Iraqi National Journal of Earth Science

www.earth.mosuljournals.com

Assessment of Groundwater Quality in Zelten City, Al Jifara Plain, NW Libya

Bahia M. Ben Ghawar[1 *], **Milad F. Elsarat**[2], **Fathi M. Salloum**[3], **Nabila A. Al tuwaybi**[4]

[1,4]*Department of Engineering Geology, College of Engineering, University of Tripoli, Tripoli, Libya.*

[2]*Department of Medical Sciences, Higher Institute of Science and Technology Zalten, Zalten, Libya.*

[3]*Earth Science Department, University of Benghazi, Benghazi, Libya.*

Article information

Received: 19-Jul-2024

Revised: 20-Aug-2024

Accepted: 07-Oct-2024

Available online: 01-Oct-2025

Keywords:
Groundwater
Al Jifara Plain
Saline Water
Hydrochemical Parameters
Water Quality

Correspondence:
Name: Bahia M. Ben Ghawar

Email: B.Ben-Ghawar@uot.edu.ly

ABSTRACT

Groundwater resources management requires water quality assessment. Nine groundwater samples were collected during 2023 and 2024 from wells within the north and south of Zelten City. These wells penetrate the unconfined Quaternary aquifer (Al Jifara plain, NW Libya). This work is concerned with monitoring and determining water quality and assessing its suitability for potable water, irrigation, and industrial use. The samples were chemically analyzed, including various hydrochemical parameters as electrical conductivity (EC), total dissolved salts (TDS), hydrogen ions (pH), total hardness (TH), chlorine (Cl^-), calcium (Ca^{+2}), total alkalinity (TA), and salinity (NaCl). The results of the April 2024 samples are generally of lower parameter alteration than those of February 2023. More increases occur in variations at the north and northwest of Zelten. Hydrochemical prepared maps display high NaCl values in the north and northwest directions, averaging about 3000 mg/l. The water is unsuitable for irrigation and is classified as C5 level, which means it contains excessive mineral content. The high concentration of Ca^{+2}, Cl^- and TDS indicates the presence of Sabkha deposits and seawater intrusions. Therefore, the water in the study area requires treatment processes before utilization.

DOI: 10.33899/earth.2024.152084.1324, ©Authors, 2025, College of Science, University of Mosul.

تقييم جودة المياه الجوفية بمدينة زلطن، سهل الجفارة، شمال غربي ليبيا

بهية بن قوار [1*]، ميلاد السراط [2]، فتحي سلوم [3]، نبيلة الطويبي [4]

[4,1] قسم الهندسة الجيولوجية، كلية الهندسة، جامعة طرابلس، طرابلس، ليبيا.

[2] قسم العلوم الطبية، المعهد العالي للعلوم والتكنولوجيا زالطن، زالطن، ليبيا.

[3] قسم علوم الأرض، جامعة بنغازي، بنغازي، ليبيا.

معلومات الارشفة

تاريخ الاستلام: 19- يوليو -2024

تاريخ المراجعة: 20- اغسطس -2024

تاريخ القبول: 07- اكتوبر -2024

تاريخ النشر الالكتروني: 01- اكتوبر -2025

الكلمات المفتاحية:

المياه الجوفية

سهل الجفارة

المياه المالحة

معاملات الهيدروكيميائية

جودة المياه

المراسلة:

الاسم: بهية بن قوار

Email: B.Ben-Ghawar@uot.edu.ly

الملخص

ادارة المياه الجوفية تتطلب تقييم جودة هذه المياه. تسع عينات مياه جوفية تم تجميعها من الخزان الجوفي المعروف بالرباعي غير المحصور بمنطقتين مختلفتين لشمالي وجنوبي مدينة زلطن بسهل الجفارة (شمال غربي ليبيا)، هذا العمل تم خلال فترتين زمنيتين هما فبراير 2023 وابريل 2024. تهتم هذه الدراسة بمراقبة وتحديد جودة المياه وتقييم مدى ملاءمتها للشرب والري والاستخدام الصناعي. ومن ثم حللت العينات لقياس معاملات هيدروكيميائية (التوصيلية الكهربائية "EC"، الاملاح الكلية الذائبة "TDS"، الرقم الهيدروجيني "pH"، العسرة الكلية "TH"، ايون الكالسيوم "Ca^{+2}"، ايون الكلوريد "Cl^{-}" والقلوية الكلية "TA" ودرجة الملوحة "NaCl"). اوضحت النتائج التغير الواضح بزيادة تراكيز المعاملات الهيدروكيميائية بالفترة الزمنية ابريل 2024 عن الفترة الزمنية فبراير 2023. حيث كانت الزيادة باتجاه الشمال والشمال الغربي للمنطقة المدروسة بمدينة زلطن. ايضا اظهرت خرائط الكنتور بتتبع زيادة درجة الملوحة باتجاه الشمال والشمال الغربي حوالي 3000 مليجرام/لتر. بالإضافة الى القياسات العالية لـ EC و-Cl و TDS وTH لعينات المياه بمدينة زلطن بحيث تصنف غير ملائمة للري وتدرج بمستويي C5، التي تحوي التمعدن بشكل كبير. وتدل التراكيز العالية لـ Ca^{+2} و Cl^{-} و TDS الى وجود رواسب السبخة وتداخل لمياه البحر. عليه، فالمياه المدروسة تحتاج الي عمليات معالجة قبل الاستخدام.

DOI: 10.33899/earth.2024.152084.1324,

Introduction

Ensuring the safety of drinking and irrigation water in regions or cities is crucial. The Mediterranean region is globally considered one of the most water-deficient areas (Châtel et al., 2014). Libya is among the countries facing a critical shortage of renewable water resources on a global scale (UNICEF Libya, 2022). According to the Libya Water Report (2020), the city of Zelten is located within the average annual rainfall isohyet range from 150 to 200 mm (Fig. 1).

