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Corrosion - Scaling Potentially of Domestic Water Pipelines and Evaluate the Applicability of Raw Water Sources in Basrah, IRAQ

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Abstract

As a result of changes in the chemical properties of the Shatt al-Arab River, especially in the last decade, as well as the lack of rainfall and the effect of seawater intrusion into the Shatt al-Arab, this study was conducted to investigate the possible changes in the water pipelines like corrosive and scaling which Shatt al-Arab River is the source of water supply for domestic use. Domestic water samples were collected from 10 various locations in Basrah to study the water's tendency to be corrosive or form scales along the pipelines. The Langelier Index, Ryznar Index, Larson-Skold Index, and Saturation Index were used to determine the corrosivity potential of water based on physical and chemical parameters. Most domestic water sources tend to form scales based on the Langelier Saturation Index, Ryznar Index, and Saturation Index. According to the evaluation, the Langelier Index ranged from -1.71 to 1.98, Ryznar Index was between 4.45 and 10.53, Larson-Skold Index was between 1.13(rainwater) 62.70 (Dibdabba Water) and Saturation Index was ranged -1.31 to 1.24. The results indicated that the rainwater and some groundwater samples are moderately corrosive. The water of all the water resources sampled in this study ranged from balanced to mild scaling. The Larson-Skold Index, on the other hand, shows that all domestic water samples are corrosive. The corrosion and scaling potential of natural water sources collected from groundwater, river water, and rainwater has also been determined.

Keywords: Scaling tendency, Corrosion, Domestic Water, Saturation Index, Basrah, Iraq

قابلية المياه المنزلية على حدوث التآكل والتقشرات في الأنابيب المائية وتقييم امكانية استخدام مصادر المياه الطبيعية الأخرى في البصرة، العراق

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الخلاصة

بسبب التغيرات في الخصائص الكيميائية لنهر شط العرب، وخاصة في العقد الاخير، فضلا عن قلة هطول الأمطار وتأثير تداخل السان البحري إلى مياه شط العرب، فقد أجريت هذه الدراسة للتحقيق في احتمال حدوث تغيرات في خطوط أنابيب المياه الناقلة كالتأكل والتقشر، أذ يعتبر نهر شط العرب مصدر إمداد المياه للاستخدام المنزلي.

اختيرت انواع مختلفة من مصادر المياه وذلك لدراسة قابلية او ميل هذه المياه على التآكل والتقشر للانابيب الحاملة او المارة بها في مدينة البصرة، جنوب العراق. اعتمدت مجموعة من ادلة التآكل والتقشر لدراسة ميل هذه المياه على التآكل منها مقاييس Langelier Index (LSI)، Ryzanr(RSI) , Index , Larson– Skold Index (LSSI) بالإضافة الى Saturation Index(SI) بالاعتماد على دراسة وتحليل الخواص الكيميائية والفيزيائية للمياه . وقد تراوحت قيم LSI بين -1.71 الى 1.98، اما قيم RSI فكانت بين4.45 و 10.35 ، في حين بلغت قيم LSSI من 1.13 والمتمثلة بمياه الامطار الى 62.70 (مياه الدبدبة الجوفي) اما قيم SI فهي بين -131 و 1.24. اغلب انواع عينات المياه المنزلية المستخدمة اعطت مؤشرا عن قابليتها للتأكل حسب مقياس. Langelier Saturation Index, Ryznar Index and Saturation Indexبينما اشار مقياس Larson–Skold Index الى ان جميع عينات المياه المنزلية ذات قابلية تآكل كما تم اختبار انواع مختلفة للمياه في قابليتها على عملية التقشر والتأكل هذه المياه تشمل مياه الشرب وشط العرب ومياه الامطار والمياه الجوفية.

1. Introduction

Corrosion is one of the most complicated and costly problems facing drinking water utilities. The corrosion in water pipeline networks is a chemical reaction between the materials made up of the metal or alloy and water flowing through it. water chemistry plays an essential role in corrosion, whether it is an oxidation or redaction reactions [1], [2]Corrosion may be accompanied by toxic metals along the drinking water pipelines, such as Lead or/and Copper. Physical damages and usage problems might be suffered by household plumping losses, stained laundry, bitter taste and green-blue stains.

The corrosion occurs in soft water due to a lack of dissolved cations of calcium and magnesium, while the carbonates of calcium or magnesium might be coating the inner of pipelines in hard water. At the same time, that carbonate coats the pipelines and then inhibits the corrosion reactions, but it clogs the water flow. Noted that waters with high concentrations of sodium, chloride, and other ions will be highly conductivity and then promote corrosion [3] [4].

