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Assessment of the drinking water quality of a rural distribution network in the north of Iran by corrosion and scaling indices

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ABSTRACT

Corrosion and scaling occur due to the physicochemical reactions between the inner surface of pipes, cations, and anions. These reactions lead to the entrance of heavy metals into the water and scale formation on the inner surface of pipes. The present cross-sectional study conducted in 2015–2017 aimed to investigate the drinking water quality of rural distribution networks in the north of Iran by using corrosion and scaling indices. Samples were taken from 53 points of the distribution network by random sampling and sent to the laboratory under standard conditions. The mean chemical parameters of the total dissolved solids, electrical conductivity, pH, chloride concentration, bicarbonate, and total hardness were 687.83 ± 267.69 mg/L; 1,058.21 ± 411.83 µmoh/cm; 7.32 ± 0.28; 173.04 ± 12.08 mg/L; 530.52 ± 157.39 mg/L; and 511.39 ± 153.00 mg/L, respectively. The corrosion and scaling indices, including the Larson–Skold index (LS), Ryznar stability index (RSI), Puckorius scaling index (PSI), Langelier saturation index (LSI), and aggressiveness index (AI) were also studied. According to the results, the average values of LSI, RSI, PSI, LS, and AI were 0.41 (±0.59), 6.50 (±0.59), 5.32 (±0.69), 0.50 (±0.24), and 10.54 (±0.46), respectively. Moreover, according to LSI, RSI, PSI, LS, and AI indices, the scaling tendency in the water network was 98.11%, 18.87%, 79.25%, 92.45%, and 1.89%. The spatial distribution of scaling indices was determined using the geographic information system.

Keywords: Water quality; Scaling and corrosion; Larson–Skold index; Ryznar stability index; Puckorius scaling index; Langelier saturation index

1. Introduction

The increase in population, urban development, industrialization, extreme utilization of water resources, and unprocessed waste and wastewater disposal have greatly affected the quality of water resources [1,2]. The report of the United Nations has raised serious concerns about the growing population and decreased access to freshwater. Due to the lack of proper management and inaccessibility to professional experts, this problem will become more severe in developing countries [3–5]. Currently, 1.1 billion people are deprived of access to safe drinking water, and 2.5 billion do not have access to basic health services. Waterborne diseases cause more than 5 million deaths/y [6]. Groundwater resources are the most important sources of water demand for agriculture and drinking in Iran and other areas with similar climatic conditions [7]. Therefore, regulatory monitoring of the quality of these resources

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seems to be essential for preventing adverse health effects. The corrosion and scaling potential is one of the most notable indices in assessing the quality of drinking water [8]. In distribution networks, corrosion occurs due to physicochemical or electrochemical reactions between water and the pipe. Corrosion of pipes results in the entrance of heavy metals such as lead and cadmium into the water, and consequently endangers the public health [9]. Scaling through the reaction of calcium and magnesium cations with the anions in water leads to the formation of a deposited layer on the inner surfaces of the pipes. The factors affecting these two processes include water flow rate, alkalinity, electrical conductivity, residual chlorine, hardness, dissolved oxygen (DO), total dissolved solids (TDS), pH, contact time, temperature, and pipe age [10,11]. An investigation of the water distribution system in Iran indicates that approximately 30% of water is wasted via leakage caused by corrosion [12]. In countries such as Australia and Japan, the annual cost of corrosion is estimated at 3%–4% of the gross domestic product (GDP). A study conducted by the Federal Highway Administration (FHWA) (2002) reported that the cost of corrosion in the US public water systems is $22 billion/y, which includes 3.1% of GDP [13].

The present study aimed to determine the physicochemical parameters and calculate the corrosion and scaling potential during 2015–2017 in the rural water distribution network of Rasht, Iran. The results of this study can help administrators to improve the quality of water. Due to the high cost of testing, seasonal sampling was not possible. This was the first study to examine the following indices in this region: Larson–Skold index (LS), Ryznar stability index (RSI), Puckorius scaling index (PSI), Langelier saturation index (LSI), and aggressiveness index (AI). The spatial distribution of corrosion indices was performed by using the geographic information system (GIS), which is a powerful tool for assessing water quality, preventing flooding, and proposing solutions for water resource problems on a regional or local scale [14].

