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Assessment of Groundwater Quality in Human Health Risk, Agriculture and Industry with the Qualitative Indices in the Bahar Plain, West Iran

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Abstract: The potential of scaling and corrosion in wells (Bahar plain, Iran) was studied during the years from 2004 to 2014. This study used the Langelier Saturation Index, Ryznar Stability Index and Puckorius Scaling Index to get the corrosion and scaling potential of water wells in Bahar plain for drinking, agricultural, industrial consumption, urban conveyance, and distribution pipes and used the Wilcox, Schoeller and Piper diagram for classifying the quality of water. Based on WHO guidelines the water samples were at the permissible limit for drinking water. The results of the Piper diagram showed that the water samples were classified into three water types of bicarbonate, calcium, and Ca-Mg-Na-K and the class of water were C_2-S_1 and C_2-S_2 using the Wilcox diagram. The mean value of the Langelier Saturation Index (LSI), Ryznar Stability Index (RSI) and Puckorius Scaling Index (PSI) was 0.18, 7.25 and 6.56 respectively. Based on the LSI index, 55.3% of the samples were low scale and the 80% and 46.1% of the samples were corrosive and low corrosive, respectively. The results indicated that the drinking and industrial consumption of the water of this plain need to be considered.

Key words: Water quality, pollution, groundwater, environmental assessment.

Introduction

Due to the limitation of precipitation and surface water, particularly in arid and semi-arid areas such as Iran, groundwater is especially important. Increasing concerns about groundwater quality (Rebolledo et al., 2016) has led to a lot of research because it can be harmful to humans through drinking and exposure pathways (Bhutiani et al., 2016; Wu and Sun, 2015). Human activities and natural environmental changes are responsible for groundwater quality variability (Li, 2014) and groundwater quality has decreased due to industrialization and urbanization, as well as soil salinization due to using non-standard irrigation system (Li et al., 2016a, b). Much storage, transmission and distribution systems of water are being destroyed in agriculture, and drinking as a result of scaling and corrosion talent of water. The effect of water quality on industrial equipment of irrigation and piping systems appears in the forms of scaling, deposition, aggression, and corrosion.

Discussion about scaling and corrosion of water was introduced by Taylor in 1950 for the first time (Ayers and Westcot, 1985). Water tendency to corrosion and scaling can have negative and harmful effects on human health. Corrosion is the result of the electrochemical response between water and the metal components. Influence factors on corrosion are pH, alkalinity, temperature, hardness, total dissolved solids, dissolved oxygen, and scale formation depends on the temperature, pH,

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and concentrations of HCO_3^-, CO_3^{2-}, Ca^{2+} and Mg^{2+} (Aiman et al., 2007). The Langelier saturation index (LSI) and Ryznar stability index (RSI) are common methods used to calculate the corrosion and scaling of water. LSI and RSI show the tendency of water to scale $CaCO_3$ or to corrode it. Puckorius Scaling Index (PSI) is another method used in industry to assess water quality. Puckorius and Broke (1991) used PSI for investigation of corrosion and scaling in cooling systems. Assessment of Groundwater Quality of Rajasthan, in India with LSI and RSI method showed that the groundwater has a tendency to scaling in comparison to corrosion (Gupta et al., 2011).

Assessment of drinking water quality of the hospital water supply system in Peru showed an average of LSI and RSI values was –2.8 and 11.8 (Bigoni et al., 2014). Studies show that corrosive waters with high pH, residual of free chlorine and low alkalinity cause cavities in the pipes which lead to premature plumbing failures (Sarver and Edwards, 2012). Scaling in the irrigation system can increase the head loss along the length of pipe and reduce the cross-section of flow. Assessment of the water quality in Malawi by testing the corrosiveness of the water using the Langelier Saturation index showed that water in the distribution line was corrosive according to negative values of LSI (Kabwazi et al., 2015).

