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Physicochemical Characterization and Evaluation of Groundwater Quality in Derna, Libya, Following Hurricane Daniel

Waleed Naser Abumaelumah [1]*, Marai A. Mohamed Elkhajkhaj [2]
[1] Department of Chemistry, Faculty of science Al Qubah, University of Derna, Al Qubah, Libya
[2] Department of Chemistry, Faculty of science, University of Derna, Derna, Libya

الخصائص الفيزيائية والكيميائية وتقييم جودة المياه الجوفية في مدينة درنة، ليبيا، عقب إعصار دانيال

وليد نصر بومعلومة [1]*، مرعي عبدالونيس الخجخاج [2]
[1] قسم الكيمياء، كلية العلوم القبة، جامعة درنة، القبة، ليبيا
[2] قسم الكيمياء، كلية العلوم، جامعة درنة، درنة، ليبيا

*Corresponding author: waleedbomaluma@gmail.com

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Abstract:

This study aims to determine the safety of groundwater in Derna for human and agricultural use following the extensive flooding and water contamination caused by Hurricane Daniel. Seven representative samples were obtained from wells situated in the most adversely impacted areas. Then, they were tested in a more advanced lab to see if they had Escherichia coli and Total Coliform bacteria. They also checked the pH, electrical conductivity (EC), total dissolved solids (TDS), ammonia (NH_3), nitrate (NO_3^-), chloride, total hardness, and total hardness. The results showed that most of the samples had levels that were higher than what the World Health Organization (WHO) and Libyan standards say is safe for drinking water. The water had a lot of nitrates, ammonia, and dissolved salts in it, as well as E. coli and Total Coliform. It wasn't safe to drink. A lot of turbidity and chloride were also signs that the water wasn't safe. This was mostly because of flooding that broke pipes and let sewage leak out. The study says we should start using better ways to clean water right away, make systems for checking water quality stronger, and set up programs in communities to teach people about the health risks of dirty water and how important it is to use safe water practices. It also talks about how important it is to make long-term plans for managing water resources so that places that are likely to have disasters have more groundwater and climate change has less of an effect.

Keywords: Groundwater quality, Hurricane Daniel, water pollution, climate change, water resources management, groundwater treatment, environmental health.

الملخص
تهدف هذه الدراسة إلى تحديد مدى سلامة المياه الجوفية في درنة للاستخدام البشري والزراعي في أعقاب الفيضانات الواسعة وتلوث المياه الناجم عن إعصار دانيال. تم الحصول على سبع عينات تمثيلية من آبار تقع في المناطق الأكثر تضررًا. ثم فُحصت في مختبر أكثر تطورًا للتحقق من وجود بكتيريا الإشريكية القولونية والقولونية الكلية. كما تم فحص الرقم الهيدروجيني(pH) ، والتوصيل الكهربائي(EC) ، والمواد الصلبة الذائبة الكلية(TDS) ، والأمونيا(NH_3) ، والنترات (NO_3^-)، والكلوريد، والصلابة الكلية، والصلابة الكلية.
أظهرت النتائج أن معظم العينات احتوت على مستويات أعلى مما تنص عليه منظمة الصحة العالمية (WHO) والمعايير الليبية بأنه آمن لمياه الشرب. احتوت المياه على نسبة عالية من النترات والأمونيا والأملاح الذائبة، بالإضافة إلى الإشريكية

القولونية والقولونية الكلية. لم تكن المياه صالحة للشرب. كما أن وجود نسبة عالية من العكارة والكلوريد كان دليلًا على عدم سلامة المياه. يعود ذلك في الغالب إلى الفيضانات التي كسرت الأنابيب وتسربت مياه الصرف الصحي.
توصي الدراسة بالبدء فورًا في استخدام طرق أفضل لتنظيف المياه، وتقوية أنظمة فحص جودة المياه، ووضع برامج في المجتمعات المحلية لتوعية الناس بالمخاطر الصحية للمياه الملوثة وأهمية اتباع ممارسات استخدام المياه الآمنة. كما تتناول الدراسة أهمية وضع خطط طويلة المدى لإدارة موارد المياه بحيث تتوفر في المناطق المعرضة للكوارث كميات أكبر من المياه الجوفية، ويكون تأثير تغير المناخ أقل.