2. Materials and methods

2.1. study area

The study area was the rural distribution network in Rasht, a city in the center of Guilan Province in the north of Iran. The three main parameters of the economy of Guilan Province include agriculture, tourism, and industry. The latitude and longitude of the city are 37°,17′N and 49°,35′E, respectively [15]. Rasht covers a land area of 180 km^2 and is located about 30 km away from the Caspian Sea [16]. The average monthly temperature and annual precipitation are 15.8°C and 1,500 mm, respectively [17]. Fig. 1 represents the study area and location of sampling points.

2.2. Sample collection and analysis

This descriptive cross-sectional study was conducted on the drinking water of Rasht's rural distribution network in 2015–2017. Fifty-three samples were collected from 19 rural areas, and simple random sampling was performed based on the population of each village. Samples were transferred to the laboratory under standard conditions, and physical and chemical parameters were measured based on APHA standard methods (Table 1) [18]. GIS is a common tool for managing spatial data and surveying the spatial and temporal quality of water [9]. GIS software version 9.3 was used

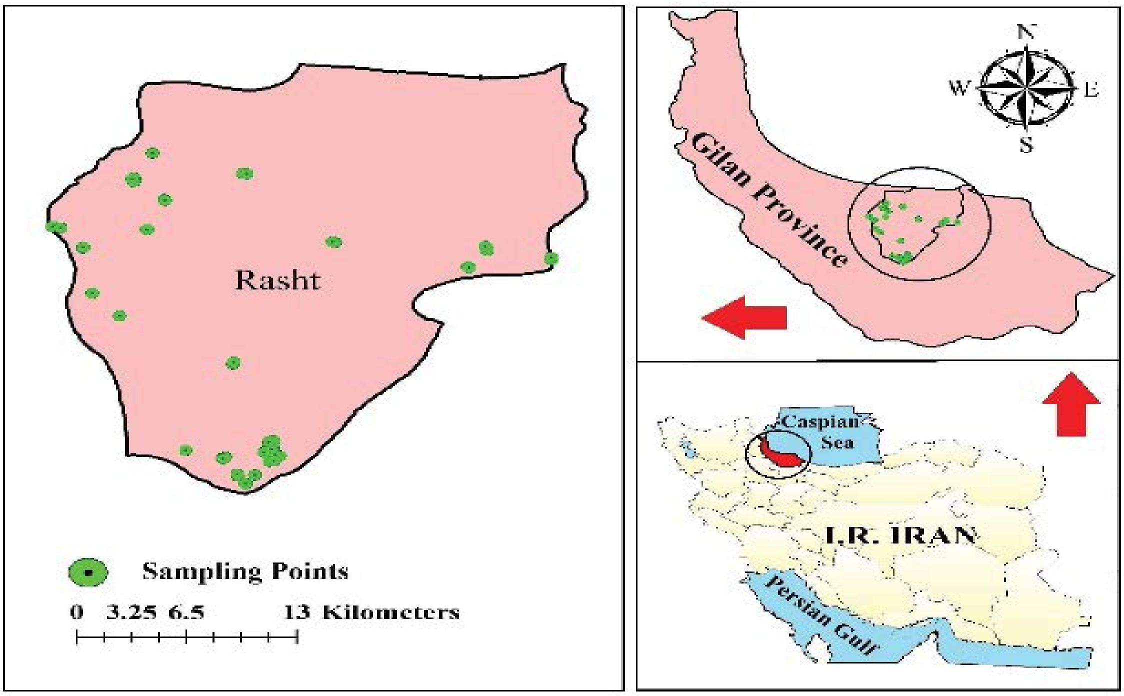

Fig. 1. Location map of the study area and sampling sites, Rasht, Iran.

Table 1
Parameter measurement methods

Parameter	Method
pH	pH meter
EC (μmoh/cm), TDS (mg/L)	EC meter
HCO_3^-, TH, Cl^-, Mg^{2+}, and Ca^{2+} (mg/L)	Titrimetric method (with EDTA)
SO_4^{2-}, NO_2^-, NO_3^-, PO_4^{2-}, and F^- (mg/L)	Spectrophotometric
K^+, Na^+ (mg/L)	Flame photometric

to display the corrosion and scaling indices in different regions.

2.3. Calculation of corrosion and scaling indices

Microsoft Office Excel 2013 was used to analyze the corrosion and scaling indices, namely LS, RSI, PSI, LSI, and AI. Table 2 presents the calculation of the above-mentioned indices [8,19,20].

