Faculty of Arts Journal

DOI: 10.36602/faj.2026.n21.07 Faculty of Arts Journal, Issue 21, June 2026

Spatial Assessment of Groundwater Quality for Drinking Purposes in Tobruk City, Libya

Jumma A. Elgali [1*], Alaa A. Khamis[2]

[1, 2] Department of Geography, Faculty of Arts, Tobruk University, Libya

* Jumma.elgali@tu.edu.ly

Citation: Elgali, J., & Khamis, A. (2026). Spatial assessment of groundwater quality for drinking purposes in Tobruk city, Libya. *Faculty of Arts Journal – Misurata University*, *21*, 128–138. https://doi.org/10.36602/faj.2026.n21.07

Received 06- 01 - 2026 **Accepted** 11- 02 - 2026 **Published Online** 12- 02 - 2026

Abstract

The research aims to assess the groundwater quality in the city of Tobruk by analyzing its physical and chemical characteristics, in order to determine its suitability for drinking according to the adopted. Ten groundwater samples were collected and analyzed for the following parameters: TDS, pH, T.H, Ca^{2+}, $^{-}NO_3^{-}$, Mg^{2+} and $^{-}SO_4^{2}$. The GIS technique was employed to analyze and illustrate the spatial distribution of groundwater quality. The results indicated that the groundwater in the study area is of poor quality. The analyses revealed that most parameters exceeded the permissible limits specified by drinking water standards. On the other hand, the spatial distribution maps showed that the water quality in the northern and northeastern parts of the study area was of lower quality than the southern parts.

Key words: groundwater quality, water characteristics assessment, spatial analysis, Drinking water.

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1. Introduction

Groundwater is a vital natural resource and a primary source of freshwater in many regions due to its relative protection from contamination and stability compared to surface water sources (Abdul Aziz et al., 2019). Periodic assessment of groundwater quality is essential to ensure its safety for human consumption. Regular monitoring directly contributes to sustainable development by preserving this vital resource and ensuring its safe and responsible use for current and future generations (Elgali & Suleiman, 2023). Water quality refers to the physical, chemical, and biological characteristics that distinguish water and are used to evaluate its suitability for various human uses by comparing it with locally and internationally adopted standards and specifications. Assessing water quality is crucial to ensuring the safety and sustainability of water resources.

Due to scarce rainfall and the absence of permanent surface water sources, Tobruk-like many cities in semi-arid regions-relies on groundwater, with limited contribution from a desalination plant, to satisfy its water needs. Groundwater represents a primary source of drinking water in the city of Tobruk; however, increasing pressures resulting from population growth, urban expansion, and human activities have raised concerns regarding its quality. In the absence of continuous monitoring and updated assessments, groundwater resources may become vulnerable to contamination, posing potential risks to public health. Therefore, evaluating groundwater quality has become a necessary step to ensure its safety and sustainability as a drinking water source. In light of these challenges, this study seeks to assess the groundwater quality in the city of Tobruk by analyzing its physical and chemical characteristics, in order to determine its suitability for drinking according to the adopted standards.

1.2. Study Area

The study area is t is the city of Tobruk, located in the northeastern part of Libya, between the Mediterranean coast and the northern edge of the Al-Butnan Plateau. It is 140 km away from the Libyan-Egyptian border, and it is the population and economic center of the Al-Butnan region, with approximately 138,282 people (Abdul Salam, 2017). Its area is estimated to be approximately 22.69 km2. Astronomically, it is located at the intersection of latitude (32º 5´) north and longitude (23º 58´), (figure 1).

1.3 Literature Review

Several studies have focused on analyzing groundwater characteristics to assess its quality and suitability for human consumption. Bishnoi and Ravinder (2008) assessed groundwater quality across 41 sites in Panipat, India. Their analysis revealed considerable spatial variations in the chemical composition of the samples. The groundwater was characterized by very high hardness and elevated concentrations of dissolved salt. Elgali and Suleiman (2023) also addressed a study of groundwater characteristics in the Bir Al-Ashhab municipality, by collecting 14 well samples. The study showed that most element concentrations exceeded permissible limits except ph. regarding the spatial variation of water quality, the northern wells having better quality than central and southern ones.

