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Assessment of Corrosion and Scaling Potential of Thermal Water in the Northern Algerian Sahara Using Hydrogeochemical Analysis and Stability Indices

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Abstract: In the Algerian Sahara, the management of thermal water quality is confronted with substantial challenges associated with corrosion and scaling issues which directly affect the durability of infrastructure, incur high economic costs, and can compromise the sanitary quality of water supplies. This research investigates thermal waters' corrosive and scaling tendencies in the Hassi Messaoud region, a vital area in the Northern Algerian Sahara. The investigation relies on the analysis of samples obtained in 2022 from thirty-one (31) thermal water boreholes, exhibiting an average temperature of 50.17°C. The approach involves evaluating four key reference indices: Langelier Saturation Index (LSI), Ryznar Stability Index (RI), Larson-Skold Index (LS), and Puckorius Index (PI). The results reveal that the total samples lie in the category indicating the supersaturated state with scaling forming tendency for both LSI and PI indices. In addition, 48.4 % of the samples point toward scaling water and their RI lies between the limit of 5.56–6,2 while the RI value of the 51.6% of samples is found to have no effect, neither corrosive nor scale behavior. With regard to the chloride sulfate effect, it has been observed that whole samples exhibit an LS value greater than 1.2, thus approving the corrosiveness of water towards the distribution system. The majority of the indices reveal significant scale potential trends in thermal water samples toward carbonates calcium and the corrosive effect concerning sulfate and chloride, suggesting that future water quality and distribution systems may become even worse. Therefore, it is crucial to consistently monitor the stability of this water at various locations within water distribution systems.

Keywords*: corrosion; scaling potential; thermal water; Hassi Messaoud.*

1. Introduction

The Algerian Sahara includes a significant portion within one of the largest cross-border aquifer systems known as the North-Western Sahara Aquifer System, which is assigned second in size only to the Nubian Sandstone (IGRAC, 2015). The deep reservoir in this multilayer aquifer holds significant reserves of groundwater. Several studies have focused on processes controlling the mineralization of groundwater from this aquifer, mainly in Algeria and Tunisia (Abdelali et al., 2020; Abid et al., 2010; Alaya et al., 2014; Elliot et al., 2014 ; Edmunds et al., 2003; Moulla et al., 2012 ; Hakimi et al., 2021). Despite the extensive coverage of the NWSA in these studies, managing this resource through the Algerian Sahara encounters considerable challenges, especially in terms of qualitative. This is attributed to several factors, including the extension of the reservoir, its considerable depth, and its geothermal properties.

As one of the pivotal issues concerning thermal water quality, corrosion and scaling problems (Ben-aazza et al., 2020; Finster et al., 2015). Investigations reveal that these issues are shaped by several factors, particularly fluid composition, temperature, and flow dynamics (Egbueri & Mgbenu, 2020;Tyagi & Sarma, 2020). Quantifying the tendency of water quality to scale and corrosiveness has been made possible through a set of mathematical models (Table.01) which were applied by many studies around the world.

A comprehensive review article was undertaken by (Anshar et al., 2023) to examine the influence of different factors on the corrosiveness and scaling of water. Additionally, it provided practical recommendations to mitigate the challenges related to corrosion and scaling forming. (Song et al., 2020) predicted scaling and corrosion tendencies of geothermal water using Langelier and Larson index models and verified by static immersion test Electrochemical performance test, where they found that the difference between the two methods could be ascribed to the significant differences in sulfate ion concentrations and pH values. (Mankikar, 2021) revealed that the majority of the samples studied Mahoba_India_ displayed a tendency to deposit calcium carbonate. A continuous monitoring of some parameters including pH, Chloride and sulfate concentration to mitigate corrosion was recommended by (Hasani et al., 2020). Other investigations have dealt with these phenomena in water: in Iran region we can cite (Shahmohammadi et al., 2018; Amin et al., 2024; Taghavi et al., 2019; Sajil Kumar, 2019; Alam & Kumar, 2023; Kumar et al., 2024) studied Indian regions, (El Baroudi et al., 2024) examined the drinking water from Morocco. Bouderbala 2021; Remini & Sayah, 2014, and Kais et al., 2023 about the Algerian territory.

The Hassi Messaoud region plays a vital role in the economy of the Northern Algerian Sahara due to its substantial hydrocarbon reserves. Annually, 205 million cubic meters of groundwater are extracted for the petroleum sector, with 63.4% of this volume allocated specifically for injection and workover activities (Touahri et al., 2022). Thermal waters stored in the Continental Intercalary aquifer are utilized for these operations.

Despite its significant impact on the sustainability of infrastructure, particularly concerning corrosion and scaling issues that lead to substantial economic costs and can compromise the sanitary quality of water supplies, a review of existing literature reveals that the geothermal water in the Hassi Messaoud area has never been investigated in terms of its corrosion behavior and scaling tendencies.

However, a good understanding of corrosion and scaling potential in thermal water is indispensable for the sustainability of infrastructure and good management of water resources. For this, considering the different indices, this study was developed with the goal of assessing the corrosion and scaling potential of the thermal water in the Northeastern of the Algerian Sahara focusing on its chemical composition.

Table 1. Equations and classification of Corrosiveness indices.

