ORIGINAL PAPER

A study on corrosion and scaling potential of drinking water supply resources in rural areas of Sarvabad, west of Iran

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Date of submission: 15 Sep 2017, ***Date of acceptance:*** 18 Mar 2018

ABSTRACT

Corrosion is a physicochemical reaction occurring between the metal and its surroundings, which usually has an electrochemical nature and results in changes in the properties of the metal. The corrosive water dissolves the pipe's material during flowing and this causes many problems. This study investigated the potential of corrosion and scaling of 46 water supply resources in the villages of Sarvabad, west of Iran during high-water (HW) and low-water (LW) periods. Parameters including pH, temperature, alkalinity, calcium hardness, and total dissolved solids (TDS) were measured and the Langelier, Rayznar, Aggressive, and Puchorius indices were calculated using the data collected. The zoning maps for the indices were prepared using ArcGIS (Ver. 9.3) software. The results showed that the mean value and standard deviation for the Langelier index were 0.23 and 0.28, respectively, while for the Rayznar index, they were 7.12 and 1.18, respectively. The values for the Aggressive index and Puchorius index were 11.6 and 1.84, and 7.03 and 1.45, respectively. The Langelier index in some water supplies showed a tendency to dissolve calcium carbonate, and meanwhile in some areas it tended to precipitate calcium carbonate. Moreover, based on the Rayznar index value, water potential for corrosion increases in steel pipes; based on the Aggressive index, the potential for corrosion is medium, whereas based on the Puchorius index, there is a potential for corrosion. A brief description about the zoning maps is also given.

Keywords: Corrosion; scaling; Water; GIS

Introduction

Corrosion, a natural process, is conversion of a refined metal to a more chemically stable form. It is the gradual destruction of materials through physicochemical reactions with their surroundings.[1,2] This process is divided into two important branches of study that involve materials resulting from erosion and electrochemical corrosion. The first type includes demolition by physical factors such as collision of solids in the water distribution systems and the second one includes creating an electrical cell and causing an electrochemical reaction between its materials with its surroundings.[3]

Scaling involves the combination of divalent metallic ions in water with hardness-causing factors. The significant parts of deposits are composed of calcium carbonate, magnesium hydroxide, calcium sulfate, and magnesium chloride.[4] In fact, issues related to scaling and corrosion cause significant costs. For instance, the United States spends annually about $300 billion (more than 4 to 5 percent of the American GDP) a year to prevent corrosion and its effects. Despite the lack of accurate statistics of

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Citation: Shahmohammadi S, Noori A, Karami Sh, Amini A, Shahmoradi B, Sobhan Ardakani S, et al. A study on corrosion and scaling potential of drinking water supply resources in rural areas of Sarvabad, West of Iran. J Adv Environ Health Res 2018; 6(1): 52-60

damages caused by corrosion and scaling in Iran, casualties of urban-treated water show that up to 30 percent of water distributed (average 8%) is lost due to decays causing by corrosion of distribution pipelines.[5-7]

pH is an important factor influencing deposits (calcium carbonate, magnesium hydroxide, and iron compounds) formation. An increasing pH value leads to the formation of deposits, and meanwhile lower pH values cause an increase in the amount of dissolved salts.[8,9] Pipes and accessories experiencing durability shortening, the need to replace corroded pipes, an increase in the amount of water loss, and the incidence of heavy metals (Cd, Pb, Cu, Cr, Fe, and Mn) released into the fluid and causing health threats are the most frequent problems caused by corrosion of water distribution pipes.[10-11] Moreover, some factors such as geological texture and type of water resource influence the chemical quality of water and as a result affect the scaling and corrosion sediments.[12] Scaling of the pipes' lining leads to pressure drops in the distribution system, dissatisfaction of consumers, pumping and heating system costs increasing, and reductions in the efficiency of valves and connections.[13] Therefore, in order to prevent the corrosion of pipes, the inner surface of the pipe can be coated with a layer of asphalt or epoxy, which provides a physical barrier between the pipe material and the water. In addition to avoid scaling, water chemical treatment processes and the application of scaling inhibitors could be effective.[14-15]