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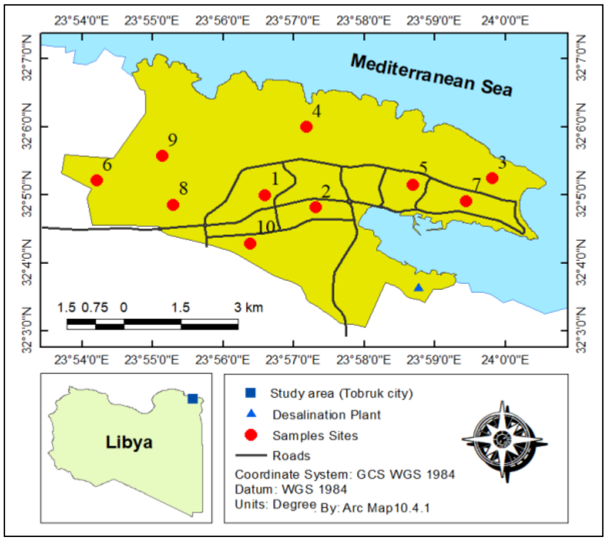

Figure (1) Location of the study area

- **Geological and climatic characteristics of the study area**

The geological formation plays a fundamental role in the presence of groundwater, both in quantity and quality, as the properties of the rocks control the percentage of dissolved salts in the water. The aquifer in the study area is part of the main Al-Jabal Al-Akhdar aquifer, which is located in Tertiary formations composed of limestone and dolomite and rests on an impermeable layer belonging to the late Cretaceous period of the second geological era (Bashir, 2005). Climatically, the study area is subject to a semi-arid climate. Climatic factors, especially temperature and precipitation, have a major impact on water resources, through which the state of water deficit or surplus is determined. Table (1), shows that the temperature rises significantly in summer and decreases in winter, with an annual average temperature of (19.3°C). As for rainfall, most of it is in winter and rarely falls in summer, and it falls in varying amounts temporally from year to year, with an annual average of 179 mm.

- **Water sources**

Groundwater is the primary source of water in the city of Tobruk. The city used to obtain water from wells in Tobruk or the surrounding area, such as the Wadi Al-Sahl and Kroum Al-Khail water, located 12 km from the city center. In 1961, a pipeline of water was built extending from the city of Derna to Tobruk for a distance of 170 km, supplying a part of the city with water. In 1976, a seawater desalination plant was established with a production capacity of 24,000 m^3/day. However, by the end of the 1990s, it became insufficient to meet all the city's needs due to the increase in population and geographical area. This led to the construction of a new plant in 2001 with a production capacity of 40,000 m3/day. The plant supplies a large part of the city through the General Water Company, while some neighborhoods do not benefit from the water due to the absence of a water supply network, especially newly developed neighborhoods. This has prompted some residents to make random connections using plastic hoses connected from the nearest neighborhood with water networks or from the main lines in the city, leading to the waste of large quantities of water. Residents of these neighborhoods also rely on other methods to provide water, which is purchasing water by specialized vehicles, either through the water company or through the private sector (Abdul Salam 2017).

Table (1): Average Temperatures and Rainfall in the study area (1985-2009)

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Temperature	13.5	13.8	15.6	18.1	20.8	23.9
Rain	47.0	32.3	12.1	3.6	6.2	0.0
Months	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Temperature	25.8	26.6	25.6	22.6	18.8	15.0
Rain	0.0	0.0	1.7	13.8	19.2	42.4

Source: Libyan National Meteorological Center, Tripoli

2. Methodology

The study employed fieldwork as a means of data collection. Ten (10) groundwater wells distributed across most neighborhoods of the city of the study area were selected, and their geographic coordinates were determined as shown in Table (2). Water samples were collected in clean plastic bottles. Prior to sampling, the bottles were thoroughly rinsed several times with the same water to be analyzed in order to avoid contamination and ensure analytical accuracy. After that, the groundwater samples were transported to Al-Aman Laboratory to assess the physicochemical characteristics of groundwater in the study area. A set of chemical and physical analyses was performed, including Total Dissolved Solids (TDS), pH, Total Hardness (TH), nitrate (NO_3^-), sulfate (SO_4^{2-}), calcium (Ca^{2+}), and magnesium (Mg^{2+}). To determine the spatial variation of groundwater quality properties in the study area, spatial distribution maps were generated in ArcMap 10.4 using the Interpolation tool based on the Inverse Distance Weighting (IDW) method.