الكلمات المفتاحية: جودة المياه الجوفية، إعصار دانيال، تلوث المياه، التغير المناخي، إدارة الموارد المائية، معالجة المياه الجوفية، الصحة البيئية.

Introduction

In Libya, especially in coastal places like Derna where there isn't much surface water and it only rains in certain months, groundwater is the main supply of water for drinking, cooking, and farming. Aquifers are vital to the people who live here, but they are growing more and more at risk because of human activities, over-extraction, and extreme weather events [3, 4]. The terrible floods that happened in September 2023 because of Hurricane Daniel highlighted how awful Derna's groundwater resources are. Dam failures and uncontrolled surface runoff carried sewage, industrial waste, and contaminated sediments into aquifers [5, 6]. These kinds of things highlight how vital it is to keep an eye on things after a disaster to safeguard public health, restrict the spread of waterborne diseases, and make sure that groundwater resources are exploited in a way that will last [7, 8]. Floodwaters are known to make groundwater a lot worse by making it saltier, cloudier, and full of germs [9, 10]. Libyan and World Health Organization (WHO) standards declared that the water in Derna was not safe to drink because it contained excessive levels of nitrate, ammonia, chloride, and Escherichia coli [6, 8]. Floods have produced the same kinds of issues in Pakistan [7], Yemen [9], and Iraq [11], as well as in other nations. In these places, sewage leaks and failing infrastructure were connected to groundwater pollution. These commonalities show that groundwater around the world is vulnerable to disasters caused by climate change [3, 12]. Earlier research in Libya has recorded persistent groundwater challenges, characterized by heightened levels of total dissolved solids (TDS), chloride, and nitrate in Benghazi, Kufra, and Tripoli [2, 13, 10, 14]. Before Hurricane Daniel, studies in Derna also showed that the water was getting saltier and that germs were getting into it. People were worried about the aquifer's long-term health because of this [15, 16]. Studies on the area's hydrogeology found that there was a significantly larger probability of seawater pouring in and the aquifer running out of water because too much water was being taken out [4]. There are just a few studies that have looked at how major floods alter the quality of Derna's groundwater over time. We are really interested in how this will effect farming, the environment, and people's health in the long run [6]. Researchers from many different countries have looked into how floods change how groundwater systems work. For example, the U.S. Environmental Protection Agency (USEPA) and the American Public Health Association (APHA) have made it normal to check areas that have been damaged by disasters for chemical and microbiological contamination [17, 18]. Research in South Asia and Sub-Saharan Africa shows that flood contamination often leads to cholera, dysentery, and other diseases that spread by water [7, 19]. The Intergovernmental Panel on Climate Change (IPCC) has also predicted that climate change will cause increasingly severe and frequent extreme weather occurrences. This will make places that are currently at risk of groundwater pollution even more likely to happen [3, 20]. Groundwater pollution not only causes health problems, but it also has a huge impact on society and the economy. Dirty aquifers make it harder to farm, make people depend more on expensive bottled water, and put more burden on healthcare systems that are already not good enough [21, 22]. Libya's aquifers are at risk of being harmed, which might put the country's food sovereignty and water security at risk. This is because more than 90% of its freshwater originates from groundwater [14, 4]. To solve these problems, we need management plans that include cutting-edge purification technology, programs to get people in the community more involved, and long-term plans for how to manage water [5, 6, 23]. This work seeks to address the research deficiency by doing a thorough physicochemical and microbiological evaluation of groundwater in Derna subsequent to Hurricane Daniel. We examined pH, electrical conductivity (EC), total dissolved solids (TDS), nitrate, ammonia, chloride, total hardness, and E. coli using globally recognized methodologies [17, 24]. The results are compared to WHO and Libyan criteria [8] to see if the groundwater is safe to consume and use for agriculture. The study also suggests long-term management plans, such as the use of new treatment technologies, the creation of strong monitoring systems, and the development of flexible water resource management plans that can react to changes in the weather [3, 20, 25]. This study examines scientific and policy matters, contributing to the safeguarding of public health, enhancing water safety, and increasing Libya's resilience to future climate-related calamities.