Most of the previous studies dealt with the chemical properties of water from purification plants, but the study of pipelines corrosion as a result of the water chemical properties effects was limited within the study area. However, some studies deal with the quality of drinking water for some water purification projects, as well as the effect of transmission networks on the chemical properties of water, such as [5] [6]

Water's physical and chemical characteristics contribute significantly to corrosive tendency. The study aims to investigate the potential corrosion efficiency of drinking water reacting the pipeline facilities in the Basrah based on four different corrosion indices (the Langelier Index, Larson-Skold Index, Ryznar Index and saturation Index). It was taken samples of groundwater and other resources for comparison as well. Based on [7], [8], even though there is no correlation between these indices and the corrosive tendency of water, the Langelier Index, Ryznar Index and Larson-Skold Index are still popularly adopted to understand possible causes of corrosion [9]. To protect the drinking water networks, it should be understanding the reactions between the water environment and pipelines materials around, especially unlined metal and cementitious. Prediction and then protection of the networks to be established by advanced consideration of the root causes of corrosion due to the chemistry of new sources, whether groundwater or surface water and the alloy materials made up pipelines [10]. In the end all outcomes will undoubtedly contribute to the corrosion database, which can be beneficial for new drinking water networks and rehabilitation of the existing properly.

1.1 Purpose

Over many decades the domestic water supplied to Basrah deteriorated in quality due to drained water and irrigation water wastes coming from the cultivated areas north of Basrah. Furthermore, the agricultural activity wastes along the areas lie on Tigris and Euphrates, which flow toward Shatt AL Arab. Recently, the salt intrusion of the Arabic Gulf was exacerbating the problem much more. On the other hand, the domestic water treatment units are still not developed, where continue sedimentation, filtration and chlorination of water before supply under extremely overdemand aligned with random population expansion over Basrah areas.

2. Materials and Procedure

2.1 Study Area

Basrah locates south of Iraq, which is bounded by latitude (30° 45′ - 31° 15′ N) and longitudes (47° 10′ - 48° 45′ E). The study undertaken covers Basrah downtown and parts of northern and southern areas. Figure 1 shows the water samples locations. Surface water sources are the ,typical intakes of domestic water in whole Basrah based on geographic location; Tigris, Euphrates, Shatt Al-Arab and Badaa channel project [11], [12]. It is just chlorinated the supplied water before pumping it to domestic water networks along kilometers of pipelines. Mostly the materials made up of pipelines are asbestos-cement and non-coated metal. There are galvanized and polyvinyl chloride pipelines in level limited over specific areas (Water Authority of Basrah) [13]. Just for knowledge that the water pumped to the houses is not used for drinking at all because it does not match are the WHO standards [14].

2.2 Sampling and Analyses

The domestic water samples have been collected from different areas in Basrah using water tabs from November to March of 2017. At the same time, it was sampled other water sources that could be applicable: groundwater, rainwater, Reverse Osmosis units and industrial water, using cleaned polyethene bottles. Before sampling, a routine procedure was adopted by rinsing all bottles for three then filled, avoiding all feasible air bubbles. The samples were kept in a refrigerator at 4°C to be analyzed within 24 hours later. Physical and chemical analyses were carried out by the Najibia power station laboratory. It was measured temperature, pH, dissolved oxygen, chemical oxygen demand COD, total suspended solids TSS, total dissolved solids TDS and electrical conductivity. Cations and anions were analyzed as well as Fe, Cu and Zn (Table 1) [15].

