dissolved solids are 7.577 ± 0.23, 173.6 ± 52.04 mg/l as $CaCO_3$, 212.57 ± 98.18 mg/l as $CaCO_3$, 418.7 ± 407.75 mg/l, 25.16 ± 1.58 °C, 597.5 ± 435.74 mg/l, respectively. The mean values of the water stability indices are 0.1158 ± 0.38, 7.345 ± 0.68, 7.132 ± 0.86, and 12.41 ± 0.35 for the Langelier saturation index (LSI), the Ryznar stability index (RSI), the Puckorius scaling index (PSI), and the aggressive index (AI), respectively. The water samples show corrosive tendencies of 41%, 75%, 97%, and 13% based on the LSI, RSI, PSI, and AI, respectively, and are considered supersaturated and likely to scale, corrosive, and non-aggressive. The water samples in Rabat, Salé, Bouknadel, and Kenitra were mostly supersaturated with a tendency to scale, with the highest percentage of stable water while the water in Khemisset and Tiflet was mostly corrosive, with Tiflet recording the highest chloride content of 3220.1 mg/l. The scaling and corrosive potential of water varied depending on the source of water in each city. Therefore, it is essential to continuously supervise the stability of water at different points of water distribution systems, create an adapted approach for each city, and instill strict national standards for the physicochemical parameters that affect corrosion and scaling to ensure safe drinking water.

Keywords: corrosion and scaling; drinking water; Morocco; water distribution systems; water quality; water stability indices.

INTRODUCTION

Drinking water quality is a major concern for public well-being and can be associated with numerous health risks stemming from the presence of chemical and microbiological contaminants (Villanueva et al. 2014; Li and Wu 2019). Several prevention measures ensure access to safe drinking water, including managing groundwater and surface water quality, operating water treatment facilities, monitoring water distribution systems, and implementing strict national standards. However, water quality can still be compromised throughout the distribution process due to a variety of factors, such as the release of pipe material, the quality and state of the water distribution network, the type of pipe and fittings materials, the chemical composition of the water, and the formation of biofilms (Liu et al. 2014; Liu et al. 2017).

In water distribution systems, corrosion is caused by a physicochemical interaction between the distribution system materials and the chemical composition of water, which engenders a modification in the properties of the materials, resulting in the gradual degradation of the pipelines (Kurdi et al. 2015; Hasani et al. 2020). This degradation can lead to the gradual release of metals like iron, lead, copper, and manganese into water. Conversely, scaling occurs as a result of the precipitation of the minerals dissolved in water, forming a hard mineralized deposit on the inner surfaces (Belattar et al. 2018; Li et al. 2022). Scale formation obstructs and decreases the water flow rate, leading to eventual congestion, reduced thermal flow in domestic appliances, and interferes with the overall performance of distribution systems (Richards et al. 2018). Furthermore, many factors affect corrosion and scaling, such as pH, hardness, temperature, alkalinity, total dissolved solids (TDS), microorganisms and biofilms, chloride, sulfate, dissolved gasses and salts, and chlorine (Hoseinzadeh et al. 2013; Khorsandi et al. 2016; Gholizadeh et al. 2017).

Iron and steel products (cast iron, ductile iron, galvanized, and steel pipes) can constitute more than half of water distribution systems (Gonzalez et al. 2013). For instance, they reach up to 53%, 56.6%, 75%, and 67.2% in Poland, the United States of America, China, and Italy, respectively (Li et al. 2016; Zhang et al. 2020). The corrosion of iron pipes occurs through an electrochemical process in which oxidants, such as chlorine and dissolved oxygen, react with zerovalent iron, releasing iron oxides and iron hydroxides into water (Zhang et al. 2022). The long-term accumulation of these iron corrosion by-products on pipe walls results in the formation of a corrosion scale composed of multilayered tubercules (Zhang et al. 2022). However, changes in water chemistry disrupt scale stability, thus causing the release of ferric or ferrous ions into the water, leading to a metallic taste and red water (Li et al. 2016; Zhang et al. 2022). Additionally, the corrosion of cement-mortar lined ductile iron pipe leaches out metals into drinking water, such as lead, cadmium, chromium, and aluminum (Gonzalez et al. 2013).

Copper and lead pipes have been widely used for decades as a component of household plumbing systems. Pitting corrosion is a localized corrosion prevalent in copper pipes. This form of corrosion penetrates the pipe walls at advanced stages of propagation, resulting in pinholes, which are the primary source of leaks in this type of pipe (Vargas et al. 2017).

Corrosion and scaling can cause the deterioration of water distribution systems. Scale deposits decrease the internal diameter of water pipes. Furthermore, continuous water corrosion of the inner surface of water pipes leads to recurring leaks, which reduces water pressure and the water network efficiency. These degradations engender additional costs, as they might require direct interventions on the affected parts of water distribution systems in order to replace the affected components as well as decrease water loss and water damage to the infrastructure due to leaks. In Morocco, the water losses in urban distribution systems due to leaks present an average of 27% (Dahan 2017). Moreover, water corrosion and scaling also decrease the efficiency of home appliances and result in their early failure and replacement. According to a study conducted by the Moroccan Confederation for Anticorrosion Certification (COMACAC), corrosion costs account for up to 5% of the national GDP of Morocco (Donadio et al. 2019).