Evaluating the corrosion and scaling potential of the drinking water in the urban distribution system using LSI, RSI, and the PSI in Tabriz showed that drinking water was corrosive (Taghipour et al., 2012). The determination of corrosion and scaling potential in water distribution networks of Urmia, Iran showed that based on the average values of LSI (–2.07), RSI (12.3) and the PSI (12.6), the water was highly corrosive (Khorsandi et al., 2016). Evaluation of drinking water supply sources of Marivan villages in Iran indicated that 97% of the springs were corrosive and 90% of the wells had scale forming potential (Amini et al., 2015). Kurdi et al. (2015) investigated the sensitivity of corrosion and scaling indices in Qareh-Sou River located in the Alborz Mountains in Iran. They concluded that Qareh-sou basin was chemically corrosive because the value of pH was in the range of 7.2 to 7.6.

Iran is located in the arid and semi-arid zone of the world and due to limit of suitable water resources the assessment of water quality is necessary. Bahar plain is the main source of Hamedan and Bahar city drinking water, agricultural and industrial and one of the four plains of Hamedan and it is especially important because of the continued loss of groundwater table also exposed to contamination for increasing the usage of waste waters, fertilizers, and chemical pesticides in this desert.

The aim of this study was to evaluate and determine the corrosion and scaling potential of groundwater in Bahar plain for drinking, agricultural and industrial consumption, urban conveyance, and distribution pipes using the Langelier saturation index, Ryznar stability index and Puckorius scaling index, and used the Wilcox, Schoeller and Piper diagram for classifying the quality of water.

Methods

Case study

This study was conducted during 2004-2014 in the Bahar plain with a total area of 2475 km^2, in Hamedan, Iran (48°17′-48°33′ E and 34°49′-35°02′ N) (Figure 1).

To study the groundwater quality of Bahar plain, 13 stations with deep and semi-deep wells were assessed. The geographical coordinates and the names of the stations have been shown in Table 1.

Statistical summary of water samples from 13 stations in Bahar plain during 2004 to 2014 indicated that pH (7.43 to 7.92) was approximately constant and tends to be alkaline, the range of EC changes was between 670.5 and 2270.3 μS/cm and total dissolved solids (TDS) and sodium absorption ratio (SAR) changed between 425.07 and 1507.53 mg/l and 0.5 and 2.61, respectively.

The Langelier Saturation Index (LSI)

The Langelier saturation index (Langelier, 1936) is based on the effect of pH on the equilibrium solubility of $CaCO_3$ and defined by equations (1-6) from Water Service Ltd (2004).

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

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

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

$$B = -13.12 \times \log_{10}(°C + 273) + 34.55 \quad (4)$$

$$C = \log_{10}(Ca^{2+} \text{ as } CaCO_3) - 0.4 \quad (5)$$

$$D = \log_{10}(\text{Alkalinity as } CaCO_3) \quad (6)$$

where pH is the measured water pH, pH_s is the pH at saturation in calcite or calcium carbonate.

The Ryznar Stability Index (RSI)

As an empirical method (Equation 7), the Ryznar saturation index (Ryznar 1944) is often used with the LSI to improve the accuracy of water scaling and corrosion results (NALCO Water Handbook 1988).

