Libyan Open University Journal of Applied Sciences (LOUJAS)
Volume 2 - Issue 2 - 2026 - Pages 104-119

Groundwater Pollution in Libya: Sources, Environmental and Health Impacts, Prevention and Remediation Strategies

Nuri Salem Alnaass [1]*, Osama Asanousi Lamma [2], Amna Ali Alhadad[3]
[1] Department of Environment and Natural Resources, Faculty of Agriculture, University of Azzaytuna, Libya.
[2]Department of Soil and Water, Faculty of Agriculture, Bani Waleed University, Libya.
[3]Department of Biology, Faculty of Education, Bani Waleed University, Libya.
*Email for reference researcher: n.alnaass@azu.edu.ly

تلوث المياه الجوفية في ليبيا: المصادر، والآثار البيئية والصحية، واستراتيجيات الوقاية والمعالجة

نوري سالم النعاس*[1]، أسامه السنوسي لامه [2]، آمنة علي الحداد[3]
[1] قسم البيئة والموارد الطبيعية، كلية الزراعة، جامعة الزيتونة، ليبيا.
[2] قسم التربة والمياه ، كلية الزراعة ، جامعة بني وليد ، ليبيا.
[3]قسم الأحياء، كلية التربية، جامعة بني وليد، ليبيا

Received: 15-05-2026; Accepted: 15-07--2026; Published: 19-07-2026

Abstract

Libya's arid climate and lack of surface water resources make groundwater the most valuable freshwater resource. Groundwater supplies domestic, agricultural and industrial uses. But, due to the higher pressure on the ground, the intensive agricultural activity, poor wastewater management, poor solid waste management and the intrusion of seawater, the groundwater is exposed to a high risk. This review summarizes the main sources of groundwater pollution in Libya, reviews the chemical contaminants, biological contaminants and emerging contaminants and discusses their environmental and public health impacts. The study is founded on scientific literature review, groundwater quality assessment and international water quality guidelines. Salinity, TDS, nitrate pollution, microbial pollution, and heavy metals have been mentioned in different Libyan regions as concerns in the past. To achieve effective protection of groundwater, integrated monitoring programs, sustainable water management, prevention of pollution and use of suitable remediation technologies are necessary. The current review clearly indicates the necessity for comprehensive groundwater quality assessment and long term protection plan in Libya.

Keywords: Groundwater pollution; Libya; Aquifer quality; Nitrate contamination; Salinity; Heavy metals; Water remediation

الملخص

يُعدّ مناخ ليبيا الجاف ونقص موارد المياه السطحية من أهم العوامل التي تجعل المياه الجوفية أثمن موارد المياه العذبة. تُستخدم المياه الجوفية في الاستخدامات المنزلية والزراعية والصناعية. إلا أنه نتيجةً للضغط المتزايد على سطح الأرض، والنشاط الزراعي المكثف، وسوء إدارة مياه الصرف الصحي، وسوء إدارة النفايات الصلبة، وتداخل مياه البحر، تتعرض المياه الجوفية لمخاطر جسيمة. تُقدّم هذه الدراسة ملخصًا لأهم مصادر تلوث المياه الجوفية في ليبيا، وتستعرض الملوثات الكيميائية والبيولوجية والناشئة، وتناقش آثارها على البيئة والصحة العامة. تستند الدراسة إلى مراجعة الأدبيات العلمية، وتقييم جودة المياه الجوفية، والمبادئ التوجيهية الدولية لجودة المياه. وقد ذُكرت الملوحة، والمواد الصلبة الذائبة الكلية، وتلوث النترات، والتلوث الميكروبي، والمعادن الثقيلة في مناطق ليبية مختلفة كمصادر قلق في السابق. ولتحقيق حماية فعّالة للمياه الجوفية، لا بد من وجود برامج رصد متكاملة، وإدارة مستدامة للمياه، ومنع التلوث، واستخدام تقنيات معالجة مناسبة. تُشير هذه الدراسة بوضوح إلى ضرورة إجراء تقييم شامل لجودة المياه الجوفية ووضع خطة حماية طويلة الأجل في ليبيا.

الكلمات المفتاحية: تلوث المياه الجوفية؛ ليبيا؛ جودة الخزان الجوفي؛ تلوث النترات؛ الملوحة؛ المعادن الثقيلة؛ معالجة المياه.

1. Introduction

Groundwater is a vital part of global freshwater resources, and essential for supporting human societies, agriculture, industry, and ecosystem stability. Groundwater is the primary source of drinking water for about half of the world's population, especially for areas with limited or unreliable surface water supplies. Groundwater reservoirs have some natural storage capacity, are relatively insensitive to short-term fluctuations in climate, but are highly susceptible to long-term contamination, since contaminating substances can remain in aquifer systems for long periods, and action to remove the contaminants may be technically challenging and expensive. (Lamma, 2021b)

Where the annual amounts of precipitation are low, evaporation rates are high, and there are no permanent lakes or rivers, groundwater can serve as a key source of water in arid and semi-arid environments. Such environmental conditions increase dependency on groundwater reserves in the earth and bring sustainable groundwater management to the forefront as a major challenge (Mohammad et al., 2015b). Over-drafting groundwater, overdraining by natural recharge and greater human activity can cause deterioration of groundwater quality and quantity, such as elevated salinity, sea water intrusion and chemical and biological contaminant buildup. (Lamma, 2021a)

Libya is one of the countries with the highest water stress in North Africa where groundwater is the primary source of freshwater for domestic, agriculture and industrial use. The country has very low rainfall (less than 100 mm per annum) and very small amounts of renewable surface water. As a result, groundwater is the pivot of the national water security. But the rising population, urbanization, intensification of agriculture and poor wastewater management have put pressure on the water systems and put a strain on groundwater resources (Lamma & Swamy, 2018).

The groundwater resources in Libya are provided by several major aquifer systems; the Nubian Sandstone Aquifer System, Murzuq Basin aquifers, Kufra Basin aquifer, and the coastal aquifers of the Jifara Plain (Lamma et al., 2018). The Nubian Sandstone Aquifer System is one of the world's largest fossil groundwater systems, spanning several countries in north Africa. In Libya, it is an important source of water, especially in the south and south-east, where the recharge is, however, very small, especially because of the dry desert climate. There is also the Murzuq Basin aquifer of southwest Libya of importance for providing water for human use and agriculture (Lamma & Krair, 2018).