Corrosion and scaling in water distribution systems cause several health problems for consumers, mainly due to the release of heavy metals, which, when present in excess amounts in drinking water, induce a variety of adverse effects, such as cancerogenic risks, impaired kidneys and liver function, and degeneration of neurological and brain function, including Alzheimer's disease, multiple sclerosis, and Parkinson's disease (Mohod and Dhote 2013; Ravindra and Mor 2019).

Water stability indices are used to determine the corrosive and scaling tendencies of water. The most widely used are the Langelier Saturation Index (LSI), the Puckorius Scaling Index (PSI), the Ryznar Stability Index (RSI), and the Aggressive Index (AI). These indices were successfully used before to determine the scaling and corrosive potential of drinking water in other countries. For example, a study in Meshginshahr City in Iran showed that drinking water was corrosive and scale-forming using LSI and RSI (Hasani et al. 2020). Another study in Ecuador found that the drinking water in Azogues City is corrosive based on the LSI, RSI, and PSI (García-Ávila et al. 2018).

Despite the numerous problems that corrosion and scaling pose in water distribution systems and their influence on drinking water quality, there is a lack of comprehensive studies centered around the corrosive and scaling potential of drinking water in Morocco, as most studies on water quality in Morocco focus on surface water and groundwater quality. As such, not much data is available on the corrosive and scaling potential of drinking water in Morocco, despite its importance for the maintenance of water distribution systems and water quality. Except for a few studies conducted on the scaling power of water in the Tiznit region and the tourist area of Agadir in Morocco, which show that the water in these areas is scaling (Ben-Aazza et al. 2017; Belattar et al. 2020). To provide more information on the water scaling and corrosive potential in Morocco and facilitate drinking water quality control to ensure safe drinking water, this study used the Langelier Saturation Index (LSI), the Ryznar Stability Index (RSI), the Puckorius Scaling Index (PSI), and the Aggressive Index (AI) as well as other relevant physicochemical parameters used for the determination of the water stability indices (pH, temperature, calcium hardness, total dissolved solids, total alkalinity), and chloride.

Therefore, taking into account the numerous health risks to the population and the economic losses that drinking water corrosion and scaling engender, as well as the lack of research on drinking water stability in Morocco, this study aimed to assess drinking water stability and investigate its corrosive and scaling potential in several cities, mainly in the Rabat-Salé-Kenitra region, of Morocco.

MATERIALS AND METHODS

Sample collection and physicochemical analysis

In this study, 100 drinking water samples were mainly collected from cities in the Rabat-Salé-Kenitra region of Morocco, between May 2022 and October 2022, according to each city's population density and area (Fig. 1). The map shows all the sampling locations and was created using the QGIS 3.28.3 software with the Esri World topographic map as the base map.

Measurement of pH, TDS, and temperature

An HI99301 portable high-range EC/TDS meter was used to detect the temperature and the total dissolved solids (TDS). The pH was measured using an HI8519 pH meter.

