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Groundwater Quality Assessment in Western Libya: Spotlight on Nitrate, Nitrites and Public Health Risks

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ABSTRACT

Groundwater is the primary source of drinking water in Libya, especially in arid regions where surface water is scarce. However, increasing agricultural activities and poor environmental regulations have contributed to groundwater contamination, particularly by nitrates. This study evaluated the physicochemical properties of groundwater from four regions in western Libya—Janzour, Ain Zara, Gharyan, and the Artificial River—focusing on nitrate and nitrite levels due to their significant health risks. Water samples were collected and analyzed using standard methods for parameters such as pH, electrical conductivity, total hardness, and nutrient pollutants. Results showed that while samples from Ain Zara and Janzour met national standards, the Gharyan sample exhibited alarmingly high nitrate (111 mg/L), total hardness (780 mg/L), and electrical conductivity (1720 µS/cm), exceeding Libyan and WHO guidelines. Nitrite was not detected in any sample. Elevated nitrate levels pose a serious health threat, particularly to infants and pregnant women, due to risks of methemoglobinemia and carcinogenic nitrosamine formation. The findings underscore the urgent need for enhanced water monitoring, public education on fertilizer use, and implementation of treatment technologies. This study provides evidence-based recommendations to guide policymakers in safeguarding groundwater quality and protecting public health in Libya.

Introduction

Water is an indispensable element for the survival of all forms of life and represents a critical natural resource for ecosystems, agriculture, and human health. In the human body, water accounts for 60–70% of body mass and plays vital physiological roles, including thermoregulation, nutrient transport, tissue hydration, and waste elimination through renal and excretory systems [1,2]. Even slight dehydration, such as a 10% fluid deficit, can cause cognitive and functional impairments, while a 20% loss may be fatal [3]. Therefore, understanding the sources, quality, and potential contaminants of water is essential for protecting public health and ensuring safe water supplies. Water molecules (H2O), composed of two hydrogen atoms and one oxygen atom, possess a polar configuration that gives rise to unique physical properties. These include a high specific heat capacity, surface tension, and its role as a universal solvent—qualities that support biological processes and environmental equilibrium [4]. On Earth, water covers nearly 71% of the surface and exists in various forms: liquid in rivers and lakes, vapor in the atmosphere, and ice in polar regions [5]. The hydrological cycle continuously redistributes water through evaporation, condensation, and precipitation, impacting water availability and quality across regions.

Water resources are typically classified into rainwater, surface water, and groundwater. Rainwater, although initially pure, can absorb atmospheric pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon dioxide (CO_2), forming weak acids that reduce its quality, especially in urban and industrial zones [6,7]. Surface water includes rivers, lakes, and seas. While freshwater rivers serve as major sources of drinking water, they are susceptible to contamination from urban runoff, industrial discharges, and agricultural activities [8]. Seawater, due to its high salinity, requires desalination before human consumption. Groundwater—water stored in aquifers beneath the Earth's surface—constitutes a major water source in arid and semi-arid regions, including Libya. It is generally clearer and more protected from surface contamination, although it may still contain high levels of dissolved salts or naturally occurring minerals such as fluoride or arsenic [9,10]. In Libya, where rainfall is limited and rivers are scarce, groundwater accessed via wells is a critical resource for domestic and agricultural use [11].

Water pollution occurs when physical, chemical, or biological substances degrade water quality, rendering it unsafe for consumption or ecosystem support. The World Health Organization (WHO) defines water pollution as any anthropogenic or natural alteration in water quality that limits its intended use [12]. Pollutants can be broadly classified into chemical (e.g., heavy metals, pesticides, nitrates), biological (e.g., bacteria, viruses), and physical (e.g., sediments, microplastics) contaminants [13]. Among the most concerning pollutants are nitrate (NO_3) and nitrite (NO_2), which enter water sources primarily through agricultural runoff, septic systems, and wastewater discharges [14]. Nitrate is frequently used in fertilizers

and is relatively stable in water. However, once ingested, it may convert to nitrite, especially in infants, which can react with hemoglobin to form methemoglobin, impairing oxygen transport—a condition known as methemoglobinemia or "blue baby syndrome" [15,16]. In addition, nitrites may form carcinogenic N-nitroso compounds in the acidic environment of the stomach, posing long-term cancer risks, particularly gastrointestinal malignancies [17,18]. Vulnerable populations include infants under six months, pregnant women, and individuals with low gastric acidity [19]. As such, WHO guidelines set maximum allowable concentrations for nitrate and nitrite in drinking water at 50 mg/L and 3 mg/L, respectively [20].