To meet the United States Environmental Protection Agency (USEPA) standards, drinking water should not be unhealthy, so the corrosion and scaling control indices must be determined for distribution networks of surface and underground supplies at least every 2 years and once a year, respectively.[5]

Several studies have reported about the status of water scaling potential including studies of the water resources of University of Benin, Nigeria. Based on the results of the Langelier index (LSI), which is an approximate indicator of the degree of saturation of calcium carbonate in water or a measure of a solution's ability to dissolve or deposit calcium carbonate, the Rayznar index (RI), that actually quantifies the relationship between calcium carbonate saturation and scale formation, and the Larson index, it was shown that water tends to be corrosive.[16] Another study conducted in Baghdad, Iraq indicated that the water was corrosive and LSI ranges at minimum and maximum levels were −0.136 and 0.156, respectively, and the RI at the minimum and maximum levels was 7.17 and 7.68, respectively.[17]

Lee et al. reported that corrosion and the resulting red water could be seen only in areas with groundwater resources.[18] Shyam and Kalwania found corrosion potential in water samples analyzed in India.[19] Zarandimotasadi et al. studied the Bojnord water distribution network for scaling and corrosion potential. They showed that the drinking water of Bojnord was relatively scaly.[20] Malakotian et al. reported the same finding for the Kerman water distribution network.[21] Mapping the corrosion and scaling is an illustrative method, which gives a clear picture about the visual situation of the parameter. One of the methods for generating such maps is the inverse distance weighted (IDW) method. The IDW interpolation method is based on the assumption that the impact of the phenomenon is reduced by increasing the distance.[22] In this model, the distances used are ascertained measured weights to predict non-measured points.[23, 24]

Due to the lack of any pervious study in Sarvabad, it is necessary to implement such a study in order to reduce the costs of maintenance and operation of the water supply and distribution network and also to meet the established standards of drinking water. Therefore, the main aim of this study was to determine the potential of corrosion and scaling in water resources of Sarvabad villages and mapping it using IDW in a GIS environment. In this study, common indicators including the Langlier Saturation Index (LSI), the Ryznar Stability Index (RI), the Puckorius scaling Index (PSI), which attempts to quantify the relationship between saturation state and scale formation by including an estimate of buffering capacity of the water into the index, and the Aggressiveness Index (AI) were used to identify the corrosion and scaling potential.[13]

Materials and Methods

A 1-year sampling program intended to determine the parameters was carried out in 2015 in the villages of Sarvabad, Kurdistan Province, Iran. Sarvabad, is located on the Iraq and Iran border (Figure 1). This area is bounded by Marivan from the north, Sanandaj from the east, and Kamyaran from the south. Based on the 2011 census, the county's population was 49841.[25] This town has 59 villages with a total population of 37278. In this study, values of corrosion indices including LSI, RI, PSI, and AI were calculated. Furthermore, some analytical tests were carried out with the collaboration of the Kurdistan Rural Water and Wastewater Company.

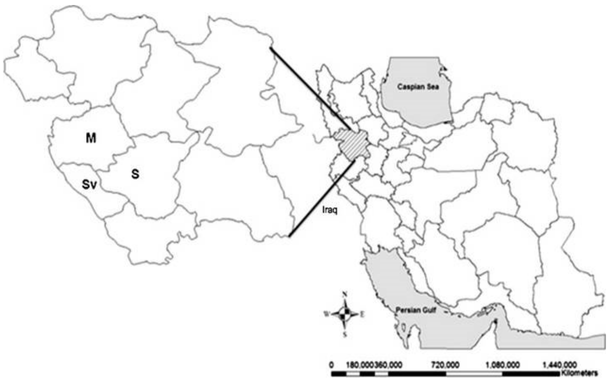

Fig. 1. The location of Sarvabad

Sampling

The collected samples from 46 villages randomly chosen in two high- water (HW) and low-water (LW) periods were assessed to study the condition of scaling and corrosion. The total number of samples was 92 duplicated samples. Samples were taken in 1 L polyethylene containers rinsed with de-ionized water and ultra-pure water. Sampling procedures were carried out according to standard methods for water and wastewater examinations.[26]