Index	Equation	Index Value	Tendency
Langelier Saturation Index (ISI)	$LSI = pH - pHs$ (1) $pHs = (9.3 + A + B) - (C + D)$ $A = (Log(TDS) - 1)/10$ $B = -13.2(Log(°C + 273)) + 34.55$ $C = Log(Ca\ as\ CaCO3) - 0.4$ $D = Log(Alkalinity\ as\ CaCo3$	LSI < 0 LSI > 0 LSI = 0	Undersaturated, Corrosive tendency Supersaturated, Scaling tendency Neutral tendency
Ryznar Stability Index (RSI)	$RSI = 2pHs - pH$ (2)	RSI < 5.5 5.5 < RSI < 6.2 6.2 < RSI < 6.8 6.8 < RSI < 8.5 RSI > 8.5	High Scaling tendency Relatively Scaling tendency Saturated equilibrium Low corrosive tendency High Corrosive tendency
Puckorius Scaling Index (PSI)	$PSI = 2pHs - pHeq$ (3)	PSI > 7 PSI < 6	Corrosive tendency Scaling tendency
Larson-Skold Index (Ls)	$Ls = (C\ Cl + C\ SO42-)/(C\ HCO_3^- + C\ CO_3^{2-})$ (4)	Ls > 1.2 0.8 < Ls < 1.2 Ls < 0.8	Greater corrosion tendency Corrosive tendency Scaling tendency

2. Study area

The Hassi Messaoud Field is situated 80 kilometers from Ouargla City and 800 kilometers south of the Mediterranean Sea. It covers an area of 1600 square kilometers. This field is positioned in the eastern part of the Saharan platform, within the Triassic province (Boudjema,1987), and lies between longitudes 5°30′ and 6°00′ E, as well as latitudes 31°00′ and 32°00′ N (Fig. 1). The study area is known for its hyper-arid climate with an average annual rainfall of 34.6 mm and 23.8 °C (ONM 2021).

Within the study area, the geology is comprised of a series of formations that constitute the North Eastern Triassic Province which was developed through a series of deformation phases that occurred from the major Pan-African orogeny to the Alpine phase (Boudjema, 1987). A first-order extensional phase oriented from northwest to southeast, known as Cambro-Ordovician distention, initiated an oceanic-opening event associated with the Paleo-Tethys. This process facilitated the deposition of the Paleozoic formations found on the Saharan platform. Subsequently, the Caledonian orogeny resulted in significant regional uplift and erosion of the Paleozoic series. The presence of Paleozoic deposits separated by a gap from the underlying granitic foundation is a defining feature of the geological formation in Sahara platform including the investigated area. Resting in discordance with the Paleozoic deposits, the Mesozoic ones form an extensive sedimentary series of evaporitic, with an estimated thickness roughly 3000 m (Fig. 2), dating back to the Triassic and Lias periods. As it progresses into the Lower Cretaceous, which is characterized by shifts in facies from marine to continental during the Barrimian, Aptian, and Albian epochs. These formations make up the continental intercalary reservoir with an impermeable roof formed by the upper cretaceous layer, represented by the Cenomanian, which is made up of alternating anhydrite, marl, and dolomite. Above this layer lies the Turonian comprised of limestone, and the Senonian consisting of marl, anhydrite, and rock salt at the base (Cornet, 1964; Busson , 1970; Castany , 1982). In Hassi Messaoud field, the Paleozoic succession is limited by the Cambrian, which measures about 637 m (Fig. 2).

The hydrogeological attributes of the investigated region form an integral part of the North-Western Sahara Aquifer System, recognized as one of the largest confined reservoirs in the world. Thus, the region benefits from the significant water resources which are predominantly made up of an aged component. The Continental Intercalary and the Complexe Terminal are the two main deep-represented aquifers. Situated in the lower Cretaceous continental formations, the Continental Intercalary (CI) which hosted geothermal water is mainly composed of sandstones, sands, and clays at the bottom. Its significant depth hinders its complete exploitation. Several aquifers are present in different geological formations within the Complex Terminal where groundwater circulates through either the Eocene and Senonian carbonates lithostratigraphic formations or the Mio-Pliocene sands with the presence of limestone and clay (Cornet et Gouscov, 1952; UNESCO, 1972).

