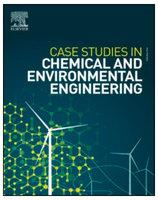
Case Studies in Chemical and Environmental Engineering 7 (2023) 100346

Contents lists available at ScienceDirect

Case Studies in Chemical and Environmental Engineering

journal homepage: www.sciencedirect.com/journal/case-studies-in-chemical-and-environmental-engineering



Case Report

Analyses of sustainable indicators of water resources for redesigning the health promoting water delivery networks: A case study in Sahneh, Iran

Seyedeh Parvin Moussavi [a,1], Abudukeremu Kadier [b,c,1,*], Raghuveer Singh [d], Reza Rostami [e], Farshid Ghanbari [f], Nur Syamimi Zaidi [g,h], Chantaraporn Phalakornkule [i,j], Perumal Asaithambi [k,**], P.T.P. Aryanti [l], F.A. Nugroho [l]

[a] Department of Renewable Resources, University of Alberta, Edmonton, Canada
[b] Laboratory of Environmental Science and Technology, The Xinjiang Technical Institute of Physics and Chemistry, Key Laboratory of Functional Materials and Devices for Special Environments, Chinese Academy of Sciences, Urumqi, 830011, China
[c] Center of Materials Science and Optoelectronics Engineering, University of Chinese Academy of Sciences, Beijing, 100049, China
[d] Research Division, James R. Randall Research Center, Archer Daniels Midland (ADM) Company, Decatur, IL, 62521, USA
[e] Student Research Committee, Kermanshah University of Medical Sciences, Kermanshah, Iran
[f] Research Center for Environmental Contaminants (RCEC), Abadan University of Medical Sciences, Abadan, Iran
[g] Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia
[h] Centre for Environmental Sustainability and Water Security (IPASA), Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia
[i] Department of Chemical Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, 10800, Thailand
[j] Research Center for Circular Products and Energy, King Mongkut's University of Technology North Bangkok, Bangkok, 10800, Thailand
[k] Department of Water Supply and Environmental Engineering, Faculty of Civil and Environmental Engineering, Jimma Institute of Technology, Jimma University, Jimma, Po Box - 378, Ethiopia
[l] Chemical Engineering Department, Universitas Jenderal Achmad Yani, Jl. Terusan Jenderal Sudirman, Cibeber, Cimahi, 40531, Indonesia

ARTICLE INFO

Keywords:
Erosion
Sedimentation
Chemical quality
Water dispensing system
Water quality

ABSTRACT

Healthy water is our prime demand however population explosion and industrialization have threatened the quality of water. Consequently, about a billion people in developing countries including Iran are struggling for a safe and sustainable water supply. Timely water sampling and analyses are critical to access and maintain healthy status. The current study investigates the state of water supply in 29 villages of Sahneh town and provides recommendations for maintaining good health. Water samples were extensively analyzed for the physical and chemical indexes using the EPA standards and the Iran national water standards (Table S1). The mean of pH, total dissolve solid, electrical conductivity, chloride concentration, sulfate, temperature, bicarbonate, total alkalinity, calcium hardness was 8.2, 326.5 mg/L, 422.4 mS/cm, 203 mg/L, 6.4 mg/L, 24.7 °C, 257.2 mg/L, 210.9 mg/L as $CaCO_3$, 233.8 mg/L $CaCO_3$, respectively that are within the permitted limit. Interactions between these factors were statistically analyzed to characterize the water samples. All sampled waters were probable to sediment according to the Langelier index (0.67 ± 0.20), corrosive according to aggressiveness (10.74 ± 0.40) and Puckhorius indexes (6.96 ± 0.63). Water samples also exhibited scaling therefore it is recommended to use cemented pipes for dispensing networks. Moreover, balancing pH, alkalinity, calcium levels and annual testing by the government should be considered to promote good health.

1. Introduction

Water is an absolute necessity to sustain life. 80% of the land is covered by water and 97% of which is in oceans and seas whose water is too saline to drink. While about 2.4% of water is trapped in large glaciers and polar ices, only less than 1% of water resources are available for drinking, agriculture and industrial consumption [1]. The quantity and quality of fresh water resources are alarmingly decreasing every day due

---

* Corresponding author. Laboratory of Environmental Science and Technology, The Xinjiang Technical Institute of Physics and Chemistry, Key Laboratory of Functional Materials and Devices for Special Environments, Chinese Academy of Sciences, Urumqi, 830011, China.

** Corresponding author.

E-mail addresses: abudukeremu@ms.xjb.ac.cn (A. Kadier), drasaithambi2014@gmail.com, asaithambi.perumal@ju.edu.et (P. Asaithambi).

[1] These authors contributed to this work equally.

https://doi.org/10.1016/j.cscee.2023.100346
Received 12 February 2023; Received in revised form 27 March 2023; Accepted 28 March 2023

to global warming, urbanization, industrialization and agricultural activities [2]. Ever-growing population, construction of new settlements and rapid industrialization have not only polluted water reservoirs (surface and underground waters) but also brought water shortages in different regions [2,3]. Due to the scarcity of water, around 1.563 billion had no choice than making a round trip of ½ hour or more from their premises to collect water and surprisingly 582 million people used unacceptable sources to get water [2,3]. According to the Joint Monitoring Program (JMP) conducted by WHO and UNICEF for water, 783 million people around the world (11% of the entire population) bitterly suffer from a lack of clean water. 84% of this population lives in rural areas [1,4]. The consumption of low-quality water can significantly impact human health. As per the WHO, 80% of diseases are caused by the consumption of low-quality water. Providing water with the right quality and quantity for the community will have a significant positive impact on human health [1,5]. Therefore, a safe, reliable, affordable and easily accessible water supply is essential for good health. Unfortunately, for several decades, about a billion people in developing countries have not had a safe and sustainable water supply [6].

The supply lines that distribute water to consumers must be properly designed considering how various components present in water could alter the composition of the water delivery network. Erosion, corrosion and sedimentation are the most critical concerns only for the water delivery networks while water production sources such as wells, subterranean and springs remain unaffected from these concerns. Erosion is a physio chemical phenomenon during which progressive removal of materials from the exposed surface of water delivery systems takes place and this can cause a plethora of changes in the material's composition [7]. On the other hand, physical corrosion can result from erosion and friction which is more probable in high velocity flow and temperature [2,8]. Corrosion dissolves water delivery systems into solutions and causes not only water leakage but also reduces the quality of potable water. It is critical to examine the factors responsible for corrosion in order to comprehend the health aspects of corrosion. The most important health problems pertaining to corrosion are associated with the release of heavy metals such as lead, copper, zinc and arsenic in drinking water [9–11]. Accumulation of unwilling materials onto or into the equipment is considered sedimentation. These materials (deposits) are mostly calcium and magnesium carbonate which are called water and lime sediments. Sedimentation affects equipment's performance in two ways: 1) the surface sediment layer has low temperature conductivity. This layer increases heat transfer resistance, and reduces the effect of heat exchangers. 2) Fluid cross-sectional is reduced by sediment and it reduces pressure [12,13]. Dire consequences of sedimentation and erosion include pipes blockage, reduction in water flow, unexpected flaws in pipes and decays in pipes walls. In all cases, a great deal of water could lead to wastage [14]. Aside from financial damages in the dispensing system due to corrosion, erosion and sedimentation, different heavy metals released during this process can cause several health problems such as chronic and acute poisoning, deterioration of the nerve system, cancers, heart disease, hypertension and skin illnesses [15].

There are several factors which can contribute to corrosion, erosion and sedimentation of the water supply system such as microbial activity, water physical-chemical quality, Oxygen concentration, chlorine concentration, sulfate, divalent Cations such as calcium and magnesium, water temperature, pH, hydraulic state of water in pipes (water velocity) and pipes materials. Furthermore, corrosion levels depend on the essence of the material which is exposed to water. Biological growth facilitates physical and chemical reactions to take place in the aqueous solutions. The low quality and inexpensive equipment used in the water-dispensing network can be reasons for corrosion and sedimentation [15,16]. Therefore, monitoring water stability, which is dependents on physical, chemical and microbial characteristics of water, is crucial to prevent water leaks and minimizing the cost of replacing water delivery components, including instruments, pipes and pumps. To prevent catastrophic failure in water supply networks, water stability indices have been developed [15].