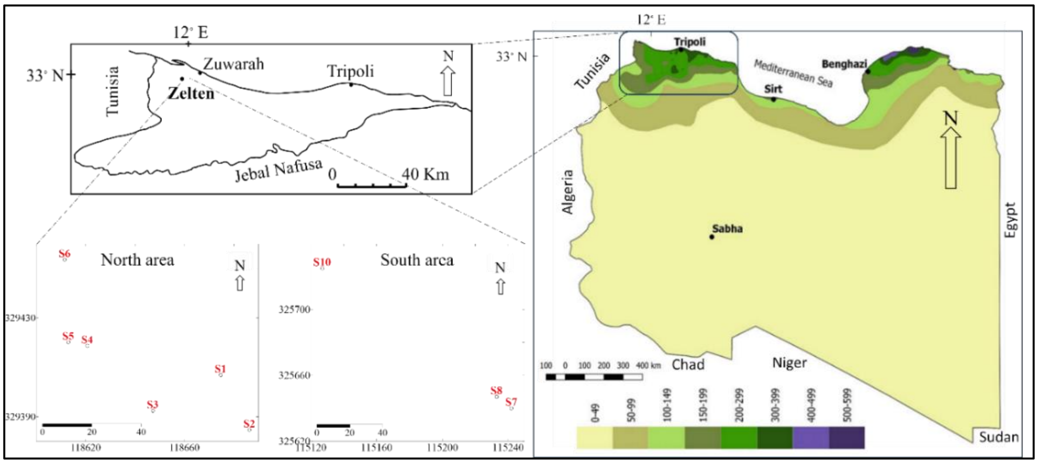

Fig. 1. Location of the study area and isohyet line of rainwater (modified and redrawn after Zurqani, 2021)

The main groundwater resources in Libya are the Quaternary-Piocene-Miocene aquifer, which has fair quality. Margat (2008) demonstrated that the entire northern Libyan region is a karstic carbonate aquifer, where most of the Libyan population lives along the coastline. According to the water stress map of Libya (UNICEF Libya, 2022). The city of Zelten experiences water stress ranging from 10% to 20%. In 2005, the total water quantity produced from the Al Jifara aquifer was about 940 million cubic meters, with 109 million cubic meters used for irrigation and urban and industrial use, respectively (Alfarrah and Walraevens, 2011). This excessive water usage is one of the major reasons for the decline in the water table and the intrusion of seawater along the northern coast of Libya. Additionally, seawater intrusion is a significant threat to freshwater aquifers in North Africa. In many studies, researchers have focused on understanding the main reasons for this phenomenon to manage and reduce risks to shallow groundwater aquifers (Agoubi, 2021). Sabratah is located east of the study area, and is considered a typical area affected by saltwater intrusion in the Al Jifara plain (Alfarrah et al., 2017). Recharging techniques for groundwater were applied along the coasts of Tunisia and Libya to combat seawater intrusion, using downscaled GRACE data for support (Gonçalvès et al., 2021).

Consequently, most of the published groundwater studies of Al Jifara plain (northwest Libya) have been concerned with water quality, contamination, as well as seawater intrusion (Hafi and Al-Samarrai, 2012; Alfarrah and Walraevens 2011; Alfarrah and Walraevens 2018; Sadeg and Rashrash, 2002; Al-Rutimi 2019; Halap et al., 2021; Riad et al., 2016). Recently, numerous studies have proposed various approaches and techniques for improving water quality in the high saline Al Jifara plain shallow aquifer (Absisah et al., 2024). Additionally, there is a discussion about sequestering carbon dioxide (CO_2) from high saline aquifers due to climate change and carbon dioxide emissions worldwide (Luo et al., 2022 and Bentham and Kirby, 2005).

This study focuses on the changes in the hydrochemical parameters of groundwater in Zelten city from February 2023 to April 2024. It also examines the permissible use of groundwater for human consumption (drinking, irrigation, and livestock) and for industrial activities such as construction and the petroleum industries. Additionally, it suggests modern techniques for utilizing high-salinity water types in Zelten's groundwater

Geology and Hydrogeological background

Zelten is a small city located on the western coastal strip of the Al Jifara plain in western Libya. It is located approximately 130 km from the capital city of Tripoli and 20 km from Zuwarah City to the east, and it borders Tunisia to the west. To the north, it is bordered by the Mediterranean Sea and to the south by Jebel Nafusa (Fig. 1). The Al Jifara plain is home to one of the renewable groundwater aquifers in northern Libya, with a south-to-north groundwater flow (Gonçalvès et al., 2021). Geologic studies showed that the Al Jifara plain is mainly defined by two north-throwing faults: the Jifara fault to the south and the Sabratah fault to the north (Kruseman and Floegel, 1980). Additionally, drilled boreholes have revealed a Permo-Triassic to Quaternary sequence stratigraphy (Hallett and Clark-Lowes, 2016). In general, Krummenacher (1982) and Industry Research Center (IRC, 1975) described the formations that comprise the Al Jifara Plain. Hence, interbedding between carbonate and sandstone beds with massive gypsum and clay strips is a common lithology of the Al Jifarah plain. In addition, Triassic formations have a thick sequence compared to Jurassic, Cretaceous, and Tertiary, whereas Quaternary sequences have the least thickness. The sequence stratigraphy of Al Jifara plain consists of three main aquifers: the upper Miocene, Pliocene, and Quaternary. The first unconfined shallow Quaternary aquifer is made up of unconsolidated sand, sandstone, and carbonate rocks, with a thickness ranging from about 30 m to 160 m and a shallow water level ranging from 10 m to 80 m (Fig. 2). The deep aquifer is a thick sandstone rock interspersed with silt and clay, with depths ranging from 300 m to 700 m.