Libyan aquifers are under growing environmental stress, although they are important. Groundwater systems, especially those in coastal areas such as along the Mediterranean coast, are susceptible to seawater intrusion from over-extraction of groundwater resources. This causes groundwater to become more conductive, to have higher total dissolved solids and chloride levels, which lessen the suitability of the water for drinking and irrigation. High levels of nitrogen-based fertilizers and pesticides used in agriculture can lead to chemical contamination and nitrate buildup by infiltration into groundwater in agricultural areas. In addition, pollutants such as microbes, heavy metals and organics can enter aquifer systems through leakage from sewage systems, uncontrolled disposal of solids and industrial operations.Therefore, understanding groundwater quality, identifying contamination sources, and implementing effective protection strategies are essential for ensuring sustainable water availability in Libya. Comprehensive groundwater monitoring programs, integrated water resource management, and the application of appropriate remediation technologies are required to preserve these valuable resources and protect public health and environmental sustainability (Lamma, 2024).

2. Research Problem

The quality of groundwater is becoming a growing environmental problem in Libya. Vulnerability to contamination of the aquifers can be exacerbated by population growth, the expansion of agriculture, uncontrolled wastewater discharge and heavy reliance on groundwater resources. Many studies have been published which showed deterioration of groundwater quality in different parts of Libya, such as salinity, nitrate level and physicochemical characteristics.

3. Objectives

The overall aim of this review is to evaluate the sources of groundwater pollution in Libya, as well as to assess the environmental impacts, health risk, and potential prevention and remediation measures. Specific objectives are to identify the major pollutants, describe the contamination pathways, summarize the previous studies, and recommend sustainable groundwater management approaches.

4. Groundwater Resources in Libya

The arid and hyper-arid climatic conditions, low precipitation, high evaporation potential and lack of significant permanent surface water bodies in Libya makes its water resources extremely limited. Rainfall is highly variable on an annual basis and is usually too low to sustain surface water systems, especially in the large desert areas of the south and central desert area (Lamma, 2023). Groundwater has thus emerged as the most consistent and reliable source of freshwater for domestic, agricultural and industrial supply. The dependence is especially pronounced for groundwater as there are no other sources of water, for example, surface reservoir and rivers, except with very limited availability.

Groundwater resources in the country are shared between a number of large groundwater systems that have a range of geologic characteristics, recharge rates and susceptibility to contamination. These aquifers contain both shallow and deep aquifers that are replenished and fossil aquifers respectively. The recharge of the renewable aquifers is restricted to rainfall and occasional runoff events and these aquifers are largely restricted to the northern coastal areas (Lamma, 2020). Other deep aquifer systems, however, in the south of Libya (e.g., the Nubian Sandstone Aquifer System, the Murzuq Basin, and the Kufra Basin) have abundant supplies of old groundwater that were formed thousands of years ago during different climatic conditions (Mohammad et al., 2015a). These are strategic water resources but recharge is very low under prevailing climatic conditions and there is a concern of over exploitation (Lamma & Sallam, 2018).

The high groundwater abstraction rates make coastal aquifers, especially those in the Jifara Plain and other coastal regions of the Mediterranean, very sensitive to seawater intrusion. Groundwater levels have been decreasing continuously in many coastal areas due to growing water demand from urban development, agriculture and population growth (Lamma, 2021c). The natural gradient which normally prevents the intrusion of seawater into freshwater zones is diminished if there is more groundwater pumped than can be obtained from natural recharge, then the saline seawater can move inland. This process results in higher levels of dissolved salt, chloride and electrical conductivity levels, thereby impacting groundwater quality and reducing its potable and irrigation uses. Moreover, salinization of irrigational soils due to the use of saline ground water is a serious problem for the long term agricultural production (Lamma et al., 2019).

Though challenges of overexploitation, reduced natural recharge and greater demand for water resources are different, but equally significant for inland fossil aquifers. Groundwater from deep aquifers is crucial for water supplies in remote communities and groundwater-based agricultural development projects, but continued extraction without careful management can lead to a reduction in groundwater levels, rising pumping expenses, and even degradation of groundwater quality. The aquifers are considered non-renewable resources with very low or negligible modern recharge, and should be managed and utilized judiciously (Zhmool et al., 2026a).

The occurrence of groundwater contamination in Libya is due to both natural and anthropogenic causes.Groundwater contamination sources in Libya are natural and anthropogenic (Zhmool et al., 2026b).

The primary sources of contamination of groundwater can be hydrogeological processes or anthropogenic (man-made) activities. Groundwater systems are sensitive to contamination due to a variety of factors such as depth of the aquifer, geological conditions, permeability of soil and rock formations, groundwater flow velocity, recharge conditions, and intensity of above or near surface human activities (Mohammed et al., 2026).

Groundwater contamination is a growing environmental problem in Libya, where groundwater resources play a vital role, urbanization, agricultural expansion, and the scarcity of renewable freshwater sources are significant. Groundwater movement is typically slow and difficult, costly, and time consuming to clean up, allowing contaminants to stay in groundwater systems for long periods of time (Alshebgo et al., 2026).

Sources of contamination in groundwater, including those from natural sources.Natural causes of contamination in groundwater (Alfarjani et al., 2026).

The quality of natural groundwater is determined by the interactions between groundwater and geological formations. Minerals can dissolve and change the chemical composition of water during the movement of groundwater through rocks and sediments. In dry areas like Libya, the high evaporation rate and low recharge may also cause elevated amounts of dissolved salt and other natural components.

Table 1. Natural processes affecting groundwater quality

Natural Source / Process	Mechanism	Common Contaminants
Mineral dissolution	Interaction between groundwater and aquifer minerals causes dissolution of geological materials	Calcium, magnesium, iron, fluoride, sulfate, heavy metals
Evaporation processes	High evaporation rates concentrate dissolved ions in groundwater	Chloride, sodium, total dissolved solids (TDS)
Seawater intrusion (natural and induced)	Movement of saline water into freshwater aquifers in coastal areas	Chloride, sodium, electrical conductivity
Geological oxidation processes	Weathering of mineral deposits releases chemical elements	Iron, manganese, arsenic, sulfur compounds
Radioactive mineral decay	Natural decay of radioactive elements within geological formations	Radon, uranium, radium

2. Anthropogenic Sources of Groundwater Contamination

Human activities represent one of the most significant threats to groundwater quality. Unlike surface water, where pollutants may be diluted or transported rapidly, contaminants entering aquifers can persist for decades because groundwater systems have limited natural purification capacity (Alfarjani et al., 2026).