Table (2): Sample locations in the study area

No	Location	Coordinates	
		North	East
1	Al-Mukhtar	32° 5′ 5″	23° 56′ 40″
2	Al-Hattia	32° 4′ 5″	23° 57′ 19″
3	Al-Zaqam	32° 5′ 15″	23° 59′ 49″
4	Al-Andalusia	32° 6′ 0″	23° 57′ 11″
5	Al-Jubaylah Al-Sharqiya	32° 5′ 9″	23° 58′ 4″
6	Al-qudus	32° 5′ 12″	23° 54′ 12″
7	Al-Manara	32° 4′ 55″	23° 59′ 27″
8	Al-Zuhur	32° 4′ 52″	23° 55′ 17″
9	Al-Hada'iq	32° 5′ 34″	23° 55′ 9″
10	Al-Hurriya	32° 4′ 15″	23° 56′ 21″

3. Results and Discussions

Deterioration of groundwater quality has several causes, including natural ones. Some impurities occur in water naturally due to the melting parts of rocks in water. In other words, the chemical characteristics of water change as it percolates through soil pores into the aquifers. Consequently, the water's mineral content may increase, leading to its classification as contaminated water. Pollution of this source will change the water's physical and microbial quality as well, rendering it unsuitable for various uses when the amount of dissolved minerals increases. Increased concentrations of certain minerals, such as iron and sulfates, can cause some adverse effects (Hashem, 2005)

The chemical properties of water are important factors to be considered; before it is used for domestic, agricultural or industrial purposes (Elgali 2013). The groundwater analysis results for the study area, as presented in Table 3, reveal that the concentrations of most examined parameters exceed the limits specified by the Libyan drinking water standards, with the notable exception of pH, which remains within the acceptable range. These findings suggest a significant deviation from the recommended guidelines for several water quality indicators, highlighting potential concerns for the suitability of groundwater for drinking purposes in the study area.

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Table (3): Characteristics of groundwater in the study area

Parameters		TDS	Ph	TH	NO_3	Ca	Mg	SO4
Permissible limit *		1200 ppm	6.5- 8.5	500 mg/l	50 mg/l	200 mg/l	150 mg/l	250 mg/l
Samples	1	10260	7.7	1828	641	1539	289	832
	2	6890	7.6	1227	429	1034	194	577
	3	12420	7.7	2212	776	1863	349	996
	4	10420	7.5	1858	651	1564	293	845
	5	7910	7.7	1409	493	1187	222	654
	6	5700	7.8	1015	355	855	160	487
	7	9510	7.9	1694	594	1427	267	776
	8	3980	7.9	709	247	597	112	357
	9	10920	7.7	1945	682	1638	307	882
	10	5950	7.6	1060	370	893	167	506

Source: Al-Aman Laboratory for Chemical Analysis and Consultations. (December 2024). Groundwater analysis results for the study area (Tobruk, Libya.

*The Libyan National Center for Standard and Specifications.2008 (as cited in Al-Ashhab et al., 2019)

Total Dissolved Solids (TDS)

This refers to the combined concentration of all dissolved minerals and salts in water as it percolates through soil and rocks. The results showed that TDS values exceeded the permissible limit according to Libyan standards in all samples; see table (2) and Figure (2), the values ranging from 12,420 ppm in well number 3 to 3,980 ppm in well number 8. The spatial distribution map (Figure 3) indicates that the highest TDS values are concentrated in the Al-Zaqam area in the northern part of the study area, likely due to its proximity to the sea.

Potential of Hydrogen (pH)

It refers to the acidity level in groundwater, usually ranging between 6.5-8.5 according to Libyan specifications shown in table (2), but it may vary depending on the nature of the soil and rocks with which the water interacts. The water in the study area is neutral in all studied wells, as the study results showed that the pH values ranged between 7.5-7.9. It was also observed that the highest pH values are concentrated in Al-Zuhour district in sample number (8) in Al-Zuhour district, while the lowest value was represented in sample number (4) in Al-Andalus district, (Figures 4, and 5).