Indicators for determining corrosion and sedimentation of drinking water are: 1- Langelier Saturation Index (LSI): A model for indicating water saturation level with respect to calcium carbonate. This index defines the concept of saturation using pH as the main changeable factor. In other words, the conception of LSI is described as pH changes in order to reach a balance point [17,18]. 2- Rayzner sustainability index (RSI): reveals a correlation of saturated state of calcium carbonate with forming layer in quantity. RSI is helpful in determining the severity of corrosion in water pipelines. In Rayzner index, pHs (saturation pH) are determined considering the factual pH, concentration of calcium and bicarbonate ions, total dissolved solids and temperature. In other words, Langelier and Rayzner indices indicate the differences between water factual pH and saturated pH by calcium carbonate [17]. 3- Aggressive Index (AI): is mostly useable for asbestos cement pipes. It considers the impacts of some items such as pH, calcium concentration and alkalinity on water corrosion and sedimentation quality. 4- Puckhorius index (PSI) shows the buffering capacity of water and represents maximum possibly-made sedimentation for reaching the balance state. The aforementioned index is experimental. Figures resulted from this equation are similar to the Rayzner index [19]. 5- Larson-skold index (LS) is used for combining the effects of chloride, sulfate and bicarbonate concentrations on water corrosion in steel pipes. The LS assumes that chloride and sulfate behave to enhance corrosion and bicarbonate mitigates corrosion [20].

In a study performed by Malakootian and et al. (2014), water resources of Rafsanjan were analyzed by Langelier, Rayzner, Puckhorius and aggressiveness indices. Their findings showed that water was highly probable to sediment [20,21]. Furthermore, in other similar study by Asghari et al. (2015), it described that drinking water of Boushehr province was rather probable to sediment (according to Rayzner index) and corrosive (according to other indices) [20–23]. A study on the rural water distribution network of Urmia (Northwestern Iran), Langelier, Ryznar, and Puckorius indices, showed water corrosion for some studied areas [24].

It is of prime importance to determine the health conditions of the drinking water resources and such studies could reduce the maintenance expenditures while ensuring to provide clean water to consumers. However, no study has ever been done to determine the sustainable indicators for the water resources from the villages of Sahneh town, West of Iran. It is documented that a significant portion of potable water in Iran is attributed to leaks because of corrosion which is also related to public health. In this regard, it becomes critical to monitor water quality and water delivery networks. The present study is not only highlighting the quality of drinking water of villages in Sahneh, but also determines the possibility of corrosion, erosion, sedimentation and impact of chemical and physical parameters. Furthermore, this study makes recommendations to design strategies to either alleviate or eradicate the probable problems associated with water-delivering networks. Because such studies have never been performed in the villages of Sahneh town before, the findings from this study are going to be critical in redesigning the water delivery infrastructure.

2. Materials and methods

In this study, 29 water resources from the villages of Sahneh town were studied and analyzed in terms of physical and chemical indices. 2 samples from each source were prepared and stored in 1-liter plastic containers prior to several analyses. These bottles had been washed with double-distilled water at least 2 times. Upon preparing and transporting samples to the laboratory, experiments were done in 2 categories of automated and titrimetric analyses [15]. Temperature and pH were measured using a multi-functional meter (HANNA-PH 211) at the sampling spots. Calcium hardness, alkalinity, residual chlorine, Total Dissolved Solids (TDS), Cations, and Anions were measured considering the standard numbers. And these numbers were compared with the national standards set by the Iran Water Standard [25]. The calculations were performed using the Langelier, Rayzner, Puckhorius and aggressiveness indices (Table 1). According to the calculated data and comparing with this table, water resources were divided into 3 categories as “probable to sediment”, “neutral”, and “corrosive”.

To calculate the corrosion indices, water quality parameters such as temperature, electrical conductivity (Conductivity ELE 4070), total dissolved solids (Gravimetric methods), turbidity (HACH-2100 P turbidity meter), and Sulfate ions were measured based on the turbidity measurement at 420 nm using a spectrophotometer (Model-DR5000). Carbonate, bicarbonate, calcium ion, alkalinity and total hardness were measured using a titration method. Residual chlorine, pH and water temperature were determined by multi-functional meter (HANNA-PH 211) at the sampling points [22].

Table 1
Sustainability indexes for estimating erosion and sedimentation state.

Water condition	Assumption/ Limitations	Index value	Equation	Index
Scaling is unlikely to occur **Likely to dissolve scale**	PSI relies on an equilibrium pH instead of the actual pH to account for the buffering effect	PSI<6 PSI>7	PSI = 2 (pHeq)-pHs pH = 1.465+log (T.ALK)+4.54 pHeq = 1.465 × log(T.ALK)+4.54	Puckorius scaling index (PSI)
Super saturated, tend to precipitate $CaCO_3$ **Saturated, $CaCO_3$ is in equilibrium** **Under saturated, tend to dissolve solid $CaCO_3$**	Equilibrium index deals with thermodynamic driving forces for $CaCO_3$ scale formation. Metals such as magnesium can exert inhibitor effect	LSI>0 LSI = 0 LSI<0	LSI = pH−pHs pHs = A + B−log (Ca^{2+})−log (Alk) pH ≤ 9.3 pHs= (9.3+A + B)-(C + D) (3) pH > 9.3	Langelier saturation index (LSI)
Super saturated, tend to precipitate $CaCO_3$ **Saturated, $CaCO_3$ is in equilibrium** **Under saturated, tend to dissolve solid $CaCO_3$**	Actual pH, concentration of calcium and bicarbonate ions, TDS and temperature define pHs for RSI	RSI<6 6<RSI<7 RSI>7	RSI = 2pHs-pH	Ryznar stability index (RSI)
Non aggressive **Moderately aggressive** **Very aggressive**	pH, calcium concentration, and alkalinity are important. Developed for Asbestos-cement pipes (4 °C–27 °C	AI>12 10<AI<12 AI<10	AI = pH + log[(Alk)(H)]	Aggressive index (AI)
Chloride and sulfate are unlikely to interfere with the formation of protecting film **Corrosion rates may be higher than expected** **High rates of localized corrosion may be expected**	–	LS < 0.8 0.8<LS < 1.2 LS > 1.2	$LS=(Cl^{-} + SO_4^{2-})/(HCO_3^{-} + CO_3^{2-})$	Larson-skold index (LS)

2.1. *Studied area*

Fig. 1 illustrates geographical location of the studied city. Sahneh is a town of Kermanshah province, located in Western Iran with longitude 72, 68, 47 and latitude 44, 48, 34. In Sahneh, 39 resources were active in 191 villages (total area 1470 km^2) with 36499 population. There exists a total of 1646 groundwater resources in Sahneh city. These resources include 283 springs, 1053 semi-deep wells, 242 deep wells and 68 aqueducts. In this study, only drinking water sources that are obtained from well sources were studied. Drinking water sources for 29 villages are wells, and there are no industrial, residential, etc. polluting sources around it. Water samples were collected within the one-year-monitoring period to have a constant view of all seasons. At each location, two samples were taken. They were also collected in the field by sampling at exactly the same time and place.

3. Results and discussion

3.1. *The major factors effecting erosion and sedimentation*

In the present study, critical parameters responsible for erosion and sedimentation were studied and the estimated numbers pertaining to turbidity, pH, TDS, total hardness, alkalinity and EC are shown in Table 2. Furthermore, the state of Cations and Anions of resources are indicated in Table 3. Table 4 shows the Langelier, Rayzner, Puckhorius and aggressiveness indexes of water resources in Sahneh town that were calculated using the recorded measurements. The pleasant level represents the acceptable water quality by the Iran water quality standards. The permitted level represents the acceptable water quality as per the EPA standards (Table S1).