Material and methods

We took seven samples of groundwater from wells in Derna's densely populated neighborhoods that were badly hit by Hurricane Daniel. The American Public Health Association (APHA) [17] set the Standard Methods for the Examination of Water and Wastewater, which were used for the sampling campaign on November 3, 2024. The chosen sites were chosen because they were likely to be flooded and have sewage flow into them after infrastructure fell apart on September 10, 2023. Figures (1) and (2) show how the sampling sites are spread out across the city, as seen on Google Maps. We collected all the samples in sterilized polyethylene bottles, kept them at 4 °C, and sent them to the labs for analysis right away, following international rules to reduce contamination [17, 24].

Figure 1: Lunar image of the study sites and the source of water sampling (by Google Maps)

Figure 2: Distribution of the sites of sampling sources within the city of Derna (by Google Maps)

Analytical Procedures:

Due to the limited availability of field equipment, some parameters were measured in situ, while others were analyzed in two specialized laboratories: the Desalination Plant Laboratory in Derna and the Al-Rayan University Laboratories. All instruments were calibrated prior to use, and reagents were freshly prepared to ensure accuracy and reproducibility [1, 17].

Physical Analyses :

The **pH** of groundwater was measured using a HACH Sension 2™ pH meter, calibrated with standard buffer solutions (pH 4, 7, and 9). **Electrical conductivity (EC)** was determined at 25 °C using a JENWAY 4310 conductivity meter with a standard KCl solution. **Total dissolved solids (TDS)** were quantified with a HANNA TDS meter, while **turbidity** was assessed using a HANNA Turbidity Meter based on the light scattering principle [17].

Chemical Analyses:

Chemical parameters were analyzed at Al-Rayan University laboratories. **Total hardness (TH)** was determined by EDTA titration using Eriochrome Black-T as an indicator, while **total alkalinity (TA)** was measured by titration with HCl using methyl orange [1]. **Chloride (Cl^-)** concentration was determined using the Mohr method with $AgNO_3$ and K_2CrO_4 as an indicator. **Calcium (Ca^{2+})** was measured by EDTA titration with murexide as an indicator, and **magnesium (Mg^{2+})** was calculated by subtracting calcium hardness from total hardness. **Ammonia (NH_3)** and **nitrate (NO_3^-)** concentrations were determined using a Hydrotest HT1000 photometer, following the manufacturer's instructions [1].

Microbiological Analyses:

Microbiological quality was assessed by detecting *Escherichia coli* (EC) and total coliform (TC)using selective nutrient media supplied by Hach Company. The procedure followed the manufacturer's protocol and the APHA standard methods [17, 24]. Positive growth was confirmed by colony morphology and colorimetric changes in the medium. **.**This methodological framework ensures that the obtained results are comparable with international standards and provide a reliable assessment of groundwater quality in post-disaster contexts [3, 8, 20].

Results and discussion

Results

The physicochemical and microbiological analyses of groundwater samples collected from seven wells in Derna after Hurricane Daniel are summarized in Tables 1–4 and Figures 3–5.

Table 1. Physical and chemical parameters of groundwater samples in Derna after Hurricane Daniel

Location	pH	EC (μs/cm)	TDS (mg/L)	Turbidity (NTU)	Total Hardness (mg/L)	Chloride (mg/L)
Al-Habs Street	7.7	1740	1230	7.5	1140	866.2
Al-Sahaba Street	7.5	1358	1060	7.3	740	411.8
Al-Kuwi Street	7.9	1487	1160	6.3	660	624.8
Al-Bahr Street	7.7	1060	1060	5.0	620	482.8
Al-Rashid Street	7.3	2531	1990	5.9	1320	710
Borda Street 2	7.2	2330	1820	5.0	960	823.6
Borda Street 1	7.3	2531	1990	5.9	1320	710