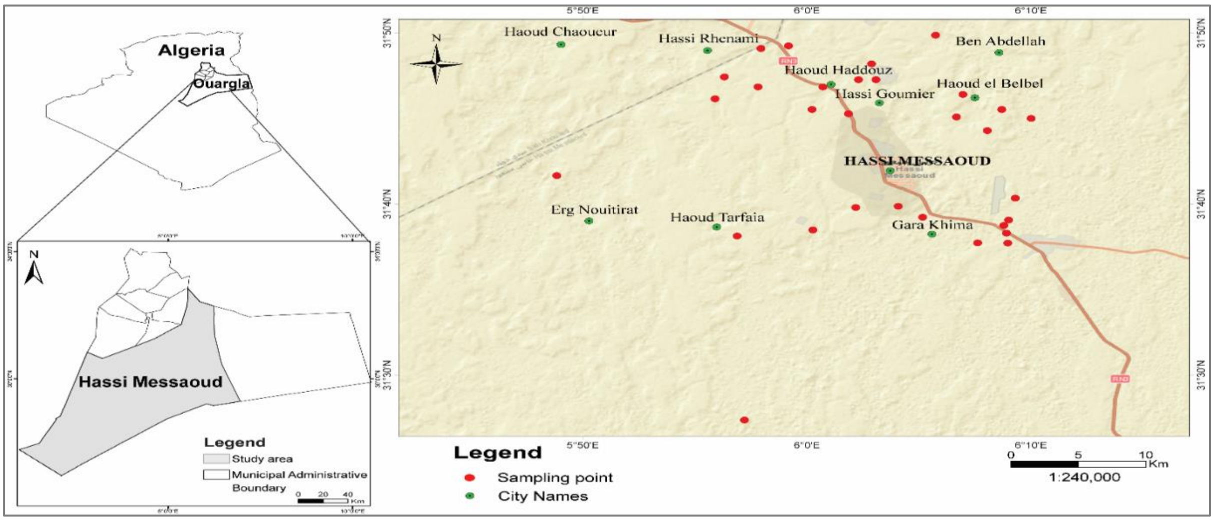

Figure 1: Map headlining the various sampling points from the study area

		Erat hem	Stage	ITHO	MD (m)	Lithological Description
CENOZOIC			MIOPLIOCEN		240	Sand, Limestone, Marl Sandy
			EOCENE		218	Sand, Limestone and Flint
MESOZOIC	CRETACEOUS	SENONIAN	CARBONATE		91	Limestone, Dolomite, Anhydrite
			ANHYDRITE		210	Anhydrite, Marne, Dolomite
			SALT		140	Massive salt and traces of Anhydrite
			TURONIEN		99	Soft chalky limestone
			CENOMANIAN		148	Anhydrite, Marne et Dolomie
			ALBIAN		350	Sandstone, Silty clay
			APTIAN		25	Dolomite and Limestone
			BARREMIAN		277	Clay, Sand, Sandstone
			NEOCOMIAN		185	Clay, sandstone, dolomite,
	JURASSIC		MALM		230	Clay, Marl, and Dolomite, Sandstone
		DOGGER	CLAY		107	Argile, Marne, Dolomites
			LAGOON		223	Anhydrite, dolomite, limestone and marl
		LIAS	LD1		66	Dolomite, Anhydrite and Clay
			LS1		90	Alternating salt, anhydrite and clay
			LD2		55	Anhydrite and crystalline dolomite
			LS2		60	Alternating salt and clay
			LD3		35	Alternating dolomite and marl
	TRIASSIC	SALT	TS1		46	Alternating Anhydrite Salt and Dolomite
			TS2		190	Massive salt with anhydrite and clay intercalation
			TS3		200	Solid salt and traces of claY
			CLAY		113	Dolomitic Red Clay or Silty Clay injected with Salt and Anhydrite
			Sandstone		0 à 35	Sandstone, Clay
			ERUPTIVE		0 à 92	Andesite
PALEOZOIC	ORDOVICIAN		Hamra Quartzite		75	Very fine sandstone
			El Atchane Sandstones		25	Fine glauconitic sandstone
			El Gassi Clay		50	Green or black clay
			Alternating zones		18	Alternating sandstone and clay
	CAMBRIAN		R Isometric		42	Isometric Sandstone, Silts
			R Anisometric		125	Anisometric Sandstone, Silts
			R2		100	Coarse Sandstone, Clay
			R3		370	Coarse Sandstone, Clay
			Infra Cambrian		45	Red clay sandstone
			Bottom			Pink porphyroid granite

Figure 2: Lithostratigraphic sequence in Hassi Messaoud Field (modified after SONATRACH, 2023)

3. Sample collection and analytical techniques

The sampling initiative involved collecting 31 samples at each thermal water drilling within the study area throughout the year 2022 to assess the characteristics of this water regarding its corrosive and scaling tendencies. Each site's position is depicted in figure 1. The vials employed for collection underwent meticulous rinsing with the sample water to confirm that the samples reflect the characteristics of the water source. After removing the stagnant water, all samples were stored to prevent any reduction in the biological or chemical responses rate during transportation to the laboratory for analysis. Using the WTW 3620 IDS SET G multiparameter, field measurements of quality parameters that could be affected during transportation which included temperature (T), hydrogen ion concentration (pH), electrical conductivity (EC), total dissolved solids (TDS), were assessed. However, the chemical Analyses Calcium (Ca2+), Magnesium (Mg2+), and Bicarbonate (HCO3-) were performed by the titration method; Chloride (Cl-) treated by the Metrohm 848 Titrino plus titrator, Sulfate (SO42+) was performed by a spectrophotometric method using Hach Lange DR 6000 spectrophotometer. Sodium (Na+) and potassium (K+) were determined using a JENWAY PFP7 flame photometer. The results are given in Table 2 on which the ion balance error test was employed to verify their accuracy, the findings reveals that all samples showed an error rate of less than ±5%.

The water under investigation was classified through the use of Piper diagram. Then, drawing from the hydrochemical analyses performed, the current research delves into the possibility of corrosive and scale behavior of the geothermal water of the studied region, which feature the Langelier Saturation Index (LSI), Ryznar Stability Index (RSI), Puckorius Scaling Index (PSI), Larson-Skold Index (Ls).

In order to evaluate the corrosion and scaling potential of geothermal water from the Hassi Messaoud region different models of indices were applied taking in to account the geochemical properties of the water under examination alongside the materials used in the piping system. By way of illustration of these models, the Langelier Saturation Index (LSI) developed by (Langelier, 1946), serves as a valuable tool to achieve water stabilization, which helps in both corrosion and prevent scale formation. In the Ryznar index (RSI) (Ryznar, 1944) the correlation between carbonate saturation state and scale formation is examined, particularly focusing on the variations in LSI. Count of the Puckorius Scaling Index (PI), also referred to as the Practical Scaling Index, provides valuable insights into the aggressiveness of water and its potential to form limescale. Moreover, it offers information about the water's buffering capacity (Puckorius & Brooke, 1991). Larson–Skold index (Ls) (Larson & Skold, 1958) is employed to evaluate the corrosion rate, whose numerical equation combines chloride, sulfates, carbonates, and bicarbonates.

4. Results and discussions

4.1. Hydrochemical characteristics

The Statistical analyses of the chemical parameters provided in Table 2 reveal that pH values range from 7 to 7.4, illustrating that neutral thermal water to close to being neutral with a mean temperature of 50.17 °C. TDS data recorded vary from 1283 mg/L to 2217 mg/L, signifying therefore that the water studied falls into the Brackich type based on Freeze and Cherrey classification (Freeze and Cherrey 1979). Regarding Electrical Conductivity (EC) it ranges between 2400 to 4170 (µS/cm).

Based on the analytical data (Table 2), Calcium (Ca2+) is identified as the leading cation in the investigated thermal water with a mean concentration of 15.25 meq/L. Followed by Sodium Na+ which was recognized as the second major cation exhibiting a concentration varying from 6.65 to 12.53 meq/L with a mean concentration of 10.28 meq/L. Chloride (Cl−) stands out as the most prevalent anion. The high concentration of this ion identifies it as a critical factor influencing thermal water quality coming from the dissolution of Halite.

Plotted on Piper trilinear, the hydrochemical grouping of the geothermal water studied was evaluated. The results (Fig.3) show that the thermal water investigated displayed two main groups, dominated by calcium Chloride type with 50 % of the total samples, whereas the other 50% with Sodium chloride character. The geological formations surrounding these geothermal waters may have a predominant effect on their mineralization.