Fig. 2 shows the overall profile of all 29 samples analyzed. Interestingly, the water samples from four villages including Abbarik, Jabarabad, Jamishan and Mouyineh showed higher levels of EC, alkalinity, total hardness and turbidity than the pleasant levels (Fig. 3) set by Iranian water standard. Hardness of water is attributed to the amount of ions/salts present in water. In this study, the water samples from Yekjofti village exhibited the highest amount (352.4 $mgCaCO_3/L$) of hardness however still lower than the pleasant level. The overall mean (233 $mg/L(CaCO_3)$) of the total hardness is comparable to another similar study (191.6 $mg/L(CaCO_3)$) performed by Fadaei [23] on well water samples located in Shahrekord, Iran. Turbidity is another measure of the quality of water and often time insoluble matter can contribute to increased turbidity. Water samples from village Jabarabad had significantly higher turbidity than any other samples but were still within the permitted limit. None of the water sources have higher turbidity than the permitted level because of the depth of water resources and filtering ability provided by the soil layers for the underground waters. The overall turbidity of 0.7 NTU is comparable to another similar study (0.94 NTU) performed by Fadaei [15,26–28] based on wells’ water samples located in Shahrekord, Iran [29]. Additionally, the present study turbidity data are consistent with the study performed by Mirzabeygi and colleagues in Khorasan city (Iran), where turbidity in water samples collected from all villages was reported to be lower than the permitted level [29].

Alkalinity and EC remained above the pleasant level for most of the samples. The water samples collected from Jamishan village showed elevated levels of both alkalinity and EC whereas water samples from Aligorzan village had the highest amount of EC (324 μs/cm). Even though the levels of Alkalinity and EC are higher but still lower than the permitted level.

According to our study, the pH of all experimental samples had

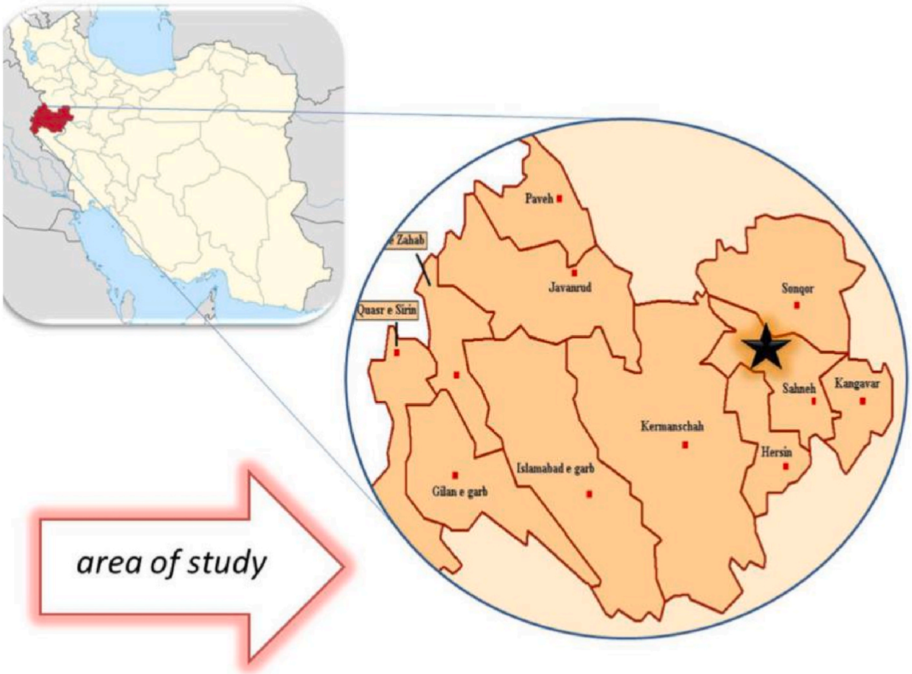


Fig. 1. Geographical location of the studied city.

Table 2
Average, pleasant and permitted levels of parameters.

District Name	Turbidity (NTU)	pH	TDS (ppm)	Total hardness (mgCaCO$_3$/l)	Alkalinity (mgCaCO$_3$/l)	EC (µS/cm)
Jeihoonabad	0.19	7.95	292	236	191.36	420
Herileh	0.89	8	286	270	247.52	460
Mirtaher	0.43	8.33	238	146	135.2	300
Jabarabad	2.8	8.2	326	286	247.52	530
Sefidkhani	0.48	8.32	254	188	174.72	330
Cheraghabad	0.23	7.94	368	276	257.92	510
Kalkanaftabro	0.22	8.54	176	102	89.44	190
Mouyineh	1.17	8.22	330	254	235.04	470
Jamishan	1.5	8.12	448	286	282.88	670
Sadol	1.34	8.62	178	156	139.36	260
Gounban	0.69	8.46	232	238	203.84	400
Ahmadabadmal	0.17	8.46	268	204	174.72	400
Tinmo	0.74	8.49	174	170	156	300
Baktarolia	1.05	8.22	290	264	235.04	440
Baktarsofla	0.41	8.51	224	200	174.72	350
Arganeh	0.36	7.88	460	281.2	251.85	450
Larkhani	0.22	8.06	404	227.7	177.39	420
Aligorzan	0.2	8	518	342.5	324.12	620
Yekjofti	0.24	7.96	508	352.4	324.12	650
Elahieh	0.96	8.25	332	176.2	127.02	340
Bidsorkh	0.31	7.99	436	275.2	262.8	460
Darakeh	0.36	8.05	478	328.7	304.41	600
Siachogha	0.3	8.45	268	132.7	118.26	240
Amoleh	0.27	8.18	304	190.1	170.82	330
Garous	0.94	7.71	408	285.1	260.61	500
Abbarik	1.52	7.83	384	259.4	234.33	450
Sangchin	0.42	8.25	290	198	177.39	320
Kondoleh	0.21	7.88	368	253.4	229.95	460
Gilaneh	1.09	8.02	226	202	208.05	380
Mean	**0.7**	**8.2**	**326.5**	**233.8**	**210.9**	**422.4**
Max	2.8	8.62	518	352.4	324.12	670
Min	0.17	7.71	174	102	89.44	190
S.D	0.58	0.24	100	62.5	61.47	120.01
Pleasant level (max allowable as per Iran national standard)	5	6.5–9	1500	500	–	2000
Permitted level (as per EPA)	1	6.5–8.2	500	–	–	–

*S.D- Standard Deviation.

Table 3
Averages of measured Cations and Anions.

