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Assessment of Groundwater Quality for Industrial Purposes Using Geographical Information System (GIS) in Zahedan, Sistan and Baluchestan Province, Iran

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ABSTRACT

Introduction: Water quality is essential for industries because they play an important role in countries' economic development. Groundwater is one of the most widely used resources, and when the ionic constituents were increasing higher than the allowable limit, it increases the cost of maintenance and production in the industries.

Materials and Methods: In order to evaluate groundwater corrosiveness and scaling potential in Zahedan City, 29 groundwater wells and GIS-based geostatistical mapping techniques were analyzed clemically. The physicochemical parameters were invetsiagted and the most popular corrosion and scaling indices were determined as Langelier Index (LI), Aggressive Index (AI), Ryznar Index (RI), Puckorius Index (PI), and Larson–Skold Index (LS). Using ArcGIS 10.6.1 software, the zoning maps were plotted for LI, AI, RI, PI, and LS indices.

Results: The results showed that total dissolved solids (TDS) and electrical conductivity (EC) values in all of the samples exceeded the World Health Organization (WHO) drinking water standard. AI values of 58.62% samples showing moderate corrosiveness, and the remaining 17 samples have a scaling nature with very less corrosivity. Based on the LI values, 55.2% of samples have a corrosive nature. Concerning RI values, 59% of the samples have a corrosive tendency. According to the PI values, the entire groundwater of this region has a significant corrosive tendency, and 96% of samples exceeded the LS > 1.2, showing a high rate of localized corrosion.

Conclusion: The zoning and spatial analysis of water quality showed that water quality was treated for industrial purposes in the entire studied region.

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Introduction

Due to environmental laws and issues related to pollution and the quality of water resources, it is necessary to pay attention to water resources quality. Population growth and water pollution, caused by urban, industrial, and agricultural wastewater discharge and leachate from landfills, have increased pollution and limited the available water resources[1]. In general, water quality in aquatic ecosystems is evaluated by physical, chemical, and biological parameters [2]. On the other hand, recognizing the contaminated sites and existing pollutants will lead to optimal and proper water use in different applications[3]. Water has various applications in different areas, such as consumption, household activities, recreation, irrigation, and industries. In this regard, certain standard values should be observed by international and national organizations with regard to water quality. Among water resourses, including the surfacewater, groundwater, snowmelt, and rainfall, groundwater is considered as one of the most widely used resources. In the case that the ionic constituents of water esceed the standard range, they can affect the living organisms' health, enter the agricultural products, and increase the costs in food maintenance and production industries [4].

Water quality is of great importance in inductrial sections and economic development of all nations[5-7]. Although water quality plays a significantr role in industries, it is ignored by most authorities due to the lack of sufficient testing facilities or ignorance. Given that groundwater is considered as an important source of water supply for industries, its quality can be affected by corrosion of the metallic parts of the machinery such as plumbing systems, heat exchangers, and coil pipelines[8,9]. In industries, corrosion is mainly attributed to the quality parameters of groundwater, which consist of pH, alkalinity, TDS, dissolved oxygen (DO), total hardness (TH), EC, and temperature (T) [10].

In this regard, Langelier saturation index (LI), Ryznar index (RI), Aggressive Index (AI), Puckorius Index (PI), and Larson–Skold Index (LS) are among the main indices applied to determine corrosion.. Many researchers applied these indices in their studies from different countries [11-15]. These indices are simple ones that do not have mathematical and statistical complexity and can reflect the water quality conditions. Besides geographic information system (GIS), these indices are an efficient tool for spatial processing and component interpolation [16-20].

The purpose of this study is to investigate the quality of groundwater using LI, RI, AI, PI, and LS indices for industrial use. These indices were used along with spatial variation mapping applying geostatistical methods in the Zahedan City in Sistan and Baluchestan province. These data can help better understand the quality of groundwater and provide information for further studies in purification and better water quality management.