3. Results and discussion

Corrosion and scaling indices were adopted to evaluate rural water quality in Rasht. After calculation indices, the layers were prepared in ArcGIS based on field information. Fig. 2 illustrates the spatial changes of the rural distribution network of drinking water in Rasht during 2015–2017. The results of physical and chemical experiments are presented in Table 3. Furthermore, Table 4 shows the values of corrosion and scaling indices.

According to the standard established in Iran, the optimum pH for drinking water falls in the range of 7–8.5. The mean pH value of the samples was 7.32, which is approximately within the normal range [21]. The average value of the samples' electrical conductivity was 1,058.21 μmoh/cm. Furthermore, the mean value of TDS was 687.83 mg/L. HCO_3^- is one of the most significant factors in the creation of hardness [21]. The mean concentration of HCO_3 was 530.52 mg/L. The average value of total hardness, in terms of calcium carbonate, was measured as 511.39 mg/L. The appearance of chloride in water can be due to the weathering of stones and soils or urban wastewater [22]. This element can create high amounts of corrosion in steel pipes [23].

The average of chloride in samples was 173.04 mg/L, which is lower than the recommended level of the standard established in Iran (600 mg/L) [21]. Sulfate and magnesium produce undesirable effects in the gastrointestinal tract at high concentrations [24]. The average sulfate and magnesium concentration in the samples equaled 86.30 and 25.66 mg/L, respectively, which is less than the standard criteria in Iran (400 and 150 mg/L, respectively). Furthermore, the average phosphate concentration in the samples was 0.61 mg/L [21].

Nitrate is one of the most common chemical pollutants in aquatic environments and groundwater resources throughout the world. It is introduced to the environment in different ways such as improper waste disposal, animal faeces, and nitrogen fertilizers [25–27]. The effects of the presence of nitrogen compounds in drinking water includes the blue baby syndrome, hypertension, thyroid dysfunction, and cancer caused by the production of nitrosamines [28]. The highest concentrations of nitrate and nitrite in this study

Table 2
Corrosion and saturation indices for categorizing the stability of water

Index	Index equation	Results index	Indication
Langelier saturation index (LSI)	pHs – pH = LSI	LSI < 0	Under saturated, tend to dissolve solid $CaCO_3$
		LSI = 0	Saturated, $CaCO_3$ is in equilibrium
		LSI > 0	Super saturated, tend to precipitate $CaCO_3$
Ryznar stability index (RSI)	RSI = 2pHs – pH	RSI < 6	Super saturated, tend to precipitate $CaCO_3$
		6 < RSI < 7	Saturated, $CaCO_3$ is in equilibrium
		RSI > 7	Under saturated, tend to dissolve solid$CaCO_3$
Puckorius scaling index (PSI)	PSI = (2pHeq) – pH_s	PSI < 6	Scaling is unlikely to occur
		PSI > 6	likely to dissolve scale
Larson–Skold index (LS)	LS = (Cl^- + SO_4^{2-})/(HCO_3 + CO_3^{2-})	LS < 0.8	Chloride and sulfate are unlikely to interfere with the formation of protecting film
		0.8 < LS < 1.2	Corrosion rates may be higher than expected
		LS > 1.2	High rates of localized corrosion may be expected
Aggressive index (AI)	Al = pH + log [(AlK)(H)]	Al > 12	Non-aggressive
		10 < Al < 12	Moderately aggressive
		Al < 10	Very aggressive