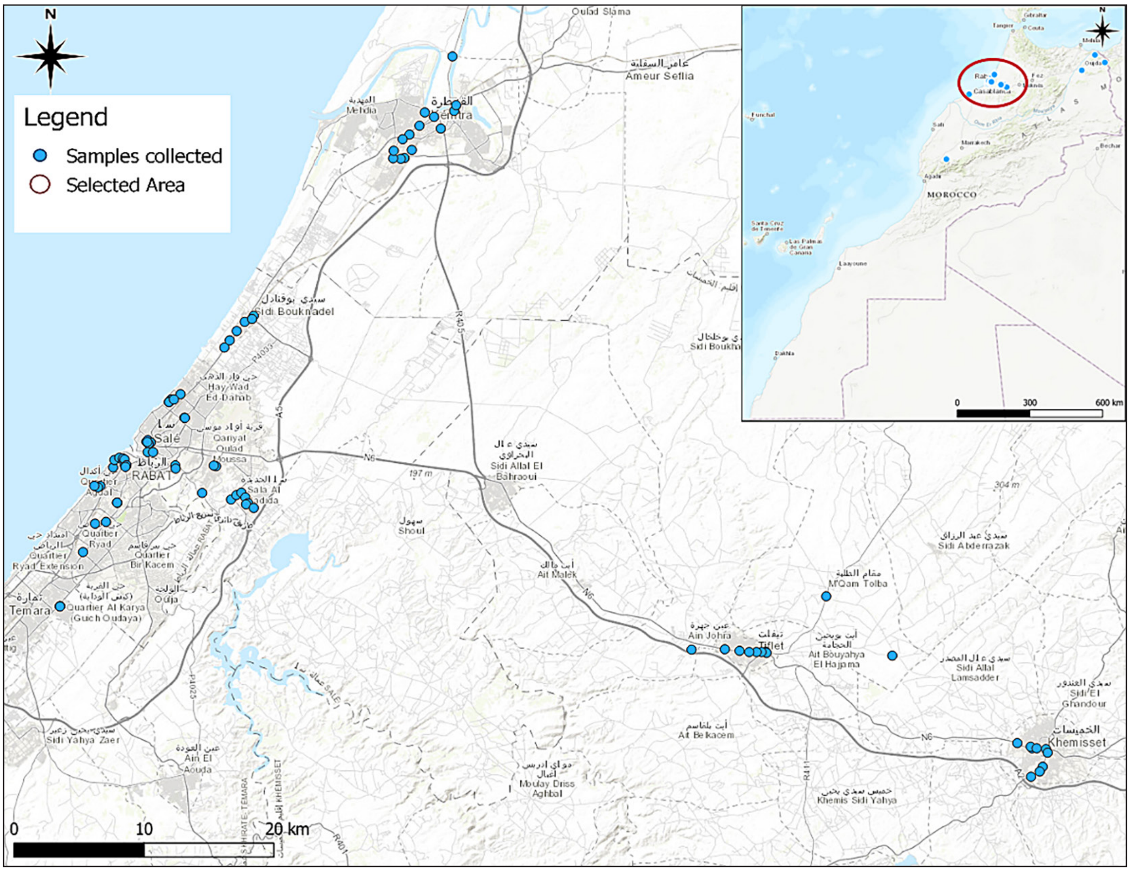

Figure 1. Map of the sampling locations in Morocco

Analyses of total alkalinity, chloride, and calcium

The total alkalinity was measured using the hydrochloric acid titration method-based HI-3811 Alkalinity test kit. A CPC method-based 80004 AT kit was used to measure the calcium. Chloride was determined using a Colorimetric Method Kit 80005, based on the thiocyanate method.

Langelier saturation index

The Langelier saturation index (LSI) determines the potential of water to precipitate calcium carbonate. It is the difference between the pH (measured) and the pHs (pH at saturation). The pHs is calculated using the values of the calcium carbonate concentration, and total dissolved solids (TDS), total alkalinity, temperature. Water is stable when the value of LSI is equal to zero. However, if LSI is negative, the water is undersaturated and tends to dissolve scale (corrosive), and if LSI is positive, the water is supersaturated and tends to scale (Khorsandi et al. 2016; Gholizadeh et al. 2017). LSI is defined as follows:

$$LSI = pH - pHs \quad (1)$$

where: pH represents the measured pH of water and pHs refers to the pH at saturation in calcite or calcium carbonate and is calculated as follows:

$$pHs = (9.3 + A + B) - (C + D) \quad (2)$$

where: the values of A, B, C, D can be obtained from:

$$A = \frac{(Log[TDS] - 1)}{10} \quad (3)$$

$$B = -13.12 \times Log(°C + 273) + 34.55 \quad (4)$$

$$C = Log[Ca^{2+}\ as\ CaCO_3] - 0.4 \quad (5)$$

$$D = Log[Total\ alkalinity\ as\ CaCO_3] \quad (6)$$

Ryznar stability index

The Ryznar stability index (RSI) resembles the Langelier saturation index, as both are based on the water saturation level and can determine the tendencies of water to precipitate calcium carbonate based on empirical data. A value of RSI between 6.2 and 6.8 means that the water is stable. When the RSI value ranges between 5.5 and 6.2, water is considered to be scaling, but a heavy scale is expected to be formed when the value of RSI is inferior to 5.5. Furthermore, when the value of RSI is between 6.8 and 8.5, the water is corrosive, and an RSI greater than 8.5 means that the studied water is very corrosive (Hoseinzadeh et al. 2013; Gholizadeh et al. 2017). RSI is a variation of LSI and is defined as follows:

$$RSI = 2(pHs) - pH \quad (7)$$

Puckorius scaling index

The Puckorius scaling index (PSI) considers the buffering capacity of water and the maximum precipitates needed to bring water to equilibrium. PSI is based on RSI, but instead of using the measured pH, equilibrium pH (pHeq) is used (Gholizadeh et al. 2017; Eslami et al. 2020). When the value of PSI is less than 6, water is supersaturated and tends to be scaling, but when PSI is greater than 6, water is undersaturated and presents corrosive tendencies. PSI can be determined as follows:

$$PSI = 2(pHs) - pHeq \quad (8)$$

where: pHs represents the pH at saturation and pHeq refers to the pH at equilibrium and is calculated as follows:

$$pHeq = 1.465 \times log[Total\ alkalinity\ as\ CaCO_3] + 4.54 \quad (9)$$

Aggressive index

The aggressive index (AI) was first designed for monitoring water in asbestos pipes. An AI value between 10 and 12 indicates that water is moderately aggressive. Water becomes highly aggressive when the AI value is less than 10. Conversely, when the AI value is greater than 12, the water is non-aggressive (Hoseinzadeh et al. 2013; Gholizadeh et al. 2017). The equation to obtain AI is as follows:

$$AI = pH + Log(A \times H) \quad (10)$$

where: A – refers to the total alkalinity (mg/l as $CaCO_3$);
H – represents the calcium hardness (mg/l as $CaCO_3$).

Statistical analyses

The R programming language (version 2022.12.0+353) was utilized for the statistical analyses and the creation of the charts. Excel spreadsheet software was employed to calculate the water stability indices (LSI, RSI, PSI, AI) and all relevant parameters (pHs, pHeq, A, B, C, D).