To evaluate the lithological nature of the reservoir source of the thermal water examined, the approach formulated by (D'Amore & Celati, 1983), known as the IIRG (Internatinal Institute for Geothermal Research), is the recognized tool.

Applied to Hassi Messaoud thermal water (Fig. 4B), all samples are compatible with the training reference standard (α) (Fig 4A), certifying their circulation in an evaporate geological formations. This aligns with the geological characteristics of the study area.

4.2. **Multiple mineral equilibrium approach**

To enhance the comprehension into the contribution of chemical elements to the mineralization of the thermal water, the calculation of saturation indices was performed using the major ions concentrations. As depicted in Figure 6, the thermal water under investigation is in a state of undersaturation with respect to Gypsum, Halite, Anhydrite, and Sylvite. However, all thermal water samples exhibited an oversaturated state regarding carbonate minerals (Aragonite, Calcite, and Dolomite) as shown in Figure 5. The graphs depicting the saturation indices of aragonite, calcite, and dolomite show notable spikes for sample W21. This occurrence may be attributed to the presence of a substantial limestone layer, suggesting implications for this territory or the predominant influence of ion exchange processes that promote the influx of Ca and Mg ions leading to their subsequent precipitation. Therefore, the over-saturation of water concerning carbonate minerals indicates that these minerals cannot dissolve in the water, thus having no impact on the saline content of the thermal waters. In contrast, the undersaturated condition of the water regarding sulfate minerals implies their ability to dissolve sulfate minerals, which can enhance mineralization.

4.3. Residence time indicator

Characterized as "fossil resource", with a severely restricted modern recharge, the thermal water from the studied region originates from previous climatic conditions that were significantly more humid than the current environment (Guendouz & Michelot, 2006). For effective resource management, it is crucial to estimate, even if only roughly, the age of this thermal water which is a key factor affecting its mineralization.

The lack of isotopic data, along with the challenges faced in determining krypton 81 (K81), considered the optimal method for dating fossil waters, drives the need to identify alternative indicators of residence time.

Research on the concentrations of major ions indicates that the Mg/Ca ratio combined with the total of Na + K tend to increase with long residence time. This correlation is expressed by the following equation:

$I = \frac{Mg^{2+}(Na^{+}+K^{+})}{(Ca)^{2}}$ (5) While this index is qualitative, It offers the practical benefit of being applicable across the study area (Frédéric Lalbat, 2006).

According to the results depicted in figure 36, It is observed that close to 40% of the thermal samples have an average residence index (i) ranging from 0.5 to 1.

The highest value was observed at borehole W23 located in the northeast, registering an index of 4.7, which indicates an extended residence time. Given its distance from recharge zones, it is expected to find water with such extended residence times. However, the dissolution of gypsum affects the calco-carbonic equilibrium and encourages the dissolution of dolomite. As a result, the i index in this area could be skewed due to the presence of gypsum.

The findings from ^{81}Kr dating offer compelling evidence for the existence of ancient groundwater, indicated by 81Kr/Kr ratios that align with atmospheric values, corresponding to residence times ranging from 150 to 630 thousand years (Matsumoto et al., 2020). The ages obtained serve as strong and dependable data essential for calibrating numerical flow models of the CI aquifer, facilitating the evaluation of the potential sustainability of this significant water resource over both medium and long-term periods.

Table 2. Statistical analyses data of the thermal water in Hassi Messaoud region

Variable	Units	Maximum	Minimum	Mean	Variation Coeffition	Standard Deviation
pH		7.65	7	7.2	2.19	0.16
T	(°C)	57.5	40	50.17	10.46	5.25
EC	µS/cm	4170	2400	3110	12.31	0.38
TDS	mg/L	2217	1283	1812.7	11.64	211.1
Ca	meq/L	15.254	5.09	10.13	23.39	2.37
Mg	meq/L	16.789	3.539	8.171	31.98	2.61
Cl	meq/L	21.20	10.716	16.094	14.18	2.28
HCO3	meq/L	3.3620	1.90	2.74	12.95	0.35
SO4	meq/L	13.52	7.8	10.61	15.6	1.66
Na	meq/L	12.528	6.65	10.28	15.24	1.57
K	meq/L	1.20	0.86	1.01	7.88	0.08