Analysis

pH and temperature of the samples were measured using a portable pH-meter (WAGTECH, England). Electrical conductivity (EC) was measured by METRHOM (Company, Country). Alkalinity, calcium, hardness, and total dissolved solids (TDS) were analyzed following the prescribed procedures[26]. Then, the indicators of corrosion (LSI, RI, PSI, and AI) were calculated using the equations given in Table 1. The results were analyzed using SPSS16 software. Finally, spatial distribution maps of all scaling and corrosion indices were generated using ArcGIS 9.3 software.

Table 1. Water Sustainability Indices[27-29]

Index	Equation	Index value	Commentary
LSI	LSI=pH-pHs	LSI>0	Supersaturated water is inclined to precipitate $CaCO_3$
		LSI=0	Water balance (not tend to sedimentation or corrosion)
		LSI<0	Under saturated and willingness to corrosive water
RI	RI=2pHs-pH	RSI<6	Supersaturated water is inclined to precipitate $CaCO_3$
		6< RSI<7	Water balance (not tend to sedimentation or corrosion)
		RSI >7	Under saturated and tendency to corrosive water
AI	AI=[pH+log[(A)(H)]	AI<10	Very corrosive water
		10<AI<12	Moderate corrosion Water
		AI>12	Water-free corrosion
PSI	PI=2pHs-pHeq	PI>6	Corrosive water
	pHeq=1.465log(T.Alk)+4.54	PI<6	Sediment water

PI = Puckorius index; AI = Aggressive index; RSI = Ryznar index; LSI = Langelier index; pHs = saturated water; pHeq = pH of water at equilibrium; T Alk = Total alkalinity

The relationship presented in Table 1 was calculated using Equation (1):

$$pH = [(9.3 + A + B) - (C + D)]^{28} \quad (1)$$

Where A is TDS in mg/l and B is temperature in Celsius degrees, C is Calcium in mg/l as $CaCO_3$, and D is alkalinity in mg/l as $CaCO_3$. Moreover, A, B, C, and D are calculated using equations 2 through 5.

$$A = (\text{Log10}\ [TDS] - 1)/10 \quad (2)$$

$$B = -13.12\ \text{Log10}\ (^{o}C + 273) + 34.55 \quad (3)$$

$$C = \text{Log10}\ [Ca^{2+}\ \text{as}\ CaCO_3] - 0.4 \quad (4)$$

$$D = \text{Log10}\ [\text{alkalinity as}\ CaCO_3] \quad (5)$$

Results and Discussion

The water quality parameters assessed in the study area were temperature, TDS, pH, and calcium hardness. Table 2 shows the results of the analysis carried out during the HW and LW periods.

Table 2. Water Quality Analysis During the HW and LW Periods

	T (ºC)	B	Ca (mg/lCaCO₃)	C	TDS (mg/l)	A	Alk (mg/lCaCO₃)	D	pH	pHs
HW	8.21	2.15	91.64	1.92	253.42	0.23	177.2	2.22	7.81	7.45
LW	22.31	2.13	88.48	1.9	262.8	0.23	175	2.22	7.75	7.448
Mean	22.06	2.14	90.06	1.91	258.11	0.23	176.1	2.22	7.78	7.449

According to Table 2, all parameters are within the allowable values given in the WHO guidelines[30] and the Iran national standards.[31]

According to the amount of phenolphthalein alkalinity, which is 0, and the pH of the samples, which was less than 8.3, it could be derived that total alkalinity is related to bicarbonate concentration.[27] An increment in the alkalinity value, more than 65 mg/l in form of calcium carbonate causes reducing corrosion meanwhile values less than 30 mg/l in form of calcium carbonate could cause scaling.[32] In addition, high values of alkalinity make the water buffered, in other words the water acidity is very unlikely to change. According to the alkalinity values of the water samples that are higher than 100 mg/l, it could be argued that the corrosion potential of water flowing in pipes is not significant. Nevertheless, the minimum and the maximum calcium value are 40.9 and 163.4 mg/l, respectively; these values are within the national standards and WHO guidelines. Tables 3 and 4 show the minimum, the maximum, mean, and standard deviation values of the indices calculated for determining scaling or corrosiveness of water samples during the HW and LW periods.