In Libya, the dependence on groundwater is increasing due to water scarcity and limited rainfall. Unfortunately, this has coincided with inadequate waste management, overuse of nitrogen-based fertilizers, and unregulated agricultural activities, leading to significant nitrate contamination in many regions [21]. The sandy and porous soils common in parts of western Libya allow nitrates to leach easily into aquifers, increasing the health risk to communities dependent on well water [22]. Studies have indicated that nitrate concentrations in Libyan groundwater frequently exceed both WHO and national standards, particularly in agricultural zones like Janzour, Gharyan, and Ain Zara [23]. These exceedances reflect poor enforcement of environmental policies, limited monitoring infrastructure, and a lack of awareness regarding fertilizer use and its implications on drinking water [24]. By evaluating physicochemical and nutrient parameters of groundwater sources, this research offers valuable insights for policymakers and environmental agencies in developing water management strategies, enhancing monitoring systems, and promoting safe agricultural practices. The current study aims to assess the quality of groundwater sources in western Libya by determining the levels of nitrate and nitrite contamination in selected wells. These findings will be compared against Libyan standard specifications and WHO benchmarks to identify potential risks to public health. This study also aligns with Sustainable Development Goal 6 (SDG 6), which advocates for universal access to clean water and improved sanitation [25].

Materials and Methods
Study Sites and Sample Collection
This study was conducted in four regions of western Libya: Janzour, Ain Zara, Gharyan, and the Artificial River area. These sites were selected based on their reliance on groundwater and proximity to agricultural activities. In August 2024, water samples were collected from wells with varying depths and ages (Table 1). Prior to sample collection, each well was pumped continuously for 30 minutes to purge stagnant water and obtain representative samples. All samples were collected in pre-cleaned polyethylene bottles. The containers were rinsed thrice with the same well water before filling to minimize cross-contamination. Immediately after collection, samples were transported in cool, insulated boxes to the Petroleum Research Center Laboratory at the Tourism Headquarters for physicochemical analysis.

Table 1. Characteristics of Sampled Wells

Sample No.	Location	Well Depth	Estimated Age	Collection Date
1	Janzour	120 m	15 years	2024-08-11
2	Artificial River	Unknown	40 years	2024-08-11
3	Ain Zara	102 m	18 years	2024-08-11
4	Gharyan	3 m	~1200 years	2024-08-11

Parameters Measured
Water samples were analyzed for physicochemical parameters (pH, electrical conductivity, turbidity, total hardness) and major ions including Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, SO_4^{2-}, and CO_3^{2-}. Nutrient pollutants such as nitrate (NO_3^-) and nitrite (NO_2^-) were prioritized due to their potential health risks. All concentrations were expressed in mg/L, while trace elements were reported in µg/L. Analytical accuracy was ensured through calibration and adherence to APHA standard methods.

Analytical Tools and Instrumentation
A pH meter was employed to determine the hydrogen ion activity of the tested solutions, providing a quantitative measure of acidity or alkalinity on a scale ranging from 0 to 14. Ionic content was evaluated using a Jenway 4310 conductivity meter, which measures electrical conductivity as an indicator of dissolved ions. Colorimetric analysis of nitrates and nitrites was performed using a DR 5000 UV–Visible spectrophotometer (Hach, USA), equipped with a dual-lamp system consisting of deuterium and tungsten sources and capable of operating across a wavelength range of 190–1100 nm.

Chemical Analysis Techniques
Acid–base titration was performed using sodium carbonate and hydrochloric acid, with methyl orange and phenolphthalein serving as the indicators. Chloride ion concentration was determined through precipitation

titration using silver nitrate, with potassium chromate employed as the indicator. Total hardness was assessed by complexometric titration with EDTA, using Eriochrome Black T as the colorimetric indicator.

Quality Assurance and Control
All instruments were calibrated before use with certified standards. Triplicate measurements were performed, and blank controls were included to ensure accuracy. All procedures complied with laboratory quality assurance protocols to minimize analytical and sampling errors.

Results
Libyan Standard Specifications for Drinking Water
The Libyan standards define the acceptable ranges for physical and chemical characteristics of drinking water. The optimum and maximum limits serve as benchmarks to assess water safety and quality. Parameters such as nitrate, nitrite, Total Dissolved Solids (TDS), hardness, and electrical conductivity are tightly regulated due to their health implications. This table serves as a reference to compare the results of samples from selected regions.