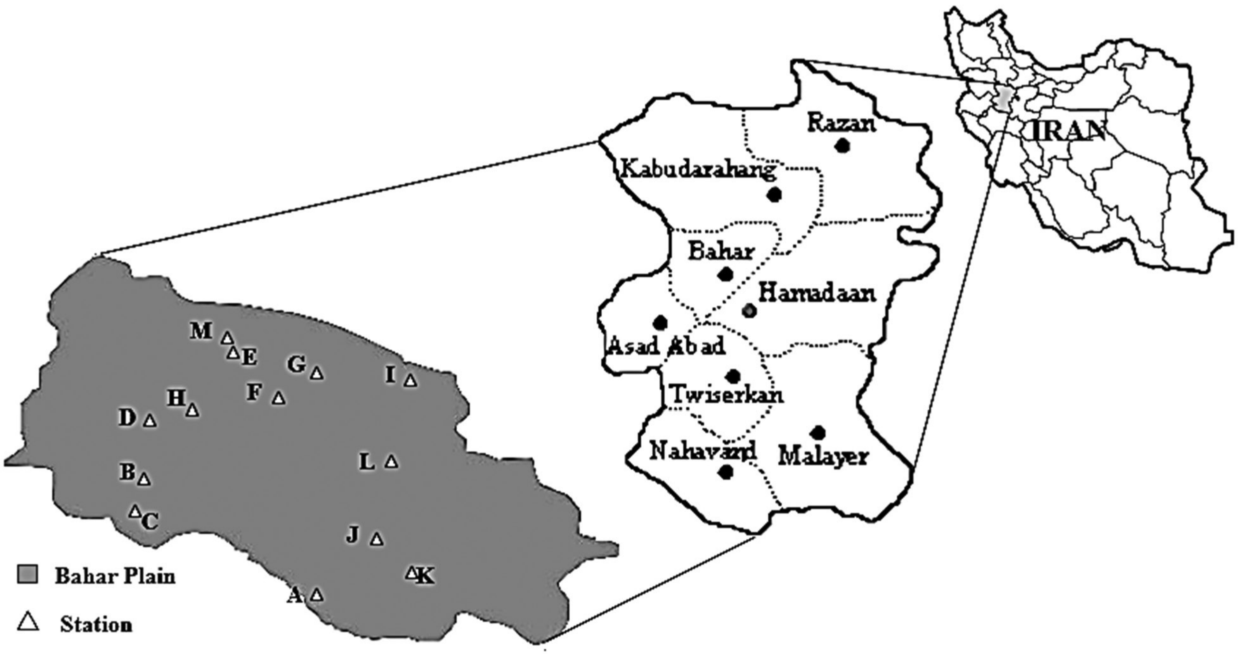

Figure 1: Location and legend map of the study area.

Table 1: Names and sampling location of the studied stations

Station	*Name*	*x*	*y*	*Type*
A	Yengijeh	268792	3861399	D[a]
B	Saleh-Abad	256537	3868212	D
C	Abroomand	255875	3866291	S[b]
D	Bahadorbeig	256940	3871614	S
E	Haroon-Abad	262913	3875576	D
F	Hesam-Abad	266115	3872900	D
G	Lalejin	268880	3874321	D
H	Karim-Abad	260015	3872205	S
I	Latgah	275488	3873901	S
J	Dehpiaz	273100	3864705	D
K	Joraghan	275593	3862673	S
L	Bahram-Abad	274110	3869210	D
M	Taghzie	262459	3876414	D

[a]Deep well, [b]Semi-deep well

$$RSI = 2pH_s - pH \qquad (7)$$

The Puckorius Scaling Index (PSI)

The Puckorius scaling index (PSI) is used for scaling and corrosion water caused by calcium carbonate (Puckorius and Broke, 1991). The PSI index is calculated as follows (equations 8 and 9):

$$PSI = 2pH_s - pH_{eq} \qquad (8)$$

$$pH_{eq} = 1.465 \times \log_{10} (Alkalinity) + 4.54 \qquad (9)$$

Interpretation of LSI, RSI and PSI as an evaluation factor of scale formation and corrosion potential of water is given in Table 3 (Esmaeili-Vardanjani et al., 2015; Shankar, 2014).

Results and Discussion

The presence of various minerals in water indicates a tendency to scaling and corrosion and can be harmful to human health, so it is necessary to use the Piper, Schoeller and Wilcox diagrams to the better description of the water quality results.

The results of the Piper diagram (Piper, 1944) showed that the most anions and cations were HCO_3 and Ca. Based on the Piper diagram suggested by Back (1961) and Hanshaw (1965), the quality of water samples were classified in three sections: bicarbonate, calcium and Ca-Mg-Na-K (Figure 2).

World Health Organization (WHO) standard expresses that the amounts of Ca, Mg and Na for drinking water should not exceed 3.7, 4.12 and 5.21 meq/l, respectively (Table 4). The results showed that Ca with a range of 8-10, Mg and Na with a range of 6-8 meq/l were higher than the desirable standard limit of drinking water and except Ca which was greater than the permissible value; the Mg and Na cations were lower than the limit. The results showed that the values of SO_4 and Cl were within the desirable limit with mean values of 4 and 7.07 meq/l, respectively (Figure 3).