District name	Cations					Anions				
	Calcium	Magnesium	Sodium	Potassium	Ammonium	Fluoride	Phosphate	Sulfate	Carbonate	Bicarbonate
Jeihoonabad	69.6	14.9	9	0.4	0.01	0.24	0	8.26	233.5	0
Herileh	81.6	15.8	9	0.2	0.02	0.31	0	3.44	302	0
Mirtaher	44.8	8.2	14	0.6	0.04	0.3	0	1.6	164.9	0
Jabarabad	98.4	9.6	7	0.4	0.01	0.21	0	1.97	302	0
Sefidkhani	53.6	13	6	0.1	0.01	0.34	0	1.81	213.2	0
Cheraghabad	84.8	15.4	9	2.2	0	0.22	0	5.38	314.7	0
Kalkanaftabro	32.8	4.8	5	0.1	0	0	0	7.65	109.1	0
Mouyineh	81.6	12	14	0.7	0	0.27	0	5.09	286.7	0
Jamishan	90.4	14.4	30	2.1	0.01	0.27	0	8.09	345.1	0
Sadol	55.2	4.3	2	0.1	0	0	0	2.07	167.9	2.08
Gounban	67.2	16.8	1	0.4	0.01	0.35	0	2.78	248.7	0
Ahmadabadmal	72	5.8	9	0.2	0	0.04	0	3.03	213.2	0
Tinmo	50.4	10.6	5	0.2	0	0.1	0	1.71	190.3	0
Baktarolia	90.4	9.1	5	0.2	0	0.12	0	5.53	286.7	0
Baktarsofla	64	9.6	4	0.2	0	0.22	0	2.96	213.2	0
Arganeh	62.6	29.9	11	1.4	0.01	0	0	10.92	307.3	0
Larkhani	59.4	19	8	0.9	0	0.08	0	9.72	216.4	0
Aligorzan	70.5	39.9	23	3.8	0.02	0.1	0	12.82	395.4	0
Yekjofti	64.9	45.6	26	1	0.01	0.04	0	19.93	395.4	0
Elahieh	49.9	12.4	8	0.4	0.01	0.03	0	5.81	155	0
Bidsorkh	80	18.1	5	0.5	0	0	0	5.69	320.6	0
Darakeh	72.9	35.2	20	0.9	0.01	0.02	0	11.92	371.4	0
Siachogha	35.6	10.5	7	0.2	0	0	0	6.67	144.3	0
Amoleh	61	9	4	0.3	0	0	0	5.54	208.4	0
Garous	80	20.4	9	0.7	0.01	0.01	0	4.74	317.9	0
Abbarik	70.5	20	12	0.6	0.01	0.04	0	4.68	285.9	0
Sangchin	49.1	18.1	3	0.4	0.01	0	0	5.49	216.4	0
Kondoleh	73.7	16.6	11	0.7	0	0.01	0	13.52	280.5	0
Gilaneh	49.9	18.5	18	0.7	0.02	0.12	0	6.12	253.8	0
Mean	**66.1**	**16.5**	**10.1**	**0.7**	**0.0**	**0.1**	**0.0**	**6.4**	**257.2**	**0.1**
Max	98.4	45.6	30	3.8	0.04	0.35	0	19.93	395.4	2.08
Min	32.8	4.3	1	0.1	0	0	0	1.6	109.1	0
S.D	16.420	9.947	7.170	0.796	0.009	0.123	0.000	4.251	75.087	0.386
Pleasant level (max allowable as per Iran national standard)	400	150	200	–	0.05	1.5	0.1	400	–	–
Permitted level by EPA	–	–	–	–	–	2.0	0.2	250	–	–

*S.D- Standard Deviation.

minimal variation and remained within the pleasant range of 6.5–8.5. The upper range of the pH in our study is 8.62 (Sadol village sample) which is slightly above the pleasant level and this is also higher than the research study (pH 7.5) published by Rahmani and colleagues (2014) on the quality of water resources of Boyinzahra town (Iran) [29]. This higher pH could be because of the higher amount of bicarbonate that was measured in this sample (Fig. 5). Such pH variations are common in the well based water resources as [30] observed a mean of pH = 7.3 and max pH = 8.4 for well water resources located in Shahrekord, Iran.

Aside from the above-mentioned parameters, TDS was also studied which remained significantly lower than the pleasant levels. The highest level, yet lower than the permitted level, was reported from Aligorzan village (518 ppm). TDS levels of the present study is comparable to the well-based water resources located in Shahrekord, Iran [31]. From our study, it is evident that EC, alkalinity, total hardness and turbidity vary from sample to sample and to determine a relationship between these parameters a linear regression was performed. Alkalinity is positively correlated with total hardness and EC. Hardness has a positive correlation with EC (Fig. 4). Because these are sensible relationships, these further validate our quantifications of these parameters from various water samples. These relationships could be useful in predicting whether water could result in corrosion or sedimentation and what measures to take to avoid any deterioration in the performance of the water delivery system. Based on the accuracy of our measurements and multi-level factors analysis that fall within the pleasant level, it can be concluded that these water samples, at the point of sample collection, are not unsafe for human consumption.

While, according to our study, all studied factors for all samples were found to be within the pleasant range which is consistent with other study based on well water resources located in Shahrekord, Iran [29], a few studies focusing on groundwater such as Rahmani observed a few factors (i.e. total hardness) outside the pleasant level [29]. High hardness is rooted in type of resource as well as lime layers. Geologically, Northern altitudes around Sahneh savannah is combined of Schist formations from transformation of shale-clay layers related to lower Jurassic. Owing to impermeability, these altitudes do not enjoy positive hydrodynamic features. Thus, water transfers just along fractions. According to lime formations after Schist layers, in appropriate conditions, water flows through springs. This water transfers along synclinal channels from valleys to savannahs, building up underground waters with joining to ground flows. Since underground waters are accumulated in savannahs and alluviums (formed of depreciating lime and schist altitudes), they are rich at hardness.

3.2. Distribution of cations and anions in the water samples and their interactions with the factors effecting erosion and sedimentation

Calcium ions were recorded higher than the pleasant level in Baktarolia, Bidsorkh, Cheraghabad, Garous, Herileh, Jabrabad, Jamishan, Mouyineh. Ammonium level in the majority of water samples remained below the pleasant levels except for the samples form village Mirtaher. Sulfate and phosphorus levels were much lower than pleasant levels. Carbonate levels varied among samples whereas no bi-carbonate was detected in any sample other than the water sample from Sadol. The presence of carbonate and bi-carbonate ions is indicator a slightly alkaline pH. One of the major components of water is fluoride that ranged from 0 to 3 mg/L which is consistent with the fluoride levels reported in the groundwater of west Azerbaijan province in Iran [29].

Table 4

Drinking water condition regarding erosion and sedimentation indexes.

District Name	Index				
	LSI	RSI	PSI	AI	LS
Jeihoonabad	0.46	7.03	6.97	12.56	0.46
Herileh	0.68	6.64	6.46	10.69	0.68
Mirtaher	0.53	7.28	7.82	10.50	0.53
Jabarabad	0.95	6.30	6.33	10.97	0.95
Sefidkhani	0.70	6.93	7.29	10.68	0.70
Cheraghabad	0.65	6.65	6.39	10.67	0.65
Kalkanaftabro	0.45	7.63	8.65	10.39	0.45
Mouyineh	0.88	6.47	6.54	10.89	0.88
Jamishan	0.87	6.39	6.25	10.92	0.87
Sadol	0.93	6.76	7.57	10.89	0.93
Gounban	0.99	6.49	6.90	10.98	0.99
Ahmadabadmal	0.95	6.56	7.07	10.95	0.95
Tinmo	0.80	6.89	7.50	10.77	0.80
Baktarolia	0.93	6.36	6.44	10.93	0.93
Baktarsofla	0.96	6.59	7.15	10.95	0.96
Arganeh	0.46	6.97	6.66	10.47	0.46
Larkhani	0.47	7.12	7.22	10.47	0.47
Aligorzan	0.71	6.59	6.24	10.75	0.71
Yekjofti	0.63	6.71	6.32	10.67	0.63
Elahieh	0.46	7.34	7.84	10.44	0.46
Bidsorkh	0.69	6.61	6.39	10.70	0.69
Darakeh	0.75	6.56	6.30	10.78	0.75
Siachogha	0.50	7.44	8.19	10.46	0.50
Amoleh	0.60	6.97	7.22	10.59	0.60
Garous	0.40	6.91	6.42	10.42	0.40
Abbarik	0.43	6.98	6.67	10.44	0.43
Sangchin	0.60	7.05	7.34	10.58	0.60
Kondoleh	0.49	6.91	6.66	10.50	0.49
Gilaneh	0.43	7.16	7.12	10.42	0.43
Mean	**0.67**	**6.84**	**6.96**	**10.74**	**0.7**
Max	0.99	7.63	8.65	12.56	0.99
Min	0.40	6.30	6.24	10.39	0.40
S.D	0.20	0.34	0.63	0.40	0.20

*S.D- Standard Deviation.

As shown in Fig. 6, multivariate analysis was performed to explain the role of Cations and Anions in total hardness, alkalinity, and EC. TDS and Na^{2+}, SO_4^{2-}, and bicarbonates levels were very low so these were not used in this analysis. Total hardness has a positive correlation with EC, alkalinity, carbonate (CO_3^{2-}), Mg^{2+}, Ca^{2+}, pH, K^+. Similarly, alkalinity, has a positive correlation with EC, total hardness, carbonate, Mg^{2+}, Ca^{2+}, pH, K^+. EC has a positive correlation with total hardness, carbonate, alkalinity, Ca^{2+}, Mg^{2+}, K^+, pH (Table 5). These relationships could be used in predictive modeling to determine the state of water.