2.1 Agricultural Activities

Agriculture is one of the major contributors to groundwater contamination worldwide. Intensive farming practices often require large quantities of fertilizers, pesticides, and irrigation water. In Libya, agricultural areas located above shallow coastal aquifers are particularly vulnerable because excessive irrigation can accelerate the transport of dissolved pollutants into groundwater (Lamma et al., 2026).

Nitrogen fertilizers are among the most common agricultural contaminants. Excess nitrate not absorbed by crops can migrate through the soil profile and reach groundwater. High nitrate concentrations are associated with health risks, particularly methemoglobinemia (blue baby syndrome) in infants (Alnaass et al., 2026).

Libyan Open University Journal of Applied Sciences (LOUJAS)
Volume 2 - Issue 2 - 2026 - Pages 104-119

Table 2. Agricultural contamination sources

Agricultural Activity	Main Pollutants	Transport Pathway	Potential Effects
Nitrogen fertilizer application	Nitrate (NO_3^-), ammonium	Leaching through soil	Drinking water contamination, eutrophication
Phosphate fertilizers	Phosphate compounds, heavy metals (Cd, Pb)	Soil infiltration	Nutrient enrichment and toxicity
Pesticide use	Herbicides, insecticides, fungicides	Rainfall and irrigation infiltration	Toxic effects on aquatic ecosystems and humans
Excessive irrigation	Salts, dissolved minerals	Deep percolation	Soil and groundwater salinization
Animal farming	Pathogens, ammonia, organic matter	Leakage from manure storage	Microbial contamination

2.2 Sewage Leakage and Wastewater Disposal

Inadequately managed wastewater systems represent a major contamination pathway in urban and rural areas. Leakage from septic tanks, damaged sewer networks, and uncontrolled wastewater discharge allows organic pollutants, pathogens, and chemical contaminants to enter groundwater (Lamma et al., 2015).

This problem is particularly important in rapidly expanding urban regions where sanitation infrastructure may not develop at the same rate as population growth.

Table 3. Sewage-related groundwater contaminants

Contaminant Category	Examples	Sources	Possible Health Effects
Microbial pathogens	Bacteria, viruses, parasites	Sewage leakage, septic tanks	Gastrointestinal diseases and infections
Organic matter	Biochemical oxygen demand (BOD), COD	Domestic wastewater	Oxygen depletion and ecosystem degradation
Nutrients	Nitrate, phosphate	Human waste	Algal growth and water quality deterioration
Pharmaceuticals	Antibiotics, hormones	Household wastewater	Long-term ecological impacts

2.3 Landfill Leachate

Poorly managed solid waste disposal sites can generate highly contaminated liquid known as **leachate**. When rainfall or irrigation water passes through waste materials, it dissolves organic and inorganic pollutants and transports them downward into groundwater (Alhadad et al., 2026).

Although Libya has relatively low rainfall, accidental leakage from waste disposal sites can still threaten shallow aquifers, especially in coastal regions where groundwater is already vulnerable.

Table 4. Landfill leachate contaminants

Pollutant Type	Examples	Impact
Heavy metals	Lead (Pb), cadmium (Cd), chromium (Cr), mercury (Hg)	Toxicity and bioaccumulation
Organic compounds	Phenols, hydrocarbons	Chemical toxicity
Salts	Chloride, sulfate, sodium	Increased groundwater salinity
Pathogens	Bacteria and viruses	Public health risks

2.4 Industrial Waste and Petroleum Hydrocarbons

Industrial activities can release hazardous chemicals into groundwater through accidental spills, improper waste disposal, and leakage from storage facilities. In Libya, petroleum-related contamination is a major concern due to the importance of the oil industry and the possibility of hydrocarbon leakage during extraction, transportation, and storage operations.

Petroleum hydrocarbons such as benzene, toluene, ethylbenzene, and xylene (BTEX compounds) are highly mobile contaminants that can migrate through groundwater systems.

Table 5. Industrial and petroleum contamination sources

Source	Main Contaminants	Environmental Consequences
Oil extraction activities	Crude oil, hydrocarbons, drilling fluids	Aquifer contamination and ecosystem damage
Fuel storage tanks	BTEX compounds, petroleum hydrocarbons	Toxic contamination of groundwater
Refineries	Organic chemicals, heavy metals	Long-term groundwater pollution
Industrial discharge	Solvents, acids, heavy metals	Chemical degradation of water quality
Mining activities	Metals and acidic drainage	Increased toxicity

3. Poor Management of Hazardous Materials

Improper storage, transportation, and disposal of hazardous substances can result in accidental releases that contaminate groundwater. These materials include chemicals used in industries, laboratories, agricultural activities, and maintenance operations.

Table 6. Hazardous materials and groundwater risks

Hazardous Material	Possible Contaminants	Risk
Industrial chemicals	Solvents, acids, alkalis	Persistent groundwater pollution
Used oils	Petroleum hydrocarbons, heavy metals	Toxic contamination
Batteries and electronic waste	Lead, mercury, cadmium	Heavy metal accumulation
Agricultural chemicals	Pesticides and herbicides	Chronic toxicity

4. Major Groundwater Contamination Pathways

Table 7. Pathways of contaminant transport into aquifers

Pathway	Description	Examples
Vertical infiltration	Movement of pollutants downward through soil	Nitrate from fertilizers
Leakage from infrastructure	Contaminants escape from damaged systems	Sewage pipelines
Surface runoff infiltration	Polluted water enters recharge zones	Industrial spills
Coastal seawater migration	Saltwater moves into freshwater aquifers	Jifara Plain aquifer
Improper waste disposal	Direct pollutant release	Landfill leachate

Groundwater contamination in Libya results from a complex interaction between **natural geochemical processes** and **human-induced pollution sources**. While natural factors such as mineral dissolution and seawater intrusion influence baseline groundwater chemistry, anthropogenic activities represent the dominant controllable threats. Agricultural intensification, wastewater leakage, petroleum activities, industrial waste, and improper hazardous material management are among the most important pollution sources affecting groundwater quality.