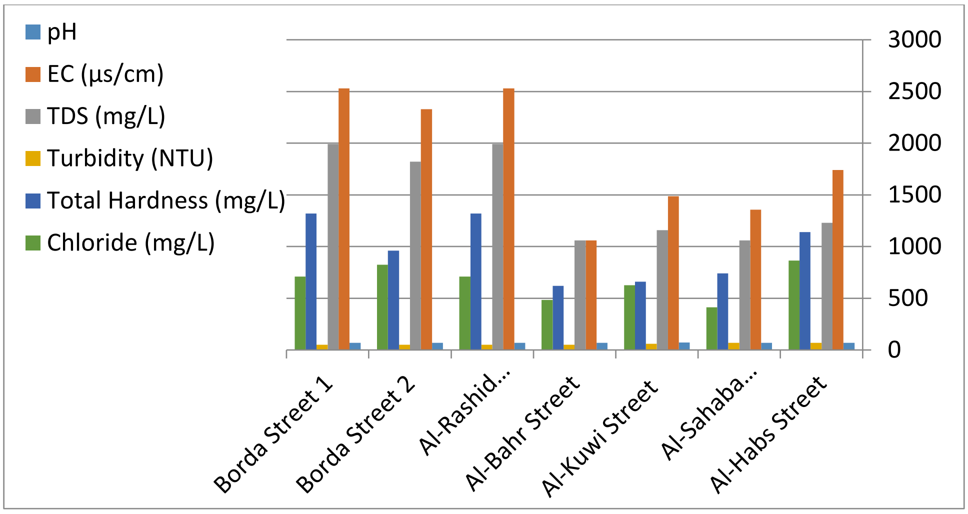

Figure 3. Water Quality Measurements by Street Location (pH, EC, TDS, NTU, TH, Cl^-)

Table 2. Major chemical parameters of groundwater samples in Derna after Hurricane Daniel

Location	Nitrate (mg/L)	Ammonia (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Bicarbonate (mg/L)
Al-Habs Street	24.0	2.85	460	680	10500
Al-Sahaba Street	0.24	3.53	380	360	5000
Al-Kuwi Street	0.2	0.52	280	340	2000
Al-Bahr Street	0.22	0.35	40	620	2000
Al-Rashid Street	0.07	205.0	280	340	2700
Borda Street 2	0.93	0.5	300	1020	3500
Borda Street 1	2.22	0.04	320	640	3800

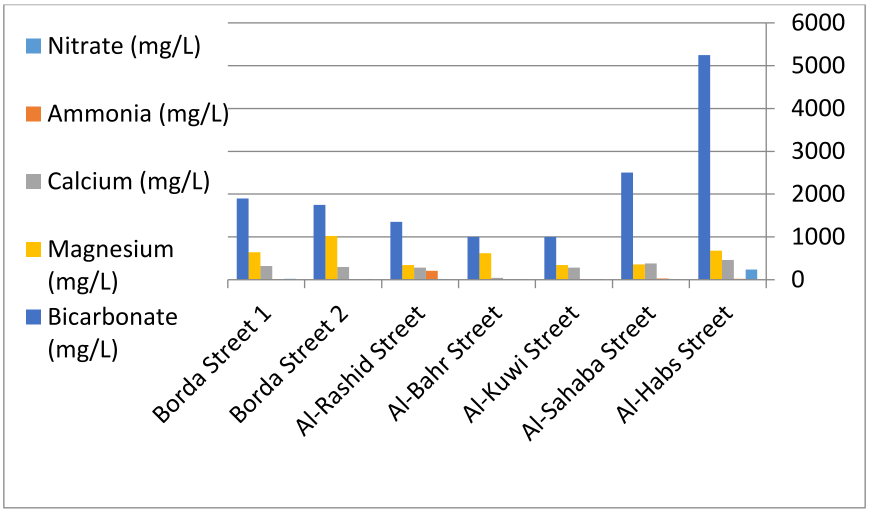

Figure 4. "Grouped Bar Chart of Water Quality Parameters (NO_3^-, NH_3, Ca^{2+}, Mg^{2+}, HCO_3^-) by Location"

Table 3. Microbial analysis of groundwater samples in Derna after Hurricane Daniel

Location	Total Coliform (CFU/100mL)	E. coli (CFU/100mL)
Al-Habs Street	150	45
Al-Sahaba Street	130	30
Al-Kuwi Street	140	35
Al-Bahr Street	160	50
Al-Rashid Street	125	25
Borda Street 2	170	55
Borda Street 1	180	60