Table 2: Statistical summary of the physical and chemical properties of Bahar groundwater samples

Parameter	*Minimum*	*Maximum*	*Mean*	*Std. deviation*
EC (µS/cm)	670.50	2270.30	1053.40	411.15
TDS (mg/l)	425.07	1507.53	684.61	277.58
pH	7.43	7.92	7.63	0.16
SAR	0.50	2.61	1.18	0.51
HCO_3 (mg/l)	4.30	8.09	5.33	1.06
CO_3 (mg/l)	0	0	0	0
Cl (mg/l)	0.76	7.11	2.15	1.89
SO_4 (mg/l)	0.92	17.25	4.06	4.36
Ca (mg/l)	3.15	8.60	4.66	1.60
Mg (mg/l)	2.32	7.24	3.36	1.30
Na (mg/l)	1.04	7.32	2.43	1.60
K (mg/l)	0.02	0.07	0.04	0.01

Table 3: The range of used water corrosion and scaling indices

LSI	*Description*	*RSI*	*Description*	*PSI*	*Description*
< -2	Very corrosive	<5.5	Heavy	<5.5	Heavy
-2- -0.5	Corrosive	5.5-6.2	Scale	5.5-6.2	Scale
-0.5-0	Low corrosive	6.2-6.8	No scale	6.2-6.8	No scale
0-0.5	Low scale	6.8-8.5	Corrosive	6.8-8.5	Low corrosive
0.5-2	Scale	>8.5	Very corrosive	>8.5	Very corrosive

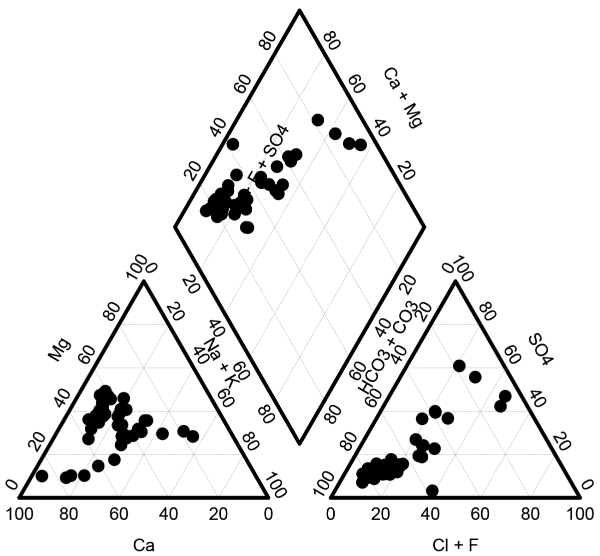

Figure 2: Plotting water samples on Piper diagram.

If EC is between 250 and 750 µS/cm, the water quality is good in terms of salinity rating, and this classification is shown in the Wilcox diagram with C_2, and if the sodium content is less than 10 mg/l, then the category is S_1 and it means that the water quality is excellent, and if the sodium content is between 10 and 18, it falls into category S_2, which indicates the good

Table 4: World Health Organization guidelines for drinking water quality (WHO, 2006)

Physical and chemical parameters	*Desirable limit*	*Permissible limit*
Temp (°C)	Variable	Variable
pH	7.0-8.5	6.5-9.2
EC (µS cm^{-1})	<250	<1480
TDS (mg L^{-1})	<500	<1000
TH (mg L^{-1})	<150	<500
Ca^{2+} (meq L^{-1})	<3.7	<9.98
Mg^{2+} (meq L^{-1})	<4.12	<12.3
Na^{+} (meq L^{-1})	<5.21	<17.3
K^{+} (meq L^{-1})	-	-
HCO_3^- (meq L^{-1})	Variable	Variable
Cl^- (meq L^{-1})	<7.07	<14.35
SO_4^2 (meq L^{-1})	<4	<8
NO_3^- (meq L^{-1})	<0.16	<0.72
Fe (meq L^{-1})	<0.001	<0.035

quality of irrigation water (Todd, 1959). Figure 4 shows Wilcox diagram (Wilcox, 1995) plotted by correlating