RESULTS

The physicochemical analyses show that the mean of calcium hardness for the cities of Rabat-Salé-Bouknadel-Kenitra was 218.26 ± 79.39 mg/l as $CaCO_3$, and the mean for Khemisset-Tiflet cities was 210.69 ± 116.76 mg/l as $CaCO_3$. Alkalinity mean values were 185.15 ± 49.92 mg/l as $CaCO_3$ and 139.42 mg/l ± 29.50 mg/l as $CaCO_3$ for Rabat-Salé-Bouknadel-Kenitra and Khemisset-Tiflet, respectively.

Compared to Khemisset-Tiflet, which had a minimum temperature of 25 °C and a maximum temperature of 25.9 °C, Rabat-Salé-Bouknadel-Kenitra cities displayed a more substantial temperature variance, with a minimum of 21.3 °C and a maximum of 28 °C.

Table 1. Summary of the analyzed physicochemical parameters

Parameter	Min.	1st Quartile	Median	Mean	3rd Quartile	Max.	Standard Deviation
Calcium hardness (mg/l as $CaCO_3$)	33.23	139.28	203.28	212.57	267.85	563.08	98.18
Total alkalinity (mg/l as $CaCO_3$)	54	128.2	178.5	173.6	213	288	52.04
pH	7	7.428	7.6	7.577	7.71	8.2	0.23
TDS (mg/l)	160	400	430	597.5	560	3460	435.74
Temperature (°C)	21.3	24.55	25.2	25.06	26.2	28.1	1.58
Chloride (mg/l)	0.1	226.7	308.3	418.7	500.1	3220.1	407.75

Table 2. Summary of the calculated water stability indices

Index	Min.	1st Quartile	Median	Mean	3rd Quartile	Max.	Standard deviation	Nature of water
LSI	-1.1248	-0.1546	0.1475	0.1158	0.397	0.8548	0.38	59% supersaturated, likely to scale
RSI	6.182	6.805	7.217	7.345	7.872	9.84	0.68	75% corrosive
PSI	5.715	6.439	6.969	7.132	7.839	10.352	0.86	95% corrosive
AI	11.42	12.19	12.45	12.41	12.67	13.15	0.35	87% non-aggressive

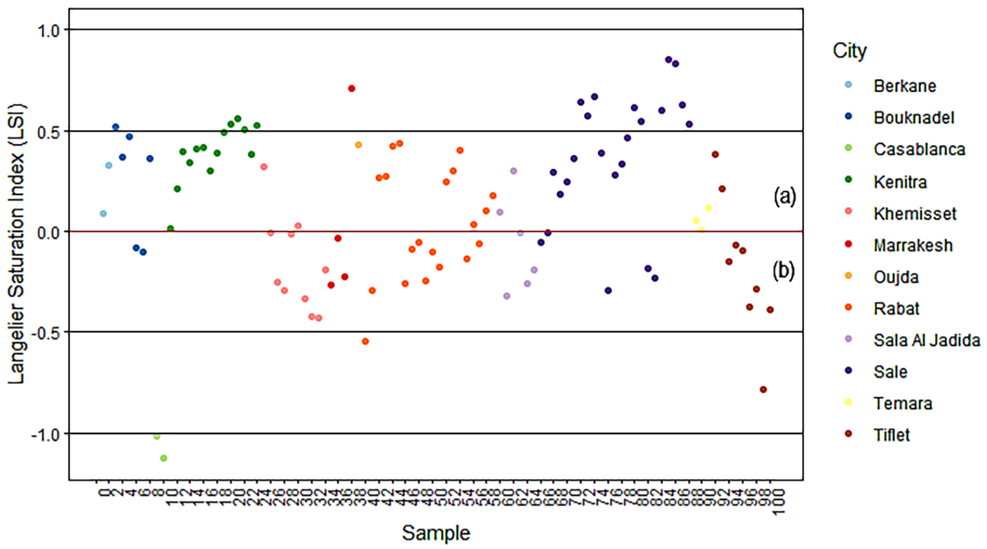

Figure 2. Values of the calculated Langelier saturation index (LSI) for each sample and city. (a) Water is supersaturated and likely to scale when the LSI is positive. (b) Water is undersaturated and tends to be corrosive when the LSI is negative