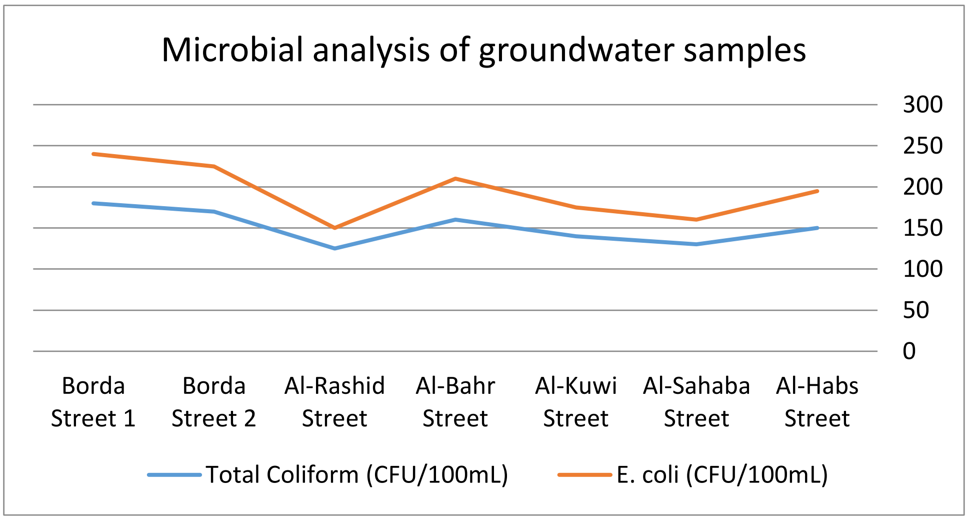

Figure 5. Concentrations of Total Coliform and E. coli in Water Samples from Different Locations in Derna.

Table 4. Classification of Water According to Total Hardness (mg/L)[1].

Water Class	Total Hardness Value (mg/L)
Soft Water	O – 60
Moderately Hard	60 – 120
Hard Water	120 – 180
Very Hard Water	‹ 180

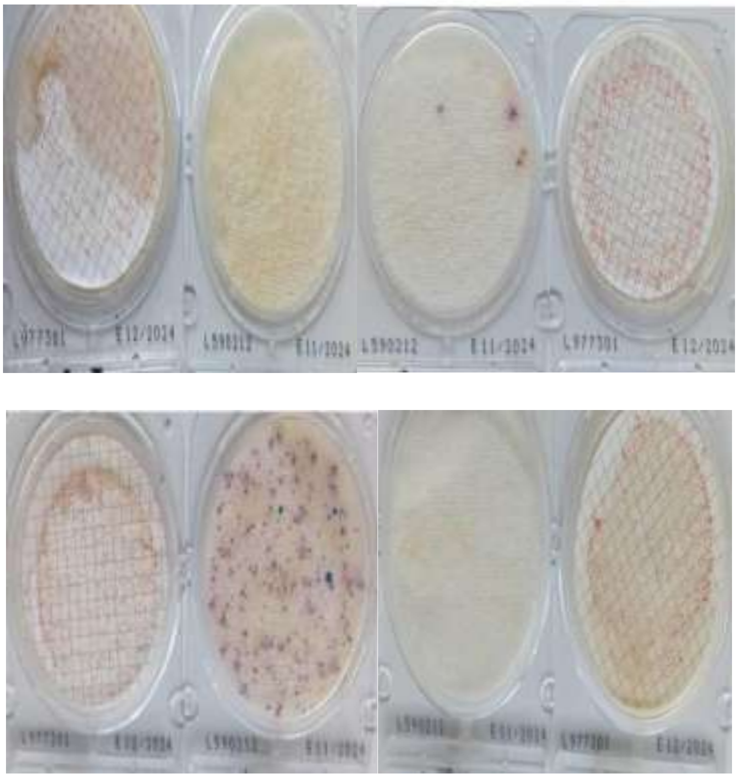

Figure 6. some result of TC and EC test using Hach m-ColiBlue 24 medium.