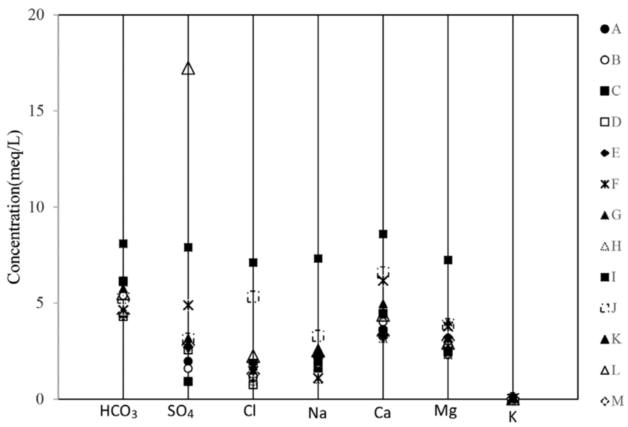

Figure 3: Classified samples according to drinking standard using Schoeller diagram.

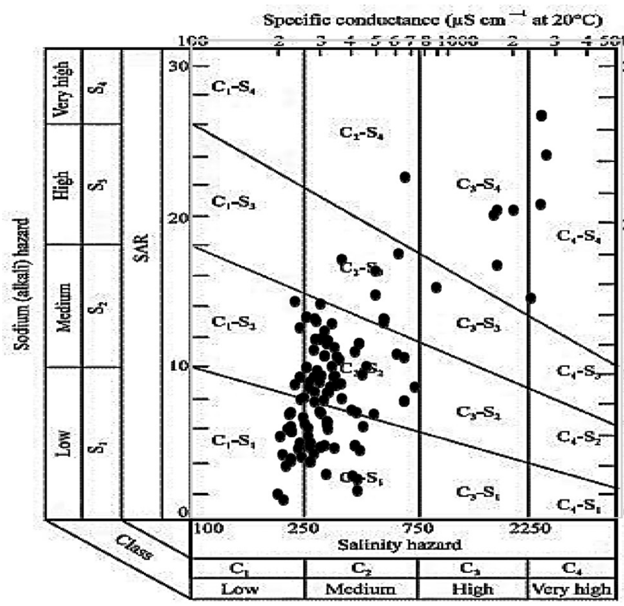

Figure 4: Classification of samples for agriculture water standards based on Wilcox diagram.

the sodium absorption ratio and electrical conductivity for irrigation classification of samples. Most water samples were in the C_2-S_1 and C_2-S_2 class, which means medium salinity (C_2) and low to moderate sodium levels and some samples were located in the high and very high sodium content (Figure 4).

Statistical summary of LSI, RSI and PSI showed that the LSI values range was from –0.43 to 1.12 and the mean value were 0.18 which expresses the tendency to scaling. Also, the range of RSI and PSI was 5.75 to 8.05 and 4.62 to 7.81, respectively; mean values of these indices indicated the tendency to lower corrosion (Table 5).

Table 5: Statistical summary of the estimated indices for all samples

Index	*N*	*Minimum*	*Maximum*	*Mean*	*Std. deviation*
LSI	130	-0.43	1.12	0.18	0.31
RSI	130	5.75	8.05	7.25	0.48
PSI	130	4.62	7.81	6.56	0.69

The changes of the indices were illustrated by histograms (Figure 5). Based on the results of Table 6 and Figure 5a, the 55.3% of the samples are classified into "Low scale" and 27% of the samples classified into "Low corrosive" category and 17.7% of the remaining samples classified into "scale". Sivasankar and Ramachandramoorthy (2009) reported that low levels of corrosion are due to the presence of carbon dioxide in water and low alkalinity of water. The result of RSI indicated that 80% of the samples were categorized into the type of "Corrosive" and 15.3% and 4.6% of the samples were classified in "No scale" and "Scale" category, respectively (Figure 5b and Table 6). According to the PSI index, the "Low corrosive" was 46.1% of the samples and 27.6% and 16.1% of the samples are classified into the type of "No scale" and "Scale" category, respectively (Figure 5c and Table 6). Similar results from the two RSI and PSI indicators indicate that they are in the same direction (Figure 5), Ravikumar and Somashekar (2012) reported that the similar calculation method to determining the RSI and PSI is the main reason for similar results.