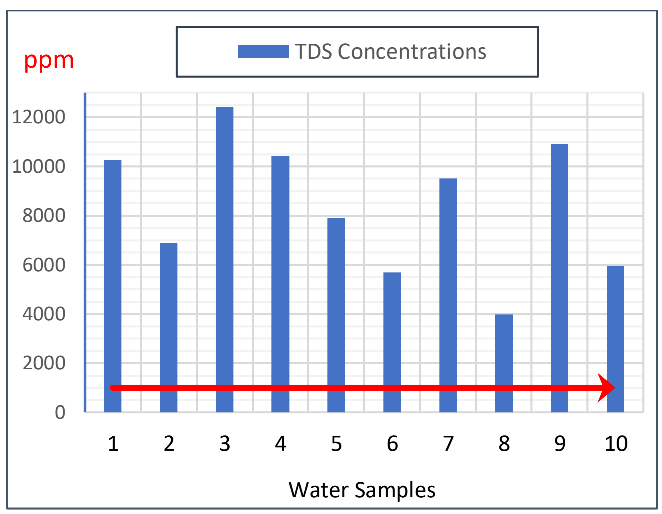

Figure (2) TDS values for water samples in the study area

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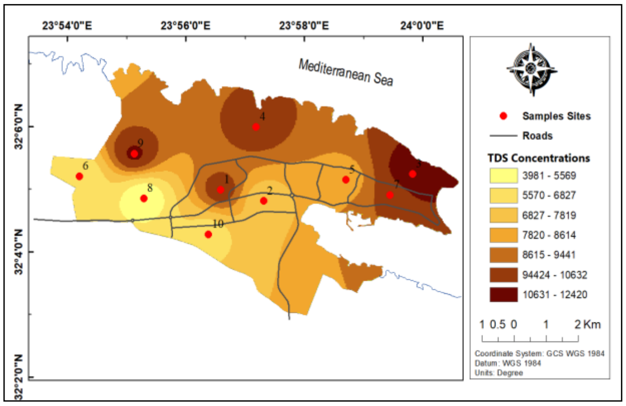

Figure (3) spatial variation of TDS concentration

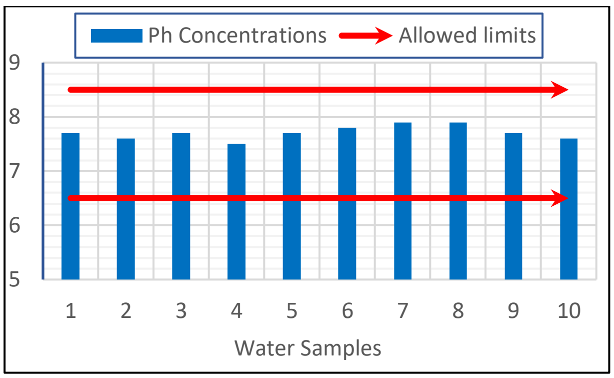

Figure (4) PH values for water samples in the study area

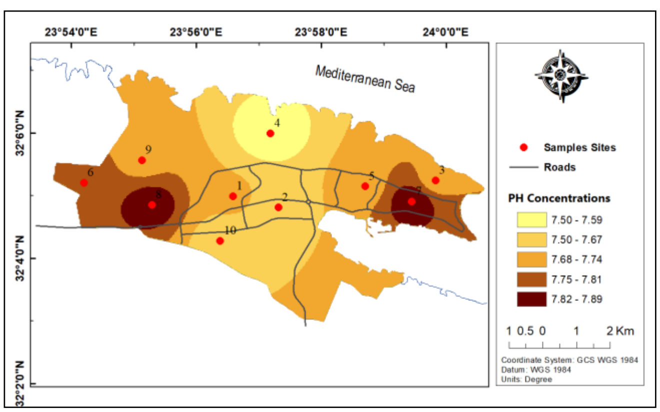

Figure (5) spatial variation of PH concentration

The total hardness (TH)

TH of the water was high in all the wells included in the study and exceeded the permissible standard limits Libyan specifications shown in table (2). Figure (6) indicates that the highest value of TH reached 2212 mg/L in well No. (3) and 1945 mg/L in well No. (9), while the lowest value was recorded in well number (8) in Al-Zuhour district, amounting to 709 mg/L. Regarding the spatial distribution of total hardness (TH), the highest concentration was found in the Al-Zaqm district, northeast of the study area, while the lowest value was concentrated in its southeast, Figure (7). These variations in total hardness are strongly influenced by the underlying geological formations. Carbonate-rich sedimentary rocks, including limestone and dolomite, which contribute high concentrations of calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions to the groundwater dominate the study area.