- **pH values** ranged from 7.2 to 7.9, indicating near-neutral conditions across all sites.
- **Electrical conductivity (EC)** and **total dissolved solids (TDS)** showed significant variation, with the highest values recorded at Borda Street 1 (2531 µS/cm; 1990 mg/L) and the lowest at Al-Sahaba and Al-Kuwi Streets (1358 µS/cm; 1060 mg/L).
- **Total hardness (TH)** exceeded 500 mg/L in all samples, with the highest value at Borda Street 1 (1320 mg/L).
- **Chloride concentrations** varied between 411.8 and 866.2 mg/L, with the highest levels at Al-Habs Street.
- **Nitrate (NO_3^-)** concentrations ranged from 0.35 to 205 mg/L, with Al-Rashid Street showing the highest level.
- **Ammonia (NH_3)** concentrations varied widely, from 0.04 mg/L at Borda Street 2 to 24 mg/L at Al-Habs Street.

- **Calcium and magnesium** levels were elevated, with calcium ranging from 300 to 680 mg/L and magnesium from 40 to 1020 mg/L.

- **Bicarbonate concentrations** were extremely high, ranging from 2000 to 10,500 mg/L.

- **Microbiological analysis** revealed total coliform counts between 125 and 180 CFU/100 mL and *E. coli* counts between 25 and 60 CFU/100 mL, exceeding WHO standards.

These results demonstrate widespread deterioration of groundwater quality in Derna following the hurricane.

Discussion

The results indicate that groundwater quality in Derna has been severely compromised by Hurricane Daniel, with multiple parameters exceeding both Libyan and WHO standards [8, 6].

- **Salinity and TDS/EC:** Elevated TDS and EC values, particularly at Borda and Al-Rashid Streets, suggest seawater intrusion and contamination from floodwaters. Similar findings were reported in Tripoli, where seawater intrusion was linked to over-extraction and aquifer depletion [14]. High salinity levels reduce water suitability for both drinking and irrigation [20, 26].

- **Hardness and Chloride:** The high total hardness values (>500 mg/L) and elevated chloride concentrations (>250 mg/L) indicate significant mineralization, likely due to geological formations and seawater mixing. Comparable results were observed in Benghazi and Kufra aquifers [2, 10].

- **Nitrate and Ammonia:** Ammonia levels at Al-Rashid Street (205 mg/L) far exceeded WHO limits, confirming sewage infiltration. High nitrate concentrations at Al-Habs Street (24 mg/L) further support this, as ammonia is a key indicator of fecal contamination [5, 24]. Similar post-flood contamination was documented in Pakistan [7] and Yemen [9]. Recent studies emphasize that nitrate and ammonia pollution pose severe risks to human health, including methemoglobinemia and hypertension [26, 27].

- **Calcium, Magnesium and Bicarbonate:** The results indicate that calcium and magnesium concentrations in most samples exceeded the recommended limits set by the World Health Organization [8]. This is attributed to the geological nature of the region, where limestone and dolomitic formations dominate, contributing to elevated levels of these ions [1, 22]. Additionally, the high bicarbonate concentrations (2000–10500 mg/L) reflect a strong buffering capacity; however, such elevated values impart an undesirable taste to the water and increase the likelihood of corrosion in distribution networks [28].

- **Microbiological Contamination:** All samples showed the presence of *Escherichia coli* and total coliform bacteria at levels exceeding permissible limits, rendering the water unsuitable for drinking. According to WHO standards [8], drinking water must be completely free of *E. coli*. These findings suggest direct infiltration of sewage into groundwater aquifers, consistent with previous studies conducted in Pakistan and Yemen following flood events [9], [7]. The simultaneous presence of ammonia and nitrate alongside microbial contamination further supports the hypothesis of recent fecal pollution [5], [24].

- **Health Implications:** Exceeding the permissible nitrate concentration in certain locations (205 mg/L) poses a direct threat to public health, as it is associated with methemoglobinemia (blue baby syndrome), hypertension, and allergic reactions [26]. Moreover, elevated ammonia levels (24 mg/L) increase the risk of bacterial toxicity and negatively affect water quality [27].

- **Environmental and Climatic Dimensions:** The findings confirm that flooding caused by Hurricane Daniel accelerated groundwater contamination. This aligns with reports from the Intergovernmental Panel on Climate Change (IPCC), which indicate that climate change will intensify the frequency and severity of natural disasters, thereby amplifying the risks of groundwater pollution [3], [20]. Recent studies also highlight that coastal regions in North Africa are particularly vulnerable to seawater intrusion and groundwater quality degradation [26], [28].