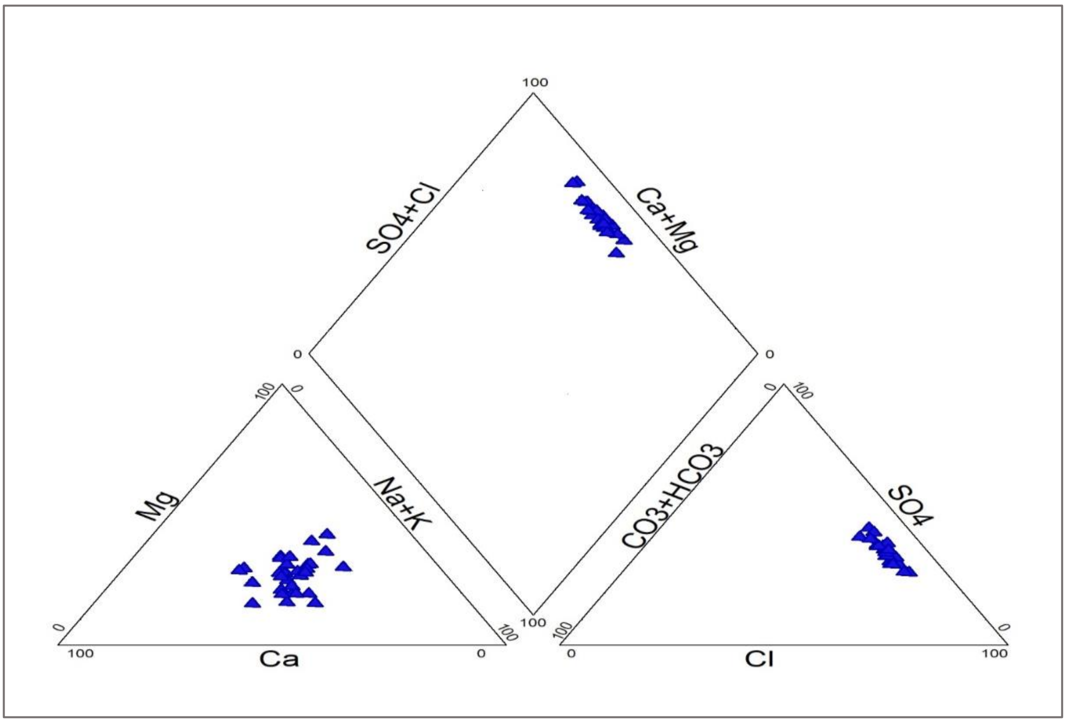

Figure 3: Piper diagram of the thermal water of Hassi Messaoud region

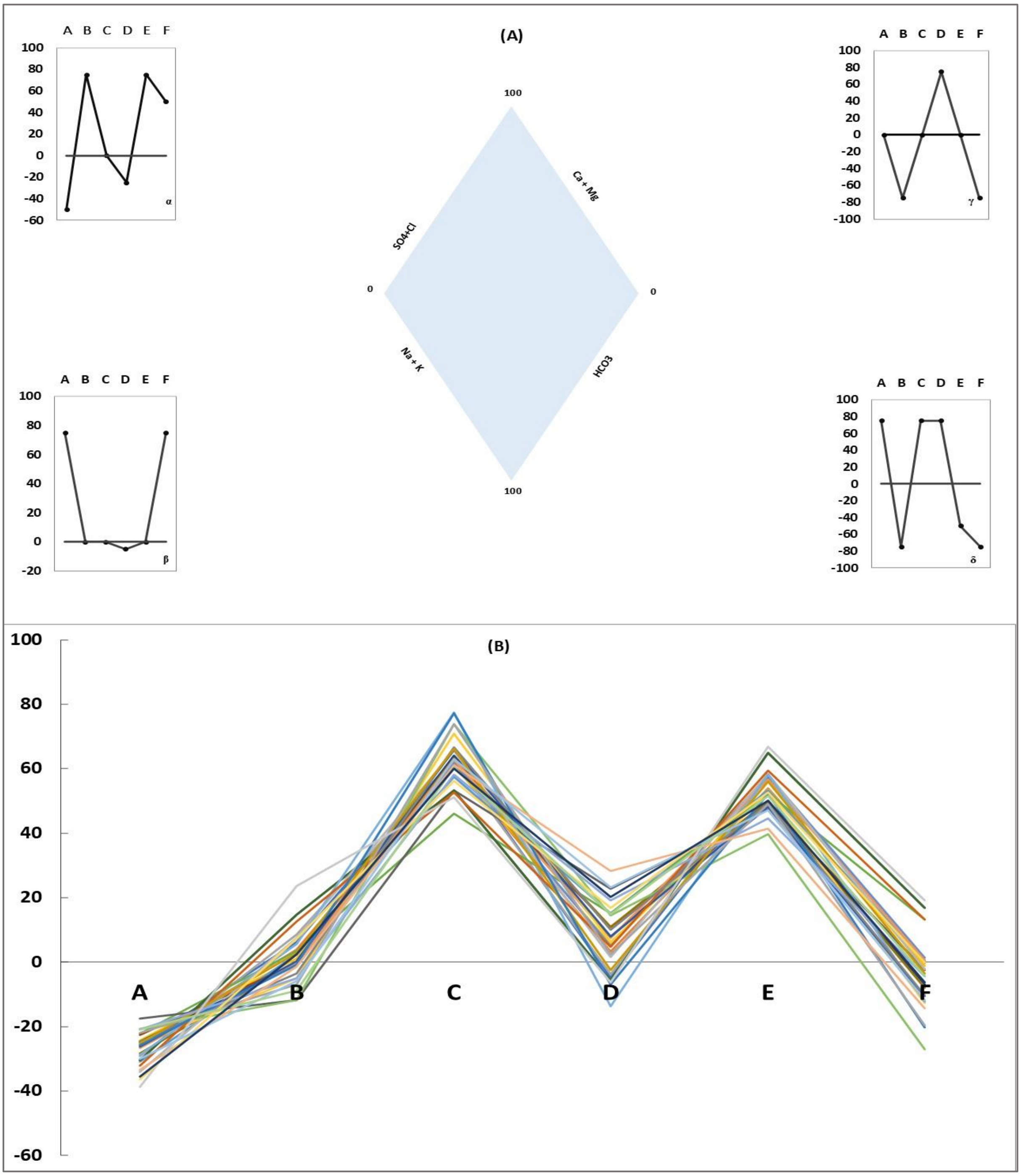

Figure 4: (A). Reference diagram of the International institute of geothermal research (IIGR).

α: evaporative sequence; β: circulation in limestone; γ: deep circulation through a crystalline basement; δ: argillaceous formation.