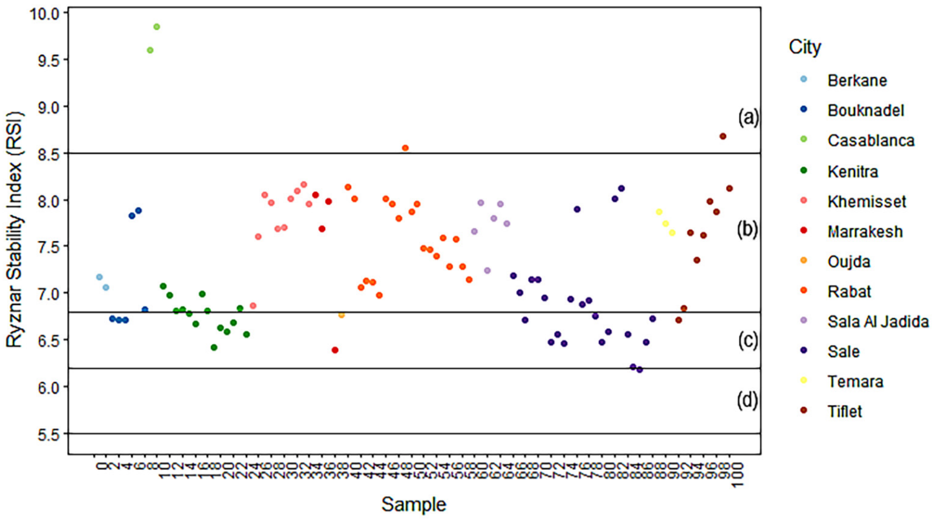

Figure 3. Values of the calculated Ryznar stability index (RSI) for each sample and city. (a) Very corrosive water, (b) Corrosive water, (c) Stable water, (d) Scaling water

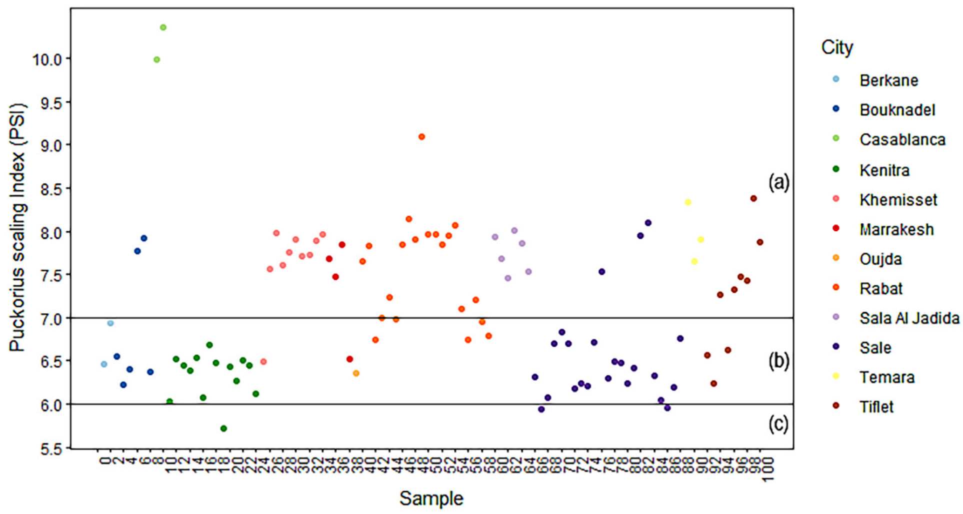

Figure 4. Values of the calculated Puckorius scaling index (PSI) for each sample and city. (a) and (b) Water is undersaturated and tends to be corrosive, (c) Water is supersaturated and tends to scale

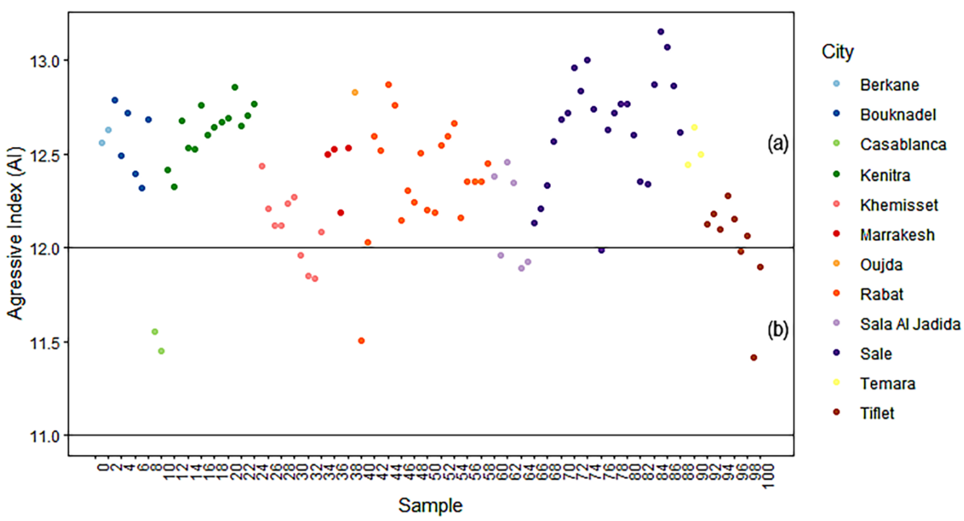

Figure 5. Values of the calculated aggressive index (AI) for each sample and city. (a) Non-aggressive water, (b) Moderately aggressive water

The mean and variance of the total dissolved solids (TDS) in the Khemisset-Tiflet cities (1131.05 ± 603.02 mg/l) were significantly greater than the cities of Rabat-Salé-Bouknadel-Kenitra (437.46 ± 82.27 mg/l). The same pattern was registered for chloride concentrations between the two groups of cities.

The pH mean values were 7.62 ± 0.23 for Rabat-Salé-Bouknadel-Kenitra and 7.40 ± 0.17 for Khemisset-Tiflet.