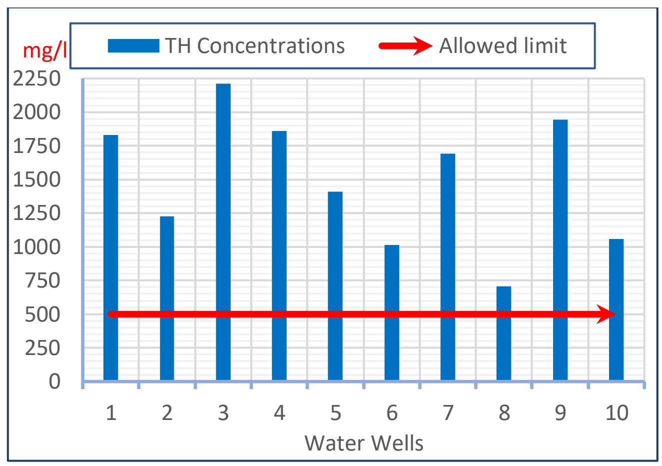

Figure (6) T.H values for water samples in the study area

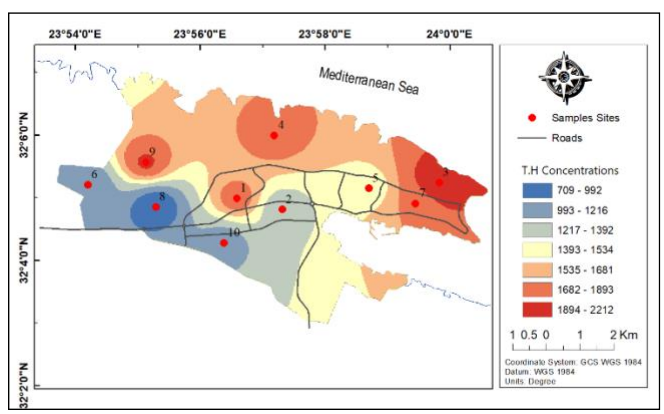

Figure (7) spatial variation of T.H concentration

Calcium (Ca)

Dissolved calcium ions in groundwater primarily originate from the chemical weathering and dissolution of carbonate rocks, particularly limestone and dolomite (Drever, 1979). The results of this study indicate that calcium concentrations in all sampled wells exceeded the permissible limits for drinking water according to the Libyan specifications (Table 2). Calcium values ranged from a maximum of 1863 mg/L in well No. (3) to a minimum of 597 mg/L in well No. (8), as illustrated in Figure (8). The spatial distribution map (Figure 9) reveals that the highest calcium concentrations are concentrated in the Al-Zaqm neighborhood, located in the northeastern part of the study area, with a gradual decrease toward the southeast. This spatial variation is closely associated with the geological setting of the area, which is dominated by carbonate-rich formations, including limestone and dolomitic rocks belonging mainly to the Tertiary formations.