(B). IIRG plot of Hassi Messaoud geothermal waters

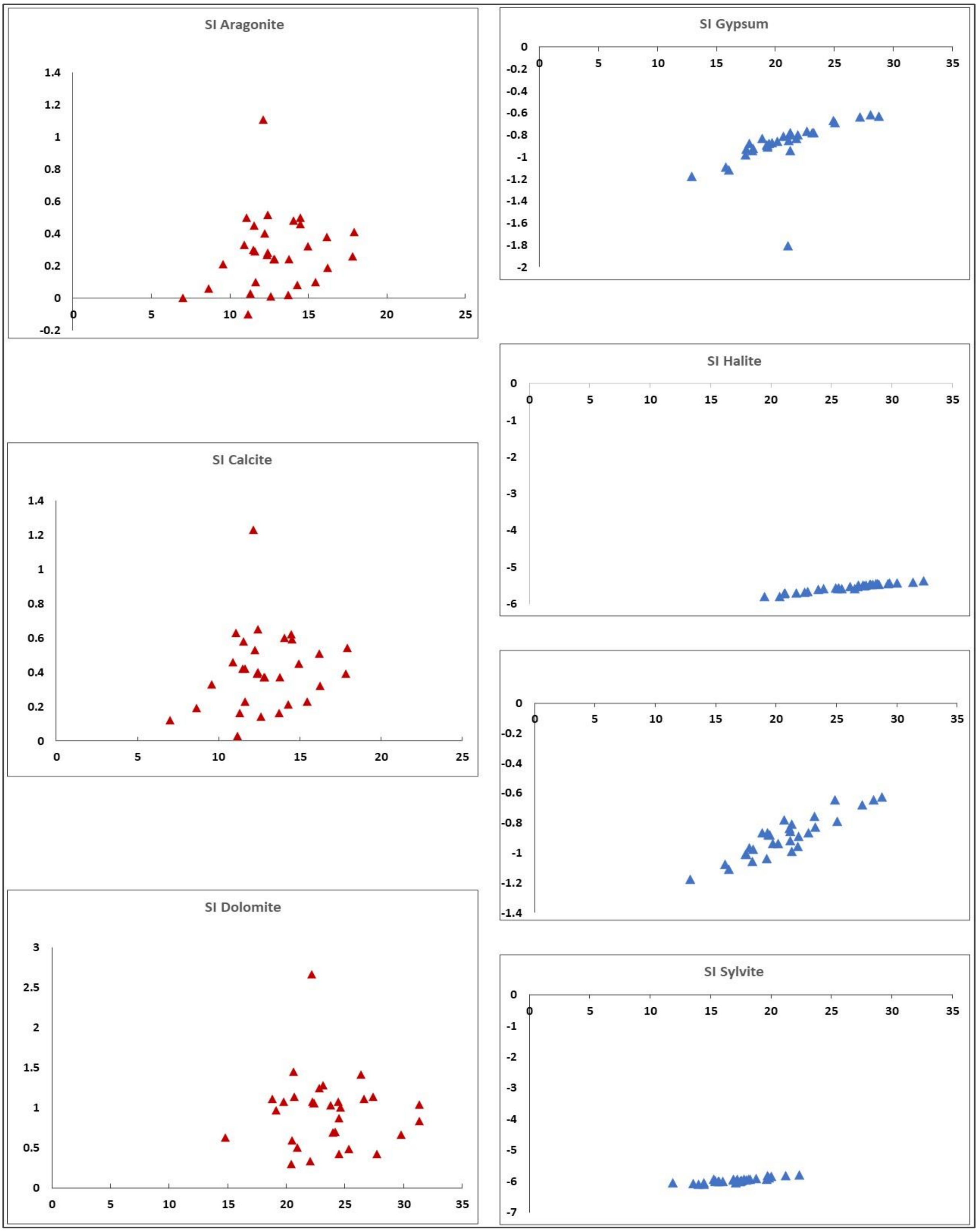

Figure 5: Saturation state of some minerals of Hassi Messaoud's thermal water

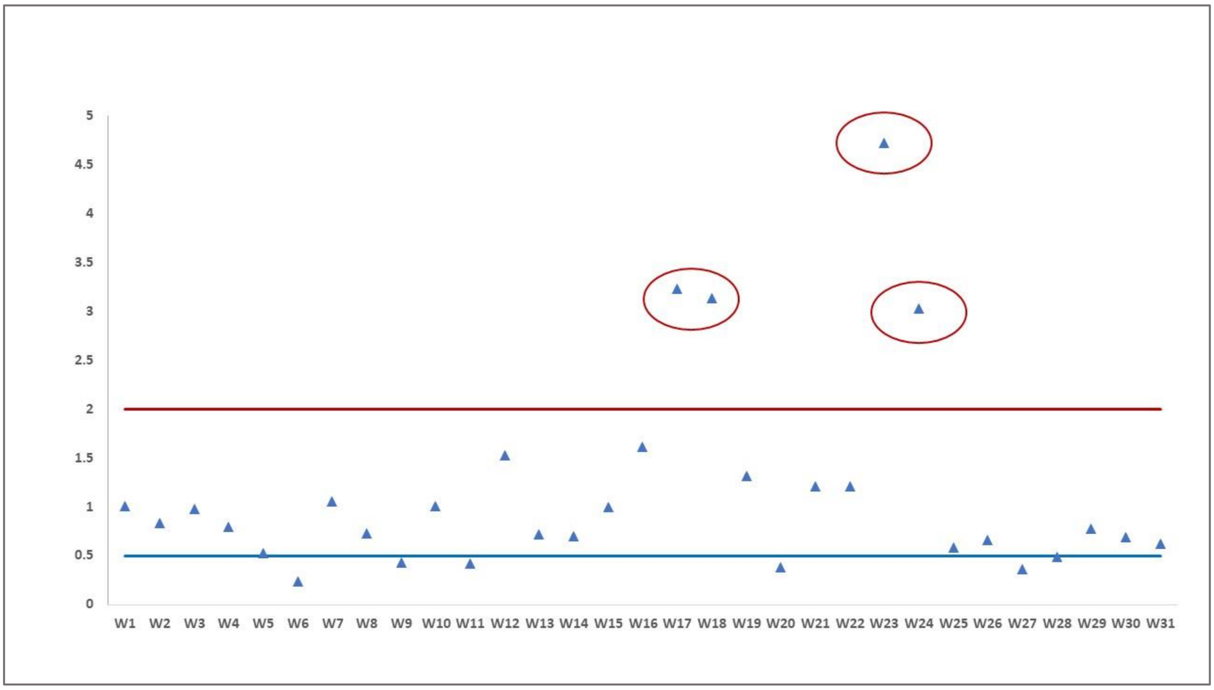

Figure 6: Residence time indicator of the thermal water studied

4.4. Corrosiveness and scaling potential

The evaluation of the thermal water's stability was conducted based on four indices, which were selected considering the geochemical characteristics of the water examined and the materials of the pipes within the system to provide a more accurate classification regarding its corrosion and scaling tendencies**.**

Langelier Saturation Index (LSI) (Langelier, 1936; Langelier, 1946)

Based on the calcium carbonate equilibrium theory, (LSI) is a valuable tool for achieving water stabilization, which helps in corrosion and prevents scale formation. It indicates the water sample's tendency to generate limescale. (Langelier, 1936; Langelier, 1946). The critical factors influencing the corrosive nature of the water are the elevated levels of free CO2 and its interactions with calcium and magnesium (Esmaeili-Vardanjani et al., 2015;Vegesna & McAnally, 1995).