Table 1 presents the minimum, maximum, median, mean, first and third quartiles, and standard deviation of the measured physicochemical parameters used for the determination of the water stability indices as well as chloride.

Table 2 shows the summary of the calculated water stability indices (LSI, RSI, PSI, and AI). Figures [2-5] provide the values and variance of the Langelier saturation index (Figure 2), the Ryznar stability index (Figure 3), the Puckorius scaling index (Figure 4), and the aggressive index (Figure 5) for each sample and city.

DISCUSSION

The analysis of the water stability indices shows a variation in the corrosive nature of the water between each index. The results show that the means of the pH, total alkalinity, calcium hardness, chloride, and temperature are 7.577 ± 0.23, 173.6 ± 52.04 mg/l as $CaCO_3$, 212.57 ± 98.18 mg/l as $CaCO_3$, 418.72 ± 407.75 mg/l, and 25.16 ± 1.5 °C (Table 1), respectively. All water samples had a pH value that respects the Moroccan standard set between 6.5 and 8.5. National standards for alkalinity, total dissolved solids, calcium, and calcium hardness are not available.

The water in the studied cities is 59% supersaturated, likely to scale, and 87% non-aggressive based on LSI (Figure 2) and AI (Figure 5), respectively, and shows a corrosive tendency of 75% and 97% based on RSI (Figure 3) and PSI (Figure 4), respectively. The samples with uniform corrosive indicators (all indices showed that water tended to dissolve scale and be corrosive) had an alkalinity value less than 100 mg/l as $CaCO_3$. Alkalinity is the measurement of the acid-neutralizing ions, such as bicarbonate and hydroxide, present in water (Trick et al. 2018). Low water alkalinity increases the rate at which cast iron pipes corrosion occurs along with the quantity of iron released into the water (Trick et al. 2018; Li et al. 2020).

The samples collected from Rabat, Bouknadel, Salé, and Kenitra were mainly supersaturated and tended to scale according to the LSI (Figure 2), with a percent of 50%, 67%, 78%, and 100%, respectively. The water in Tiflet and Khemisset was mainly corrosive based on the LSI (Figure 2). Rabat, Salé, Bouknadel, and Kenitra are all coastal cities with two drinking water supply systems. The Bouregreg drinking water production system mainly supplies Rabat, Salé, and Bouknadel, while the North Fouarat supply system supplies Salé, Bouknadel, and Kenitra. Meanwhile, Khemisset and Tiflet are inland cities with the El Kansera Dam as the water supply source. Thus, the variation in the corrosive and scaling tendencies of water between Rabat-Salé-Bouknadel-Kenitra and Tiflet-Khemisset may be due to the difference in water sources between the two groups.

According to RSI (Figure 3), the highest percentage of stable water was found in Kenitra (50%), Bouknadel (50%), and Salé (48%). These three cities are the only ones where all samples were non-aggressive based on AI (Figure 5). All of these samples had a calcium hardness value higher than 240 mg/l as $CaCO_3$. Calcium carbonate forms a protective layer on the surface of pipes, thus decreasing the rate of corrosion (B. Baird et al. 2017). Compared to soft water, galvanized, steel, and cast-iron piping have better performance and lower corrosion rates in hard water, whereas copper pipes experience pitted corrosion in hard water (Brossia 2018). Calcium carbonate precipitation rate increases in high temperatures, leading to water scale formation, excess deposits, plugging issues, and decreased thermal conductivity in domestic appliances (Richards et al. 2018). Casablanca was the only city where all the water samples were corrosive (LSI and PSI), highly corrosive (RSI), and aggressive (AI).

Kenitra recorded the lowest chloride concentrations (0.1 mg/l and 6.3 mg/l). The highest chloride values were recorded in Bouknadel and Tiflet, with 1424.57 mg/l and 3220.1 mg/l, respectively, surpassing the national standard set at 750 mg/l. At concentrations as low as ten mg/l, chloride may damage metallic pipes and accelerate corrosion by forming complexes with metals such as lead (Brossia 2018). High chloride content increases salinity and affects microbial growth, including the bacteria that reduce or oxidize iron, known to increase corrosion (Xu et al. 2022). Chloride could also increase the corrosive and scaling tendencies of the samples found to be scaling and stable according to the LSI, RSI, PSI, and AI. Moreover, the studied samples had a high chloride mean value of 418.7 ± 407.75 mg/l. Thus, chloride should be closely monitored to avoid potential corrosion and pipe materials release, notably heavy metals.

An assessment of the corrosive and scaling potential of drinking water supplied from Disi to Amman in Jordan using the LSI, RSI, PSI, and AI showed that the water had corrosive tendencies of 34%, 31%, 28%, and 31%, respectively (AlShamaileh and AlRawajfeh 2017). A study conducted in the north of Iran on drinking water quality showed that 98.11%, 79.25%, 18.88%, and 1.89% of samples were scaling based on the LSI, PSI, RSI, and AI, respectively (Mokhtari et al. 2020). In another study in Iran evaluating corrosion and scaling tendencies in water distribution systems of Torbat Heydariye, 40%, 100%, 93.3%, and 33.3% of the water network had corrosive tendencies based on the LSI, RSI, PSI, and AI, respectively (Mirzabeygi et al. 2017).