- **Proposed Solutions:**

To address these challenges, the study recommends the following:

1. **Implementation of advanced treatment technologies** such as nanofiltration and reverse osmosis to remove salts and nitrogen-based contaminants [26], [29].
2. **Utilization of bioremediation techniques** and natural adsorbents like biochar to reduce concentrations of nitrate and ammonia in groundwater [27].
3. **Strengthening periodic monitoring programs** using standardized protocols from APHA and USEPA to ensure early detection of contamination [17], [18].
4. **Raising community awareness** about the health risks associated with consuming contaminated water and encouraging the use of safe water sources [12].
5. **Developing sustainable water resource management plans** that incorporate climate change adaptation and population growth considerations, in alignment with recommendations from UNEP and UNESCO [20], [25].

Conclusion

This research provides a comprehensive assessment of groundwater quality in Derna, Libya, following the catastrophic flooding caused by Hurricane Daniel. The results showed that most of the physicochemical and microbiological parameters were higher than the acceptable limits set by Libyan and WHO rules [6, 8]. The presence of high levels of total dissolved solids, electrical conductivity, hardness, chloride, nitrate, and ammonia, as well as the widespread presence of Escherichia coli and total coliform, indicated that groundwater resources were severely contaminated. These results demonstrate the vulnerability of aquifers in coastal or flood-prone regions, where seawater intrusion, sewage infiltration, and geological factors collectively degrade water quality [14, 26, 28]. The consequences of this study extend beyond immediate health risks, such as methemoglobinemia, gastrointestinal disorders, and microbial infections [7, 26], resulting in persistent challenges for water security, agriculture, and sustainable development in Libya. The results underscore the imperative for advanced treatment techniques, including nanofiltration, reverse osmosis, and biochar-based remediation, to alleviate nitrate, ammonia, and microbial contamination [27, 29]. To stop public health disasters from happening, we also need strong monitoring systems that follow APHA and USEPA rules [17, 18]. These systems should be able to find contamination early. Also, community awareness programs should be a top priority to teach people about the risks of drinking untreated groundwater and to promote safe water use [12]. Integrated water resource management policies that include adapting to climate change are very important for making us more resilient to future disasters [3, 20, 25]. The study shows that the groundwater in Derna is not safe to drink right now and needs to be fixed right away. Libya can safeguard its groundwater resources and mitigate the impacts of future climate-related disasters through scientific monitoring, enhanced treatment, andsustainable.

Recommendations

Based on the findings of this study, several recommendations are proposed to improve groundwater quality management in Derna and similar flood-prone regions:

1. **Implementation of Advanced Treatment Technologies:**
   Adoption of nanofiltration, reverse osmosis, and biochar-supported remediation techniques is essential to reduce nitrate, ammonia, and microbial contamination [26, 27, 29].
2. **Establishment of Continuous Monitoring Programs:**
   Regular monitoring of groundwater quality using standardized protocols (APHA, USEPA) should be institutionalized to ensure early detection of contamination and to guide timely interventions [17, 18].
3. **Protection of Groundwater Sources:**
   Contaminated wells should be sealed or rehabilitated, and protective zones should be established around vulnerable aquifers to prevent further sewage infiltration [6, 28].
4. **Community Awareness and Public Health Campaigns:**
   Educational programs should be launched to inform residents about the risks of consuming untreated groundwater and to promote safe water practices [12].
5. **Integration of Climate Change Adaptation into Water Management:**
   Policymakers should incorporate climate resilience into national water strategies, as highlighted by IPCC and UNEP reports, to mitigate the impacts of future extreme weather events [3, 20, 25].
6. **Promotion of Sustainable Agricultural Practices:**
   Reducing excessive fertilizer use and improving irrigation efficiency can minimize nitrate leaching into aquifers, thereby protecting groundwater quality [19, 26].
7. **Strengthening Institutional and Legal Frameworks:**

Updating Libyan water quality standards and enforcing stricter regulations on wastewater management are critical steps toward sustainable groundwater governance [8, 6].

By implementing these recommendations, Libya can enhance the resilience of its groundwater resources, safeguard public health, and ensure sustainable water security in the face of climate change and future disasters.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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