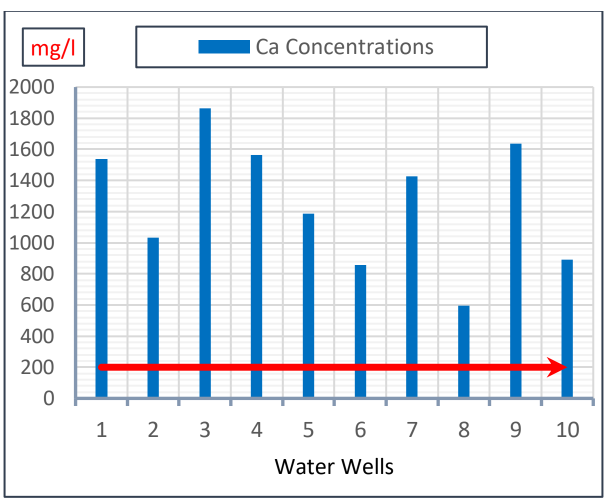

Figure (8) Ca values for water samples in the study area

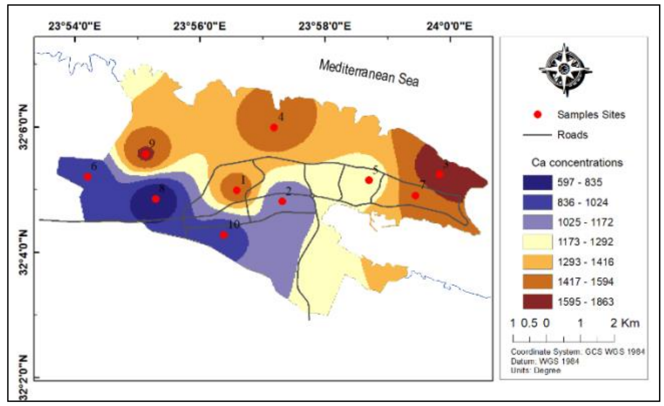

Figure (9) spatial variation of Ca concentration

Magnesium (Mg)

Magnesium is a naturally abundant element and an essential nutrient for humans; it also represents the second major contributor to total water hardness after calcium (Elgali, 2013). The results of the present study show that magnesium concentrations in groundwater varied between 349 mg/L in well No. (3), located in the northeastern part of the study area, and 112 mg/L in well No. (8) in the southwestern part, as illustrated in Figures (10) and (11). According to the Libyan drinking water specifications (Table 2), only the water from well No. (8) complied with the permissible limit of 150 mg/L, while the remaining wells exceeded this threshold. The elevated magnesium concentrations observed in the northeastern sector are closely linked to the geological formations prevailing in the area, which are dominated by dolomitic limestone and dolomite-rich units belonging mainly to the Tertiary formations. The dissolution of these magnesium-bearing carbonate rocks significantly enhances Mg^{2+} levels in groundwater.

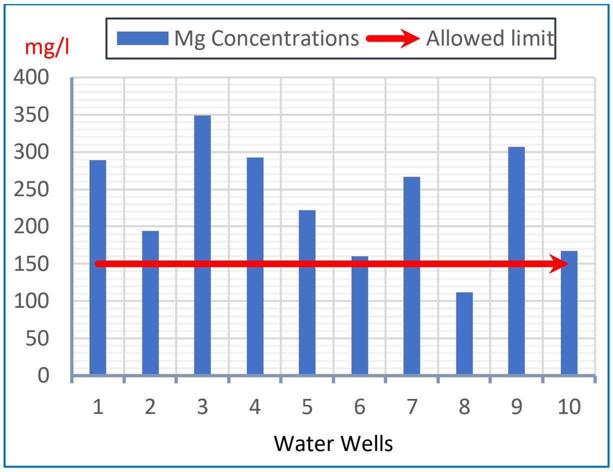

Figure (10) Mg values for water samples in the study area

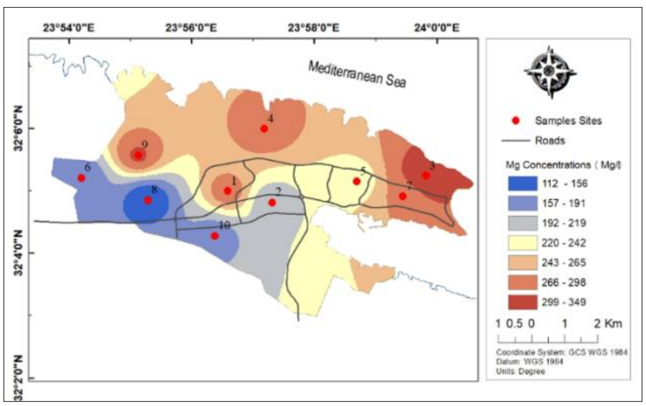

Figure (11) spatial variation of Mg concentration

Nitrates (NO3): The presence of nitrate ions in groundwater is an indicator of its contamination. Increased concentrations in water are linked to the presence of nitrogenous sources on the Earth's surface or in the shallow subsurface, such as sewage, agricultural processes involving fertilizers and waste, and some industrial activities. In this regard, the results revealed that nitrate concentrations in the study area exceeded the permissible limit of Libyan specifications shown in table (2), with the highest nitrate values reaching (776 mg/L) in well number (3) and (682 mg/L) in well number (9), while the lowest value was approximately (247 mg/L) in well number (8), as shown in Figure (12). Through the spatial variation map in Figure (13), we observe that the highest nitrate values are concentrated in the northwest and north-northwest of the study area, while decreasing in the south.