Statistical analysis, model fitting and factor interactions were performed using JMP Pro 13.2 and the data were interpreted according to the previously published study [31]. A statistical analysis test was carried out to determine the factors that control the total hardness in water and these are statistically significant. Based on the stepwise fit analysis, EC, Ca^{2+}, Mg^{2+}, Na^+ and CO_3^{2-} have some relationships. A final model was developed after removing the factor for which the p values were above 0.05. Ca^{2+} and Mg^{2+} were found to be statistically significant. Therefore, Ca^{2+}, Mg^{2+} controls the total hardness. Total hardness can be controlled by changing the amount of Ca^{2+}, Mg^{2+} in water. From the current study, the following formula was developed that can be used to determine the total hardness in water.

$$\text{Total hardness} = -0.115809367560871 + 2.50082835689021^* Ca^{2+} + 4.16831555428716^* Mg^{2+}.$$

Similarly, statistically significant factors that affect alkalinity were determined. CO_3^{2-} and HCO_3^-, based on the experimental data, were found to be statistically significant. Based on the experimental data from our study, the following formula can be used to determine alkalinity.

$$\text{Alkalinity} = -0.0148474295503718) + 0.837757574190874 * HCO_3^- + 0.819727883711932 *CO_3^{2-}$$

Considering the inter-factor relationships that are statistically significant, the health of water can be determined and new strategies or remedies can be proposed to control corrosion and sedimentation to maintain a healthy status of water and water delivery systems.

3.3. Standard indexes for the water quality control check

According to Table 4, the values of LSI, RSI, corrosion or aggressiveness, PSI were 0.67, 6.84,10.74 and 6.96, respectively. According to the results, water resources of Sahneh town were highly likely to sediment based on LGI, corrosive based on PSI, neutral based on RSI, and corrosive based on aggressiveness indexes. As per LSI, water samples from all studied villages were over the zero-level suggesting inclination

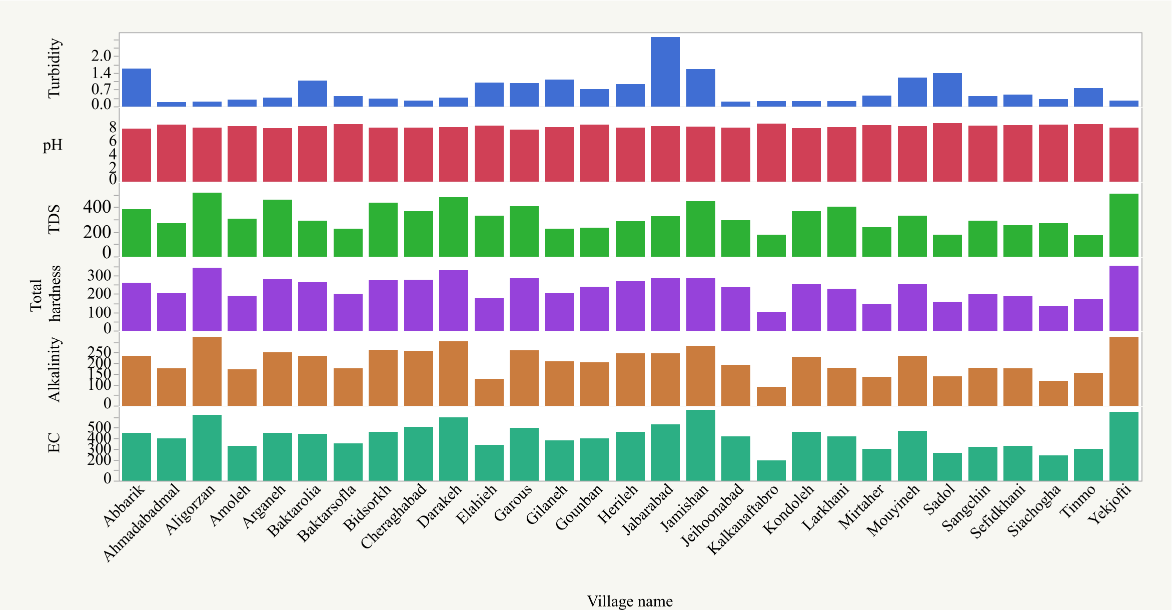
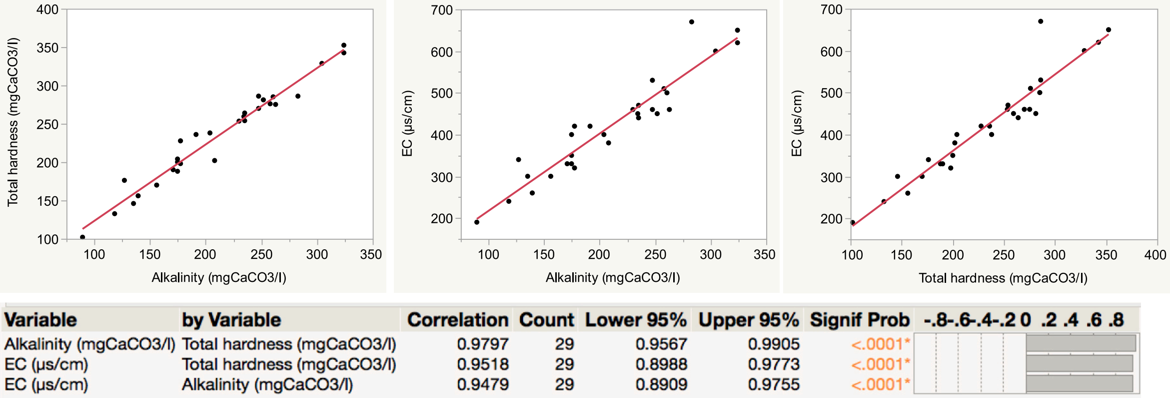


Fig. 2. The critical parameters for 29 collected water samples contributing to corrosion and sedimentation. Water samples from 29 villages were analyzed for EC, alkalinity, total hardness, pH and turbidity.

Fig. 3. Selected factors above the pleasant level in four villages. The four villages including Abbarik, Jabarabad, Jamishan and Mouyineh showed higher levels of EC, alkalinity, total hardness and turbidity than the pleasant level.



Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8-.6-.4-.2 0 .2 .4 .6 .8
Alkalinity (mgCaCO3/l)	Total hardness (mgCaCO3/l)	0.9797	29	0.9567	0.9905	<.0001*	
EC (µs/cm)	Total hardness (mgCaCO3/l)	0.9518	29	0.8988	0.9773	<.0001*	
EC (µs/cm)	Alkalinity (mgCaCO3/l)	0.9479	29	0.8909	0.9755	<.0001*	

Fig. 4. A positive correlation between the critical parameters (alkalinity, total hardness and EC) affecting erosion and sedimentation. Alkalinity is positively correlated with total hardness and EC. Whereas EC is positively correlated with total hardness. JMP Pro 13.2 was used to fit the data and R^2 value for all three plots remained above 0.89. Correlations between these factors are statistically significant (shown by significance probability).

towards sedimentation. The Gounban village had the highest level of LSI of 0.99. Therefore, it is the most probable village to experience sedimentation. According to RSI, 72.4% of Sahneh villages are neutral and only 27.6% are corrosive. Kalkanaftab village had the maximum level of RSI (7.36) among all villages.

The Aggressiveness index reported 96% of studied villages as corrosive while sedimentation was reported for Jeihoonabad village. As per PSI, water from all villages is corrosive and strikingly Kalkanaftab village had the maximum level of 8.65. Thus, the water sample from this village has the stronger tendency to become corrosive than all other villages. A similar finding was reported by Gholizadeh showing the 7.12 ± 0.57 as the mean value of RSI. In this study, most of the water resources had low to moderate corrosivity [32]. According to the Aggressive index, 96% of studied villages were found to be moderately aggressive. Jeihoonabad was the only village with nonaggressive index of 12.56, the maximum amount.