Materials and Methods

Study area and data collection

Zahedan City, the capital of Sistan and Baluchestan Province in Iran, is located between longitude 60º35' to 61°22' eastern and latitude 29°07' north (Figure 1). This area has a dry climate with dispersed observational wells. To conduct this study, 29 wells were considered in a flow zone that covers an area of about 210 km^2. The average annual rainfall is 61.94 mm in this aquifer and the maximum and minimum temperatures are estimated as 42°C and -7.20°C, respectively [21].

Groundwater data were collected in 2019 (winter, spring, summer, and autumn). The samples were stored in thoroughly cleaned the 2 L capacity bottles at a suitable temperature with necessary precautions for further analyses based on the APHA[22]. Parameters such as pH, EC, and TDS were measured by a Multiparameter (86505, AZ). EDTA titration was used in analyzing major ions such as magnesium (Mg^{2+}) and calcium (Ca^{2+}). A flame photometer (M410, Sherwood) was used in measuring sodium (Na^{+}). Sulfates (SO_4^{2-}) were calculated by a Double Beam Ultraviolet-Visible (UV-Vis) Spectrophotometer (LUV-100A, LABNICS). Bicarbonates (HCO_3^{-}) and chlorides (Cl^{-}) were analyzed to the laboratory by titration with sulfuric acid and silver nitrate, respectively[22].

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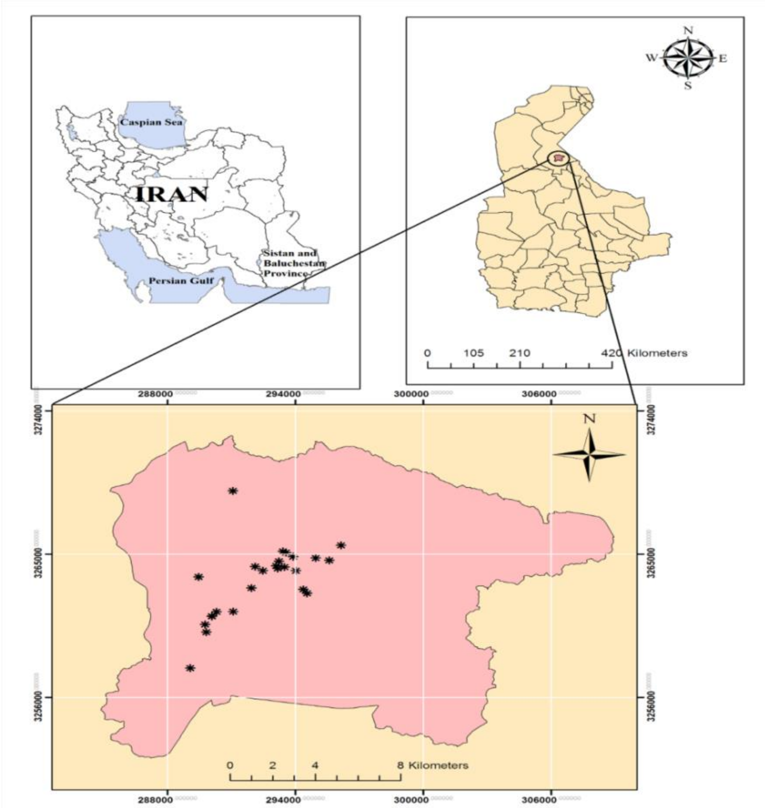

Figure 1: The geographical location of the area of study, Zahedan, Iran.

Spatial analysis and calculation of corrosion indices

Geographic Information System (GIS) maps were developed to investigate the corrosion intensity, and the corrosion indices were calculated on the average data. All spatial analyses were conducted by ArcGIS 10.6.1 software and Excel software for analyzing and charting other data. Data were normalized by the Logarithmic method and then interpolated by Inverse Distance Weighing (IDW) in the GIS environment. A detailed explanation of the calculation of indices and their interpretation is given in table 1 [23]. The IDW method was used to zoning maps of the indices because IDW is simpler than Kriging [24, 25]. The kriging method only works for normal distributions, while IDW can handle parameters that are not normally distributed [26]. The IDW method assumes that the unsampled points' values are more similar to the closer sampled points' values [27].