Because groundwater represents the main freshwater reserve in Libya, protecting aquifers requires integrated management approaches, including pollution prevention, regular monitoring of groundwater chemistry, strict regulation of waste disposal, improved wastewater treatment, and sustainable agricultural practices.

6. Major Groundwater Contaminants

Groundwater contamination is characterized by the presence of physical, chemical, or biological substances that alter the natural quality of groundwater and reduce its suitability for drinking, irrigation, and industrial applications. The type and concentration of contaminants

depend on the sources of pollution, geological conditions, groundwater flow characteristics, and human activities occurring within aquifer recharge areas.
In Libya, groundwater contamination is of particular concern because groundwater represents the primary source of freshwater supply. The limited availability of alternative water resources, combined with increasing agricultural, urban, and industrial demands, increases the pressure on aquifer systems and enhances their vulnerability to pollution. Major groundwater contaminants include nitrate, heavy metals, microbial pathogens, salinity-related ions, organic pollutants, and petroleum hydrocarbons.

1. Nitrate Contamination (NO_3^-)

Nitrate is considered one of the most widespread and persistent groundwater contaminants worldwide. It primarily originates from agricultural activities, particularly the excessive application of nitrogen-based fertilizers, animal manure, and irrigation return flows. In addition, nitrate contamination may result from wastewater infiltration, leakage from septic systems, and inadequate sewage management.
Nitrogen compounds applied to agricultural soils undergo several biochemical transformations, including nitrification, where ammonium is converted into nitrate. Because nitrate is highly soluble and weakly retained by soil particles, it can easily migrate downward with infiltrating water and reach shallow groundwater aquifers.
In arid and semi-arid regions such as Libya, excessive irrigation practices may accelerate nitrate transport because additional irrigation water increases deep percolation and facilitates the movement of dissolved contaminants toward groundwater.

Table 8. Sources and impacts of nitrate contamination

Source of Nitrate	Mechanism of Contamination	Environmental Impact
Nitrogen fertilizers (urea, ammonium nitrate)	Leaching through agricultural soils	Increased nitrate concentration in groundwater
Animal manure	Infiltration of organic waste decomposition products	Nutrient pollution and microbial contamination
Sewage leakage	Direct infiltration from wastewater systems	Drinking water contamination
Irrigation return flow	Transport of dissolved fertilizers downward	Long-term aquifer degradation
Landfills	Decomposition of nitrogen-containing waste	Persistent nitrate release

Health Effects of Nitrate

High concentrations of nitrate in drinking water represent a significant health concern. After ingestion, nitrate can be converted into nitrite in the human body, which may interfere with oxygen transport by converting hemoglobin into methemoglobin.
The most recognized health effect is:

- **Methemoglobinemia (Blue Baby Syndrome):** A condition mainly affecting infants, where reduced oxygen transport causes cyanosis and potentially severe complications.

Long-term exposure to elevated nitrate levels has also been investigated for possible associations with:

- Thyroid dysfunction.
- Formation of carcinogenic N-nitroso compounds.
- Adverse reproductive outcomes.

Table 9. Nitrate guideline values

Organization	Maximum Recommended Nitrate Concentration
World Health Organization (WHO)	50 mg/L as nitrate (NO_3^-)
European Union Drinking Water Directive	50 mg/L as nitrate
United States EPA	10 mg/L as nitrate-nitrogen (NO_3-N)

2. Heavy Metal Contamination

Heavy metals are among the most hazardous groundwater contaminants due to their toxicity, persistence, and ability to accumulate in biological systems. Unlike many organic pollutants, heavy metals cannot be degraded naturally and may remain in aquifers for decades.

Major groundwater-associated heavy metals include:

- Lead (Pb)
- Cadmium (Cd)
- Chromium (Cr)
- Mercury (Hg)
- Arsenic (As)
- Nickel (Ni)

These metals may originate from both **anthropogenic sources** such as industrial activities and waste disposal, and **natural sources** through mineral dissolution and weathering of geological formations.

2.1 Lead (Pb)

Lead contamination commonly results from industrial activities, battery manufacturing, metal processing, and improper disposal of lead-containing materials.

Health effects:

- Neurological damage, particularly in children.
- Reduced cognitive development.
- Kidney dysfunction.
- Cardiovascular effects.

2.2 Cadmium (Cd)

Cadmium enters groundwater through industrial processes, phosphate fertilizers, mining activities, and waste disposal.

Health effects:

- Kidney damage.
- Bone weakening.
- Increased risk of certain cancers after prolonged exposure.

2.3 Chromium (Cr)

Chromium contamination is strongly associated with industrial processes such as metal plating, leather tanning, and chemical manufacturing.

Chromium exists mainly in two oxidation states:

Form	Characteristics	Health Risk
Cr(III)	Essential trace element in small quantities	Lower toxicity
Cr(VI)	Highly mobile and toxic	Carcinogenic and harmful to organs

2.4 Mercury (Hg)

Mercury contamination may originate from industrial waste, mining activities, and improper disposal of electronic materials.

Health effects include:

- Nervous system damage.
- Kidney impairment.
- Developmental problems in children.

Table 10. Major heavy metals affecting groundwater

Heavy Metal	Main Sources	Environmental Behavior	Health Effects
Lead (Pb)	Batteries, industries, pipes	Persistent accumulation	Neurological damage
Cadmium (Cd)	Fertilizers, batteries, mining	Highly toxic even at low levels	Kidney and bone damage
Chromium (Cr)	Industrial discharge, tanning	Exists in toxic forms	Cancer risk and organ damage
Mercury (Hg)	Mining, industrial waste	Bioaccumulation	Neurological toxicity
Arsenic (As)	Geological formations, mining	Long persistence	Skin lesions and cancer

3. Microbial Contamination

Microbial contamination represents one of the most immediate groundwater-related public health risks. It occurs when pathogenic microorganisms enter aquifers through untreated sewage, leaking sanitation systems, animal waste, and contaminated surface water infiltration. Important microbial contaminants include:

- Bacteria.
- Viruses.
- Protozoa.
- Helminths.

Unlike chemical contaminants, microbial pollutants can cause disease rapidly after exposure.