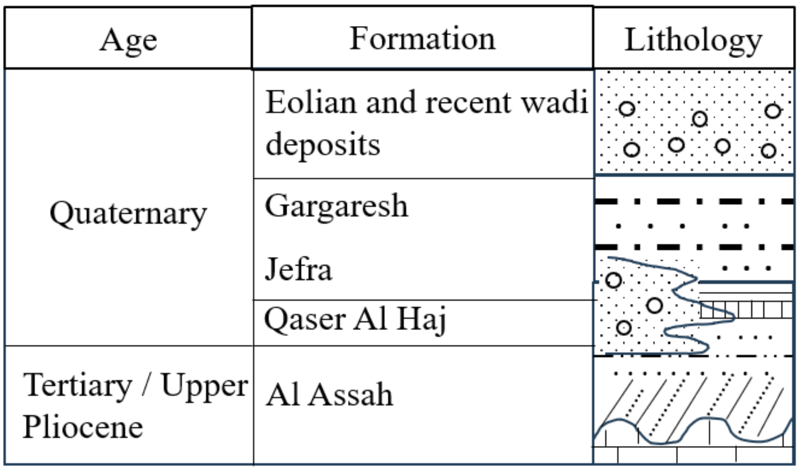

Fig. 2. General sketch of the sequence stratigraphy of the unconfined shallow aquifer, Al Jifara plain

Materials and Methods

Nine water samples were collected from different water wells with an average depth of 9.5 m water level in Zelten City. The geographical location of the water wells is marked using a Global Positioning System (GPS) tool, covering an area of about 5 km^2 in Zelten. The wells are six in the north area and three in the south, as shown in Figure 1. The water samples were collected in February 2023 and April 2024 using routine procedures in sterile bottles at surface conditions. Eight hydrochemical parameters were measured, including (EC), (TDS), pH, TH, (Cl^-), TA, and Salinity (NaCl, mg/l). Figure 3 illustrates a comparison of the measurement parameters of the water samples over the two periods of time.

Results and Discussion

The water samples of Zelten City were analyzed for four water quality indicators: pH, TDS, EC, and TH. parameters are used to classify the groundwater and determine its suitability for various purposes. The classification system is used based on the FAO (1999), Klimentove (1983), Todd (1980), Todd and Mays (2004), Freeze and Cherry (1979), Altoviski (1962), Hem (1985), Detay (1997), Ayer (1985), Richards (1954), Deere and Miller (1966). Therefore, Figure 3 illustrates an increase in the hydrochemical parameters, particularly TDS, TH, and Cl^- values, in the water samples between February 2023 and April 2024. Jalal et al., (2024) concluded lower concentration in physiochemical parameters of the eastern Erbil groundwater basin than the western basin during the wet season. Table 1 contains the statistical analysis results of the Zelten water samples. The changes in these hydrochemical parameters are attributed to environmental and climatic influences on the groundwater within Al Jifara plan (Alfarrah and Walraevens, 2018 and Riad et al., 2016). Additionally, the total dissolved solids (TDS) are higher than attributed to high dissolved salts in the shallower aquifer, ranging from 3000 ppm near Zuwarah city to over 10000 ppm at the Sabkah of the Tunisia border (Al-Rujaibi, 2009). Meanwhile, Hafi and Al-Samarrai (2012) reported TDS levels ranging from less than 2000 to less than 1000 mg/l in the Quaternary aquifer.

Table 1: Statistical analysis of hydrochemical parameters of Zelten groundwater (2024)

	PH	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)	Cl^- (mg/l)	Ca^{+2} (mg/l)	NaCl (mg/l)
Min	7.1	5890	3900	126	1398.4	2977.8	620	114000
Max	7.7	27730	16600	218	6482.6	11202	2165	542000
Average	7.32	13928.9	8827.8	178.9	3267.4	5853.1	1260.6	271777.8