Table 1: Calculation of the corrosiveness and scaling potential of the groundwater and classification of groundwater quality based on these indices

Index	Calculation method	Classification and interpretation
	LI = pH–pHs; pHs = (9.3 + *A* + *B*) − (*C* + *D*)	LI < 0: not saturated water with corroding tendency
Langelier index (LI)	$A = (\text{Log}_{10}\ (\text{TDS}) - 1)/10$ $B = -13.12 \times \text{Log10}\ (T + 273) + 34.55$	LI = 0: saturated water with no scaling tendency
	$C = \text{Log}_{10}\ (Ca^{2+}) - 0.4$ $D = \text{Log}_{10}\ (\text{Alk})$	LI > 0: supersaturated water with a scaling tendency
		AI < 10: severely corrosive water (highly aggressive)
Aggressive index (AI)	$\text{AI} = \text{pH} + \text{Log}_{10}\ (\text{Alk} \times Ca^{2+})$	10 ≤ AI ≤ 12: moderately corrosive water
		AI > 12: Water with a scaling and non-aggressive

Index	Calculation method	Classification and interpretation
		tendency
		RI ≤ 5.5: Water with a rigorous scaling tendency
		5.5 < RI < 6.2: Water with a scaling tendency
Ryznar index (RI)	RI = 2pHs–pH	6.2 ≤ RI ≤ 6.8: Water is balanced with no scaling or corrosive tendency
		6.8 < RI < 8.5: Water with a corrosive tendency
		RI ≥ 8.5: Water with a rigorous corrosive tendency
Puckorius index (PI)	PI = 2pHs–pHeq	PI < 6: Water with a scaling tendency
	$pHeq = 1.465 \times Log_{10}(Alk) + 4.54$	6 ≤ PI ≤ 7: Water with little scaling and corrosive tendencies
		PI > 7: Water with a significant corrosive tendency
		LS < 0.8: Water with a scaling tendency
Larson–Skold index (L–S index)	$LS = (Cl^- + SO_4^{2-})/(Balk + Calk)$	0.8 ≤ LS B 1.2: Higher corrosion rates are obtainable
		LS > 1.2: High localized corrosion rates are expected

In calculations of pH, the mentioned abbreviations and explanations are the real pHs of water; pHs show the pH in saturation state of $CaCO_3$; TDS stands for the total dissolved solids (mg/L); T representstemperature (°C), Ca^{2+} is the calcium hardness of mg/L $CaCO_3$; Alk shows the alkalinity of mg/L $CaCO_3$; pH eq is the pH at equilibrium; Cl^- is chloride (mg/L); SO_4^{2-} is sulfate (mg/L); Balk represents the bicarbonate alkalinity of mg/L $CaCO_3$, and C_{alk} is carbonate alkalinity of mg/L $CaCO_3$

Results

Since the water quality change is continuous, and the water quality was greatly affected by closer observation points, IDW was used in this study. The findings achieved from the groundwater quality parameters in Zahedan district are tabulated in Table 2. The pHs ranged from 6.55 to8.01. In general, most water samples were alkaline and had a good quality within the standard range of 6.5–8.5 for drinking water set by WHO [28]. EC and TDS are recorded to be a maximum of 12200 µS/cm and 7251.81 mg/L, respectively. The average values were 6543.6 µS/cm and 4258.8 mg/L. The average values of both parameters are higher than the WHO guideline. In this study, the mean values of cations such as sodium, calcium, and magnesium were 990.7, 271.97, and 140.71mg/L, respectively. The average concentration of Na^+, $Ca^{2+}$and Mg^{2+} shows that these ions' concentration exceeded the standard values. With regard to anions, sulfate had the highest rate of anion in the study area with a concentration range of 613.2 - 2522.75 mg/L. Chloride is the second dominant anion in the study area's groundwater, mainly originated from saline formations' dissolution. The average concentration of HCO_3^- is 567.7mg/L, and carbonate concentration ranged from 249.61 to 974.78 mg/L.