Table 3. Calculated corrosion and scaling index for water supplies in rural areas of Sarvabad

	LSI			
Stage	Min[1]	Max[2]	Mean	SD[3]
HW	-0.62	0.8	0.26	0.27
LW	-0.68	0.93	0.2	0.2
	RI			
HW	0	8.49	7.09	1.182
LW	0	8.56	7.147	1.19
	PSI			
HW	0	9.1	9.98	1.6
LW	0	9.03	7.08	1.3
	AI			
HW	0	12.47	11.57	1.92
LW	0	12.53	11.63	1.77

[1] Min= Minimum
[2] Max= Maximum
[3]SD = Standard Deviation

Table 4. Results of the corrosive potential of rural water supplies of Sarvabad

Mean corrosion indices	LSI	RI	PSI	AI
Results	0.23 Scaling	7.12 corrosive	7.03 Corrosive	11.6 Moderate corrosive

Based on these results, 35 samples of water supplies (which equals to 76% of all water supplies) to Sarvabad villages showed a tendency to deposit calcium carbonate, and 11 samples of water resources (24%) tended to dissolve calcium carbonate according to the LSI. Based on the RI value, 30 samples of water resources (65.2%) were corrosive and 13 samples (28.26%) were slightly scaling and only 3 samples (6.52%) were highly corrosive. Based on the PSI, no sample showed scaling potential.

Based on the AI, 32 samples (69.6%) had a medium corrosive potential and 14 samples (30.43%) were non-corrosive. Mahvi et al. studied the characteristics of the Bandar Abbas drinking water along with measurements of chemical parameters; they found that 6.6% of samples had a balanced LSI while 93.4% of samples were corrosive. The RI value in 20% of the samples was moderate and for 80% it was corrosive.[33] Rezai Kalantari et al. in 2012, based on the measured mean values of LSI (1.62), RI (10.5), and Aggressive (2.03) index values, reported that the drinking water of villages in Qom was corrosive.[34]

Asgari et al. in a determination of the chemical quality, scaling, and corrosion characteristics of Bushehr drinking water found that the LSI value (0.27) showed slight scaling, while meanwhile the RI (7.24), AI (12.02) and PSI (7.81) values showed a corrosive potential, which is similar to the results drawn from this study.[35]

In addition, in a study by Chien et al., it was concluded that the chemical quality of drinking water was in a corrosive condition.[36] Alrwajfeh and Alshmalyh studied the potential of scale formation and corrosion in Tafilah drinking water (south Jordon) using LSI and RI values. They showed LSI ranges with negative values (−1.5 to −0.39) and RI ranges from 8.7 to 9.8, which indicated that the tested water was corrosive due to the water heating and evaporation, causing release of CO_2.[32] It must be noted that the individual parameters met the national standard, but the values of the scaling and corrosion indices were not in the appropriate range. Based on *t*-test statistical analysis, LSI, RI, and PSI in both HW and LW periods in our study did not show a significant difference (p value > 0.05). In other words, the values of these indices in both periods were nearly identical. Since calculating pHs based on statistical analysis needs information from some parameters including temperature, TDS, calcium hardness, and alkalinity, the TDS ($p_{value} = 0.006$), alkalinity ($p_{value} = 0.001$) and calcium hardness ($p_{value} = 0.005$) in both the HW and LW periods were different. It is noteworthy that TDS and alkalinity increased in the LW (fall) period versus the HW (spring) period while calcium hardness decreased. It has been observed that as a result of these changes, some of the measured indices have shown a tendency to support a corrosive condition.