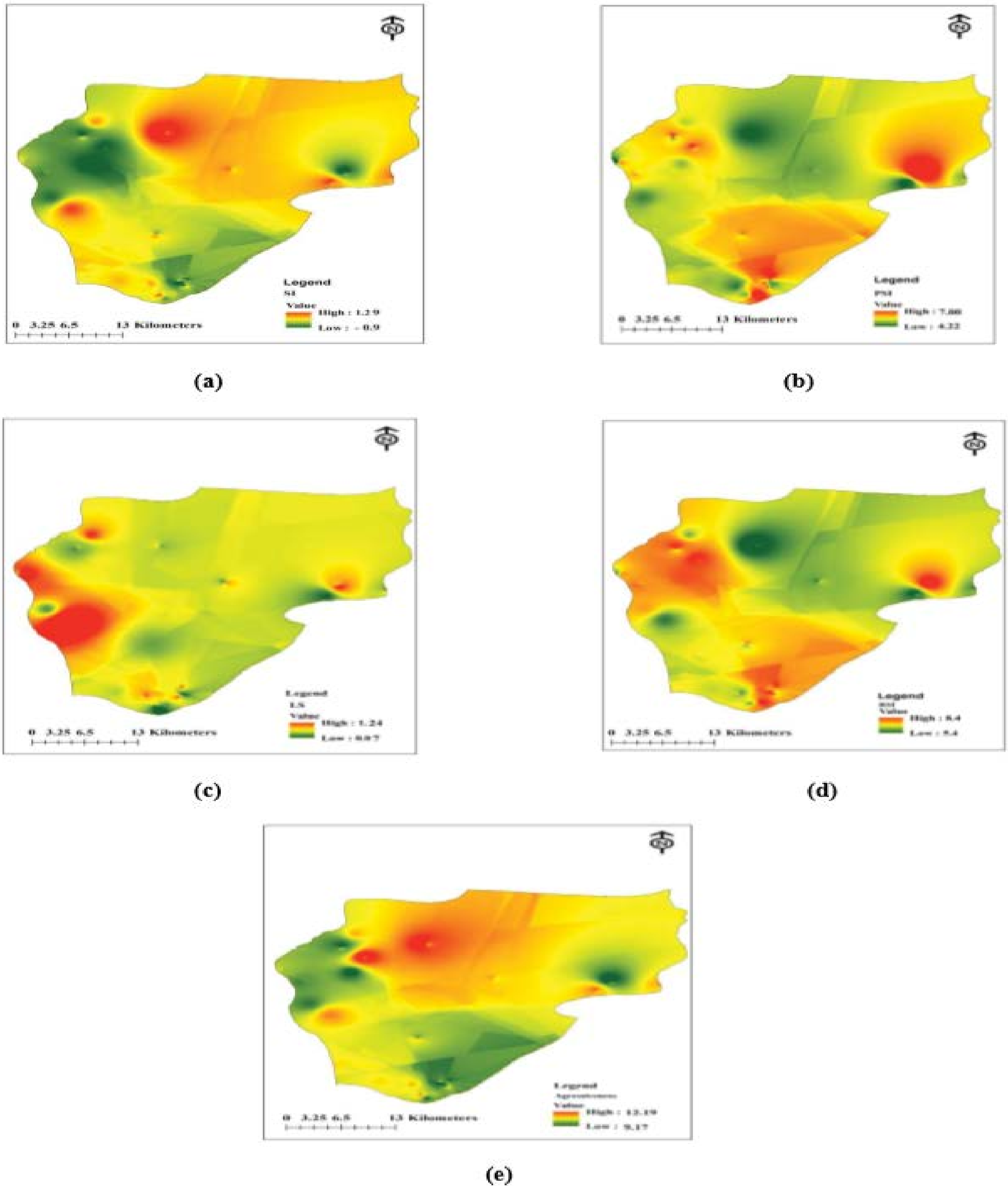

Fig. 2. Spatial distribution of (a) Langelier, (b) Puckorius, (c) Larson–Skold, (d) Ryznar, and (e) aggressive indices of the rural distribution network in the Rasht, Iran.

were 40 mg/L and 0.07 mg/L, respectively. Both concentrations were lower than the World Health Organization (WHO) guidelines [21].

Fluoride is a fundamental micro-element for the body. According to WHO guidelines, the optimal concentration of fluoride in drinking water is 1.5 mg/L [21,29]. The average concentration of fluoride was 0.38 mg/L in this study. A fluoride concentration less or more than these standard concentrations can cause problems such as tooth decay and skeletal fluorosis [7,8]. Given that the announced concentration is much lower than the permitted level, its control is critical for preventing tooth decay in consumers.