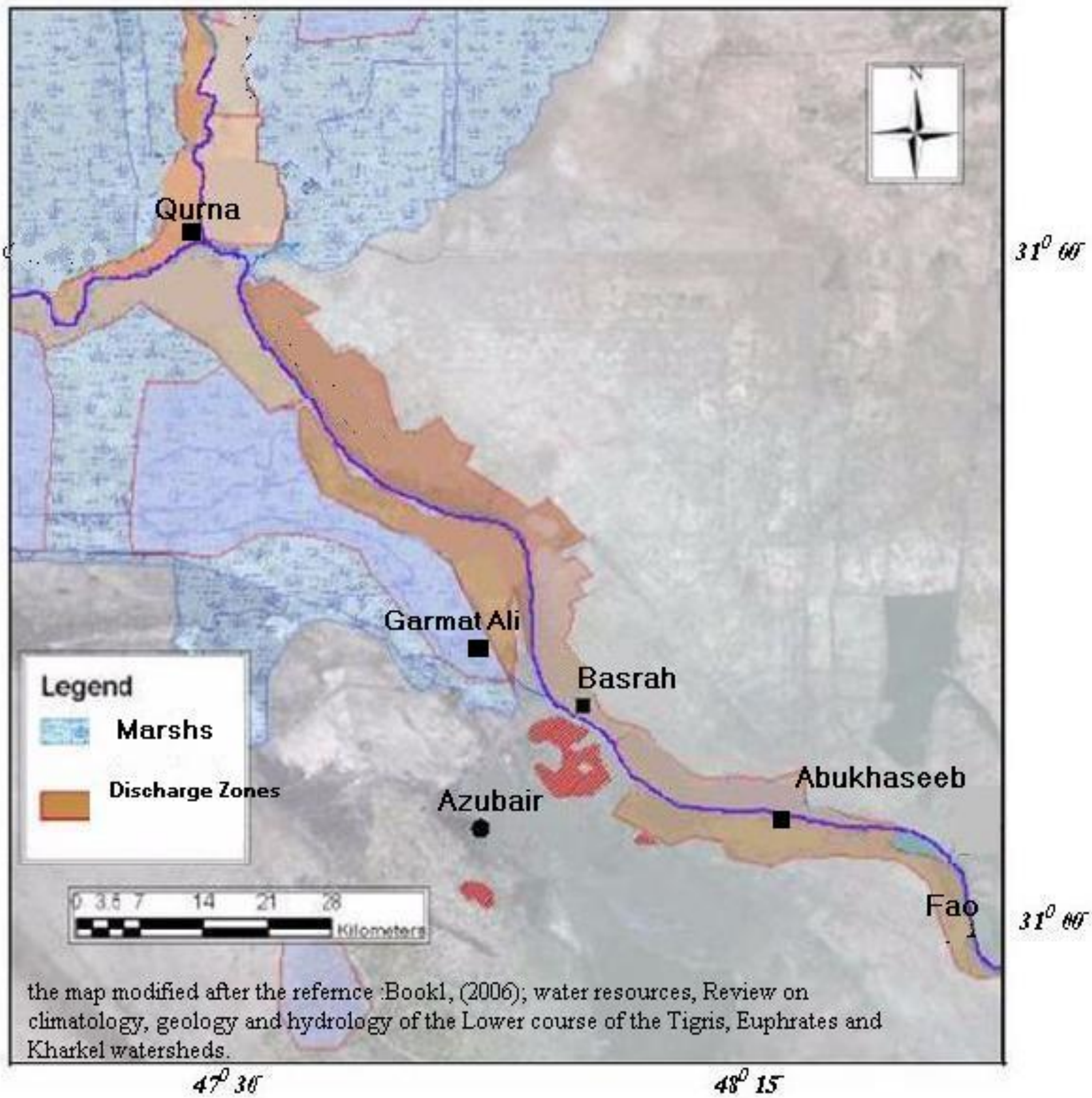

Figure 1- Locations of water samples in the study area

3. Results and Discussion

3.1 Domestic Water

Approved corrosion indicators have been used to detect the susceptibility of water to corrosion in general. This can be recognized by iron concentration along domestic water pipelines, which intake the water from different sources. Table 1 shows the physical and chemical parameters of domestic water.

Table 1- Physical and chemical parameters of domestic water in the study area

Location / Parameter		AbulKasib (1) - Intake from ShatalArab	Qurna (2) - Intake from the Euphrates	Ribat (3) - Intake from ShatalArab	Arab Gulf (4) - Intake from Badaa Channel	Maaqal (5) - Intake from ShatalArab	Qarmat Ali (6) - Intake from ShatalArab	Bradaia (7) - Intake from ShatalArab	Mudaina (8) - Intake from the Euphrates	Zubair (9) - Intake from Badaa Channel	Mithaq (10) - Intake from ShatalArab	Average	Lowest	Highest
pH		7.4	7.5	7.8	8.3	6.6	7.6	7.1	7.9	6.7	7.7	7.5	6.6	8.3
EC (μs/cm)		4305	5000	4010	1457	4160	4170	4320	5240	1380	3660	3770	1380	5240
TDS	Part per Million (ppm)	3013	3500	2807	1019	2933	2919	3024	3668	966	2562	2641	966	3668
COD		3.6	2.8	2.6	3	3.2	2.5	2.4	2.4	4.6	3.9	3.1	2.4	4.6
TSS		9.9	9.7	8.3	3.2	1.2	0.9	0.02	0.02	0.02	0.01	3.33	0.01	9.9
SO_4^{2-}		609	1052	600	230	500	600	650	900	17	625	578	17	1052
Cl^{1-}		730	620	530	150	800	750	808	1120	200	540	625	150	1120
Ca^{2+}		550	750	600	350	520	500	400	500	400	500	507	350	750
Mg^{2+}		750	450	650	150	930	700	800	620	100	700	585	100	930
Alkal		325	400	399	100	190	300	300	150	125	150	244	100	400
SiO_2		5.25	1.3	6.9	7	8.05	5.6	6.9	9.9	1.1	4.4	5.64	1.1	9.9
Fe		0.36	0.2	0.1	0.09	0.2	0.1	0.02	0.2	0.01	0.3	0.16	0.01	0.36
Zn		0.8	0.61	0.97	0.54	0.87	0.56	1.1	0.64	0.72	0.52	0.73	0.52	1.1
Cu		0.017	0.015	0.017	0.016	0.017	0.019	0.016	0.015	0.018	0.016	0.017	0.015	0.019

The average pH is 7.5, which lies within acceptable criteria. H the water samples had been collected during the wet period, which should be the lowest salinity of rivers water. The TDS average is 2641ppm, which is not acceptable supplied to the domestic purposes. Note that the locations have TDS ±1000ppm intake the raw water from Badaa channel project like locations 4 and 9. There is no significant difference in COD figures over the adopted locations, where the average is 3.1 confirming the reduction condition. A wide range of TSS can be attributed to the cause and roots of turbidity and the physical treatment efficiency before pumping to the export line. The TSS average is 3.33ppm. The sulfate average is 578ppm with the notation that the level is higher in the locations that intake the water from the Euphrates like 2 and 8, while it is diluted in other areas. It is recognized a high chloride level in site 8 compared to other sources. A significantly lowest levels had been observed in locations 4 and 9. An overall average is 625ppm. The averages of calcium and magnesium are 507ppm and 585ppm respectively, which confirm that all water sources have very hard tendency. This can be explained why the scales grow along pipelines. The alkalinity ranges are acceptable for domestic water, where its average is 244ppm. Those high levels of alkalinity contribute to form the scales as well. The average of silicon dioxide aligned to permissible standard, which is 5.64ppm. Iron contents are acceptable, with an average of 0.16ppm. Zinc limits are lie allowed standards, where the average is 0.73ppm. There are acceptable ranges of copper. It has an average of 0.017ppm.