Table 2. Libyan Standard Specifications for Drinking Water

Article	Optimum Limit (mg/L)	Maximum Limit (mg/L)
Electric conductivity	1000	1500
pH	6.5	8.5
Bicarbonate	200	250
Sodium	100	200
Potassium	5	10
Sulphate	25	250
Nitrite	0.02	0.1
Nitrate	30	50
Turbidity	1	5
T.D.S	500	1000
Total Hardness	200	500
Ca^{2+}	50	75
Mg^{2+}	200	250

T.D.S: Total Dissolved Solids. ND: Not Detected (below the method detection limit)

Janzour Water Sample Analysis
The water sample from Janzour meets the Libyan standards for most parameters. Nitrate concentration is at the maximum permissible level (50 mg/L), which raises concern for long-term use. The TDS, electrical conductivity, and hardness are within acceptable limits, indicating general potability. Nitrite was not detected. Calcium and magnesium levels are moderate.

Table 3. Results of the Janzour Water Sample Analysis

Test	Range	Result	Unit	Test Method
Electric conductivity	(1500–1000)	1482	µS/cm	ASTM D-1125
pH	(8.5–6.5)	6.7	-	pH Meter
Bicarbonate	(250–200)	157	mg/L	ASTM D-1067
Sodium	(200–100)	130	mg/L	ASTM D-2791
Potassium	(10–5)	8	mg/L	ASTM D-2791
Sulphate	(250–25)	130	mg/L	DR 5000
Nitrite	(0.1–0.02)	ND	mg/L	DR 5000
Nitrate	(50–30)	50	mg/L	DR 5000
Turbidity	(5–1)	0.11	NTU	Turbidity Meter
T.D.S	(1000–500)	983	mg/L	Calculated
Total Hardness	(500–200)	442	mg/L	EDTA Titration
Ca^{2+}	(75–50)	56	mg/L	EDTA Titration
Mg^{2+}	(250–200)	33.6	mg/L	EDTA Titration

T.D.S: Total Dissolved Solids. ND: Not Detected (below the method detection limit)

Artificial River Water Sample Analysis
The Artificial River sample closely resembles the Janzour results in quality. The nitrate level slightly exceeds the permissible limit (50.4 mg/L), warranting monitoring. TDS and electrical conductivity are high but still

within the maximum allowable range. All other parameters, including nitrite, turbidity, and pH, are satisfactory. Water quality remains acceptable for use.

Table 4. Results of the Artificial River Water Sample Analysis

Test	Range	Result	Unit	Test Method
Electric conductivity	(1500–1000)	1486	µS/cm	ASTM D-1125
pH	(8.5–6.5)	6.9	-	pH Meter
Bicarbonate	(250–200)	161	mg/L	ASTM D-1067
Sodium	(200–100)	132	mg/L	ASTM D-2791
Potassium	(10–5)	7	mg/L	ASTM D-2791
Sulphate	(250–25)	140	mg/L	DR 5000
Nitrite	(0.1–0.02)	ND	mg/L	DR 5000
Nitrate	(50–30)	50.4	mg/L	DR 5000
Turbidity	(5–1)	0.01	NTU	Turbidity Meter
T.D.S	(1000–500)	965	mg/L	Calculated
Total Hardness	(500–200)	422.4	mg/L	EDTA Titration
Ca^{2+}	(75–50)	51.2	mg/L	EDTA Titration
Mg^{2+}	(250–200)	30.7	mg/L	EDTA Titration

T.D.S: Total Dissolved Solids. ND: Not Detected (below the method detection limit)

Ain Zara Water Sample Analysis

The Ain Zara sample reflects superior water quality compared to other sites. Nitrate concentration is significantly below the maximum limit (24.7 mg/L), and TDS is also low (307 mg/L), indicating minimal contamination. Hardness and sodium levels are within optimal values. All tested parameters meet the Libyan standards, making it a safe drinking water source.

Table 5. Results of the Ain Zara Water Sample Analysis

Test	Range	Result	Unit	Test Method
Electric conductivity	(1500–1000)	417	µS/cm	ASTM D-1125
pH	(8.5–6.5)	7.25	-	pH Meter
Bicarbonate	(250–200)	104	mg/L	ASTM D-1067
Sodium	(200–100)	28	mg/L	ASTM D-2791
Potassium	(10–5)	8	mg/L	ASTM D-2791
Sulphate	(250–25)	54	mg/L	DR 5000
Nitrite	(0.1–0.02)	ND	mg/L	DR 5000
Nitrate	(50–30)	24.7	mg/L	DR 5000
Turbidity	(5–1)	0.08	NTU	Turbidity Meter
T.D.S	(1000–500)	307	mg/L	Calculated
Total Hardness	(500–200)	214.4	mg/L	EDTA Titration
Ca^{2+}	(75–50)	28.8	mg/L	EDTA Titration
Mg^{2+}	(250–200)	17.8	mg/L	EDTA Titration

T.D.S: Total Dissolved Solids. ND: Not Detected (below the method detection limit)

Gharyan Water Sample Analysis

Unlike other regions, the Gharyan sample exceeds the Libyan standards for nitrate (111 mg/L), total hardness (780 mg/L), and electrical conductivity (1720 µS/cm). These values suggest significant contamination, possibly from agricultural runoff or geological sources. Such concentrations pose health risks, especially to infants and pregnant women. Treatment is necessary before consumption.