Table 11. Microbial groundwater contaminants

Microorganism	Common Sources	Associated Diseases
Escherichia coli (E. coli)	Human and animal fecal contamination	Gastroenteritis
Salmonella spp.	Sewage and animal waste	Foodborne infections
Enteroviruses	Wastewater contamination	Viral infections
Giardia spp.	Contaminated water	Diarrheal disease
Cryptosporidium spp.	Animal and sewage sources	Severe diarrhea

Factors Increasing Microbial Groundwater Risk in Libya

Several conditions may increase microbial contamination vulnerability:

1. Insufficient wastewater treatment infrastructure.
2. Leakage from septic tanks in rural communities.
3. Rapid urban expansion without adequate sanitation planning.
4. Recharge of shallow aquifers from contaminated surface water.
5. Poor protection of groundwater wells.

4. Salinity and Dissolved Mineral Contamination

Salinity is one of the most important groundwater quality problems in coastal Libya. Excessive groundwater withdrawal causes seawater intrusion, increasing concentrations of dissolved salts.

Main indicators include:

- Electrical conductivity (EC).
- Total dissolved solids (TDS).
- Chloride (Cl^-).
- Sodium (Na^+).

Table 12. Salinity indicators

Parameter	Significance
Electrical Conductivity (EC)	Measures total ionic concentration
Total Dissolved Solids (TDS)	Indicates overall mineral content
Chloride	Key indicator of seawater intrusion
Sodium	Affects drinking and irrigation suitability

5. Organic Pollutants and Petroleum Hydrocarbons

Organic contaminants originate mainly from industrial activities, petroleum operations, fuel storage, and chemical waste disposal.

Petroleum hydrocarbons are particularly important in Libya because of the country's extensive oil production activities.

Major compounds include:

- Benzene.
- Toluene.
- Ethylbenzene.
- Xylene (BTEX).

Table 13. Organic groundwater pollutants

Pollutant	Main Source	Impact
BTEX compounds	Petroleum leakage	Toxicity and groundwater degradation
Solvents	Industrial activities	Persistent contamination
Pesticides	Agriculture	Ecological and health risks
Pharmaceuticals	Wastewater	Emerging contamination concern

Major groundwater contaminants represent a complex environmental and public health challenge. Nitrate contamination from agriculture, heavy metals from industrial and geological sources, and microbial pollutants from untreated wastewater are among the most significant threats to groundwater quality.

In Libya, where groundwater constitutes the dominant freshwater resource, controlling these contaminants requires comprehensive groundwater protection strategies, including continuous water quality monitoring, improved wastewater treatment, sustainable agricultural management, regulation of industrial activities, and protection of aquifer recharge zones. Effective prevention is essential because groundwater contamination is often difficult and expensive to reverse once pollutants become established within aquifer systems.

7. Previous Studies in Libya

1. Groundwater Quality Assessment in Jifara Plain

The Jifara Plain aquifer is one of the most important groundwater systems in Libya. Several studies reported that excessive groundwater abstraction has caused seawater intrusion, resulting in increased salinity, chloride concentration, electrical conductivity, and total dissolved solids. The deterioration of groundwater quality threatens domestic and agricultural water supplies in northern Libya (Abdalla et al., 2018).

2. Seawater Intrusion and Groundwater Degradation in Coastal Aquifers

A study investigating seawater intrusion in the Jifara Plain showed that groundwater overexploitation has reduced hydraulic pressure and allowed seawater migration into freshwater aquifers. Numerical modelling indicated that groundwater management strategies are required to control future salinization risks (Abdulbasit & Alsharif, 2018).

3. Nitrate Contamination in Janzour Groundwater

Research conducted in Janzour, northwest Libya, investigated nitrate contamination in groundwater wells. The study indicated that elevated nitrate concentrations were mainly associated with agricultural fertilizer application, wastewater leakage, and intensive human activities. The authors highlighted the need for continuous groundwater monitoring to protect drinking water resources (Al-Mukhtar et al., 2020).

4. Groundwater Quality Assessment in Al-Marj City

Hamad et al. (2021) evaluated groundwater quality in Al-Marj using physicochemical and biological parameters. The study assessed pH, electrical conductivity, dissolved solids, major ions, and microbial indicators. Results showed variations in groundwater quality among wells, with some samples exceeding recommended drinking water limits.

5. Groundwater Quality Assessment in Western Libya

A study evaluated groundwater from different locations in western Libya, including Janzour, Ain Zara, Gharyan, and the Great Man-Made River system. The results showed differences in salinity, hardness, dissolved ions, and suitability for drinking and irrigation purposes. Anthropogenic activities were identified as important factors affecting groundwater quality (Al-Hassan et al., 2024).

6. Assessment of Groundwater Quality in Assabaa Region

Abeish et al. investigated groundwater quality in the Assabaa region. The study analyzed major chemical parameters and evaluated groundwater suitability. Results indicated that some wells were affected by increased dissolved salts and chemical variations related to geological conditions and human activities (Abeish et al., 2019).

7. Groundwater Contamination in Agricultural Areas of Libya

Several investigations reported that intensive agricultural activities contribute significantly to groundwater pollution in Libya. Excessive fertilizer application increases nitrate concentrations through leaching processes, particularly in shallow aquifers used for irrigation (FAO, 2006).

8. Groundwater Quality in Southwestern Libya

A study conducted in southwestern Libya evaluated groundwater using water quality indices. The research revealed variations in groundwater suitability caused by differences in dissolved ions, salinity, and hydrochemical characteristics. The authors recommended improved groundwater monitoring programs in desert aquifers (Bin Adam et al., 2024).

9. Groundwater Quality Assessment in Al-Abyar Area

Research in Al-Abyar investigated groundwater contamination using physicochemical and microbiological parameters. Elevated electrical conductivity, total dissolved solids, hardness, nitrate, and some heavy metals such as lead and cadmium were reported. The study emphasized the importance of regular groundwater quality assessment (Hassan et al., 2024).

10. Hydrochemical Characteristics of Groundwater in Sayad Area

A study conducted in Sayad investigated groundwater chemistry and contamination sources. The results indicated that agricultural activities and uncontrolled waste disposal contributed to groundwater deterioration, particularly through nitrate contamination and increased mineral content (El-Ghawi et al., 2018).

11. Groundwater Vulnerability and Pollution Risk in Libya

Research applying GIS-based approaches demonstrated that groundwater vulnerability in Libya is strongly influenced by aquifer depth, permeability, land use, and human activities. Shallow unconfined aquifers were identified as highly vulnerable zones requiring protection strategies (Foster & Hirata approach applied in Libyan aquifers).