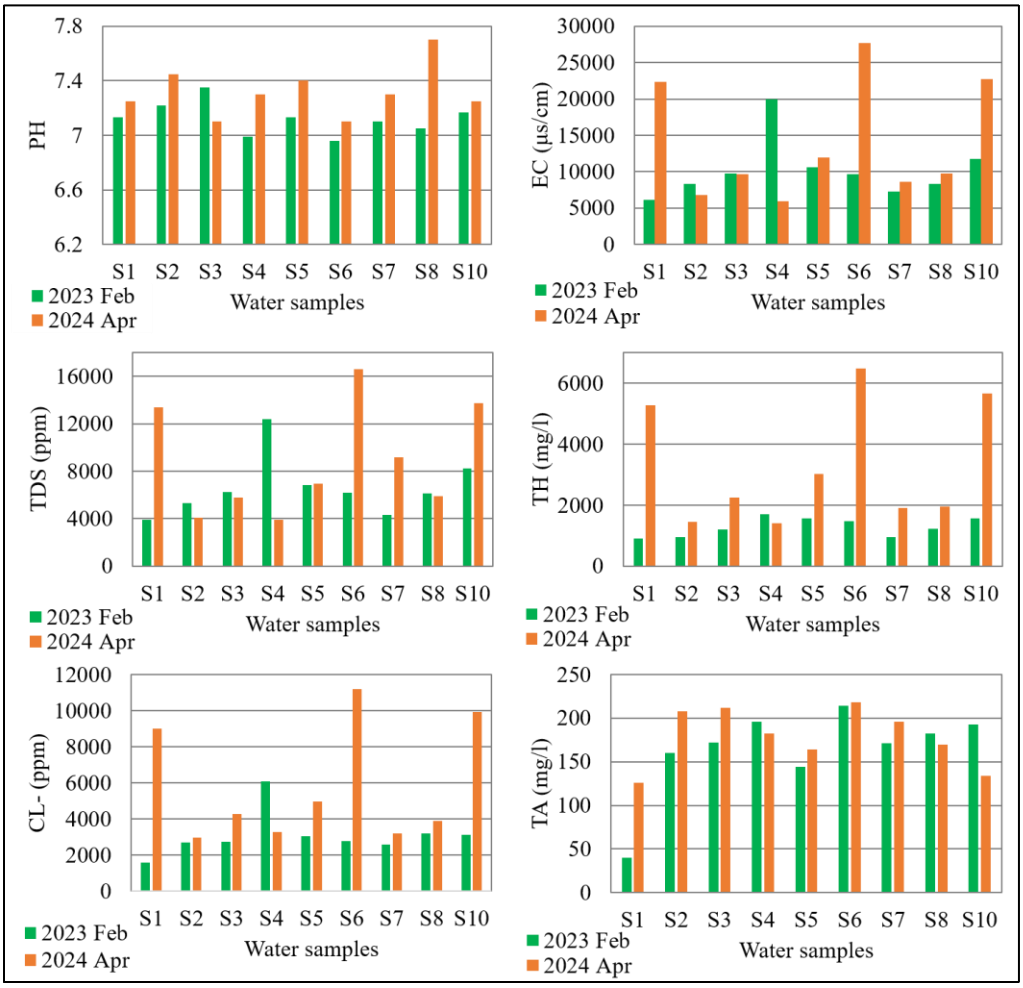

Fig. 3. Comparison of hydrochemical parameters of the Zelten water samples

Distribution of the Hydrochemical parameters

It is useful to distribute ion concentrations of groundwater, as it allows tracking the variation of these ions throughout the aquifer. As previously mentioned, the shallow Quaternary aquifer is composed of heterogeneous sedimentary rocks (sandstone and carbonate), which can change due to geochemical processes. Mapping the concentration of the hydrochemical parameters (TDS, Cl^-, Ca^{+2}, TH, TA, and NaCl) of the Zelten groundwater is taken into consideration during both periods of time, 2023 and 2024. According to that, the NaCl concentration is selected to demonstrate the fluctuation of the Zelten groundwater salinity. Therefore, Figure 4 illustrates contour maps of the NaCl concentration distribution within two different locations of Zelten City: the north area and the south area. The NaCl contour lines of the whole study area reveal an increase toward the northwest direction. While in the northern area, the NaCl concentration contour lines increase toward the north direction, close to well S6. Also, the southern area displays an increase in NaCl in the northwest direction. This can be attributed to various factors, including the presence of sabkha deposits and seawater intrusions. In addition, two calcium (Ca^{+2}) and chlorine (Cl^-) ions are also taken into consideration to interpret the high groundwater salinity. Thus, Figure 5 shows these ions concentration distribution of the whole study area, which demonstrates the Ca^{+2} increase towards the northwest as NaCl increases. While the Cl^- is increased in the southwest (the southern area location).

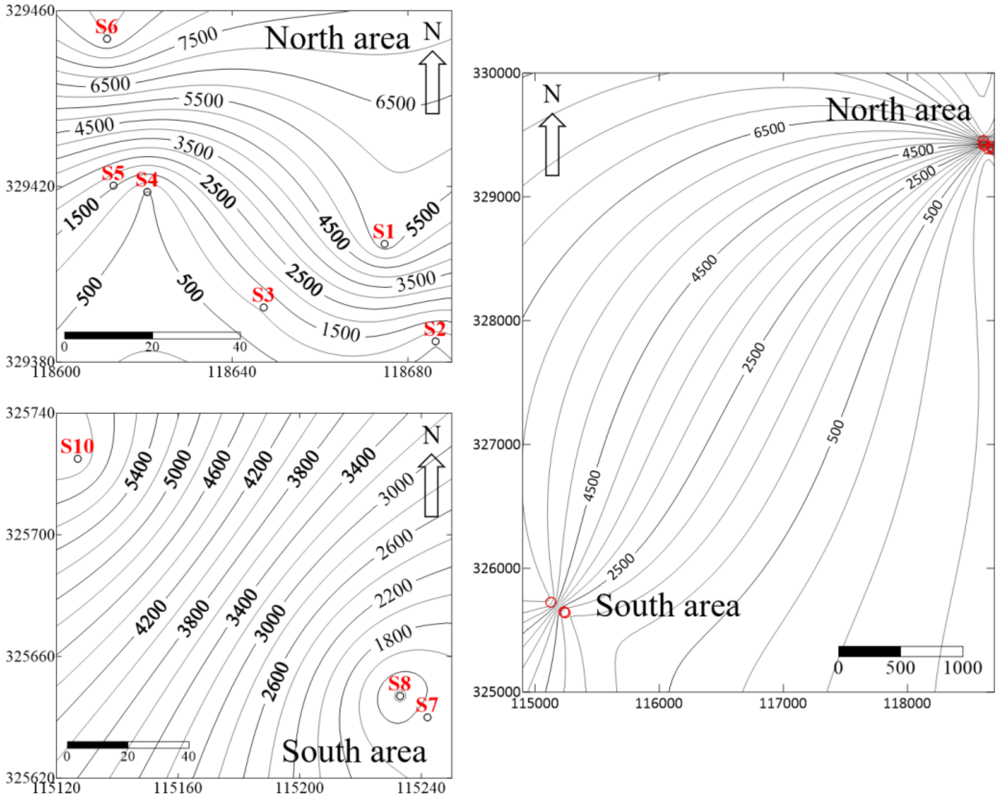

Fig. 4. Salinity (NaCl) concentration distribution of study area in 2024 April, mg/l.