Table 3
Statistics of distribution network parameters

Measured parameters	Unit	Minimum	Maximum	Mean	Standard deviation	WHO guideline (2017)	Iran standard (1,053)
pH	–	6.6	8	7.32	0.28	–	7–8.5
EC	µmoh/cm	102	1,980	1,058.21	411.83	–	–
TDS	mg/L	198	1,574	771.3	286.13	–	–
HCO_3^-	mg/L	183	756	530.52	157.39	–	–
TH	mg/L	161.9	806.2	511.39	153.00	–	500
Cl^-	mg/L	5	525	173.04	120.81	–	600
SO_4^{2-}	mg/L	6	240	86.30	50.78	–	400
PO_4^{2-}	mg/L	0.1	2.46	0.61	0.51	–	0.2
NO_3^-	mg/L	0.6	40	7.14	6.36	50	45
NO_2^-	mg/L	0.01	0.07	0.02	0.01	3	0.004
F^-	mg/L	0.03	1	0.38	0.22	1.5	0.6–1.7
K^+	mg/L	0.3	100	13.13	18.16	–	–
Na^+	mg/L	0.96	490	164.72	173.73	50	–
Mg^{2+}	mg/L	4	58	25.66	14.80	–	150
Ca^{2+}	mg/L	50	270	162.47	52.23	–	200

Table 4
Drinking water stability of Rasht rural distribution network

Index	Minimum	Maximum	Mean	Standard deviation
LS	0.07	1.25	0.50	0.24
PSI	4.22	7.00	5.32	0.69
LSI	–0.90	1.29	0.41	0.59
RSI	5.42	8.41	6.50	0.59
AI	9.17	12.19	10.54	0.46

The minimum amount of cations belonged to potassium with an average of 13.13 mg/L. In addition, the average concentration of sodium was 164.72 mg/L. The presence of this element in water may be attributed to the weathering or dissolution of salts in the soil, human activities, and agriculture [24]. The mean concentrations of calcium and magnesium were 162.47 and 25.66 mg/L, respectively. Calcium and magnesium, in combination with anions such as bicarbonate, sulfate, and chloride, can cause hardness. A high concentration of these two elements causes abdominal discomfort and increases the costs of scaling on the tube surface [24,30]. Table 4 presents the results of calculating the following indices: LS, PSI, LSI, RSI, and AI.

Based on the results of the studied indices, the average values of the LS and PSI indices were 0.5 (±0.24) and 5.32 (±0.69), respectively, indicating the scaling of the water distribution network. It is evident that water can form a protective film without the interference of chloride and sulfate ions. The value of LSI was 0.41 (±0.59); thus, the water quality belongs to the scaling category. Moreover, according to the RSI (6.50 ± 0.59) and AI (10.54 ± 0.46) indices, the water belongs to the categories of stabilized and corrosive, respectively.

The findings showed that based on LSI and PSI, 98.11% and 79.25% of samples were scale-forming, respectively. These indices are depicted in Figs. 2a and b. The evaluation of water stability with the LS indicated that 92.45% of the samples belonged to the scaling category (Fig. 2c); moreover, based on the RSI and AI indices, 18.88% and 1.89% of the samples were scale-forming. These indices are shown in Figs. 2d and e. The severity of scaling in the water of the rural distribution network of Rasht was examined by using a GIS, as shown in Fig. 2.

According to the study by Alipour et al. [10] evaluating the corrosion and scaling tendency indices in the drinking water distribution system of Bandar Abbas, Iran, the nature of water was slightly scale-forming based on RSI, PSI, and AI indices. In the case study conducted by Mirzabeygi et al. [8] to assess the corrosion and scaling potential of the drinking water distribution network of Torbat Heydarieh, Iran, the tendencies for corrosion were reported to be 40%, 100%, 93.3%, 94%, and 33.3%, respectively, based on LSI, RSI, PSI, LS, and AI indices. Moreover, Taghipour et al. [12] analyzed 80 samples to evaluate the corrosion and scaling potential of the water distribution network of Tabriz, Iran. The values of LSI, RSI, PSI, and AI indices equaled –0.68

(±0.43), 8.34 (±0.54), 7.86 (±0.36), and 11.23 (±0.36), in that order, suggesting that the water distribution network of Tabriz was corrosive. An assessment of the quality of tap water resources and the potential of scale formation and corrosivity in Tafila Province, south of Jordan, showed that the water samples were slightly corrosive according to the RSI and LSI values [31].