The frequency of major ions in the groundwater was in the following order:

$Na^+ > Ca^{2+} > Mg^{2+}$ and $SO_4^{2-} > Cl^- > HCO_3^-$

Table 2: Physical and chemical parameters of groundwater samples in Zahedan

Parameter	Mean	Min	Max	Threshold standards(WHO 2017)
Temp(°C)	16.8	4	28	-
pH	6.99	6.55	8.01	6.5-8.5
EC(µS/cm)	6543.6	3530	12200	1500
TDS(mg/L)	4258.8	2114.79	7251.81	1500
TH (mg/L)	1254.2	488.53	2273	500
Na^+(mg/L)	990.7	567	1660	200
Ca^{2+}(mg/L)	271.97	73.93	576.62	200
Mg^{2+}(mg/L)	140.71	66.83	308.12	150
Cl^-(mg/L)	1025.6	451.5	1956.75	600
HCO_3^-(mg/L)	567.7	249.61	974.78	300
SO_4^{2-}(mg/L)	1338.4	613.2	2522.75	400
Alkalinity (mg/L $CaCO_3$)	469.2	204.9	799	500

Based on the findings, the Langelier Index (LI) values were within the range of 0.66 – 0.98 with an mean of -0.0232 (Figure 2). We also found that 55.2% of samples had LI values lower than zero that showed a corrosive nature. However, LI values of other samples (44.8%) were higher than zero. So, samples were supersaturated using scaling tendency.

According to Figure 3, negative values are observed in the southwest area and just very few values are related to the northwest region of the studied region. Furthermore, most studied areas have positive LI values indiacting the scaling nature of the water samples. The negative mean values of LI show that most water samples are not saturated and have a corroding tendency.