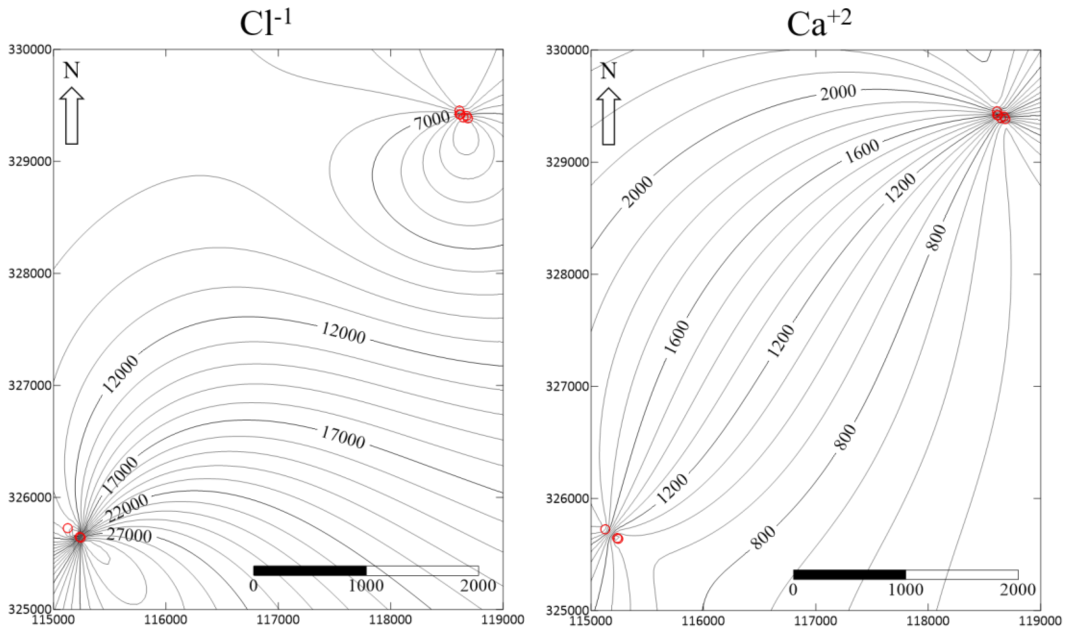

Fig. 5. Calcium (Ca^{+2}) and chlorine (Cl^{-}) ions concentration distribution of the study area in April 2024, mg/l.

Zelten groundwater classification

Table 2 summarizes the classification of the groundwater samples based on total dissolved salts (TDS). Other factors such as electrical conductivity (EC), total hardness (TH), total alkalinity (TA), pH, and chlorine ion concentration (Cl^{-}) are also considered to classify the water for municipal, irrigation, and industrial use. The Zelten groundwater, based on the TDS, falls within the brackish ranges (2000-20000) of Drever (1997) and Todd (1980) classifications, except for sample (S4). While chlorine ion concentration (Cl^-) is less common in groundwater compared to seawater, levels exceeding 600 mg/l suggest seawater intrusion (Revelle, 1941). Thus, a cross plot between the EC and Cl^- reveals a higher influence of the seawater intrusion of the Zelten City in April 2024 than in February 2023 (Fig. 6). Additionally, the presence of high levels of Cl^- in sample S7 may indicate sewage and industrial contamination in the absence of measured carbonate and bicarbonate ion concentrations.

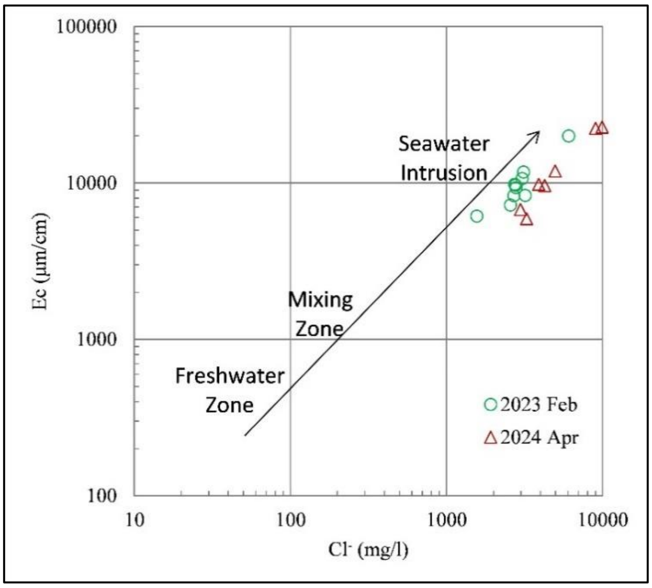

Fig. 6. Electrical conductivity (EC) and chlorine concentration (Cl^-) for seawater intrusion indicator

The pH values indicate the acidity or alkalinity and the concentration of hydrogen ions in the groundwater. According to the WHO (2006) guideline for drinking water quality in the Zelten area, the pH results fall within the permissible range of 7 to 8.5. The pH results are also suitable for irrigation, within the Libyan standards of 6.5 to 8.8, and as per (FAO, 1999) from 5 to 9. However, the EC, TDS, TH, Cl^-, and Ca^{+2} values are out of the acceptable range for drinking according to WHO (2011) and Libyan standards. Additionally, the EC, TDS, and TH are the main contributors to water classification, which affect the overall water quality. The high measured values of the Zelten groundwater samples show that they are not suitable for irrigation due to excessive mineralization. According to Detay (1997). The electrical conductivity (EC) of these samples is greater than 1000 μs/cm, classifying them as C5. Additionally, the water samples are very hard and hazardous, as classified by both Sawyer and McCarty (1967) and Todd (1980) based on total hardness (TH) and electrical conductivity (EC) (refer to Table 3). High chlorine concentration in water is an important indicator of poor water quality and can be toxic, inhibiting plant growth.

Table 2: Groundwater classification by TDS (mg/l).

Altoviski (1962)	Todd (1980)	Klimentove (1983)	Drever (1997)	Todd (2007)	Water type	Water samples
-	-	200	-	-	Super fresh	Out of limit
0 - 1000	0-1000	200 - 1000	< 1000	10 - 1000	Fresh	Out of limit
1000-3000	-	1000-2000	1000 - 10000	-	Slightly brackish	Out of limit
3000-10000	1000-10000	-	2000-20000	1000-10000	Brackish	All samples within Drever (1997) and Todd (1980) limits
-	-	3000-10000	-	-	Strongly brackish	Out of limits
10000-100000	-	-		10000-100000	Salty	Out of limits
-	10000-100000	10000-35000	35000	-	saline	Out of limits
>100000	>100000	>35000	>35000	>100000	Brine	Out of limit

Table 3: The groundwater Total Hardness and Electrical conductivity classification.