3.1.1 Langelier Saturation Index (LSI)

The Langelier Saturation Index is defined as the difference between actual pH (measured) and calculated pHs. The magnitude and sign of the LSI value show water's tendency to form or dissolve scale, thus inhibiting or encouraging corrosion [16].

$$LSI = pH_{actual} - H_s \quad \ldots (1)$$

where,

pHactual is the actual pH of a solution.

pHS is the pH of calcium carbonate saturation.

The calculated pHS can be determined using the following equation [17]:

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

where,

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

$$B = -13.12 \times Log_{10}(℃ + 273) + 34.55 \quad \ldots (4)$$

$$C = Log_{10}[C^{+2} as\ CaCo_3] - 0.4 \quad \ldots (5)$$

$$D = Log_{10}[Alkalinity\ as\ CaCo_3] \quad \ldots (6)$$

Based on Table 2 can be clarified that most calculated pH is less than measured in actual. This indicates that the water tends to deposit calcium carbonate and is scale-forming (nonaggressive). Only two locations (7 and 9) have calculated pH higher than measured. The water is not saturated and will dissolve calcium carbonate (aggressive). Location No. 5 has semi balance conditions between two pH, then that calcium carbonate will not be dissolved or precipitated[16, 17] [18] [19].

Positive figures of the Langelier Saturation Index confirm above. Most locations of water samples tend to form scales [20]. The two areas (7 and 9) tend to dissolve then potentially corrode. The positive regression of the Langelier Index of iron level indicates that corrosion could be the reason for a little increment of iron in the water supplied to domestic pipelines (Figure 2).

these formation of scales related to the pH, bicarbonate, calcium carbonate, dissolved solids, and the temperature of the solution. Then, each parameter has a separate mechanism that leads to the corrosive tendency of water. The Langelier Saturation Index is applicable to determine the corrosivity of waters that contain higher than 40ppm of alkalinity and calcium and the pH range should be between 6.5 to 9.5.

Table 2- Concluded indices of the study area

	Location No.									
Calculated Criteria	1	2	3	4	5	6	7	8	9	10
pH_S	6.31	6.40	6.19	7.20	6.57	6.39	9.2	6.82	6.84	6.78
Langelier Index	1.09	1.10	1.61	1.98	0.03	1.21	-1.71	1.08	-0.14	0.92
Ryznar Index	5.22	5.29	4.57	5.74	6.54	5.18	10.53	5.73	7.98	5.85
Larson-Skold Index	2.48	4.34	1.59	1.99	4.38	2.74	5.72	10.96	1.32	5.30
Saturation Index	0.80	1.03	1.32	1.14	-0.05	0.93	0.33	0.90	-2.20	0.86

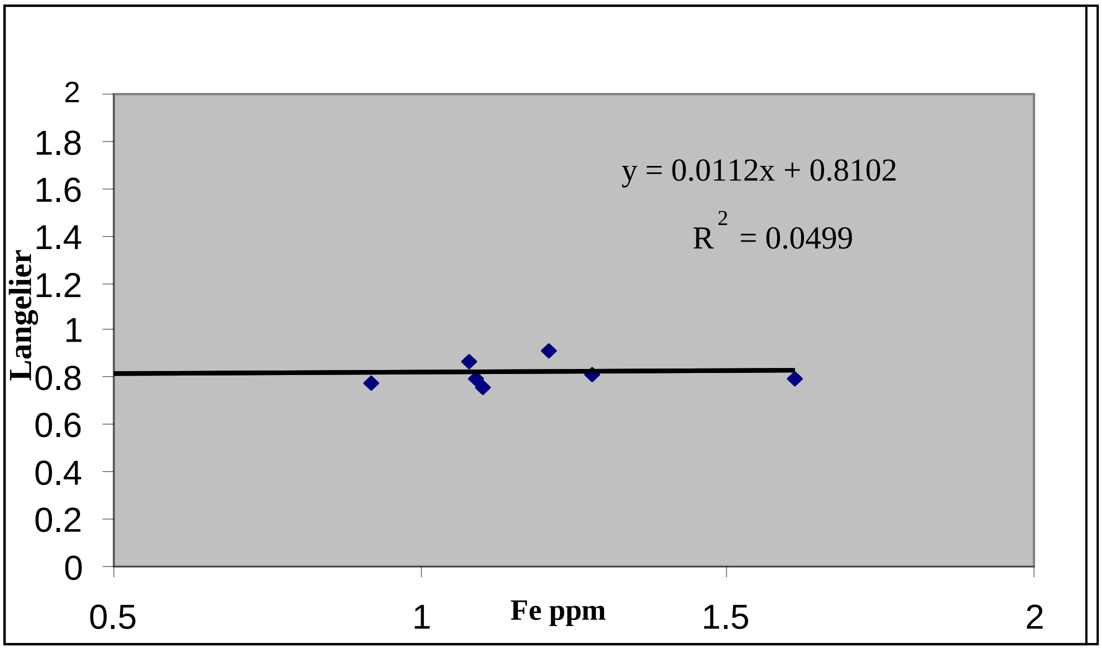

Figure 2-Langelier index Regression of iron level

3.1.2 Ryznar Index (RSI)

Ryznar Index is like other indices used to predict the potentially forming the calcium carbonate in water. It is calculated using the equation below [21].