Table 6. Results of the Gharyan Water Sample Analysis

Test	Range	Result	Unit	Test Method
Electric conductivity	(1500–1000)	1720	µS/cm	ASTM D-1125
pH	(8.5–6.5)	7.08	-	pH Meter
Bicarbonate	(250–200)	110	mg/L	ASTM D-1067
Sodium	(200–100)	120	mg/L	ASTM D-2791
Potassium	(10–5)	7	mg/L	ASTM D-2791
Sulphate	(250–25)	34	mg/L	DR 5000
Nitrite	(0.1–0.02)	ND	mg/L	DR 5000
Nitrate	(50–30)	111	mg/L	DR 5000

Turbidity	(5–1)	0.31	NTU	Turbidity Meter
T.D.S	(1000–500)	980	mg/L	Calculated
Total Hardness	(500–200)	780	mg/L	EDTA Titration
Ca^{2+}	(75–50)	26.4	mg/L	EDTA Titration
Mg^{2+}	(250–200)	158.4	mg/L	EDTA Titration

T.D.S: Total Dissolved Solids. ND: Not Detected (below the method detection limit)

Discussion

This study aimed to evaluate the chemical quality of groundwater samples from various Libyan regions, with a particular focus on nitrate and nitrite concentrations due to their established risks to public health. Groundwater remains a major source of drinking water in many arid regions, including Libya, and its quality is subject to both natural geochemical processes and anthropogenic influences such as agriculture and waste disposal [26,27]. The chemical properties analyzed in this research—such as electrical conductivity, pH, bicarbonate, sodium, potassium, sulfate, nitrate, nitrite, TDS (Total Dissolved Solids), and total hardness—provide essential indicators of water potability and potential health hazards. These parameters were evaluated in reference to Libyan drinking water standards (No. 82/1992), which set optimal and maximum permissible limits for each component [28].

The findings revealed that most samples, including those from Janzour, Ain Zara, and the Artificial River, fell within acceptable limits. However, the Gharyan sample displayed significant deviations. Specifically, it contained a nitrate concentration of 111 mg/L, more than double the allowable threshold of 50 mg/L, and similarly exceeded limits for TDS and total hardness, which were measured at 980 mg/L and 780 mg/L, respectively. These elevated levels of nitrate are concerning as they are linked to methemoglobinemia (blue baby syndrome), a condition in which nitrate impairs oxygen transport in infants by converting hemoglobin to methemoglobin [15,29]. Additionally, nitrate may act as a precursor to nitrosamines—compounds formed in the acidic environment of the stomach—that have been implicated in various cancers [30,31]. These findings are consistent with previous studies conducted in other arid and semi-arid regions, such as those by Parvizishad et al., which documented similar nitrate contamination trends in groundwater used for drinking and agriculture [32].

While nitrite was not detected in any of the samples, this does not necessarily rule out its presence, as nitrite is often transient and readily oxidized to nitrate in oxygen-rich aquifers. The inability to detect nitrite might also reflect analytical limitations or temporal sampling variability. It is critical to enhance the sensitivity of testing methods for accurate risk assessment. The high TDS levels observed in Gharyan can influence water taste, cause scaling in pipes, and increase turbidity, potentially signaling the presence of suspended solids or pollutants. Elevated total hardness, in turn, is known to contribute to plumbing system degradation and skin irritation upon contact, especially in vulnerable populations [27].

Conclusion

This study highlights the chemical variability of groundwater sources in Libya, with most samples falling within safe limits as per national standards, except for the Gharyan region. Elevated levels of nitrate, TDS, and total hardness in this region present clear health and infrastructural risks. Nitrate contamination, in particular, poses a significant threat to infant health and may contribute to long-term carcinogenic outcomes. Although nitrite levels were undetectable, further refined testing is necessary. Overall, the study underscores the urgent need for comprehensive water quality monitoring, sustainable water management, and public health intervention strategies to ensure safe drinking water across Libya.

Conflict of interest. Nil

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