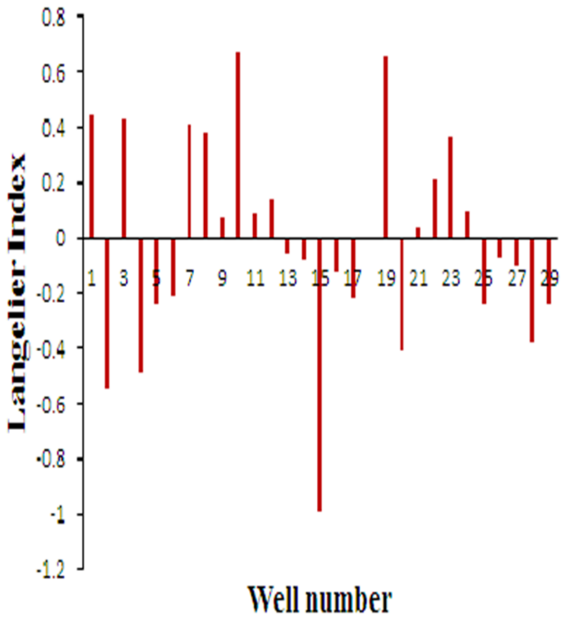

Figure 2: Evaluation of LI for the groundwater samples in the study area

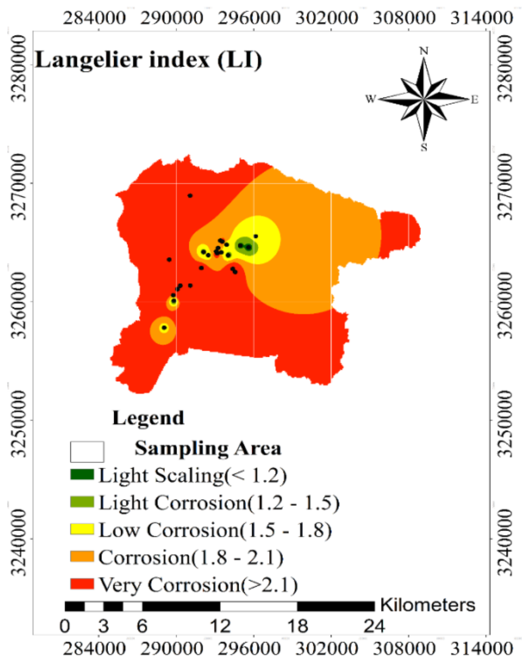

Figure 3: Spatial variation of LI in the study area

The AI values ranged from 11.23 to 12.79, with an average of 11.94. Figure 4 shows the AI values of individual water samples in the study area. The AI values of 58.62% of the samples were within the range of 10 - 12, which indicate moderate corrosiveness. In the other 17 samples, AI > 12, showing very low corrosivity. Moreover, corrosivity, in the other samples is 38% below the 11.9 and 14% in the range of 11.9 to 12, and 14% in the range of 12.1 to 12.2 is observed respectively. Also 10% of the area is allocated 12 to 12.1 and 24% for 12.2. (Figure 5).

So, the AI values showed water in the southwest of the district, and in the region of the southeast and northwest has a scaling tendency. However, water has a scaling and non-aggressive tendency in other regions.

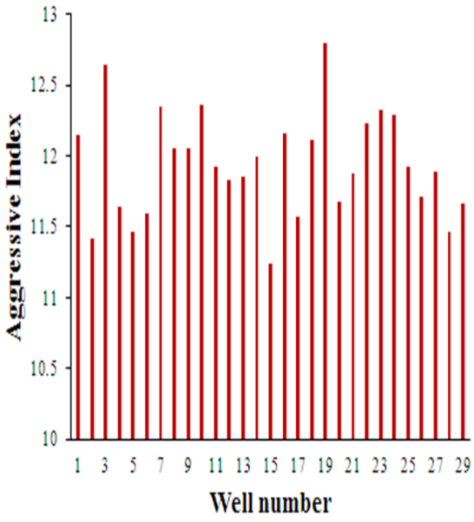

Figure 4: AI Evaluation of in groundwater samples from the study area

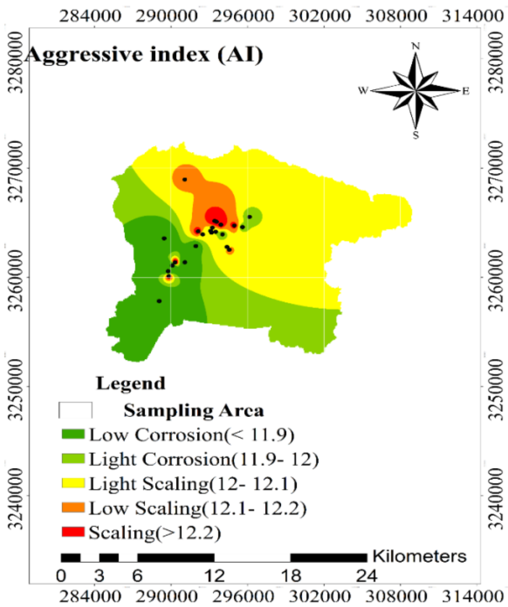

Figure 5: Spatial variation of AI in the studied area

The Ryznar Index (RI) values were within the range of 5.89 - 8.53, with a mean of 7.03. Figure 6 illustartes RI values of the groundwater samples collected from the strudy area. Based on the finidngs, 3 of 29 samples had RI values within the range of 5.5 < RI < 6.2; thus, water has a scaling tendency, 9 out of 29 samples have RI values ranging from 6.2 < RI < 6.8. Therefore, water is balanced with no scaling or corrosive tendencies. Moreover, RI values of the remaining 59% of the samples were within the range of 6.8 < RI < 8.5; in other words, the water samples had a corrosive tendency. The RI findings agreed with the index mentioned previousely and showed the same pattern (Figure 7).