4. Conclusion

The quality of drinking water in the rural distribution network of Rasht was examined. Among the studied chemical parameters, only the concentrations of fluoride and sodium were higher and lower than the WHO guidelines, respectively. The high concentration of sodium can lead to consumer dissatisfaction. Also, a fluoride concentration less than the standard limit can lead to tooth decay. It is essential to control the water quality for protecting health and maintaining the aesthetic effects of these elements. According to the LSI and PSI indices, 93.11% and 79.25% of samples had a tendency to scale formation, respectively. The results obtained from LS and RSI revealed that 92.45% and 18.87% of the water samples can be classified into the scale-forming category. Based on the AI index, only 1.89% of samples were scale-forming. A reduced flow in pipes and clogging are the main effects of scaling. Based on the results of the present study, the rural distribution network of Rasht has a scaling tendency. To overcome this problem, pH, temperature, DO content, and TDS must be periodically monitored.

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References

[1] M. Mirzabeygi, A. Abbasnia, M. Yunesian, R.N. Nodehi, N. Yousefi, M. Hadi, A.H. Mahvi, Heavy metal contamination and health risk assessment in drinking water of Sistan and Baluchistan, Southeastern Iran, Hum. Ecol. Risk Assess, 23 (2017) 1893–1905.

[2] S. Yousefzadeh, E. Ahmadi, M. Gholami, H.R. Ghaffari, A. Azari, M. Ansari, M. Miri, K. Sharafi, S. Rezaei, A comparative study of anaerobic fixed film baffled reactor and up-flow anaerobic fixed film fixed bed reactor for biological removal of diethyl phthalate from wastewater: a performance, kinetic, biogas, and metabolic pathway study, Biotechnol. Biofuels, 10 (2017) 139.

[3] A. Azizullah, M.N.K. Khattak, P. Richter, D.-P. Häder, Water pollution in Pakistan and its impact on public health—a review, Environ. Int., 37 (2011) 479–497.

[4] S. Yousefzadeh, A.R. Matin, E. Ahmadi, Z. Sabeti, M. Alimohammadi, H. Aslani, R. Nabizadeh, Response surface methodology as a tool for modeling and optimization of bacillus subtilis spores inactivation by UV/nano-Fe0 process for safe water production, Food Chem. Toxicol., 114 (2018) 334–345.

[5] E. Ahmadi, S. Yousefzadeh, A. Mokammel, M. Miri, M. Ansari, H. Arfaeinia, M.Y. Badi, H.R. Ghaffari, S. Rezaei, A.H. Mahvi, Kinetic study and performance evaluation of an integrated two-phase fixed-film baffled bioreactor for bioenergy recovery from wastewater and bio-wasted sludge, Renewable Sustainable Energy Rev., 121 (2020) 109674, doi: 10.1016/j.rser.2019.109674.

[6] L. Haller, G. Hutton, J. Bartram, Estimating the costs and health benefits of water and sanitation improvements at global level, J. Water Health, 5 (2007) 467–480.

[7] A.A. Mohammadi, K. Yaghmaeian, F. Hossein, R. Nabizadeh, M.H. Dehghani, J.K. Khaili, A. Mahvi, Temporal and spatial variation of chemical parameter concentration in drinking water resources of Bandar-e Gaz City using geographic information system, Desal. Water Treat., 68 (2017) 170–176.

[8] M. Mirzabeygi, M. Naji, N. Yousefi, M. Shams, H. Biglari, M.H. Mahvi, Evaluation of corrosion and scaling tendency indices in water distribution system: a case study of Torbat Heydariye, Iran, Desal. Water Treat., 57 (2016) 25918–25926.

[9] F.B. Asghari, J. Jaafari, M. Yousefi, A.A. Mohammadi, R. Dehghanzadeh, 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., 24 (2018) 1138–1149.

[10] V. Alipour, K. Dindarloo, A.H. Mahvi, L. Rezaei, Evaluation of corrosion and scaling tendency indices in a drinking water distribution system: a case study of Bandar Abbas city, Iran, J. Water Health, 13 (2014) 203–209.

[11] H. Khorsandi, A. Mohammadi, S. Karimzadeh, J. Khorsandi, Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran, Desal. Water Treat., 57 (2016) 10585–10592.

[12] H. Taghipour, M. Shakerkhatibi, M. Pourakbar, M. Belvasi, Corrosion and scaling potential in drinking water distribution system of Tabriz, northwestern Iran, Health Promotion Perspect., 2 (2012) 103–111.

[13] M. Edwards, Controlling corrosion in drinking water distribution systems: a grand challenge for the 21st century, Water Sci. Technol., 49 (2004) 1–8.