In the present study, it was found in all samples a supersaturated state with CaCO3 (LSI > 0) (Figure 7a) indicating scaling characteristics of the thermal water. Where the maximum value was observed in the W21 sample (LI = 1.04) (Table 3). This implies the potential for calcium carbonate to precipitate. Furthermore, Figure 7 depicts that the water under analysis turns corrosive at temperatures below 21 °C. At that temperature, the thermal water of Hassi Messaoud leads to the corrosion and dissolution of metals within the pipes. his indicates that water temperature plays a crucial role in significantly altering the behavior of the water.

The Pearson correlation coefficients (Table 3) indicate a robust relationship between the LSI and the saturation indices of carbonate minerals. This finding supports the hypothesis presented in section III.2 regarding the existence of a calcium carbonate source that precipitates in water.

Ryznar Stability Index (RSI) (Ryznar, 1944)

Based on LSI, an empirical model was developed by Ryznar in 1944 to determine the water's aggressiveness or scaling behavior.

The results of RSI reported in Figure 7b were found with an average of 6.23 (Table 3), indicate that about 50 % of the total thermal water samples are mainly characterized by a scaling trend with a supersaturation state regarding the calcium carbonate, confirming thus the results of LSI. However, the rest of the samples have neither corrosive nor scaling properties which reflect an equilibrium state of these sample

Figure 8 highlights the significant impact of temperature on the RSI results. It reveals that below 35 °C, the RSI values rise above 6.8, which makes the thermal water corrosive.

Puckorius Scaling Index (PSI)

The PSI adopts the same numeric framework and general representation as the RSI, effectively illustrating the relationship between scale formation and saturation.

In Hassi Messaoud, about 84 % of the thermal water is likely to scale with regards to PI values (Figure 7c) with an average of 5.78. Nevertheless, once the temperature decreases to 25 °C, the water will have the ability to corrode the system.

Larson Index (Ls) (LARSON & SKOLD, 1958)

Acting as a natural inhibitor, alkalinity reduces the corrosion of mild steel by establishing a protective coating. The levels of chlorine and sulfate significantly influence corrosion rates and enhance corrosivity, owing to their abrasive characteristics.

The results of Larson and Skold index classify the thermal water studied as corrosive water. This can be explained by the high concentration of chloride and sulfate ions, as indicated by the hydrochemical study (figure 3).

The thermal water examined across multiple samples was found to be fully supersaturated with calcium carbonate with a localized potential of corrosion. However, the findings presented in Figure 8 indicate that this classification is applicable only at the temperature recorded in the boreholes. As the temperature decreases, the tendency for scaling shifts more towards corrosion.

The occurrence of scale in thermal water presents considerable difficulties for industrial processes and residential systems alike. These undesirable scale deposits can result in a range of technical problems that may adversely affect safety and economic efficiency. o counter these challenges, it is essential to employ effective management techniques, including the use of scaling inhibitors and the selection of materials that resist corrosion, which have been extensively researched. It is recommended to consider the application of economical and eco-friendly inhibitors.

In Algeria, the study conducted in South Algeria by Kais et al. in 2023, reveals that the use of softening methods, namely the addition of lime and soda and the addition of an excess of lime and soda, were effective in reducing the concentrations of calcium and magnesium ion.

Previously, (Belarbi et al., 2014) introduced an innovative green inhibitor, formulated from the aqueous extract of Paronychia argentea (PA), designed to decrease the accumulation of CaCO3 on metal surfaces. An additional green inhibitor has been evaluated by (Aidoud et al., 2017), specifically examining its effect on the scaling of Hammam drinking water. The author studies involved different scaling inhibitors (Liu et al., 2024; Freire et al., 2024; Lorena Freire 2024; Aidoud et al., 2017).