AI index is for water monitoring in Asbestos pipes. Since AI, as an analytical index, does not include influences of temperature or dissolved solids, it would be unfair to compare it with the Larson-skold index. In this case, AI index is not appropriate, because Asbestos pipes have not been used in studied villages [33]. With regard to applying steel pipes in Sahneh distribution network, LSI seems much more suitable for determining the condition of villages of Hrasin.

According to Table 4, Larson-skold index shows that 100% of the villages are in Scaling condition. Scaling is a process in which calcium and magnesium ions upon reactions with other water-soluble substances form a thin layer in the inner walls of water pipes. Because the concentrations of chloride and sulfate is the lowest in the Sahneh distribution network (Fig. 4), these are unlikely to interfere with the formation of a natural film. The Larsson–Sckold (LS) index has been used in a similar study performed by Abbasnia in which water sources according to AI, PSI and RSI were very lightly corrosive however corrosive to the Larsson–Sckold index [23]. In the same study, PSI was used for the scaling possibility and Kalkanaftabro village showed the highest PSI of 8.65. Therefore, scaling possibility of this village was higher than other villages. It is essential to note that PSI for areas with pH less than 8 is not a good indicator for scaling and corrosion [25]. Another study in Iran conducted by Khademian also explored the potential of drinking waters

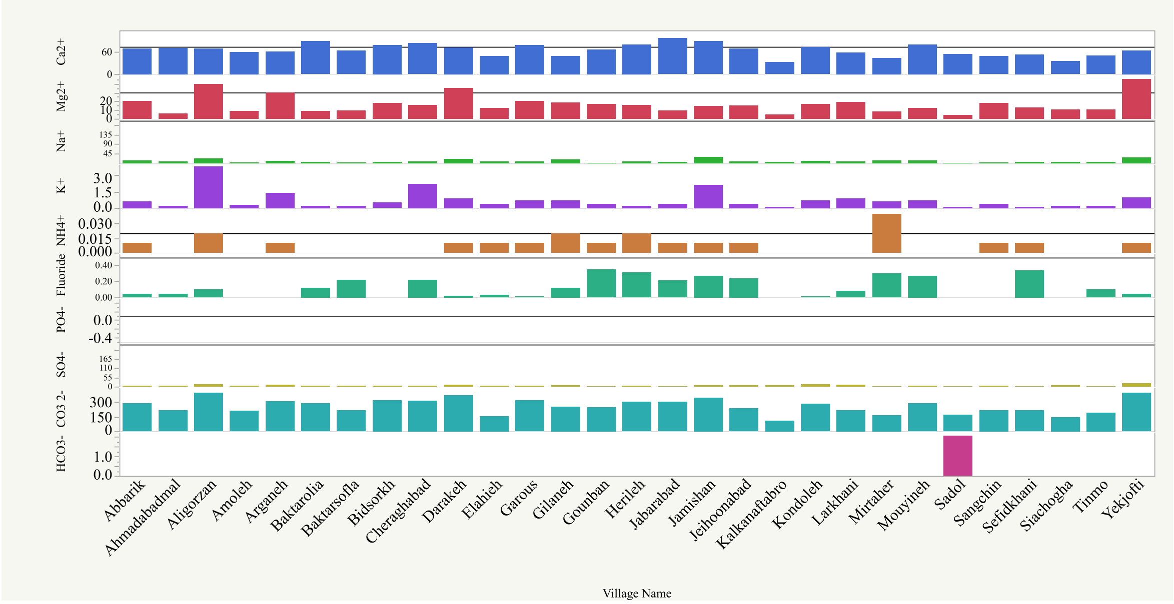
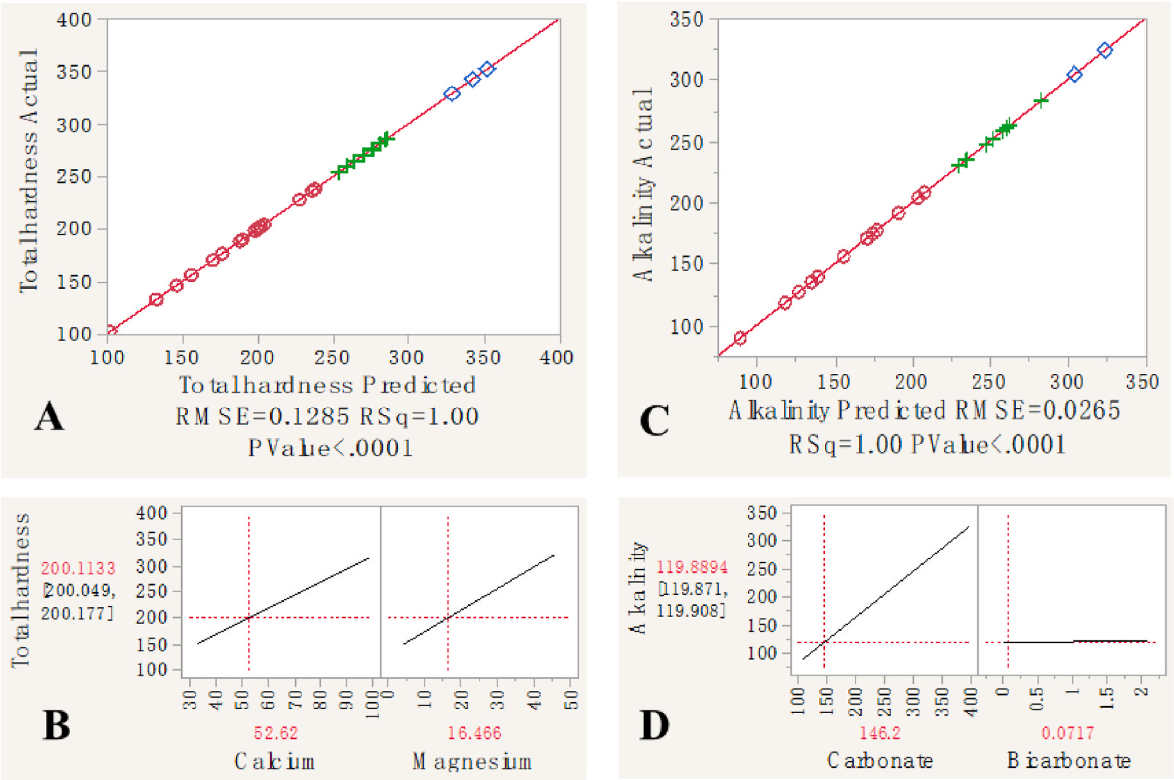
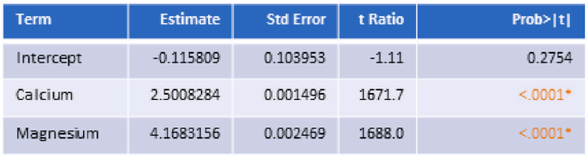


Fig. 5. Major ions present in the 29 collected water samples. The water samples from 29 villages were analyzed for HCO_3^-, SO_4^{2-}, PO_4^{2-}, Fluoride, NH_4^+, K^+, Na^+, Mg^{2+} and Ca^{2+}. A horizontal line in each plot represents the pleasant level. The overall mean for each measurement is shown in the plot.





Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.115809	0.103953	-1.11	0.2754
Calcium	2.5008284	0.001496	1671.7	<.0001*
Magnesium	4.1683156	0.002469	1688.0	<.0001*

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	-0.014847	0.018499	-0.80	0.4295
Carbonate	0.8197279	6.839e-5	11986	<.0001*
Bicarbonate	0.8377576	0.013295	63.01	<.0001*

Fig. 6. Factors affecting total hardness and alkalinity in all water samples. A. The experimental data fitting with predicted data for total hardness. **B.** An increase in Ca^{2+} and Mg^{2+} ion concentration results in increase of total hardness. **C.** The experimental data fitting with predicted data for alkalinity. **D.** Carbonate ions play a crucial role in alkalinity. Data were fitted in the model and a prediction profiler was generated for the pleasant level (shown in green). Numbers shown in red are the optimized numbers for the target concentration (total hardness or alkalinity). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 5
Multivariate analysis of factors.