	Sawyer and McMcartly (1967)	Todd (1980)	Classification	Water samples
TH	> 75	0 <TH ≤ 60	Soft	Out of limit
	75 – 150	60 < TH ≤ 120	Moderately	Out of limit
	150 – 300	120 < TH ≤ 180	Hard	Out of limit
	< 300	> 180	Very Hard	All samples
EC (µS/cm)				
< 1500	-	-	Permissible	Out of limit
1500 – 3000	-	-	Not permissible	Out of limit
>3000	-	-	Hazardous	All samples

According to Table 4, the TDS of the Zelten groundwater samples exceeds 3000 mg/l, which means it does not meet the criteria for potable water as per the classification by WHO (1993).

Table 4: The allowable potable water (WHO, 1993).

	Most desirable limit	Max. allowable limit	Water samples
pH	6.5 – 8.5	9.2	All samples within the limits
TDS (mg/l)	500	1500	All samples out of limit
Cl^- (mg/l)	200	600	All samples out of limit

The consumption of groundwater is essential for human use, irrigation, construction, and industry worldwide. In the last decades, the groundwater of Zelten City has been used for agricultural purposes, with the main products being grains (barley and wheat), olive trees, grapes, figs, almonds, and palm trees. Therefore, the ability of consumption of the Zelten groundwater for other industries by researchers like Hem (1985); Train (1979); and Altoviski (1962) has been classified. Table 5 provides the irrigation water classification in Zelten, while Table 6 compares hydrochemical parameters between standard values and Zelten groundwater for use in a concrete mixture. Therefore, the studies by Richards (1954) and Davis and De Weist (1966) suggest that the groundwater in Zelten is not suitable for irrigation purposes. Additionally, all the water samples are of poor quality for construction purposes. However, the quality of the water samples varies, ranging from good to not recommended for livestock and poultry drinking water. Moreover, the electrical conductivity (EC) classification for crop response indicates two ranges.

Table 5: Groundwater Suitability for irrigation, construction, and livestock.

Irrigation water				Water samples
Ec (µS/cm)	Richards (1954)	100-250	Excellent	Out of limit
		250-750	Good	Out of limit
		750-2250	Doubtful	Out of limit
		>2250	Unsuitable	All samples
TDS (mg/l)	Davis and DeWiest (1966)	1000-3000	Useful for irrigation	Out of limit
		>3000	Unfit for irrigation	All samples
Construction				
Cl^- (mg/l)		0 -175	Good	Out of limit
		170 - 290	Fair	Out of limit
		> 290	Poor	All samples
Livestock and poultry drinking water				
EC (µs/cm)	Ayers and Westcot (1985)	< 1500	Excellent	Out of limit
		1500-5000	Very Satisfactory	Out of limit
		5000-8000	Satisfactory for Livestock	S1 (Feb, 2023) S2 and S4 (Apr, 2024)
		8000-11000	Limited Use for Livestock	S2, S3, S5, S6, and S8 (Feb, 2023) S3, S7 and S8 (Apr, 2024)
		11000-16000	Very limited used	S10 (Feb, 2023) S5 (Apr, 2024)

	> 16000	Not recommended	S4 (Feb, 2023) S1, S6 and S10 (Apr, 2024)
Related crop response			
Ec (μm/cm)	4000 - 8000	More sensitive crops in this group: Grape, Cantaloup, Cucumber, peas, onion, carrot, bell pepper, potato, sweet corn and lettuce.	S1 and S7 (Feb, 2023) S2 and S4 (Apr, 2024)
	8000 - 16000	Only salt-tolerant crops yield satisfactorily. These include: Date palm. Asparagus, kale, garden beets. Birdsfoot trefoil, barley, many species of wheatgrasses and wild ryes, Rhodes grass, Bermuda grass, salt grass. Some varieties of cotton, sugar beet.	S2, S3, S5, S6, S8 and S10 (Feb, 2023) S3, S5, S7 and S8 (Apr, 2024)
	> 16000	Satisfactory yields from only a few very salt-tolerant species: Certain native range plants	S4 (Feb, 2023) S1, S6 and S10 (Apr, 2024)

The fluctuation of groundwater levels, sewage water, and the presence of certain salt ions can cause common problems such as foundation subsidence, cracked floors, wall cracks, and chemical corrosion of concrete foundations. High concentrations of chloride and alkaline ions in the water used for mixing concrete can lead to rust and carbonation in construction buildings. There is allowed maximum standard levels for ion concentrations in the water used to mix concrete, which are 2 g/l for TDS, 0.5 g/l for Cl^-, and 1 g/l for TA. Table 6 compares the hydrochemical parameters of the studied samples with the standard ranges for concrete mixture water. The results show that the TDS and Cl^- levels in the Zelten water samples are unsuitable for use as concrete mixture water.

Table 6: Zelten groundwater suitability for concrete mixture water.

	TDS (mg/l)	Cl^- (mg/l)	TA (mg/l)	pH
Standard level	2000	500	1000	6-8
Water samples	3923.2 - 12371.2	1562 - 6070.5	40 - 218	6.96 - 7.35

The suitability of investing in the Zelten groundwater for industrial use, based on Hem's (1985) classification, is shown in Table 7. The table indicates that the water's quality is poor due to high salinity, making it unsuitable for industrial use. Therefore, different techniques need to be considered to improve the water quality of the Zelten water to be suitable for industrial investment. Criteria such as low cost, minimal environmental impacts, and potential for fresh water production should be considered when selecting a suitable technique for treating high saline water, as mentioned by Khlaifat et al., (2023), Samba et al., (2023) and Mkilima et al., (2022).