The results indicate that the collected drinking water samples show corrosive tendencies of 41%, 75%, 97%, and 13% based on the LSI (Figure 2), RSI (Figure 3), PSI (Figure 4), and AI (Figure 5), respectively. The variation between each index is also present in other studies. Therefore, it is recommended to take into consideration revising and instilling strict national standards of the parameters analyzed in this work, namely alkalinity, calcium hardness, total dissolved solids, and chloride as they can affect the corrosive and scaling nature of water and the overall quality of drinking water. This work shows the variation in the corrosive and scaling potential of drinking water between different cities in Morocco. The findings might help with better monitoring of drinking water quality throughout water distribution systems in Morocco to maintain the quality and stability of water and decrease corrosion and scaling, thus providing safe drinking water to the population and minimizing the health risks associated with heavy metal release, and reducing economic losses due to water corrosion and scaling impact on water distribution systems and domestic appliances.

CONCLUSIONS

This study investigated the corrosive and scaling potential of 100 samples collected mainly from the Rabat-Salé-Kenitra region of Morocco. The drinking water in the different studied cities was found to be 59% supersaturated and likely to scale based on LSI, showing corrosive tendencies of 75% and 95% according to the RSI and PSI respectively, and 87% non-aggressive based on the AI. The drinking water samples in the cities of Rabat, Salé, Bouknadel, and Kenitra were mostly supersaturated and likely to scale, and the highest percentage of stable water was registered among the samples collected from Kenitra, Salé, and Bouknadel. Meanwhile, the drinking water samples from the Khemisset and Tiflet cities were mostly corrosive. The corrosive and scaling nature of water varied according to the city drinking water supply system source, and the cities with the same drinking water supply system recorded similar corrosive and scaling tendencies, explaining the variation of drinking water scaling and corrosive potential between the cities of Rabat-Salé-Bouknadel-Kenitra and the cities of Khemisset-Tiflet. The pH values were all within national standards. The chloride mean value was 418.7 ± 407.75 mg/l, with a maximum registered concentration of 3220.1 mg/l in Tiflet, much higher than the national standard set at 750 mg/l. This study gives more insight into the scaling and corrosive potential of drinking water in Morocco and its variation between different cities of the Rabat-Salé-Kenitra region. Due to the importance of chloride, total dissolved solids, alkalinity, and calcium in water quality control and the determination of the corrosive and scaling potential of drinking water, it is recommended that national standards be revised and instilled to ensure better supervision of these parameters, improved stabilization of drinking water, and provide safe drinking water to avoid potential health risks.

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REFERENCES

1. AlShamaileh E, AlRawajfeh A. 2017. Assessment of Quality and Potential of Scale Formation and Corrosivity of Drinking Water Supplied From Disi To Amman, Jordan. Fresenius Environ Bull, 26(January), 634–645.