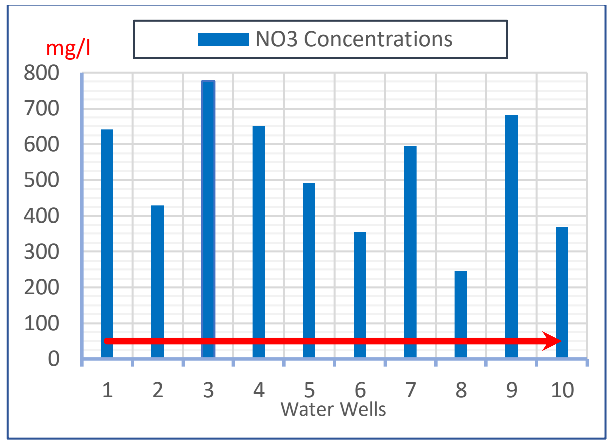

Figure (12) NO3 values for water samples in the study area

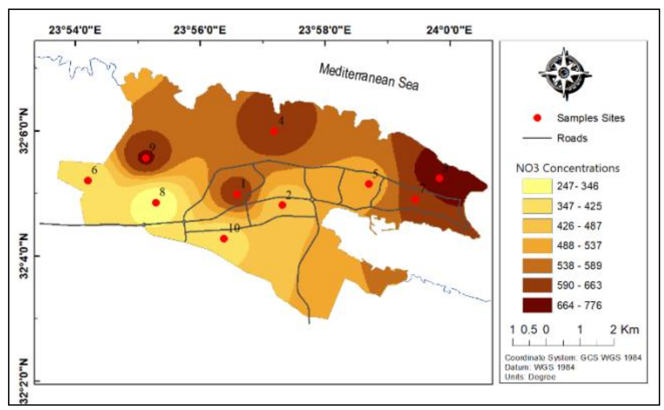

Figure (13) spatial variation of NO3 concentration

Sulfates (SO4): Sulfates are commonly present in groundwater due to the dissolution of sulfate-rich rocks and minerals, or because of human activities such as industrial and agricultural sewage. Concentrations exceeding the permissible limit of Libyan specifications shown in table (2), can impart a bitter or salty taste to the water (WHO, 2017 & Sharma, & Kumar, 2020). The results indicate that all the studied well water samples exceeded the permissible limit for sulfate concentrations, ranging between 357 and 996 mg/L, as shown in Figure (14). The spatial distribution, shown in Figure (15), indicates that the highest values are concentrated in the northeast of the study area, decreasing slightly in the south and southwest.