Conducting a research study in Esfahan, Iran, Setayesh et al. reported that there was no significant difference between the indices of corrosion.[37] Using common corrosion indices to evaluate water scaling potential may show different results. For example, it has been noticed that an index may classify samples as corrosive water while meanwhile other indices show non-corrosive and balanced conditions. A measurement by conventional corrosion indices may show different results in comparison with laboratory results due to differences between complex experimental tests with the basic determination of corrosion in samples, which are exposed to water corrosion and erosion. However, water corrosion indices are applied as an indicator to predict the development of holes and protuberances on the inner surface of iron or cement pipes.[38] Using corrosion indices, Chang et al. stated that the indices show different results; one index defines the water as corrosive while the other one shows non-corrosive conditions.[39] Due to lack of uniformity in the indices used for determination of water scaling and corrosion, using an index cannot fully determine the status of the water, because it is more liable to evaluate several indicators simultaneously.

Finally, all obtained data were entered into the ArcGIS 9.3 software and zoning maps for each parameter were prepared. Figures 2 and 3 show the zoning maps of drinking water resources in rural areas of Sarvabad, Iran based on corrosion indices in the HW and LW periods respectively.

Mapping corrosion indices in Sarvabad drinking water samples using ArcGIS 9.3 software indicated that the samples were not chemically balanced, and results showed that in some areas, the water tended to scale, while in other areas it tended to be corrosive. Based on Figure 2(a), which shows the RI zoning map, it is obvious that most of the villages located in the south and southwest of the study area have corrosive water and most village in the north and northwest have a scaling tendency.