	EC (µs/cm)	Alkalinity (mgCaCO$_3$/)	Total hardness (mgCaCO$_3$/l)	pH	Turbidity (NTU)	Calcium	Magnesium	Potassium	Ammonium	Fluoride	Carbonate	Bicarbonate
EC (µs/cm)	1.0000	0.9479	0.9518	−0.6549	0.1760	0.7537	0.6892	0.6535	0.1588	0.1372	0.9482	−0.2603
Alkalinity (mgCaCO$_3$/l)	0.9479	1.0000	0.9797	−0.7013	0.1199	0.7296	0.7551	0.6258	0.1529	0.0707	1.0000	−0.2238
Total hardness (mgCaCO$_3$/l)	0.9518	0.9797	1.0000	−0.7135	0.1190	0.7551	0.7605	0.5885	0.1152	0.0599	0.9798	−0.2393
pH	−0.6549	−0.7013	−0.7135	1.0000	0.0158	−0.4758	−0.6050	−0.4467	−0.2206	0.1276	−0.7023	0.3573
Turbidity (NTU)	0.1760	0.1199	0.1190	0.0158	1.0000	0.4307	−0.2476	−0.1208	0.1055	0.2272	0.1186	0.2156
Calcium	0.7537	0.7296	0.7551	−0.4758	0.4307	1.0000	0.1485	0.2955	−0.0997	0.2856	0.7294	−0.1276
Magnesium	0.6892	0.7551	0.7605	−0.6050	−0.2476	0.1485	1.0000	0.5953	0.2725	−0.1924	0.7554	−0.2352
Potassium	0.6535	0.6258	0.5885	−0.4467	−0.1208	0.2955	0.5953	1.0000	0.2446	0.0484	0.6258	−0.1475
Ammonium	0.1588	0.1529	0.1152	−0.2206	0.1055	−0.0997	0.2725	0.2446	1.0000	0.3827	0.1536	−0.1599
Fluoride	0.1372	0.0707	0.0599	0.1276	0.2272	0.2856	−0.1924	0.0484	0.3827	1.0000	0.0717	−0.1858
Carbonate	0.9482	1.0000	0.9798	−0.7023	0.1186	0.7294	0.7554	0.6258	0.1536	0.0717	1.0000	−0.2288
Bicarbonate	−0.2603	−0.2238	−0.2393	0.3573	0.2156	−0.1276	−0.2352	−0.1475	−0.1599	−0.1858	−0.2288	1.0000

of villages of Ghaemshahr in terms of erosion and sedimentation. This study reported the average values along with standard deviations for LGI, RSI, PSI and aggressiveness indexes as 0.438 ± 0.052, 6.99 ± 0.785, 5.85 ± 0.81, and 11.90 ± 0.5, respectively. Drinking waters of villages of Ghaemshahr tended less to sediment [34].

3.4. *Considerations to improve water distribution network*

Every year, a huge investment is put into establishing a potable water distributing network of villages. In this process, it would be wise to utilize the scientific and technical criteria to make the water distributing networks effective. There exist various methods for corrosion realization, study and control. Corrosion control techniques include the use of corrosion inhibitors, designing distribution and piping system, improving water quality and cathodic protection. Plumbing system design considerations, water quality modifications are more appropriate and applicable for villages [30].

Operators can promote the formation of a protective calcium carbonate scaling on the metal surface of plumbing by adjusting pH, alkalinity, and calcium levels. Calcium carbonate scaling occurs when water is oversaturated with it. It is important to note that pH levels well suited for corrosion control may not be optimal for other water treatment processes, such as coagulation and disinfection. To avoid this conflict, the pH level should be adjusted for the corrosion control immediately prior to water distribution, and after the other water treatment requirements have been satisfied [35]. Lime softening affects metal solubility by changing the water's pH and carbonate levels. Hydroxide ions are then present and they decrease metal solubility by promoting the formation of solid basic carbonates that protect the surface of the pipe [36].

4. Conclusions

Due to the potential negative health effects of corrosiveness, heavy metals, erosion and sedimentation, water systems must be thoroughly studied. The current study is based on the extensive analyses of water samples collected from 29 villages of Sahneh town. Cations, Anions, hardness, fluoride, physical and chemical parameters of water resources of most of Sahneh villages were found to be in the pleasant level. Interrelationships between these factors were studied to determine how these could impact erosion and sedimentation. Total hardness, alkalinity and EC were found to be strongly correlated in all water samples. Total hardness of the all water samples was dictated by the Ca^{2+} and Mg^{2+} ions whereas alkalinity was primarily defined by carbonates (CO_3^{2-}). The water stability indices were used to determine the state of the water delivering network. According to the Langelier index (LSI), all water samples were oriented to sediment and corrosive in nature as per the aggressiveness and Pockurius indexes (PSI). Water stability indices are important in alleviating corrosion and scaling in water-providing systems. According to the Larsson–Sckold index (LS), water samples were slightly in the range of scaling. In order to prevent scaling, control of sulfate, carbonate and bicarbonate chloride Anions is recommended. It is critical to control chemical features of water annually by the government and offering solutions such as balancing pH of aeration, and using pipes with appropriate texture (like polypropylene).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

This research work has received support from Xinjiang Uygur Autonomous Region Department of Science and Technology, Shanghai Cooperation Organization (SCO) Science and Technology Partnership Program and the International Science and Technology Cooperation Program [Grant number: 2022E01015], and in part by the Tianchi Doctor Program of Xinjiang Uygur Autonomous Region [Grant number: E33H6301]. The opinions or assertions contained herein are views of the authors and are not to be construed as official or as reflecting the views or policy of the Archer Daniels Midland (ADM) Company.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cscee.2023.100346.

References

[1] A. Othmani, A. Kadier, R. Singh, C.A. Igwegbe, M. Bouzid, M.O. Aquatar, W. A. Khanday, M.E. Bote, F. Damiri, Ö. Gökkuş, F. Sher, A comprehensive review on green perspectives of electrocoagulation integrated with advanced processes for effective pollutants removal from water environment, Environ. Res. 215 (2022), 114294, https://doi.org/10.1016/j.envres.2022.114294.

[2] S.P. Moussavi, A. Kadier, R. Singh, R. Ashoori, M. Shirinkar, J. Lu, N.S. Zaidi, F. Sher, Superior removal of humic acid from aqueous stream using novel calf bones charcoal nanoadsorbent in a reversible process, Chemosphere 301 (2022), 134673, https://doi.org/10.1016/j.chemosphere.2022.134673.

[3] H. Aydin, F. Ustaoğlu, Y. Tepe, E.N. Soylu, Assessment of water quality of streams in northeast Turkey by water quality index and multiple statistical methods, Environ. Forensics 22 (1–2) (2021) 270–287, https://doi.org/10.1080/15275922.2020.1836074.

[4] K.R. Singh, A.P. Goswami, A.S. Kalamdhad, B. Kumar, Development of irrigation water quality index incorporating information entropy, Environ. Dev. Sustain. 22 (4) (2020) 3119–3132, https://doi.org/10.1007/s10668-019-00338-z.

[5] T. Bhadra, S. Das, S. Hazra, B.C. Barman, Assessing the demand, availability and accessibility of potable water in Indian Sundarban biosphere reserve area, Int. J. Recent Sci. Res. 9 (3) (2018) 25437–25443, https://doi.org/10.1016/j.gsd.2020.100438, 10.24327/IJRSR.

[6] W.U. World Health Organization, Joint Water Supply, Sanitation Monitoring Programme, Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment, World Health Organization, 2015.

[7] Y. Fakhri, A. Mohseni-Bandpei, G. Oliveri Conti, H. Keramati, Y. Zandsalimi, N. Amanidaz, R. Hosseini Pouya, B. Moradi, Z. Bahmani, L. Rasouli Amirhajeloo, Health risk assessment induced by chloroform content of the drinking water in Iran: systematic review, Toxin Rev. 36 (4) (2017) 342–351, https://doi.org/10.1080/15569543.2017.1370601.