The results showed that the majority of samples were classified in the range of low scale, according to the Langelier saturation index, and the values of the RSI and PSI indices indicated the low scaling and average corrosivity (Figure 5 and Table 6). Hancke and Wilhelm (1996) in their study expressed that when the pH is 7 to 8.5 the dissolved solids in water were scaled. The pH of water samples with a mean value of 7.63 indicated that the water quality was "low scale" or tendency to corrode. Analysis of the groundwater quality with the standard indices showed that moderate corrosion of water can cause the problem for drinking and industries in a long time and can hazard health. Kurdi et al. (2015) expressed that the corrosive waters can cause secondary contamination such as the appearance of iron, copper and magnesium in drinkable water, which changes the colour, smell and taste of water.

Figure 6 shows that the change of TDS and HCO_3 can be effective on RSI and PSI values. By increasing the amounts of TDS and HCO_3 the RSI and PSI values were reduced and it is clear that there was an inverse

Table 6: Percent of LSI, RSI and PSI values of water samples in Bahar Plain

LSI	*No. of samples*	*Percent*	*RSI*	*No. of samples*	*Percent*	*PSI*	*No. of samples*	*Percent*
< -2	0	0	<5.5	0	0	<5.5	13	10
-2- -0.5	0	0	5.5-6.2	6	4.6	5.5-6.2	21	16.2
-0.5-0	35	27	6.2-6.8	20	15.3	6.2-6.8	36	27.6
0-0.5	72	55.3	6.8-8.5	104	80	6.8-8.5	60	46.2
0.5-2	23	17.7	>8.5	0	0	>8.5	0	0

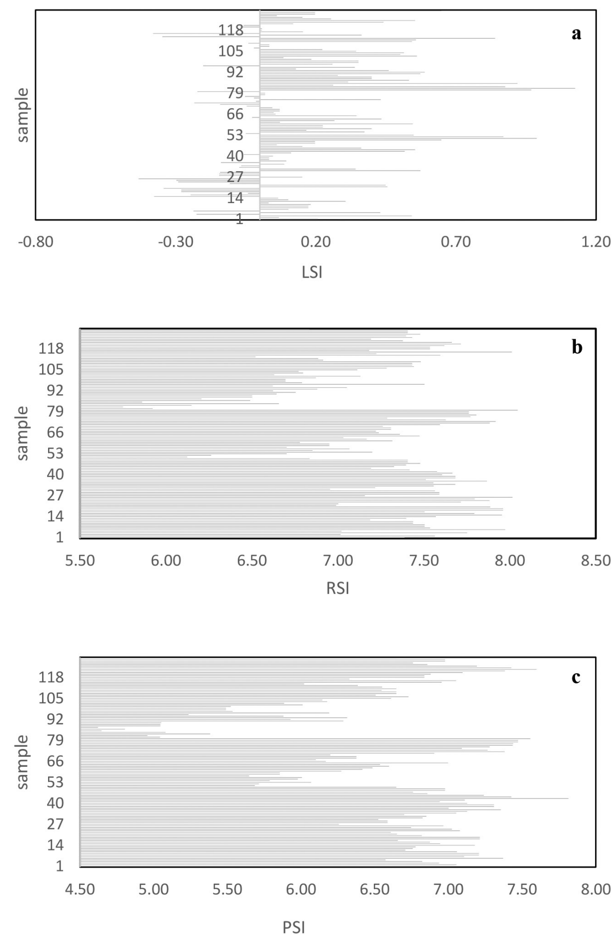

Figure 5: Evaluation of LSI, RSI and PSI for the groundwater samples (a: The Langelier, b: The Ryznar and c: The Puckorius index).