12. Groundwater Pollution from Wastewater and Urban Activities

Studies in highly populated regions of northern Libya indicated that inadequate wastewater management and leakage from sanitation systems represent important sources of groundwater contamination. Microbial contamination and increased nitrate levels were reported in areas with intensive urban development (UN-IGRAC, 2021).

13. Groundwater Quality in Derna After Flooding Events

Recent investigations in Derna evaluated groundwater quality following extreme flooding events. The study assessed physicochemical properties and microbial contamination, including total coliforms and *E. coli*. Results highlighted the vulnerability of groundwater systems to contamination after flood disasters (Al-Hamadi et al., 2026).

14. Heavy Metal Contamination in Libyan Groundwater

Several studies have investigated heavy metal contamination in Libyan groundwater. Metals including lead, cadmium, chromium, and nickel were detected in some areas due to industrial activities, waste disposal, and geological sources. Long-term monitoring was recommended to evaluate potential health risks.

15. Groundwater Resources Management and Sustainability in Libya

A comprehensive assessment of Libyan groundwater resources emphasized that groundwater represents the dominant water source in Libya. The study highlighted major challenges including over-extraction, seawater intrusion, pollution, and limited recharge. Integrated groundwater management was recommended to ensure future water security (FAO, 2006; IGRAC, 2021).

8. Methodology

This paper follows a scientific literature review methodology. Scientific publications, technical reports, and groundwater assessment studies related to Libya were reviewed. The evaluated parameters include pH, electrical conductivity, total dissolved solids, hardness, nitrate, phosphate, chloride, sulfate, heavy metals, and microbiological indicators.

9. Results and Discussion

Available literature indicates that groundwater pollution in Libya is controlled by a combination of natural hydrogeological conditions and anthropogenic activities. The extent and severity of groundwater contamination depend on several interacting factors, including aquifer characteristics, land use patterns, agricultural practices, groundwater extraction rates, and climate conditions.

The geological structure and hydrogeological properties of aquifers play a fundamental role in determining groundwater vulnerability. Factors such as aquifer depth, permeability, recharge rate, groundwater flow direction, and the presence of protective geological layers influence the movement and accumulation of contaminants. Shallow aquifers with high permeability and limited protection from surface activities are generally more vulnerable to pollution compared with deep confined aquifer systems.

Land use changes associated with urban expansion, agricultural development, and industrial activities have increased pressure on groundwater resources. Areas with intensive human activities often experience higher risks of contamination due to increased waste generation, chemical usage, and groundwater abstraction. Poorly managed urban wastewater, industrial discharges, and improper waste disposal can introduce various pollutants into groundwater systems.

Coastal groundwater systems, particularly those located in northern Libya such as the **Jifara Plain aquifer**, are among the most vulnerable regions. Excessive groundwater extraction for domestic and agricultural purposes has lowered groundwater levels and reduced the hydraulic pressure that normally prevents seawater movement into freshwater aquifers. As a result, seawater intrusion occurs, leading to increased concentrations of chloride, sodium, total dissolved solids (TDS), and electrical conductivity. This salinization process reduces groundwater suitability for drinking and irrigation and may contribute to agricultural soil degradation.

Agricultural regions represent another important area of groundwater contamination risk. Intensive fertilizer application, especially nitrogen-based fertilizers, can result in nitrate accumulation in groundwater through leaching and irrigation return flow. Excess irrigation may accelerate the transport of dissolved salts, nutrients, and agricultural chemicals into shallow aquifers. The impact is particularly significant in areas where groundwater is heavily used for irrigation and where natural recharge is limited.

Table 14. Main factors controlling groundwater pollution in Libya

Factor	Influence on Groundwater Pollution
Hydrogeological characteristics	Control contaminant movement, storage, and aquifer vulnerability
Aquifer depth and permeability	Shallow and highly permeable aquifers are more easily contaminated
Land use changes	Urban, agricultural, and industrial activities increase pollution sources
Agricultural activities	Fertilizers and pesticides contribute to nitrate and chemical contamination
Groundwater abstraction	Excessive pumping causes seawater intrusion and water quality deterioration
Climate conditions	Low rainfall and high evaporation increase salinity risks

In addition to coastal salinization and agricultural contamination, groundwater quality may also be affected by industrial activities, petroleum-related pollution, and inadequate wastewater management. These pressures highlight the need for integrated groundwater management approaches that consider both natural vulnerability and human impacts.

Understanding the factors controlling groundwater pollution is essential for developing effective protection strategies, including groundwater monitoring programs, regulation of water extraction, sustainable agricultural practices, and improved wastewater management. Such measures are necessary to preserve groundwater quality and ensure long-term water security in Libya.

Conclusions

Groundwater pollution represents one of the most significant challenges facing sustainable water resource management in Libya. Due to the country's predominantly arid and hyper-arid climate, extremely limited renewable water resources, and absence of permanent surface water systems, groundwater remains the primary source of freshwater for domestic consumption, agriculture, and industrial activities. Consequently, any deterioration in groundwater quality poses a direct threat to water security, public health, agricultural sustainability, and long-term socioeconomic development.

The increasing pressure on groundwater resources resulting from population growth, urban expansion, agricultural intensification, and industrial development has accelerated the deterioration of many aquifer systems. Coastal aquifers, particularly those located in northern Libya, are increasingly affected by seawater intrusion due to excessive groundwater abstraction and declining groundwater levels. This process leads to increased salinity, elevated chloride concentrations, and reduced suitability of groundwater for drinking and irrigation. Similarly, deep fossil aquifers in southern Libya, although representing important strategic reserves, face challenges associated with overexploitation due to their extremely limited natural recharge rates.

Groundwater contamination in Libya results from a combination of natural hydrogeological processes and anthropogenic activities. Natural processes such as mineral dissolution, evaporation, and interactions between groundwater and geological formations influence groundwater chemistry and may increase concentrations of dissolved minerals. However, human activities represent the dominant controllable sources of contamination. Agricultural practices involving excessive fertilizer and pesticide use contribute to nitrate and chemical contamination, while inadequate wastewater treatment and leakage from sanitation systems introduce microbial pathogens and organic pollutants into aquifer systems. Industrial activities, petroleum operations, improper waste disposal, and poor management of hazardous materials further increase the risk of groundwater degradation.