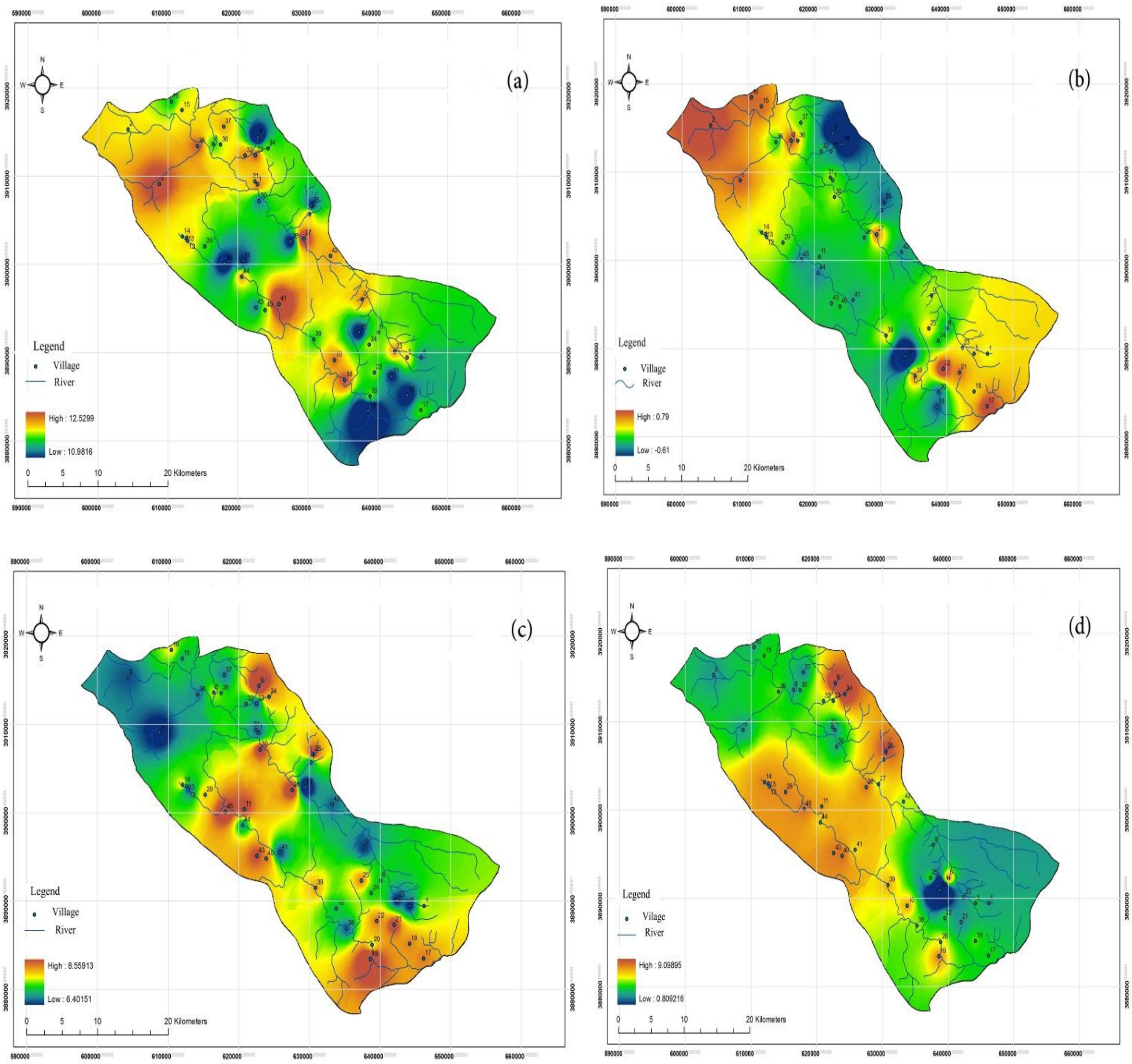

Fig. 2. Spatial distribution of water resources based on different indices during a low rain season (fall): a) AI, b) LSI, c) RI, and d) PSI

According to Figure 2 (a and b), the maximum and the minimum LSI and RI values are 0.8 and −0.62 for LSI and 8.49 and zero for RI, respectively. The LSI values showed that most of the corrosive areas are located in the west and south and some regions of the east and the west, meanwhile a significant scaling tendency was observed in the west and central areas. Based on the RI, the north west and south east areas are aggressively corrosive, and most villages in the west and central regions have a scaling tendency. In addition, the zoning map shown in Figure 2(c) represents the PSI observed in different areas. Based on this index, water resources of villages located in the west, east and south west of the studied area tend to be corrosive and villages with a tendency of scaling are mostly seen in the north west and south east. The maximum and minimum values of PSI were 9.1 and 0, respectively. Fig. 1(d) of the zoning map of AI indicates most villages in the region in the south have an average corrosive potential. The maximum and minimum AI values are 12.47 and 0, respectively. It is obvious that the zoning map of each index is quite different from the others.

According to Fig. 3 (a and b), the maximum and the minimum LSI and RI values are 0.93