2. Baird BR, Eaton DA, Rice WE. 2017. Standard methods: For the Examination of Water and Waste water 23rd Edition. 23rd ed. B. Baird R, D.Eaton A, W.Rice E, editors. Washington, D.C: American Water Works Association (AWWA, WEF and APHA).
3. Belattar M., Hadfi A., Aazza S Ben, Mohareb S, Hafid N, Driouiche A. 2018. Characterization of scale deposits formed in sanitary hot water pipelines in the northern tourist zone of Agadir city. Mediterr J Chem., 7(2), 86–92.
4. Belattar M., Hadfi A., Ben-Aazza S., Mohareb S., Karmal I., Hafid N., Driouiche A. 2020. Kinetic study of the scaling power of sanitary water in the tourist area of Agadir. Mater Today Proc., 22, 61–63.
5. Ben-Aazza S, Hadfi A, Belattar M, Hafid N, Driouiche A. 2017. Characterization of Scaling Power of Tiznit Region Waters. J Water Resour Prot. 09(04):339–344.
6. Brossia S. 2018. Corrosion of pipes in drinking water systems. Third Edit. Elsevier Inc.
7. Dahan S. 2017. Managing Urban Water Scarcity in Morocco. World Bank, Washington, DC.
8. Donadio M, Bakalli M, Dan Z. 2019. Reinforced concrete corrosion prevention/reduction by hydrophobic impregnation. MATEC Web Conf. 289.
9. Eslami F, Salari M, Yousefi N, Mahvi AH. 2020. Evaluation of quality, scaling and corrosion potential of groundwater resources using stability index; case study Kerman province (Iran). Desalin Water Treat, 179, 19–27.
10. García-Ávila F, Ramos-Fernández L, Zhindón-Arévalo C. 2018. Estimation of corrosive and scaling trend in drinking water systems in the city of Azogues, Ecuador. Rev Ambient Água.
11. Gholizadeh A, Mokhtari M, Naimi N, Shiravand B, Ehrampoush MH, Miri M, Ebrahimi A. 2017. Assessment of corrosion and scaling potential in groundwater resources; a case study of Yazd-Ardakan Plain, Iran. Groundw Sustain Dev., 5, 59–65.
12. Gonzalez S, Lopez-Roldan R, Cortina JL. 2013. Presence of metals in drinking water distribution networks due to pipe material leaching: A review. Toxicol Environ Chem., 95(6), 870–889.
13. Hasani K, Sadeghi H, Dargahi A, Vosoughi M, Mokhtari A, Pirasteh M. 2020. Scaling and Corrosion Potential in Drinking Water Distribution Systems of Meshginshahr City, Iran Using Langelier Saturation Index and Ryznar Stability Index. J Adv Environ Heal Res., 9(3), 201–208.
14. Hoseinzadeh E, Yusefzadeh A, Rahimi N, Khorsandi H. 2013. Evaluation of Corrosion and Scaling Potential of a Water Treatment Plant. Arch Hyg Sci, 2(2), 41–47.
15. Khorsandi H, Mohammadi A, Karimzadeh S, Khorsandi J. 2016. Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran. Desalin Water Treat., 57(23), 10585–10592.
16. Kurdi M, Ferdows MS, Maghsoudi A. 2015. Sensitivity of Corrosion and Scaling Indices Based on Ions; Case Study Iran. Water Qual Expo Heal., 7(3), 363–372.
17. Li C Geng, Liu C, Xu W Hui, Shan M Gang, Wu H Xia. 2022. Formation mechanisms and supervisory prediction of scaling in water supply pipelines: A review. Water Res., 222(April), 118922.
18. Li M, Liu Z, Chen Y, Hai Y. 2016. Characteristics of iron corrosion scales and water quality variations in drinking water distribution systems of different pipe materials. Water Res., 106, 593–603.
19. Li M, Liu Z, Chen Y, Korshin G V. 2020. Effects of varying temperatures and alkalinities on the corrosion and heavy metal release from low-lead galvanized steel. Environ Sci Pollut Res., 27(2), 2412–2422.
20. Li P, Wu J. 2019. Drinking Water Quality and Public Health. Expo Heal., 11(2), 73–79.
21. Liu G, Bakker GL, Li S, Vreeburg JHG, Verberk JQJC, Medema GJ, Liu WT, Van Dijk JC. 2014. Pyrosequencing reveals bacterial communities in unchlorinated drinking water distribution system: An integral study of bulk water, suspended solids, loose deposits, and pipe wall biofilm. Environ Sci Technol., 48(10), 5467–5476.
22. Liu G, Zhang Y, Knibbe WJ, Feng C, Liu W, Medema G, van der Meer W. 2017. Potential impacts of changing supply-water quality on drinking water distribution: A review. Water Res., 116, 135–148.
23. Mirzabeygi M, Yousefi N, Abbasnia A, Youzi H, Alikhani M, Mahvi AH. 2017. Evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water supply networks, Iran. J Water Supply Res Technol., 66(6), 416–425.
24. Mohod CV, Dhote J. 2013. Review of Heavy Metals in Drinking Water and Their Effect on Human Health. Int J Innov Res Sci Eng Technol, 2(7), 2992–2996.
25. Mokhtari Z, Yousefzadeh S, Safari M, Brahmand MB, Soleimani H, Yaghmaeian K. 2020. Assessment of the drinking water quality of a rural distribution network in the north of iran by corrosion and scaling indices. Desalin Water Treat., 206, 27–33.
26. Ravindra K, Mor S. 2019. Distribution and health risk assessment of arsenic and selected heavy metals in Groundwater of Chandigarh, India. Environ Pollut., 250, 820–830.
27. Richards CS, Wang F, Becker WC, Edwards MA. 2018. A 21st-Century Perspective on Calcium Carbonate Formation in Potable Water Systems. Environ Eng Sci. 35(3), 143–158.

28. Trick JK, Stuart M, Reeder S. 2018. Contaminated Groundwater Sampling and Quality Control of Water Analyses. 2nd ed. Elsevier B.V.
29. Vargas IT, Fischer DA, Alsina MA, Pavissich JP, Pablo P, Pizarro GE. 2017. Copper corrosion and biocorrosion events in premise plumbing. Materials (Basel), 10(9), 1–30.
30. Villanueva CM, Kogevinas M, Cordier S, Templeton MR, Vermeulen R, Nuckols JR, Nieuwenhuijsen MJ, Levallois P. 2014. Assessing exposure and health consequences of chemicals in drinking water: Current state of knowledge and research needs. Environ Health Perspect, 122(3), 213–221.
31. Xu P, Zhao M, Fu X, Zhao C. 2022. Effect of chloride ions on the corrosion behavior of carbon steel in an iron bacteria system. RSC Adv., 12(24), 15158–15166.
32. Zhang H, Liu D, Zhao L, Wang J, Xie S, Liu S, Lin P, Zhang X, Chen C. 2022. Review on corrosion and corrosion scale formation upon unlined cast iron pipes in drinking water distribution systems. J Environ Sci (China)., 117, 173–189. doi:10.1016/j.jes.2022.04.024.
33. Zhang H, Zhao L, Liu D, Wang J, Zhang X, Chen C. 2020. Early period corrosion and scaling characteristics of ductile iron pipe for ground water supply with sodium hypochlorite disinfection. Water Res., 176, 115742.