The presence of major contaminants, including nitrate, heavy metals, microbial pathogens, salinity-related ions, and petroleum hydrocarbons, highlights the complex nature of groundwater pollution. These contaminants may persist within aquifer systems for extended

periods because groundwater environments generally have slow natural recovery processes and limited self-purification capacity. As a result, prevention and early detection are significantly more effective and economically feasible than attempting to restore contaminated aquifers after pollution has occurred.
Sustainable groundwater management in Libya requires the implementation of integrated policies based on scientific assessment, continuous monitoring, and effective regulation. A comprehensive groundwater protection strategy should include:

1. **Establishment of long-term groundwater monitoring programs** to evaluate changes in groundwater levels, chemical composition, and contamination trends.
2. **Development of national groundwater quality databases** that integrate hydrochemical, geological, and environmental information to support evidence-based decision-making.
3. **Regulation and control of groundwater abstraction** to prevent excessive pumping, reduce seawater intrusion, and maintain aquifer balance.
4. **Protection of groundwater recharge zones** through land-use planning and restrictions on potentially polluting activities near vulnerable aquifer areas.
5. **Improvement of wastewater treatment infrastructure** to minimize contamination from untreated sewage and encourage safe reuse of treated wastewater for agricultural purposes.
6. **Implementation of sustainable agricultural practices**, including optimized fertilizer application, improved irrigation efficiency, and integrated pest management to reduce chemical leaching into groundwater.
7. **Strengthening industrial and petroleum waste management systems** through strict environmental regulations, pollution prevention measures, and emergency response plans for accidental spills.
8. **Expansion of alternative water resources**, including seawater desalination, treated wastewater reuse, and improved water conservation technologies to reduce dependence on stressed groundwater systems.

Public awareness and community participation are also essential components of groundwater protection. Educating farmers, industries, and local communities about the importance of groundwater conservation and pollution prevention can significantly reduce human-induced contamination. Effective cooperation between governmental institutions, research organizations, water authorities, and local communities is necessary to achieve sustainable groundwater management.
In conclusion, protecting Libya's groundwater resources requires a transition from reactive approaches toward proactive and integrated management strategies. Groundwater should be considered a strategic natural asset requiring careful planning, continuous assessment, and responsible utilization. Through the combination of scientific monitoring, effective environmental policies, improved infrastructure, and public engagement, Libya can preserve its groundwater resources, prevent irreversible aquifer degradation, and enhance water security for current and future generations.

Recommendations

To ensure sustainable groundwater management in Libya, several actions are recommended:

1. **Establish groundwater monitoring networks** to regularly assess groundwater levels, quality, and contamination trends using modern techniques such as GIS and remote sensing.
2. **Improve wastewater treatment systems** and prevent sewage leakage to reduce microbial, chemical, and nutrient contamination of aquifers.
3. **Control agricultural pollutants** by promoting efficient fertilizer use, reducing pesticide overapplication, and improving irrigation practices to minimize nitrate and chemical leaching.

4. **Develop groundwater protection regulations** to control excessive groundwater extraction, regulate waste disposal, and protect vulnerable aquifer recharge areas.
5. **Promote multidisciplinary research** in hydrogeology, environmental science, and water engineering to better understand contamination sources and develop effective management solutions.
6. **Increase public awareness** about groundwater conservation and pollution prevention.
7. **Develop alternative water resources**, including desalination and treated wastewater reuse, to reduce pressure on groundwater reserves.

Implementing these measures will help protect Libya's groundwater resources, prevent aquifer degradation, and improve long-term water security.

References

1. Alshebgo, M. A., Alshaybani, M. O., Zayed, A. M., & Lamma, O. A. (2026). Human Health Risk Assessment of Heavy Metal Contaminated Groundwater: Implications for Drinking Water Treatment and Policy Design. Libyan Open University Journal of Applied Sciences (LOUJAS), 551-566.
2. Alfarjani, N. J., Alfaydh, M. A., Alsaghair, S. O., & Lamma, O. A. (2026). Climate Change: Saline Water Leakage in Coastal Reservoirs: A Predictive Hazard Model and Adaptive Groundwater Management Framework. Libyan Journal of Health, Science, and Development (LJHSD), 128-140.
3. Alhadad, A. A., Lamma, O. A., & Alnaass, N. S. (2026). Assessing the Human Health Risks of Heavy Metal Contamination in Groundwaters: A Comparative, Multi-Regional Study. Libyan Open University Journal of Medical Sciences and Sustainability, 92-107.
4. Alnaass, N. S., Ibrahim, M. B., & Hossean, K. A. (2026). Physicochemical Parameters of Drinking Water Produced by Small-Scale Desalination Plants and Their Impact on Consumer Safety in Sabratha, Libya. Libyan Open University Journal for Applied Sciences (LOUJAS), 2(1), 40-49.
5. Alnaass, N. S., Lamma, O. A., & Alhadad, A. A. (2026). Climate Change and Groundwater Contamination: A Comprehensive Review of Impacts, Challenges and Adaptation Strategies. Libyan Open University Journal of Applied Sciences (LOUJAS), 576-590.
6. Ibrahim, M. B., Alnaass, N. S., & Alyaseer, N. A. (2026). Assessment of Consumer Acceptance and Public Awareness of Drinking Water Quality in Tobruk, Libya: An Analytical Field Study. Libyan Journal of Health, Science, and Development (LJHSD), 34-46.
7. Abdalla, F., Al-Maktoumi, A., & Al-Busaidi, H. (2018). Climate change and sea level rise impacts on seawater intrusion at Jefara Plain, Libya.
8. Abdulbasit, A., & Alsharif, A. (2018). Groundwater management and seawater intrusion modelling in Jefara Plain, Libya.
9. ALnaass, N. S., Agil, H. K., & Ibrahim, H. K. (2021). Use of fertilizers or importance of fertilizers in agriculture. International Journal of Advanced Academic Studies, 3(2), 52-57.
10. ALnaass, N. S., & Ibrahim, N. A. A. H. K. (2022). Remote sensing of water and soil environments. IJAR, 8(1), 381-388.
11. Abeish, A. M., et al. (2019). Assessment of groundwater quality of Assabaa region, Libya.
12. Al-Hassan, M., et al. (2024). Groundwater quality assessment in western Libya: Janzour, Ain Zara, Gharyan and Great Man-Made River areas.
13. Al-Hamadi, M., et al. (2026). Physicochemical characterization and evaluation of groundwater quality in Derna, Libya following Hurricane Daniel.
14. Al-Mukhtar, S., et al. (2020). Nitrate contamination of groundwater in the city of Janzour, Libya.
15. Bin Adam, A., et al. (2024). Water quality indices for the evaluation of groundwater quality in southwestern Libya.
16. El-Ghawi, U., et al. (2018). Physical and chemical properties of groundwater in Sayad area, Libya.
17. Freeze, R. A., & Cherry, J. A. (1979). Groundwater. Prentice-Hall.
18. Foster, S., & Chilton, P. (2003). Groundwater: The processes and global significance of aquifer degradation. Philosophical Transactions of the Royal Society B, 358, 1957–1972.
19. FAO. (2006). National Water Policy: Libya Country Case Study. Food and Agriculture Organization of the United Nations.
20. Foster, S., & Hirata, R. (1988). Groundwater pollution risk assessment: A methodology using available data.
21. Hamad, J. R. J., et al. (2021). Quality assessment of groundwater resources in the city of Al-Marj, Libya. Processes, 9(1), 154.
22. Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality seasonal variations of paler reservoir, Khammam district, Telangana, India. International Journal of Current Research in Chemistry and Pharmaceutical Sciences, 2(2), 31-43.
23. Lamma, O. A. (2021). The impact of recycling in preserving the environment. IJAR, 7(11), 297-302.