$$RSI = 2pH_S - pH_{actual} \quad (7)$$

When the outcome value of RSI is less than 6, this indicates the potential forming of calcium carbonate. The further away from the reference value, then greater the probability for scaling tendency and protection of corrosivity. Vice versa, when the value of RSI is higher than 6, then high potentially dissolves the calcium carbonate, then the high likelihood of water will be corrosive and no corrosion protective films [22]. In logic, when the value is close to 6, the water tends to be in a balance condition.

Locations 7 and 9 have more tendency to dissolution the calcium carbonate to interpret that the water could be more corrosive. Mostly the samples undertaken tend to form the scale. Notable that the tendency of water samples matches based on the outcomes of RSI and LSI (Table 2). The Ryzar Index is empirical and applicable only to the flowing water, where the condition at the pipeline is quite different from that of the bulk water body. While even that the Langelier Index can be applied to domestic water at the pipelines, but it is more useful for the bulk water such as reservoirs. Using both indices provide insights into what can be happened due to interaction between the water and environment along the flowing water and stored water.

The Ryznar Index has positive regression of iron level in the study area (Figure 3). This clarifies that iron probably dissolute into the water along the domestic pipelines. It should be aware that chloride and sulphate could be significantly causing increased the aggressiveness of the water.

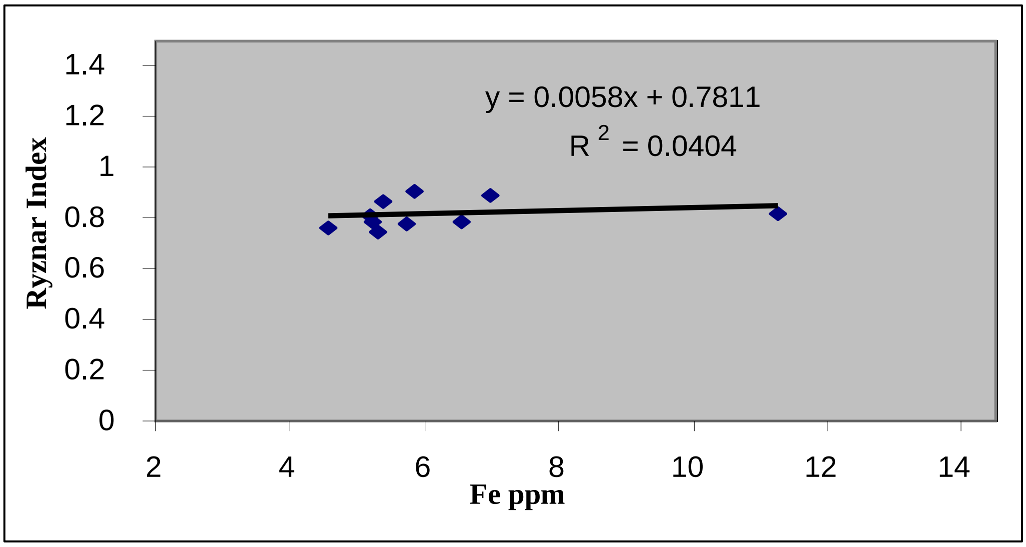

Figure 3-Ryznar index Regression of iron level

3.1.3 Larson-Skold Index

The Larson-Skold Index (Larson Ratio) is an empirical equation adopted to estimate the corrosiveness of water relative to mild steel metal of water pipelines. It is calculated by the following [23]:

$$Larson - Skold\ Index = \frac{\left[Cl^{-1}_{(epm)}\right] + \left[SO^{-2}_{4(epm)}\right]}{HCO^{-1}_{3(epm)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

It considers the role of chloride and sulphate of flowing water versus the mild steel of pipelines [23]. The level of bicarbonate represented by alkalinity amount has effectiveness as well. Differently, conclusions could be noted versus the previous indices because adopting different singly dominated parameters for each index.

Based on moderate to high alkalinity levels of the studied waters versus high levels of chloride and sulphate, The Larson-Skold Index was applied. Note that waters that have low and extreme alkalinity could be not reliable [23], [24]. In the end, this index can prove an aggressiveness of water corrosion against the environment and then adopt the prohibition in advance.

If the Larson-Skold Index is less than 0.8, the water does not have a corrosive tendency; if the index lies between 0.8 and 1.2, then the water is corrosive, and when it is higher than 1.2, the water tends to be highly corrosive.

Table 2 shows that all water sources may have a high corrosion tendency. Because only chloride and sulphate are driving to calculate the Larson-Skold Index with taken consider alkalinity was reduced slightly, it is noted that water's tendency to be corrosive is dominated. To adjust between corrosion scaling likelihood, should adopt the pH as well, which be a controller in the process. The regression of iron is proving the roles of both cations to increase the corrosive tendency of water. Also, the increase in iron level could be due to COD's role in water sources and intakes pollutions.