Table 7: Water used for industry application (Hem, 1985)

Industrial type	pH	TDS (mg/l)	TH (mg/l)	Cl^- (mg/l)	Ca^{+2} (mg/l)	Water samples
Canning and Beverage Industry	-	-	-	500	100	Out of limits
Canned fruit industry	6.5-8.5	500	250	250	NA	Out of limits due to high TDS, TH, and Cl^-
petroleum industry	6-9	1000	300	300	75	Out of limits due to high TDS, TH, Cl^- and Ca^{-+}
Plastic	6.5-8.3	-	350	-	80	Not able due to high TH and Ca^+
Textile Industries	6.5-8	1000	900	500	100	Out of limits due to high TDS, TH, Cl^- and Ca^{-+}
paper manufacturing	6-10	-	100	200-250	20	Out of limits due to high TH, Cl^- and Ca^{+2}
leather industry	6-8	-	Soft	250	-	Out of limits due to high TH and Cl^-
cement industry	6.5-8.5	600	-	250	-	Out of limits due to high TDS and Cl^-
Construction material	-	-	-	2187	437	Out of limits due to changes in Apr 2024

Conclusion

Measurements of hydrochemical parameters in Zelten City indicate higher values in April 2024 compared to February 2023. Shallow groundwater is affected by hydrogeochemical processes from gypsum, halite, and limestone rocks, resulting in high calcium (Ca^{+2}) and chlorine (Cl^-) ion concentrations. Water samples show a brackish type and are excessively mineralized, making it unsuitable for irrigation. The high chlorine (Cl^-) ion concentration also indicates seawater intrusion. As a result, the groundwater is not suitable for potable water according to WHO (2006) and Libyan standards (1992). The increasing concentration of salt ions in the Zelten area negatively affects crop productivity, causes soil damage, and leads to corrosion of downhole tools. Furthermore, the Hem (1985) classification reveals the potential uselessness of Zelten groundwater for industrial purposes.

Consequently, the poor quality of the Zelten groundwater caused by high salinity should be improved in such a way, and invested in to produce potable water and other industrial purposes. Thus, the demand increases to water desalination in the coastal areas characterized by high population with increasing urban and industrial activities increases.

Acknowledgements

The authors present their deep thanks to Eng. Najeeb A. Shtwi for laboratory work and support.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript. And admit that no research support was received from either the universities or any other organizations.

References

Absisah, H.A.E., Hasheesh, W.S., Mohamed, H.A., and Abdel-Khalek, A.A., 2024. Detoxification of groundwater pollutants from Al Jifara plain (Libya) using naturally synthesized chitosan: Histological and antioxidant status in Wistar Rats. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 76(2), pp. 207–216. https://doi.org/https://doi.org/10.1590/1678-4162-13145

Agoubi, B., 2021. origin, heating process, and groundwater flow system of non-volcanic thermal aquifers in Tunisia. Arabian Journal of Geosciences, 14(5), 369. https://doi.org/https://doi.org/10.1007/s12517-021-06632-3

Al-Rujaibi, A.A.R., 2009. Groundwater in the northwestern coastal region of Libya. Journal of the Libyan Geographical Society, 3, pp. 49–59. https://www.researchgate.net/publication/363541038_almyah_aljwfyt_fy_shmal_ghrb_shl_aljfart

Al-Rutimi, I.M., 2019. Spatial characteristics of the aquifers in the Jaffara plain area. Al-Qurtas Journal of Humanities and Applied Sciences, 6(6), pp. 176–193. https://alqurtas.alandalus-libya.org.ly/ojs/index.php/qjhar/article/view/166

Alfarrah, N., Berhane, G., Bakundukize, C. and Walraevens, K., 2017. Degradation of groundwater quality in coastal aquifer of Sabratah area, NW Libya. Environmental Earth Sciences, 76, pp. 1–23. https://doi.org/https://doi.org/10.1007/s12665-017-6999-5

Alfarrah, N. and Walraevens, K., 2011. Hydrogeological and hydrogeochemical investigation of the coastal area of Jifarah Plain, NW Libya. Afrika Focus, 24(1). https://doi.org/https://doi.org/10.1163/2031356X-02401008

Alfarrah, N. and Walraevens, K., 2018. Groundwater overexploitation and seawater intrusion in coastal areas of arid and semi-arid regions. Water, 10(2), 143. https://doi.org/https://doi.org/10.3390/w10020143

Altoviski, M.E., 1962. Handbook of hydrogeology. Geogoelitzet, Moscow, USSR (In Russian), 614 P.

Ayers, R.S. and Westcot, D.W., 1985. Water quality for agriculture (Vol. 29). Food and Agriculture Organization of the United Nations, Rome.

Bentham, M. and Kirby, M., 2005. CO2 storage in saline aquifers. Oil and Gas Science and Technology, 60(3), pp. 559–567. https://ogst.ifpenergiesnouvelles.fr/articles/ogst/pdf/2005/03/benthman_vol60n3.pdf

Châtel, F. de, Holst-Warhaft, G. and Steenhuis, T., 2014. Water Scarcity, Security and Democracy: A Mediterranean Mosaic, Athens and Ithaca, Global Water Partnership Mediterranean, Cornell University, and Atkinson Center for a Sustainable Future.

Davis, S.N. and De Weist, R.J.M., 1966. Hydrogeology. John Wile and Sons.

Deere, D.U. and Miller, R.P. 1966. Engineering classification and index properties for intact rock. https://trid.trb.org/View/11904

Detay, M., 1997. Water wells: implementation, maintenance and restoration. John Wiley and Sons, Chichester (UK). 379 P.

Drever, J.I., 1997. The geochemistry of natural waters: surface and groundwater environments. In Upper Saddle River (3rd Edition). Prentice-Hall. Inc.