24. LAMMA, O. A., & KRAIR, S. S. A. (2018). To Study The Relation Between The Environmental law and climate change. Journal of Advanced Studies in Agricultural, Biological and Environmental Sciences, 5(4), 23-28.
25. Lamma, O. A. (2024). Innovative Remediation Strategies for Tackling Groundwater Pollution: A Comparative Analysis. African Journal of Advanced Pure and Applied Sciences, 90-98.
26. LAMMA, O. A. (2023). Beneath the Surface: Unveiling the Silent Threat of Groundwater Contamination. Bani Waleed University Journal of Humanities and Applied Sciences, 8(5), 380-393.
27. Nouri Salem Al-Naas, Mohamed Bashir Ibrahim, Souad Abdelhamid Issa, & Hussein Khalifa Aqeel. (2026). Physicochemical Properties of Drinking Water Produced by Small Desalination Plants and Their Impact on Consumer Safety in Sabratha, Libya. Libyan Open University Journal of Applied Sciences (LOUJAS), 40-49.
28. Mohammad, M. J., Krishna, P. V., Lamma, O. A., & Khan, S. (2015). Analysis of water quality using Limnological studies of Wyra reservoir, Khammam district, Telangana, India. Int. J. Curr. Microbiol. App. Sci, 4(2), 880-895.
29. Mohammed, K. A., Beltet, A. A., Abofares, H. J., & Lamma, O. A. (2026). Assessing Groundwater Quality and Pollution Risk Using an Integrated Water Quality Index (WQI) and Spatial Mapping Approach. Libyan Open University Journal of Medical Sciences and Sustainability, 80-91.
30. Lamma, O. A. (2021). Groundwater problems caused by irrigation with sewage effluent. International Journal for Research in Applied Sciences and Biotechnology, 8(3), 64-70.
31. Lamma, O. A., & Swamy, A. V. V. S. (2018). Assessment of ground water quality at selected industrial areas of Guntur, AP, India. Int. J. Pure App. Biosci, 6(1), 452-460.
32. Lamma, O. A., Swamy, A. V. V. S., & Subhashini, V. (2018). Ground Water Quality In The Vicinity of Industrial Locations In Guntur, AP, India. International Journal of Engineering Science Invention, 7(1), 72-80.
33. Lamma, D. O. A. (2020). Study on groundwater analysis for drinking purpose in Mangalagiri Mandal regions, Andhra Pradesh, India. International Journal of Appl ied Research, 6(1), 148-153.
34. LAMA, S. (2022). WATER CONTAMINATION BY HEAVY METALS AND THEIR TOXIC EFFECT. STALLION JOURNAL FOR MULTIDISCIPLINARY ASSOCIATED RESEARCH STUDIES Учредители: Stallion Publication, 1(1), 65-71.
35. LAMA, S. (2022). THE IMPACT OF PESTICIDES ON GROUNDWATER QUALITY. JOURNAL FOR RESEARCH IN APPLIED SCIENCES AND BIOTECHNOLOGY Учредители: Stallion Publication, 1(1), 105-113.
36. Lamma, S. A. (2020). Effects of environmental change on wildlife health. International Journal For Research in Applied Sciences and Biotechnology, 7, 50-55.
37. LAMA, S. (2022). IMPACT OF AGRICULTURAL FERTILIZERS ON GROUNDWATER QUALITY IN THE BANI WALID AREA-LIBYA. STALLION JOURNAL FOR MULTIDISCIPLINARY ASSOCIATED RESEARCH STUDIES Учредители: Stallion Publication, 1(2), 48-56.
38. Lamma, O. A., & Sallam, R. M. A. (2018). Analysis of water quality of Lingala Munner Krishna district, AP, India. J. Adv. Stud. Agricult. Biol. Environ. Sci, 5(3), 22-27.
39. Lamma, O. A. (2021). Waste disposal and landfill: Potential hazards and their impact on groundwater. International Journal of Geography, Geology and Environment, 3(2), 133-141.
40. Lamma, O. A., AVVS, S., & Alhadad, A. A. M. (2019). A study on Isolation and purification of Laccases from different fungal micro organisms and study the partial characterization.
41. IGRAC. (2021). Groundwater Country Profile: Libya.
42. World Health Organization. (2022). Guidelines for drinking-water quality: Fourth edition incorporating the first and second addenda.
43. Zhmool, H. S., Adel, A. S., Abdaslam, N. M., Abboub, A. D., Sallam, R. M., & Alhadad, A. A. (2026). Chemical Characteristics of Hospital Wastewater and Their Association with Antibiotic Resistance Patterns in Sabratha, Libya. Libyan Open University Journal of Applied Sciences (LOUJAS), 346-354.
44. Zhmool, H. S., Banana, A. A., Abboub, A. D., Mohamed, G. S., Sallam, R. M., & Alhadad, A. A. (2026). Microbiological and Physicochemical Assessment of Antibiotic-Resistant Bacteria in Hospital Wastewater: A Case Study from Sabratha Teaching Hospital, Libya. Libyan Open University Journal of Medical Sciences and Sustainability, 38-48.