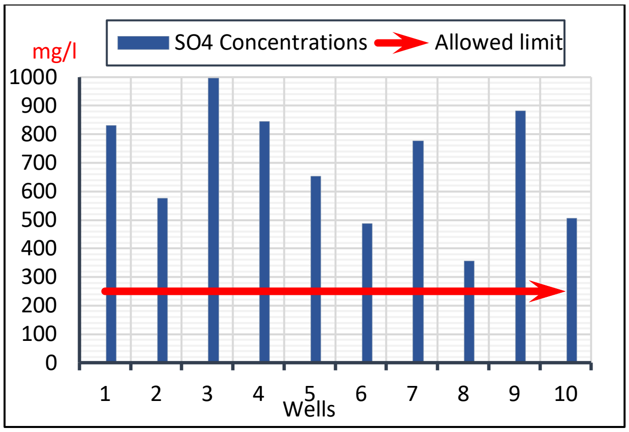

Figure (14) SO4 values for water samples in the study area

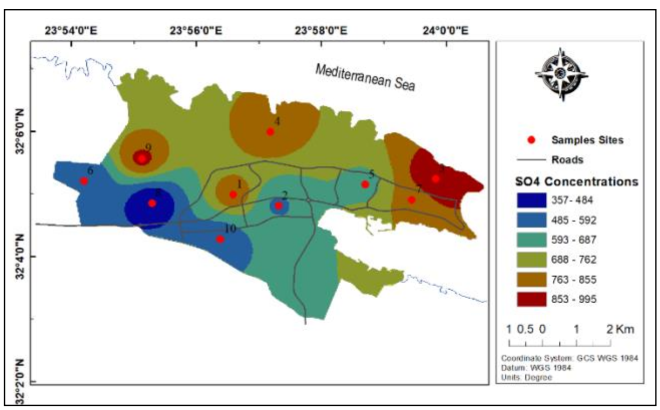

Figure (15) spatial variation of SO4 concentration

4. Conclusion

The findings of this research indicate that groundwater in the city of Tobruk is of poor quality. The analyses revealed that most elements exceed the permissible limits set by drinking water standards, providing clear evidence of significant water quality deterioration. These results emphasize the urgent need to adopt effective strategies for managing water resources in Tobruk, including continuous monitoring, regulating water use, and mitigating pollution sources. Furthermore, this study highlights the importance of promoting the wider application of this assessment methodology, given that groundwater is the primary source of freshwater in the study area, making its protection essential for safeguarding both human health and environmental sustainability.

5. Recommendations

Based on the findings, this study recommends the following:

1. Establishing a periodic monitoring system for groundwater quality in Tobruk, including chemical, physical, and biological analyses, to track changes and identify potential sources of contamination.
2. Enforcing environmental laws and implementing strict measures to reduce the uncontrolled discharge of wastewater and industrial waste, particularly in areas close to groundwater sources.
3. Utilizing advanced technologies such as Geographic Information Systems (GIS) and remote sensing to develop accurate maps of well distribution and pollution zones, thereby enhancing water management.
4. Expanding hydrological and geological studies to better understand groundwater movement and the geological characteristics of aquifers, which will contribute to data-driven decision-making.
5. It is strongly recommended to immediately suspend the use of the most highly contaminated wells, in order to protect

public health and prevent further exposure to unsafe drinking water.

Conflict of Interest:

The authors declare no conflict of interest.

Declaration of AI Use

The authors declare that AI tools (e.g., ChatGPT) were used for linguistic assistance and searching for related references. The authors also confirm that no AI tools were used for data collection, analysis, discussion, or conclusions.

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https://doi.org/10.36602/faj.2026.n21.07

التقييم المكاني لجودة المياه الجوفية لأغراض الشرب في مدينة طبرق، ليبيا

جمعة أرحومة الجالي *[1] آلاء عاشور خميس[2]

[1، 2] قسم الجغرافيا، كلية الآداب، جامعة طبرق، ليبيا

*Jumma.elgali@tu.edu.ly

تاريخ التقديم :06-01-2026 تاريخ القبول :11 -02-2026 نشر إلكترونيا في: 12-02-2026

ملخص البحث:

تهدف هذه الدراسة إلى تقييم جودة المياه الجوفية في مدينة طبرق من خلال تحليل خصائصها الفيزيائية والكيميائية، من أجل تحديد مدى صلاحيتها للشرب وفقًا لمعايير مياه الشرب المعتمدة. تم جمع وتحليل عشر عينات من المياه الجوفية للمعايير التالية: الأملاح الكلية الذائبة، الأس الهيدروجيني، العسرة الكلية، الكالسيوم، -النترات، الماغنسيوم والكبريتات. كما تم استخدام تقنية نظم المعلومات الجغرافية (GIS) لتحليل وتوضيح التوزيع المكاني لجودة المياه الجوفية. أشارت النتائج إلى أن جودة المياه الجوفية في منطقة الدراسة رديئة إلى حد كبير ولا تعد ملائمة لأغراض الشرب، فقد كشفت تحاليل خصائص المياه أن معظم المعايير قد تجاوزت الحدود المسموح بها وفقًا لمعايير مياه الشرب الليبية والعالمية، كما أوضحت خرائط التوزيع المكاني أن جودة المياه في الأجزاء الشمالية والشمالية الشرقية في منطقة الدراسة كانت أقل جودة من الأجزاء الجنوبية.

الكلمات المفتاحية: *خصائص المياه، تقييم جودة المياه الجوفية، التحليل المكاني، مياه الشرب.*