FAO., 1999. Food and Agriculture Organization. https://www.fao.org/faolex/results/details/en/c/LEX-FAOC053079/

Freeze, R.A. and Cherry, J.A., 1979. Groundwater prentice-hall. Englewood Cliffs, NJ, 176, pp. 161–177.

Gonçalvès, J., Séraphin, P., Stieglitz, T., Chekireb, A., Hamelin, B., and Deschamps, P., 2021. Coastal aquifer recharge and groundwater–seawater exchanges using downscaled GRACE data: case study of the Djeffara plain (Libya–Tunisia). Comptes Rendus. Géoscience, 353(1), pp. 297–318. https://doi.org/10.5802/crgeos.74

Hafi, Z.B. and Al-Samarrai, K.I., 2012. Evolution of hydrochemical facies of the groundwater of the shallow aquifer, NW Libya. Journal of Hydrocarbons Mines and Environmental Research Volume, 3(2), pp. 37–46.

Halap, A.A., Al Gadabe, A., and Al Hasarei, E., 2021. The Third Engineering Conference of the Engineering Professions Syndicate in Zawiya. Water Quality Assessment of Wells, Zuwara City, Libya. https://third.leabz.org.ly/

Hallett, D. and Clark-Lowes, D., 2016. Petroleum Geology of Libya: Second Edition (2nd Ed.). Elsevier.

Hem, J.D., 1985. Study and interpretation of the chemical characteristics of natural water (Vol. 2254). Department of the Interior, US Geological Survey.

IRC, 1975. Geological map of Libya, 1:250,000 sheets.

Jalal, H.B., Dara, R.N., Jirjees, S.J., Saber, B.P., and Ismael, P.B., 2024. Hydrochemical Assessment and Groundwater Quality of Eastern and Western Catchments of Erbil City, Northern Iraq. Iraqi National Journal of Earth Science (INJES), 24(2), pp. 154–176. https://doi.org/10.33899/earth.2023.142687.1132

Khlaifat, A., Fakher, S., Ibrahim, A.D., Elsese, M. and Nour, A., 2023. High-salinity produced water treatment and desalination. LHB, 109(1), 2284957. https://doi.org/https://doi.org/10.1080/27678490.2023.2284957

Klimentove, P.P., 1983. General Hydrology (Mir. Publ.).

Krummenacher, R., 1982. Report on the groundwater resources of the Gefara Plain.

Kruseman, G.P., and Floegel, H., 1980. Hydrogeology of the Jifanah, NW Libya.

Luo, A., Li, Y., Chen, X., Zhu, Z. and Peng, Y., 2022. Review of CO2 sequestration mechanism in saline aquifers. Natural Gas Industry B, 9(4), pp. 383–393. https://doi.org/https://doi.org/10.1016/j.ngib.2022.07.002

Margat, J., 2008. L'eau des Méditerranéens: situation et perspectives. https://doi.org/http://digital.casalini.it/9782296205499

Mkilima, T., Devrishov, D., Assel, K., Ubaidulayeva, N., Tleukulov, A., Khassenova, A., Yussupova, N., and Birimzhanova, D., 2022. Natural Zeolite for The Purification of Saline Groundwater and Irrigation Potential Analysis. Molecules, 27(22), 7729. https://doi.org/https://doi.org/10.3390/molecules27227729

Revelle, R., 1941. Criteria for recognition of the seawater in groundwater. Eos, Transactions American Geophysical Union, 22(3), pp. 593–597.

Riad, A.G.P., Gad, M.A., Rashed, K.A. and Hasan, N.A., 2016. Climate change and sea level rise impacts on seawater intrusion at Jefara Plain, Libya. Nature and Science, 14(3), pp. 75-81. https://doi.org/10.7537/marsnsj14031611

Richards, L.A., 1954. Diagnosis and Improvement of. Saline and Alkali Soils. Handbook, 60, pp. 129-134.

Sadeg, S. and Rashrash, S.S.M., 2002. Study of Seawater Intrusion North West Libya, Seawater Intrusion Study in the Jifara Plain, NW-Libya. Unpublished Report, General Water Authority.

Samba, M., Li, Y., Farhat, M., Ebrahim, T., Milad, M., Fenniche, F. and Elsharaf, M., 2023. Reducing the Salinity of the Produced Water from Oil Field Using Activated Carbon Extracted from Waste Date Kernel. Journal of Pure and Applied Sciences, 22(3), pp. 266-270. https://doi.org/10.51984/JOPAS.V22I3.2824

Sawyer, C.N. and McCarty, P.L., 1967. Chemistry for sanitary engineers (Vol. 518). McGraw-Hill, New York.

Todd, D.K., 1980. Groundwater Hydrology (2nd Edition). John Wiley.

Todd, D.K. and Mays, L.W., 2004. Groundwater Hydrology. Wiley. https://books.google.com.ly/books?id=X3T6DwAAQBAJ

Train, R.E., 1979. Quality Criteria for Water, Castle House Publ. Castle House Publication, Ltd. https://doi.org/doi:10.1017/S0376892900028332

UNICEF Libya., 2022. UNICEF Libya Water Scarcity and Climate Change: an analysis on WASH enabling environment in Libya. https://www.unicef.org/mena/media/19321/file/Libya water scarcity analysis and recommendations_ UNICEF Sep 2022.pdf

WHO., 1993. Research guidelines for evaluating the safety and efficacy of herbal medicines. WHO Regional Office for the Western Pacific.

WHO., 2006. Guidelines for drinking-water quality [electronic resource]: incorporating first addendum. Vol. 1, Recommendations. 1, 595.

WHO, 2011. WHO model list of essential medicines: 17th list, March 2011.

Zurqani, H.A., 2021. The soils of Libya (1st Ed.). Springer. https://doi.org/https://doi.org/10.1007/978-3-030-66368-1