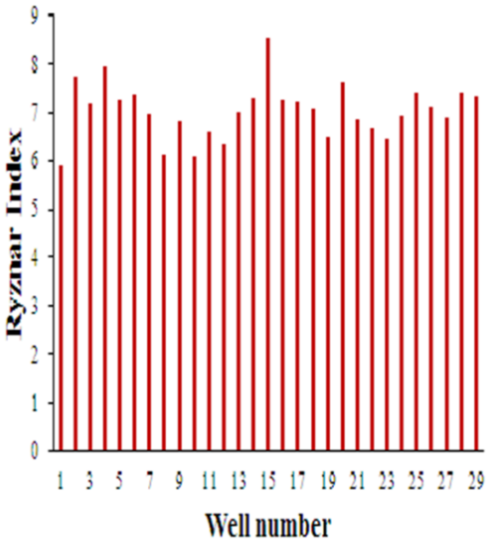

Figure 6: RI Evaluation of the groundwater samples in the study area

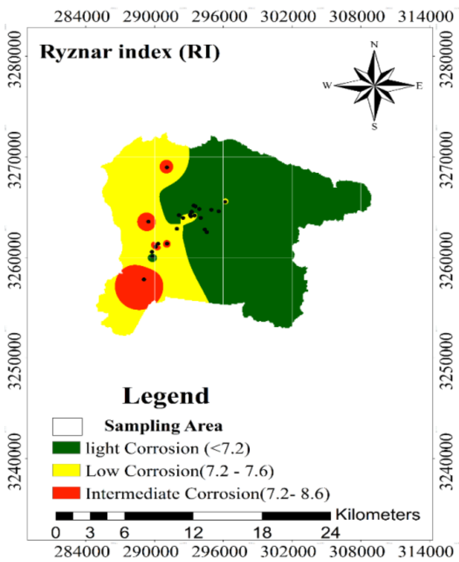

Figure 7: Spatial variation of RI in the study area

The general classification of Puckorius Index (PI) can be classified as PI > 7, with significant scaling tendencies. The PI varied from 7.53 to 8.68 with a meanof 8.16. All samples showed PI > 7, indicating that water samples had a considerable scaling tendency (Figure 8). The entire groundwater of this region has a significant corrosive tendency (Figure 9).