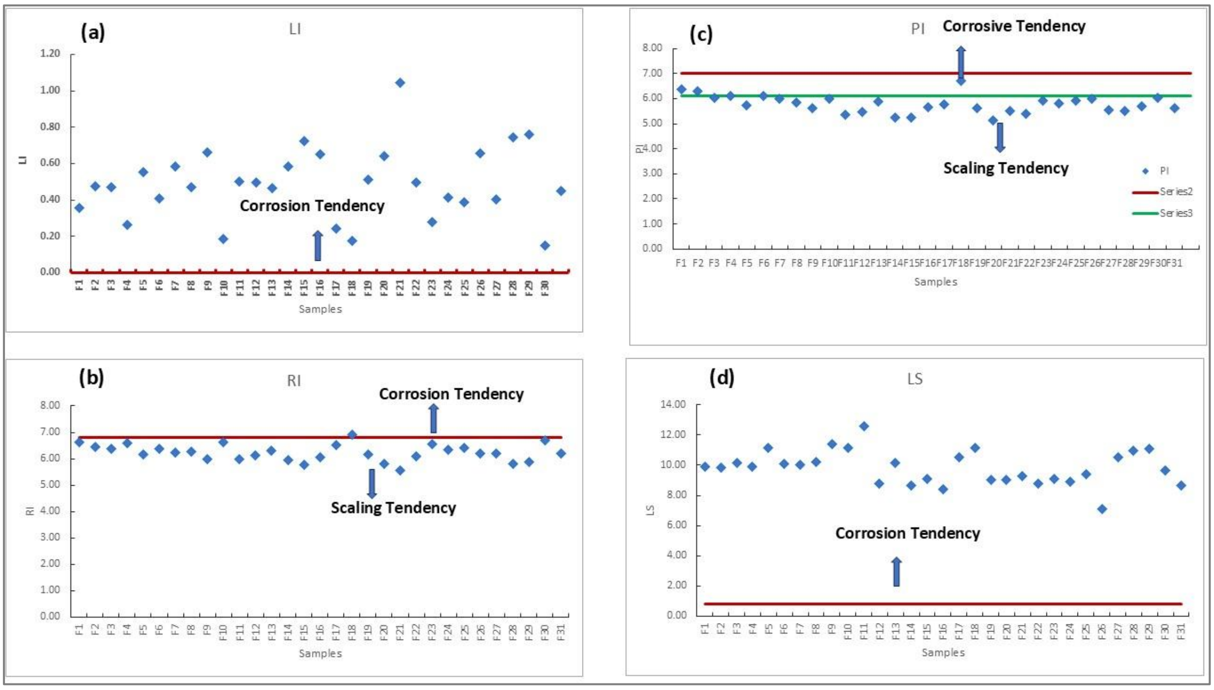

Figure 7: Thermal water corrosion indices: a) LI, b) RI, c) PI, d) LS

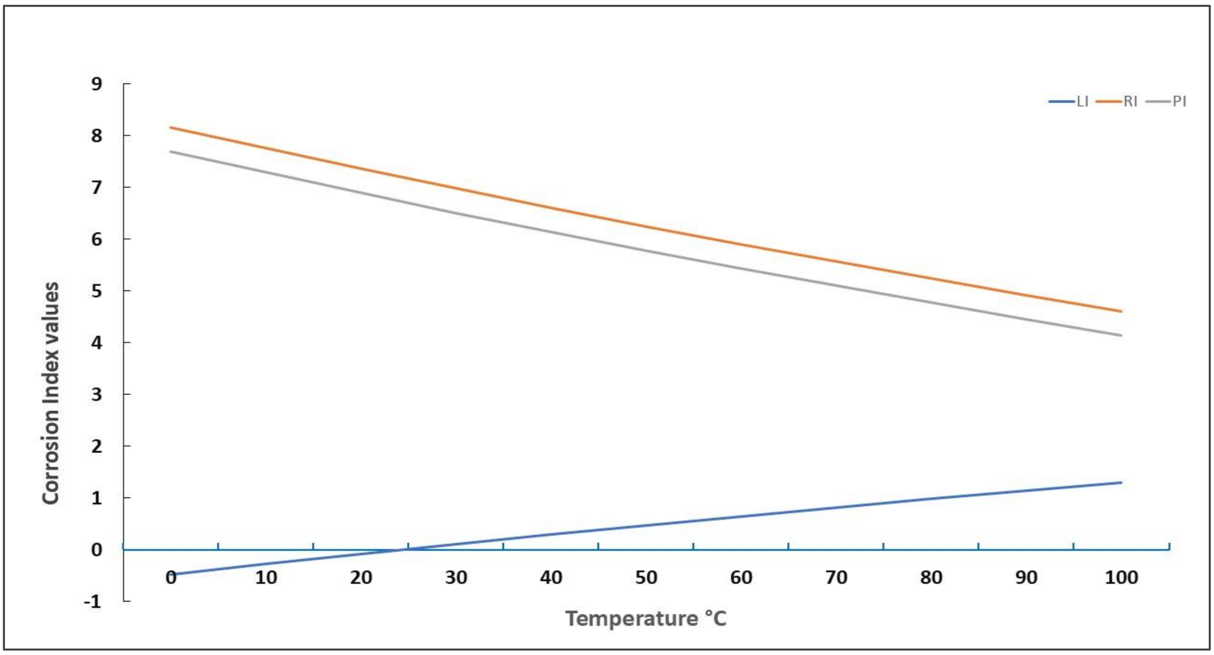

Figure 8: Effect of temperature on thermal water stability indices

Table 3. Statistical data of corrosion indices

Variable	Mean	Max	Min	VarCoeff	SD
LSI	0.49	1.04	0.15	39.83	0.2
RSI	6.23	6.90	5.56	4.94	0.30
PSI	5.78	6.71	5.14	6.07	0.35
Ls	9.83	12.57	7.09	11.38	1.12

5. Conclusion

Groundwater is recognized as the exclusive water supply source in the Algerian Sahara. The area features a significant reservoir of thermal water, whose properties change based on geochemical processes and interactions. This study investigated the stability of thermal water from the Algerian Sahara region (Hassi Messaoud) based on the scaling and corrosion potential. Four indices were selected considering the geochemical characteristics of the water examined and the materials of the pipes within the system.

The results show that Hassi Messaoud thermal water is characterized by high temperature related to the reservoir's deep and high salinity originating from the aquifer's geology.

Two main classes were depicted in the Piper plot: sodium chloride, accounting for 74 %, and Sodium sulfate, representing 12 % of the samples. Geochemical modeling performed with the PhreeqC model reveals that the examined thermal water is found to be in a state of undersaturation with respect to evaporate minerals. Nevertheless, all thermal water samples exhibit positive saturation values regarding carbonate minerals.

The thermal water analyzed in various samples was determined to be entirely supersaturated regarding calcium carbonate and potentially susceptible to scaling, as indicated by the findings from the Langelier Saturation Index (LSI) and Packorius Index (PI). 48.4 % of the samples were recorded with a scale forming according to the Ryznar Index (RI) results, where 51.6 % was neutrally balanced without behavior. However, a corrosive characteristic was noticed as regard to LARSON & SKOLD index which results exceed 1.2 value.

This research provides valuable information on the scaling and corrosive characteristics of thermal water in the Algerian Sahara where it was noticed a corrosive behavior regarding chloride and sulfate ions.

To ensure effective management of these resources, it is crucial to consistently track key parameters such as pH, temperature, and the concentrations of chloride and sulfate ions. The use of ecological inhibitors and softening techniques could present feasible and sustainable solutions that align with the region's geochemical profile.

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