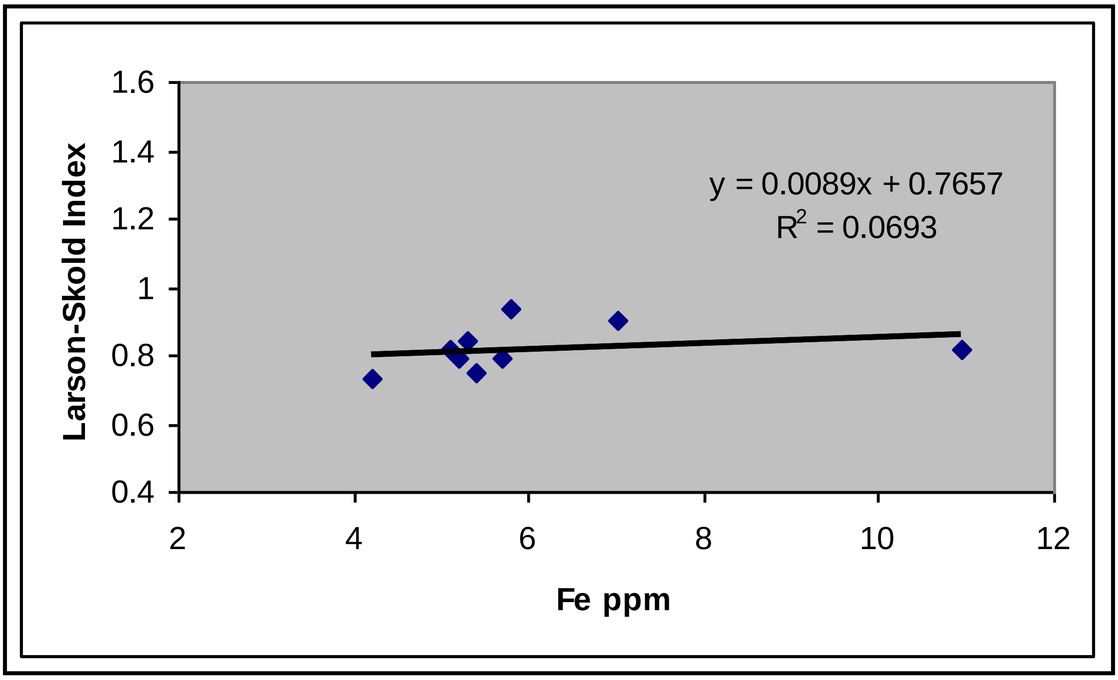

Figure 4-Larson-Skold Index Regression of the iron level

3.1.4 Saturation Index (SI)

The saturation indices are helpful to express the water tendency towards precipitation or dissolution. The degree of water saturation concerning a mineral is given by the following [23]:

$$SI = Log\left({K_{AIP}}/{K_{SP}} \right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (9)$$

where,

K_{AIP} is the ionic activity product.

K_{SP} is the solubility product.

SI is the saturation index of the concerned mineral.

When the Saturation Index equals zero, the water will be under an equilibrium condition. There is no dissolution and precipitation. If it is less than zero, this indicates that the condition is under saturation. Then the minerals phase tends to dissolve and corrosive. Contrarily when the Saturation Index is greater than zero, it means the solution is supersaturation and that mineral phase tends to precipitate and form scales [25].

Table 3 summarizes the Saturation Index figures and shows domestic water's corrosivity / scaling tendency in the study area. Most water sources have tendency to form scales based on physical and chemical parameters. The pH plays dominated role, where it is noted that Locations No. 5 and 9 have a corrosive tendency (Table 1).

Table 3- Domestic waters corrosivity and scaling tendency based on Saturation Index

Location No.	Saturation Index of Calcium Carbonate	Corrosivity / Scaling Tendency
1	0.80	Mild scale forming
2	1.03	Mild scale forming
3	1.32	Mild scale forming
4	1.14	Mild scale forming
5	-0.05	Mild corrosive
6	0.93	Mild scale forming

7	0.33	Some Faint coating
8	0.90	Mild scale forming
9	-0.212	Mild corrosive
10	0.86	Mild scale forming

According to the classification of corrosivity and scaling using the Saturation Index, which attempts to recommend the appropriate treatment, treatment may not be required for corrosion. [25]. Only it has been recognized aesthetic problems occasionally due to mild scales coating and forming (Table 4).

Table 4 -Corrosivity / Scaling classification and recommendations by Saturation Index

Saturation Index (SI)	Classification	Recommendation
-5.0	Severe corrosion	Treatment recommended
-4.0	Moderate corrosion	Treatment recommended
-3.0	Moderate corrosion	Treatment recommended
-2.0	Moderate corrosion	Treatment should be considered
-1.0	Mild corrosion	Treatment should be considered
-0.5	Mild corrosion	Treatment is probably not needed
0.0	Balanced	Treatment is typically not needed
0.5	Some faint coating	Treatment is typically not needed
1.0	Mild scale forming	Some aesthetics problems
2.0	Mild scale forming	Some aesthetics - considered
3.0	Moderate scale forming	Treatment should be considered
4.0	Severe scale forming	Treatment probably required
5.0	Severe scale forming	Treatment required

3.2 Applicability of raw water sources

Overall the water sources are always demanded for different purposes in the lifedays. The most important criteria before usage that the water should be not cause to deteriorate the industrial processes and human health as well as fully comply to other purposes. The waters potentiality of corrosivity and scaling is often due to the water chemistry interacting with the environment, whether flowing or used for storage, such as the pipelines, boilers, vessels, reservoirs etc.