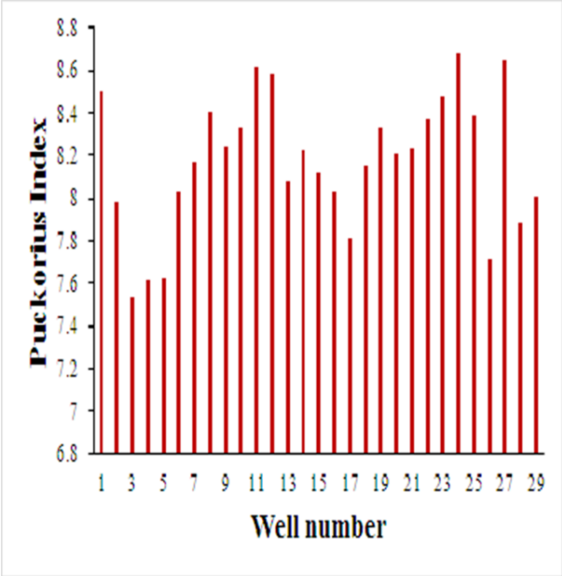

Figure 8: PI evaluation for the groundwater samples in the studied area

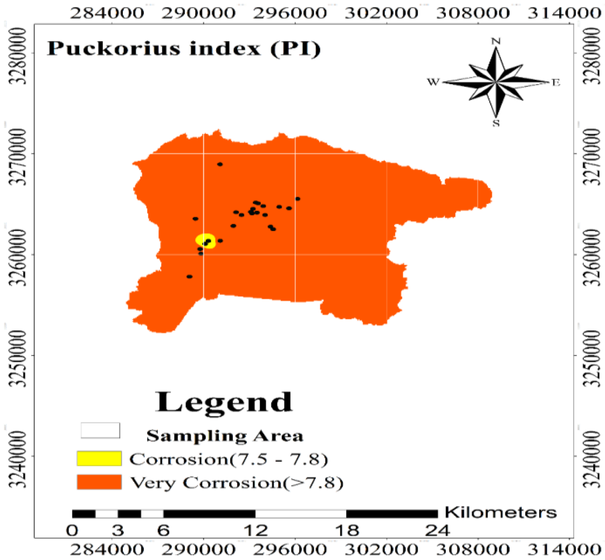

Figure 9: Spatial variation of PI in the study area

In Zahedan City, Larson–Skold index (L–S index) of the groundwater samples was within the range of 0.98 - 5.00, with a mean of 2.39 (Figure 10). In this regard, 14% of samples were with within the range of 0.8 ≤ LS ≤1.2, showing high rates of corrosion. The remaining samples exceeded the LS > 1.2, which indicate a high rate of localized corrosion. The LS's spatial variation shows that water with high corroding tendency is distributed all over the region, which is in agreement with the findings of other indices (Figure 11).