[8] P.R. Hunter, A.M. MacDonald, R.C. Carter, Water supply and health, PLoS Med. 7 (11) (2010), e1000361, https://doi.org/10.1371/journal.pmed.1000361.

[9] M. Mirzabeygi, M. Naji, N. Yousefi, M. Shams, H. Biglari, A.H. Mahvi, Evaluation of corrosion and scaling tendency indices in water distribution system: a case study of Torbat Heydariye, Iran, Desalination, Water Treat. 57 (54) (2016) 25918–25926, https://doi.org/10.1080/19443994.2016.1162206.

[10] M. Mirzabeygi, M. Yousefi, H. Soleimani, A.A. Mohammadi, A.H. Mahvi, A. Abbasnia, The concentration data of fluoride and health risk assessment in drinking water in the Ardakan city of Yazd province, Iran, Data Brief 18 (2018) 40–46, https://doi.org/10.1016/j.dib.2018.02.069.

[11] M. Long, Sea-water infiltration: the dramatic corrosion of ductile-iron rising mains, Water Environ. J. 8 (5) (1994) 538–545, https://doi.org/10.1111/j.1747-6593.1994.tb01147.x.

[12] S. Agarwal, I. Tyagi, V.K. Gupta, M. Dehghani, J. Jaafari, D. Balarak, M. Asif, Rapid removal of noxious nickel (II) using novel γ-alumina nanoparticles and multiwalled carbon nanotubes: kinetic and isotherm studies, J. Mol. Liq. 224 (2016) 618–623, https://doi.org/10.1016/j.molliq.2016.10.032.

[13] H. Ha, C. Taxen, K. Williams, J. Scully, Effects of selected water chemistry variables on copper pitting propagation in potable water, Electrochim. Acta 56 (17) (2011) 6165–6183, https://doi.org/10.1016/j.electacta.2011.04.008.

[14] W. Edmunds, K. Ahmed, P. Whitehead, A review of arsenic and its impacts in groundwater of the Ganges–Brahmaputra–Meghna delta, Bangladesh, Environ. Sci. Process Impacts. 17 (6) (2015) 1032–1046, https://doi.org/10.1039/C4EM00673A.

[15] 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. Eco. Risk Assess. 24 (4) (2018) 1138–1149, https://doi.org/10.1080/10807039.2017.1407632.

[16] H. Sun, B. Shi, D.A. Lytle, Y. Bai, D. Wang, Formation and release behavior of iron corrosion products under the influence of bacterial communities in a simulated water distribution system, Environ. Sci. Process Impacts 16 (3) (2014) 576–585, https://doi.org/10.1039/C3EM00544E.

[17] A. Mesdaghinia, R. Nabizadeh Nodehi, S. Nasseri, S.A. Imran, M.T. Samadi, M. Hadi, Potential for iron release in drinking water distribution system: a case study of Hamedan city, Iran, Desalination Water Treat. 57 (31) (2016) 14461–14472, https://doi.org/10.1080/19443994.2015.1066269.

[18] S. Masters, H. Wang, A. Pruden, M.A. Edwards, Redox gradients in distribution systems influence water quality, corrosion, and microbial ecology, Water Res. 68 (2015) 140–149, https://doi.org/10.1016/j.watres.2014.09.048.

[19] E. Deshommes, L. Laroche, S. Nour, C. Cartier, M. Prévost, Source and occurrence of particulate lead in tap water, Water Res. 44 (12) (2010) 3734–3744, https://doi.org/10.1016/j.watres.2010.04.019.

[20] M. Shams, A. Mohamadi, S.A. Sajadi, Evaluation of corrosion and scaling potential of water in rural water supply distribution networks of Tabas, Iran, World Appl. Sci. J. 17 (11) (2012) 1484–1489.

[21] R.R. Kalantary, E. Ahmadi, M.A. Jebelli, Quality Evaluation and Stability Index Determination of Qom Rural Drinking Water Resources, 2013.

[22] R. Rezaei Kalantari, A.R. Yari, E. Ahmadi, A. Azari, M. Tahmasbi Zade, F. Gharagazlo, Survey of corrosion and scaling potential in drinking water resources of the villages in Qom province by use of four stability indexes (With Quantitative and qualitative analysis, Arch. Hyg. Sci. 2 (4) (2013) 127–134. http://jhygiene.muq.ac.ir/article-1-18-en.html.

[23] A. Gholizadeh, M. Mokhtari, N. Naimi, B. Shiravand, M.H. Ehrampoush, M. Miri, A. Ebrahimi, Assessment of corrosion and scaling potential in groundwater resources; a case study of Yazd-Ardakan Plain, Iran, Groundw. Sustain. Dev. 5 (2017) 59–65, https://doi.org/10.1016/j.gsd.2017.04.002.

[24] M. Malakootian, M. Mobini, I. Sharife, A. Haghighi fard, Evaluation of corrosion and scaling potential of wells drinking water and aqueducts in rural areas adjacent to Rafsanjan fault in during october to December 2013, J. Rafsanjan Univ. Med. Sci. 13 (3) (2014) 293–304.

[25] H. Khorsandi, A. Mohammadi, S. Karimzadeh, J. Khorsandi, Evaluation of corrosion and scaling potential in rural water distribution network of Urmia, Iran, Desalination Water Treat. 57 (23) (2016) 10585–10592, https://doi.org/10.1080/19443994.2015.1042058.

[26] P. Melidis, M. Sanozidou, A. Mandusa, K. Ouzounis, Corrosion control by using indirect methods, Desalination 213 (1–3) (2007) 152–158, https://doi.org/10.1016/j.desal.2006.03.606.

[27] A.C.M. Meireles, E.M.d. Andrade, L.C.G. Chaves, H. Frischkorn, L.A. Crisostomo, A new proposal of the classification of irrigation water, Rev. Cienc. Agron. 41 (2010) 349–357, https://doi.org/10.1590/S1806-66902010000300005.

[28] 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 (1) (2015) 203–209, https://doi.org/10.2166/wh.2014.157.

[29] A. Fadaei, M. Sadeghi, Evaluation and assessment of drinking water quality in Shahrekord, Iran, Resour. Environ. 4 (3) (2014) 168–172, https://doi.org/10.5923/j.re.20140403.05.

[30] 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 (6) (2017) 416–425, https://doi.org/10.2166/aqua.2017.128.

[31] Z. Rahmani, M. Gholami, A. KhoshnevisZadeh, R. RezayeeKalantari, Investigation of Buin Zahra drinking water resources quality by using of GWQI, Alborz University Medical Journal 2 (3) (2013) 147–155, https://doi.org/10.18869/acadpub.aums.2.3.147.

[32] M. Radfard, H. Soleimani, A. Azhdarpoor, H. Faraji, A.H. Mahvi, Dataset on assessment of physical and chemical quality of groundwater in rural drinking water, west Azerbaijan Province in Iran, Data Brief 21 (2018) 556–561, https://doi.org/10.1016/j.dib.2018.09.078.

[33] R. Singh, R. Tevatia, D. White, Y. Demirel, P. Blum, Comparative kinetic modeling of growth and molecular hydrogen overproduction by engineered strains of *Thermotoga maritima*, Int. J. Hydrogen Energy 44 (14) (2019) 7125–7136, https://doi.org/10.1016/j.ijhydene.2019.01.124.

[34] 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 (4) (2019) 988–1005, https://doi.org/10.1080/10807039.2018.1458596.

[35] M. Khademian Ghadekolai, M. Zamani, F. Ghafari, M. Rahimi, S. Mahmoodpor, Evaluation of corrosion and precipitation potential in Ghaemshahr, s village drinking water, Hum. Environ. 14 (4) (2016) 1–7.

[36] R.W. Revie, Corrosion and Corrosion Control: an Introduction to Corrosion Science and Engineering, John Wiley & Sons, 2008.