This topic has been taken here, so it was an opportunity to evaluate the applicability of other natural sources of fresh water in the study area based on water chemistry (Table 5). It had been applicated the Saturation Index on the raw water samples such as groundwater collected from the Dibdiba aquifer, river water collected from Shatt AL Arab and rainwater. The raw water of the river tends to form the scales a little bit, while the raw rainwater tends to be corrosive (Table 6).

Table 5-physio-chemical characteristics of other natural sources

Source	Parameter												
	pH	TDS	EC	COD	Ca	Mg	Na	K	SO_4	Cl	Fe	Zn	Cu
Groundwater	7	3445	4160	1.1	543	265	266	21	568	1602	6.12	0.8	3.5
Rainwater	6.1	154	269		20.5	12.3	15.4	0.09	30.21	38	0.06	0.012	0.01
River Water	7.6	3153	5069	6.8	288	167	910	46	450	774	2.5	2.1	1.3

Table 6-Raw waters corrosivity and scaling tendency based on Saturation Index

Source	Sample	Saturation Index of Calcium Carbonate	Corrosivity / Scaling Tendency
Rainwater	R1	-1.19	Mild Corrosive
	R2	-0.38	Mild Corrosive
Groundwater	D1	0.98	Mild scale forming
	D2	-0.2	Mild Corrosive
	D3	-0.4	Mild Corrosive
	D4	0.86	Mild scale forming
River water		0.16	Some Faint coating

It is restricted to apply three saturation indices on the groundwater samples only, which are Langelier Saturation Index, Ryznar Index and Saturation Index. The Langelier Saturation Index shows that the groundwater tends to precipitate the calcium carbonate mostly and less tends to dissolve it (Figure 5).

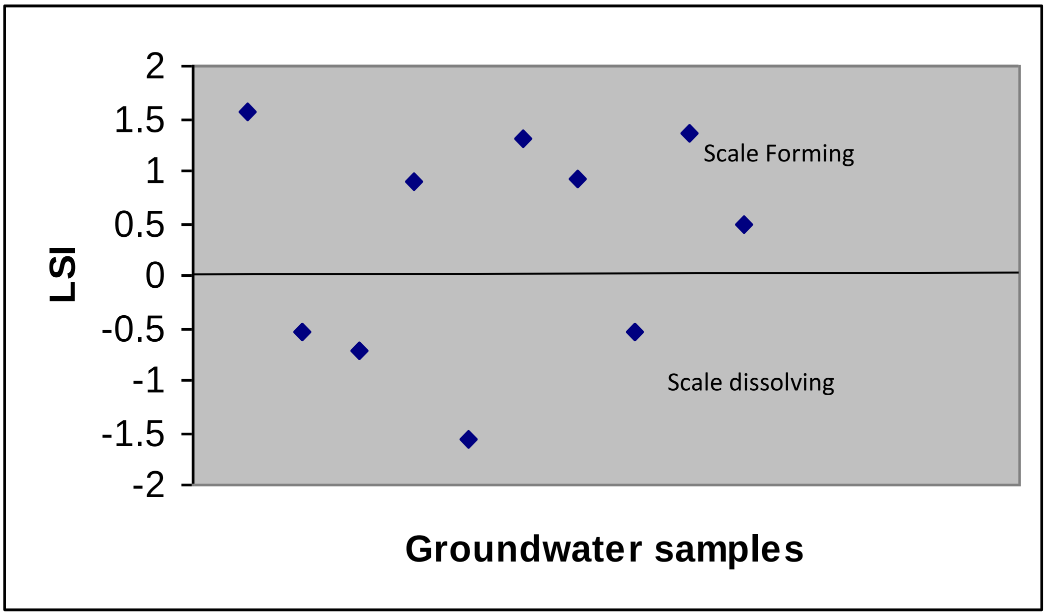

Figure -5 Langelier Saturation Index shows the groundwater tendency.

Based on Ryznar and Saturation applied indices, the groundwater samples tended equally to be precipitated the calcium carbonate and dissolved it to be corrosive (Figures 6 and 7). The conclusion is matching to the Langelier Saturation Index.