[14] S. Sadat-Noori, K. Ebrahimi, A. Liaghat, Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer, Iran, Environ. Earth Sci., 71 (2014) 3827–3843.

[15] M.A. Moghadam, N. Mokhtarani, B. Mokhtarani, Municipal solid waste management in Rasht City, Iran, Waste Manage., 29 (2009) 485–489.

[16] H. Akbarzadeh Kasani, A. Eslami, Geotechnical properties of Rasht clay and silt in Northern Iran, Int. J. Geotech. Eng., 13 (2019) 566–580.

[17] S. Dezhkam, B.J. Amiri, A.A. Darvishsefat, Y. Sakieh, Simulating the urban growth dimensions and scenario prediction through sleuth model: a case study of Rasht County, Guilan, Iran, GeoJournal, 79 (2014) 591–604.

[18] Association APH, Association AWW, Federation WPC, Federation WE, Standard Methods for the Examination of Water and Wastewater, American Public Health Association, Washington, DC, 1920.

[19] A. Abbasnia, N. Yousefi, A.H. Mahvi, R. Nabizadeh, M. Radfard, M. Yousefi, M. Alimohammadi, Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: Case study of Sistan and Baluchistan province (Iran), Hum. Ecol. Risk Assess., 25 (2019) 988–1005.

[20] D. Rabbani, M. Miranzadeh, A.A. Motlagh, Study for determination of industrial water corrosivity in Kashan Fajre Sepahan Galvanizing Mills during 2005–2006 Iran, Pak. J. Biol. Sci., 11 (2008) 131–134.

[21] F. Edition, Guidelines for drinking-water quality, WHO Chronicle, 38 (2011) 104–108.

[22] S.S. Prasanth, N. Magesh, K. Jitheshlal, N. Chandrasekar, K. Gangadhar, Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India, Appl. Water Sci., 2 (2012) 165–175.

[23] M. Mirzabeygi, N. Yousefi, A. Abbasnia, H. Youzi, M. Alikhani, A.H. Mahvi, Evaluation of groundwater quality and assessment of scaling potential and corrosiveness of water supply networks, Iran, J. Water Supply Res. Technol. AQUA, 66 (2017) 416–425.

[24] A. Logeshkumaran, N. Magesh, P.S. Godson, N. Chandrasekar, Hydro-geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu, India, Appl. Water Sci., 5 (2015) 335–343.
[25] A.H. Mahvi, M. Malakootian, A. Fatehizadeh, M.H. Ehrampoush, Nitrate removal from aqueous solutions by nanofiltration, Desal. Water Treat., 29 (2011) 326–330.
[26] R. Sadler, B. Maetam, B. Edokpolo, D. Connell, J. Yu, D. Stewart, M.-J. Park, D. Gray, B. Laksono, Health risk assessment for exposure to nitrate in drinking water from village wells in Semarang, Indonesia, Environ. Pollut., 216 (2016) 738–745.
[27] R. Nabizadeh, M.V. Amin, M. Alimohammadi, K. Naddafi, A.H. Mahvi, S. Yousefzadeh, Development of innovative computer software to facilitate the setup and computation of water quality index, J. Environ. Health Sci. Eng., 11 (2013), doi: 10.1186/2052-336X-11-1.
[28] M. Malakootian, N. Yousefi, A. Fatehizadeh, Survey efficiency of electrocoagulation on nitrate removal from aqueous solution, Int. J. Environ. Sci. Technol., 8 (2011) 107–114.
[29] M. Badi, A. Azari, A. Esrafili, E. Ahmadi, M. Gholami, Performance evaluation of magnetized multiwall carbon nanotubes by iron oxide nanoparticles in removing fluoride from aqueous solution, J. Mazandaran Univ. Med. Sci., 25 (2015) 128–142.
[30] E. Gharehchahi, A.H. Mahvi, S.M.T. Shahri, R. Davani, Possibility of application of kenaf fibers (*Hibiscus cannabinus* L.) in water hardness reduction, Desal. Water Treat., 52 (2014) 6257–6262.
[31] A.E. Al-Rawajfeh, E.M. Al-Shamaileh, Assessment of tap water resources quality and its potential of scale formation and corrosivity in Tafila Province, South Jordan, Desalination, 206 (2007) 322–332.