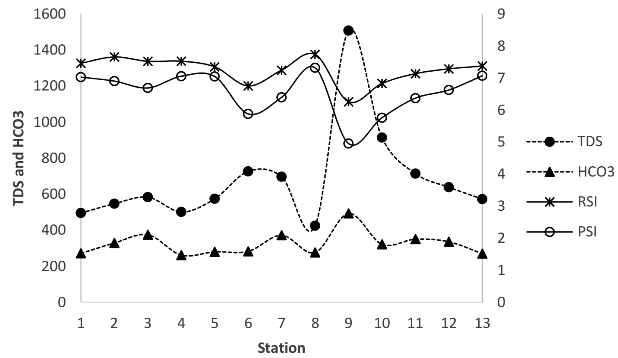

Figure 6: Process of changing TDS (mg/l) and HCO_3 (mg/l) versus RSI and PSI for all water samples (2004-2014).

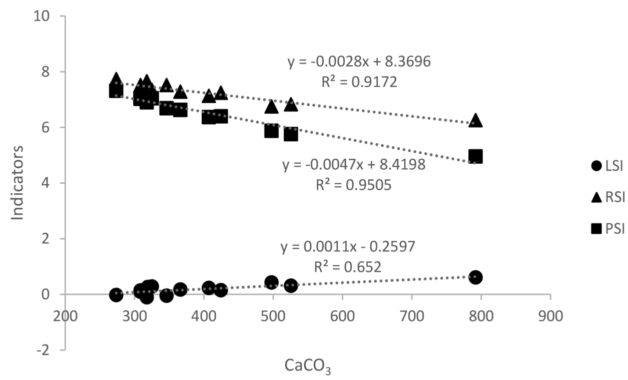

Figure 7: The average values of indicators versus amounts of $CaCO_3$ (mg/l).

relationship between these indices with TDS and HCO_3 values in all situations (Figure 6), because the cations with two capacities (Mg^{2+} and Ca^{2+} that calculated by TDS) react with other material in water and precipitated in the walls (Kurdi et al., 2015). A minor difference was observed between the RSI and PSI and it can be due to the variable pH of the samples (Figure 6). Fang (2004) reported that carbonate and bicarbonate reduced corrosion, but chloride and sulfate markedly accelerated corrosion.

Shams El Din (2009) stated that the proper pH value and enough amounts of Ca^{2+} and HCO_3^- is necessary for successful sediment of $CaCO_3$. Water hardness can impact on scaling and corrosion. The determination coefficient (R^2) between the $CaCO_3$ and LSI was 0.65 and the high correlation was observed between the $CaCO_3$ and RSI and PSI with 0.91 and 0.95, respectively (Figure 7).

Conclusion

Assessment of the water quality is important to know the potential of corrosion and scaling to the possibility of using this water for human and industrial consumption and also in irrigation systems in agriculture. Ground water is the primary source of drinking and agricultural water for rural communities in Bahar plain. In one part of this study, the groundwater quality is evaluated in the study area using Schoeller and Wilcox diagram and WHO guidelines. The results showed that the values of SO_4 and Cl were at the desirable limit and Mg and Na were at the permissible limit in the ground water and in the irrigated area most wells were found classified to medium salinity and low to medium sodium type with a class of C_2-S_1 and C_2-S_2.

The results indicated that the quality of 55.3% of the water samples is classified into "low scale" and based on the RSI and PSI indices. It can be seen that 80% and 46.1% of the samples were classified into "Corrosive" and "Low corrosive" respectively; that showed that most wells of Bahar Plain have the potential of low scale and moderate corrosion and this range can be problematic for various uses of these waters, especially for human health. In comparison, between LSI with RSI and PSI, Awatif et al. (2014) have interpreted that LSI cannot be used as a quantitative index for different waters, but it is possible with RSI and PSI.

Finally, due to the low scaling potential of water it was observed not to be a problem for agricultural purposes in this area, but with the moderate corrosion of groundwater quality, the necessary measurement should be considered to reduce the risks of drinking and industrial consumption.

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