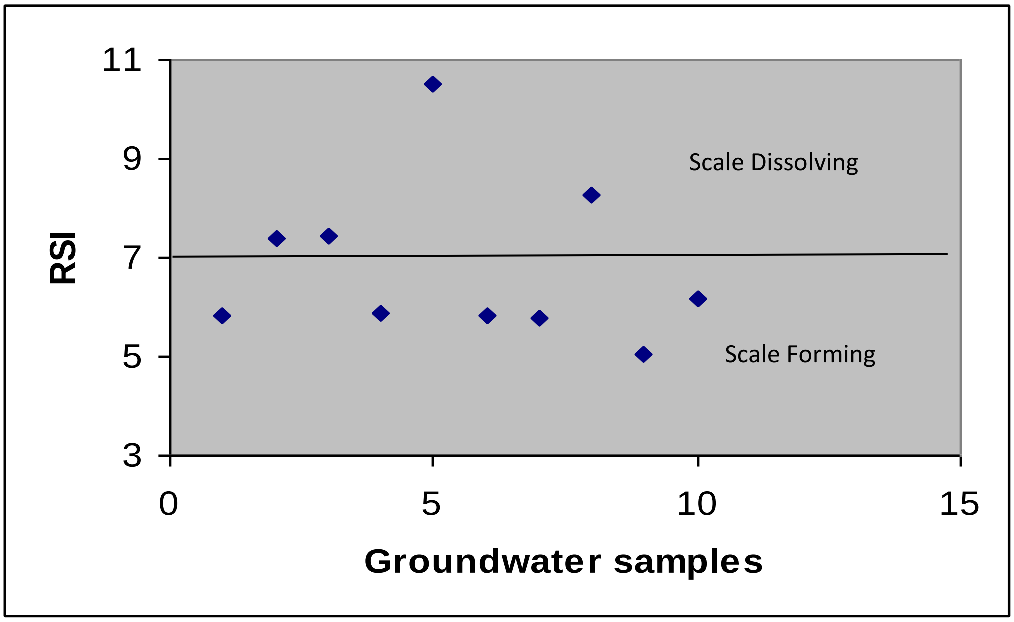

Figure 6-Ryznar Index shows the ground groundwater tendency.

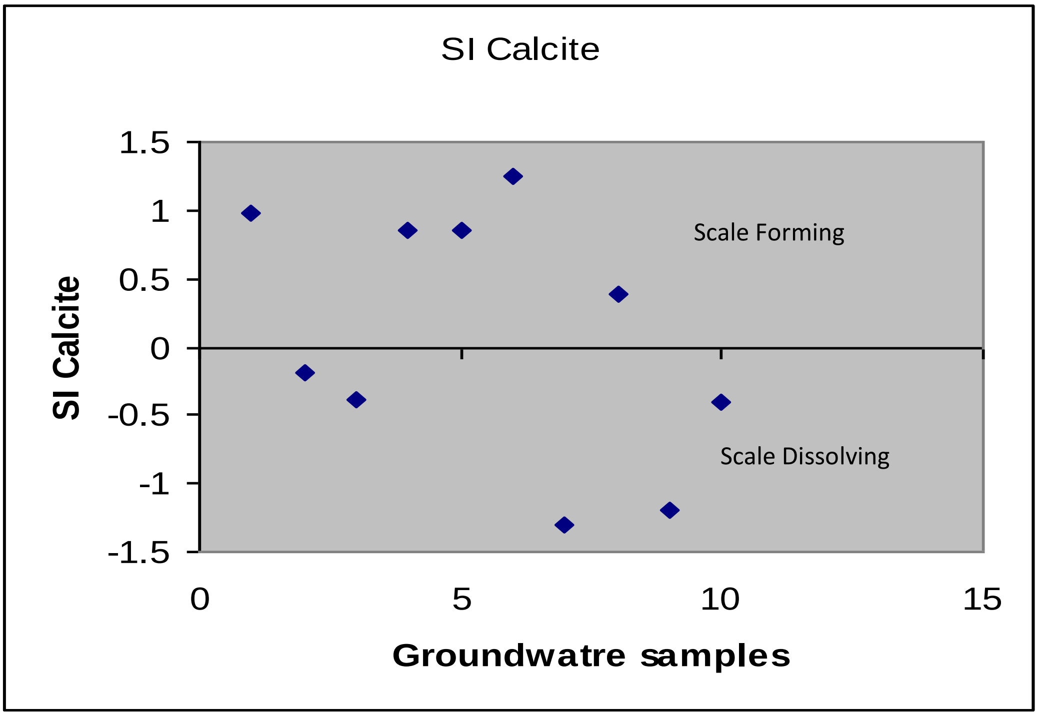

Figure 7-Saturation Index shows the gr groundwater tendency.

4. Conclusions and Recommendations

The results from adopted corrosion indices show that there is corrosion tendency overall. Most domestic water sources have a tendency form the scales based on Langelier Saturation Index, Ryznar Index and Saturation Index. There are only two locations have water tends to be corrosive (Maaqal and Zubair). On the contrary, the Larson-Skold Index shows that all domestic water samples are corrosive. This difference indicates that each adopted index depends on adependent single chemical or/and physical parameter. Then, the index adopted one or two the parameters and ignored others. Other water characteristics should be taken into consideration to study the corrosion like microbiological activities which play significant role. However, the pH and alkalinity are the keys to form the scaling based on Saturation Index, Ryznar Index and Saturation Index, whereas the chloride and sulphate have clear effect leading the water to be corrosive by adopting the Larson-Skold Index. All indices have positive regression line of iron level, which stimulate ongoing to detailed study. It should be not forgotten the chemical oxygen demand and water sources pollution when interpret the causes and roots of corrosion in pipelines. The corrosion and scaling tendency of raw water sources like groundwater, river water and rainwater have been concluded based on to the water chemistry and the applied indices.

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