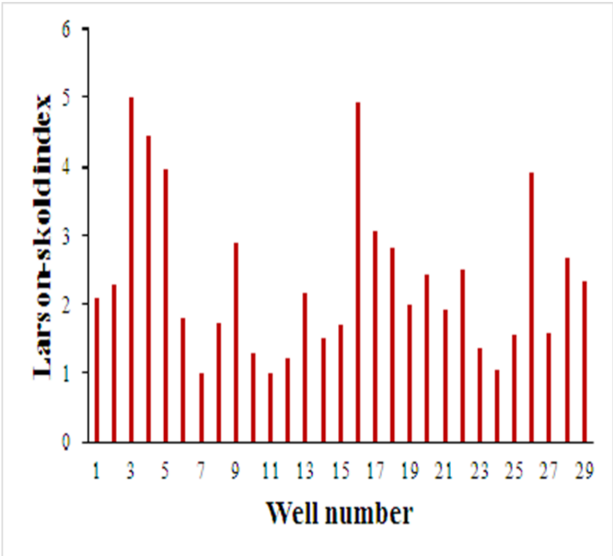

Figure 10: LS Evaluation for the groundwater samples in the study area

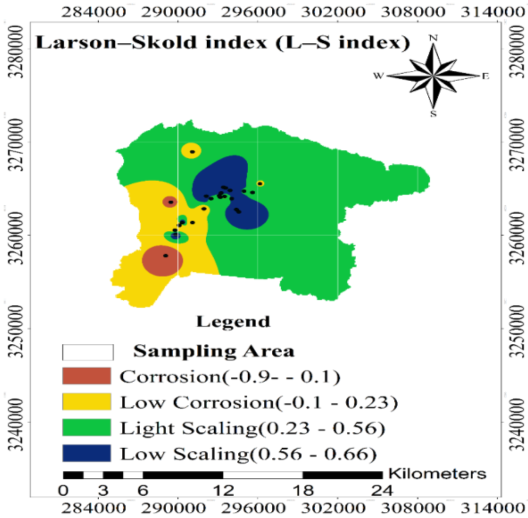

Figure 11: Spatial variation of LS in the study area

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Discussion

The values of the Zahedan district's physical-chemical parameters displayed that the groundwater quality results from the effect of the nature of climate and aquifer materials and human influences. The water in the alluvium adjacent to the young flysch formation, a marine facies, has higher salt concentrations. The waters with the lowest ion concentrations are located in the coarser alluvium adjacent to the granite formation that high recharge rate occurs at valley bed alluvium of these formations[21]. Through a discharge of sewage into absorbing wells, the urban effect has caused the EC to increase in some places from about 3530 to about 12200µS/cm. In addition to the nature of the aquifer, people have had a much greater impact on groundwater quality [29]. In hard rock regions, calcium and magnesium are mainly derived from minerals like pyroxenes and amphiboles [21]. Some minerals including pyroxenes and amphiboles in the silicate rocks and dolomite and calcite are considerd as important sources of calcium and magnesium production in groundwaters. In some regions of the studied area, Na^{+} was higher than Ca^{2+}, indicating the inverse cation exchange process, in which Ca^{2+} from the groundwater replaces na+ from the aquifer. However, studies of the natural origin of Na-Cl have been reported in cases such as dry sedimentation and dissolution of halite minerals. Sulfate concentration is high in location. High values of SO_4^{2-} along with Ca^{2+}, suggest a possible dissolution of gypsum.

The LI index, as a system of estimating and predicting the frequency of problems raised by limescale in a particular water supply, indicates the corrosiveness or incrusting ability of a water sample[30]. In other terms, this system is able to predict water tendencies to precipitate or dissolve calcium carbonate, which is considered as the main parameter in determining water corrosivity. According to this index, water's corrosive action is basically caused bythe excess of free CO_2 and its interaction with calcium and magnesium carbonates. These salts are in solution as bicarbonates in the presence of carbon dioxide. As a result, a corresponding concentration of carbon dioxide is considerd for all concentrations of calcium and magnesium in orderto prevent decomposition of these bicarbonates back into carbonates[31]. Acidic pH accelerates corrosion; in water with low alkalinity and high free carbon dioxide, the attack is more rapid than water, which has high alkalinity and low carbon dioxide contents. Consequently, we can say that pH change is required to make water in equilibrium. Generally, this index value lies between −3 and +3. A negative index shows that the water sample is under-saturated, dissolving $CaCO_3$, and corrosive. A value near zero indicates that the water sample is at saturation (equilibrium) and the positive value of LSI indicates that the water is over or supersaturated, that deposits $CaCO_3$ on the surface of metal. Therefore, the corrosion rates will be negligible [32, 33].

Aggressive index depends on the pH, total alkalinity, and calcium hardness [5]. This index is often used as an alternative method for Langeler Index and it is a parameter to determine water corrosiveness. Since temperature and TDS values are not required in this calculation, it is more user-friendly than LI. However, given that AI is less accurate than LI, it is considered a general indicator other than a quantitative measurement.

According to pH and pHs values of water, Ryznar index proved improvement over the LI[34]. It also quantified the water scaling properties in numerical values better [31].

Alkalinity and pH of water value represent the buffering capacity and water samples' precipitation characteristics to reach equilibrium [35, 36]. Puckorius index is derived from these parameters, and the equilibrium pH is used instead of the actual pH of the water. The PI uses the same numbering systems and general interpretation as does the RI [30].

Eventually, Larson-Skold index [37] was provided according to the hydrochemical parameters, including chlorides, sulfates, carbonate alkalinity, and bicarbonate alkalinity. The water will evaporate more corrosivity in the case of a high concentration of sulfate and chloride.

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Conclusion

Qualitative assessment of groundwater for industrial purposes was assessed for the Zahedan district in Sistan and Baluchestan Province, Iran. The order of dominance of cations was $Na^+ > Ca^{2+} > Mg^{2+}$ and that of anions was $SO_4^{2-} > Cl^- > HCO_3^-$. The average values of EC and TDS parameters are higher than the WHO guidelines. The corrosion and scaling indices were evaluated using five most frequently applied indexes. In this regard, using multiple indices provided more accurate information on the corrosive or scaling tendency. Spatial variation mapping of the indices indicates that the main part of groundwater in Zahedan area has a corrosion tendency. The dataset classified groundwater as unsuitable, and this indicates that the water is unreliable for industrial usage and will need further treatment.

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Conflict of interest

All authors declare that there are no competing interests.

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