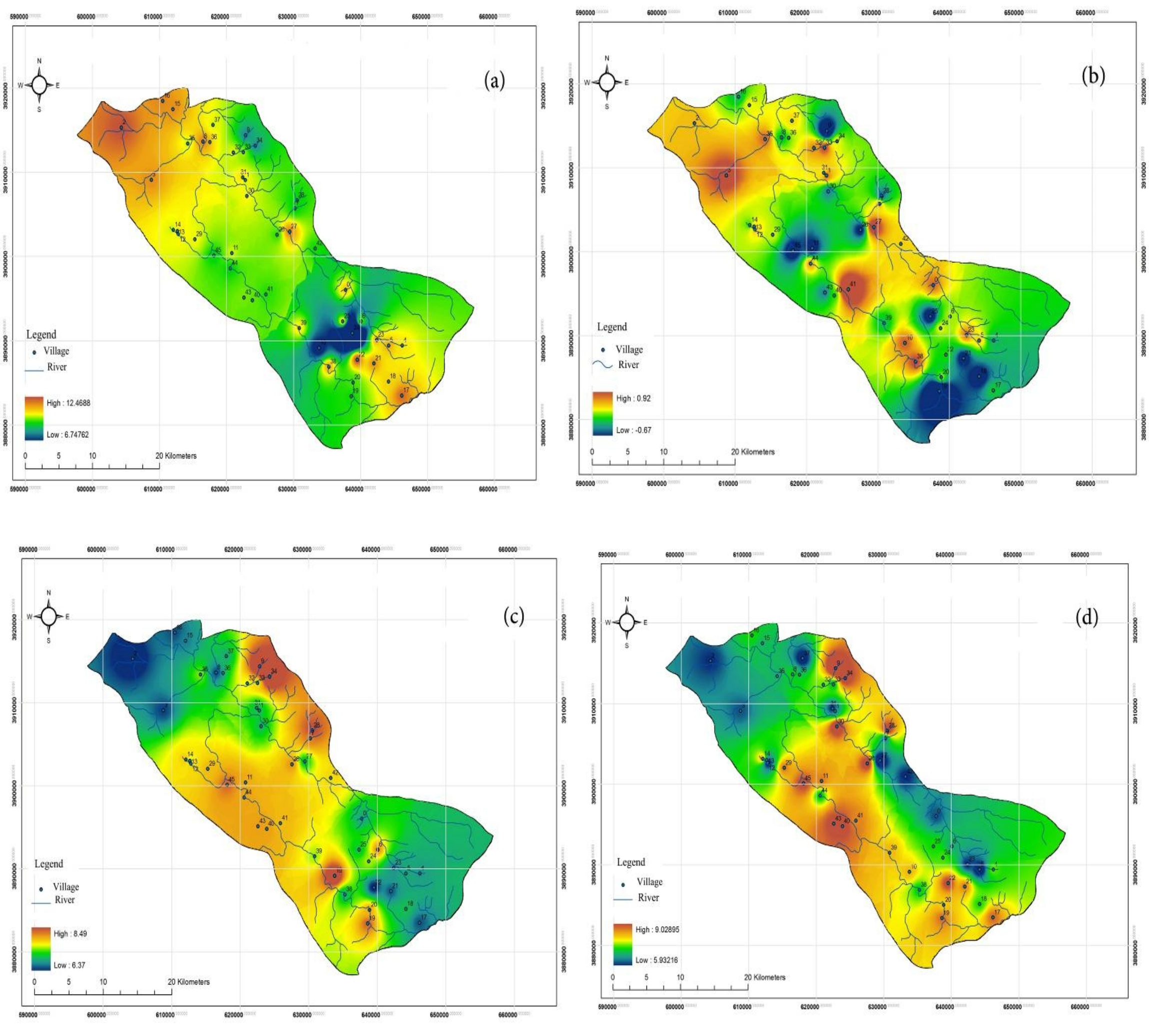

Fig. 3. Spatial distribution of water resources based on different indices during a high rain season (spring): a) AI, b) LSI, c) RI, and d) PSI

and −0.68 for LSI and 8.56 and 0 for RI, respectively. LSI values show that most of the corrosive areas are located in the south and some regions of the east, and meanwhile a significant scaling tendency was observed in the north west. Based on the RI zoning map, the water resources of the villages in the west and south west are corrosive, and most villages in the north west and north regions of the area have a scaling nature. In addition, the zoning map shown in Fig. 3(c) represents the PSI observed in different areas. This index shows that the water resources of villages located in the west, east and center of the studied area tend to be corrosive and villages with a tendency for scaling are mostly seen in the south. The maximum and minimum values of PSI were 9.03 and 0, respectively. Fig. 3(d) shows the significantly corrosive areas in the south west villages of the region and in other areas an average corrosive potential was observed while the northern areas did not show corrosive potential.

Conclusion

Based on our results, it is obvious that the south and east areas showed more corrosive potential while the north areas showed a higher sedimentation potential based on the GIS zoning maps. The results included LSI, RI, AI, and PSI values and an analysis of the drinking water supply in the rural Sarvabad area during both HW and LW stages showed sedimentation and varying degrees of corrosiveness potential. According to the findings of this research and other studies, it is not reasonable to rely only on the results of chemical analysis of water. In addition, the apparent adaptation of some parameters to international standards does not imply a qualitative balance of the water. The results of this study show that the parameters are not a problem, while in general, considering the indicators discussed, they indicate there is a probability of a problem in the water resources of the study area. Therefore, it is recommended that, in addition to performing water quality control in the area, the water pipelines be protected against corrosion.

Acknowledgment

The experimental activities of this research were performed with the assistance of the Rural Water and Wastewater Company of Kurdistan province. The authors hereby express their appreciation and gratitude.

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