

Bacteriological assessment of coastal waters: A case study of terga beach

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Abstract

This study investigates the bacteriological quality of coastal waters at Terga Beach, Ain Temouchent, Algeria. In August 2024, five water samples were collected using sterile 900 mL glass bottles and analyzed within six hours using ISO-standard membrane filtration methods to detect total coliforms, faecal coliforms (*Escherichia coli*), faecal streptococci, and clostridia (*Clostridium perfringens*). Results showed uncountable levels of total and faecal coliforms (>2400 CFU/100 mL), indicating severe recent faecal contamination, likely from untreated domestic wastewater. Faecal streptococci averaged 5 CFU/100 mL (± 1.58), while clostridia averaged 11.2 CFU/100 mL (± 1.30), pointing to intermittent and historical pollution. These values exceed national and international bathing water standards, raising public health concerns. The study calls for improved wastewater infrastructure, stricter environmental enforcement, and routine microbiological monitoring using advanced techniques. These measures are vital for protecting coastal ecosystems and ensuring safe recreational water use.

Keywords: Bacteriological analysis, total coliforms, faecal coliforms, faecal streptococci, clostridia.

Évaluation bactériologique des eaux côtières : étude de cas de la plage de Terga

Résumé

Cette étude évalue la qualité bactériologique des eaux côtières de la plage de Terga, dans la wilaya d'Aïn Témouchent, en Algérie. En août 2024, cinq échantillons d'eau ont été prélevés à l'aide de bouteilles stériles de 900 mL et analysés sous six heures selon les méthodes de filtration sur membrane normalisées ISO pour détecter les coliformes totaux, les coliformes fécaux (*Escherichia coli*), les streptocoques fécaux et les clostridies (*Clostridium perfringens*). Les résultats ont révélé des niveaux incalculables de coliformes totaux et fécaux (>2400 UFC/100 mL), indiquant une contamination fécale récente et sévère, probablement liée aux rejets d'eaux usées domestiques non traitées. Les streptocoques fécaux affichaient une moyenne de 5 UFC/100 mL ($\pm 1,58$) et les clostridies 11,2 UFC/100 mL ($\pm 1,30$), témoignant d'une pollution intermittente et ancienne. Ces valeurs dépassent les normes nationales et internationales. L'étude recommande un renforcement des infrastructures d'assainissement, une surveillance microbiologique régulière et l'application stricte des réglementations pour préserver la santé publique et les écosystèmes côtiers.

Mots clés: Analyse bactériologique, coliformes totaux, coliformes fécaux, streptocoques fécaux, clostridies.

INTRODUCTION

In summer, beaches are among the most frequented destinations for tourists and swimmers, who often base their choices on the apparent cleanliness and clarity of the water. However, the aesthetic appearance of water does not always reflect its microbiological quality, as it may still harbor harmful microbial contaminants (De Giglio et al., 2022).

Monitoring the bacteriological quality of coastal waters is therefore essential to ensure the safety of recreational water users and to protect public health.

The disruption of marine ecosystems through contamination by harmful microorganisms has emerged as a significant ecological and public health issue. Coastal areas,

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such as Terga Beach in Ain Temouchent, Algeria, are particularly vulnerable to pollution from various sources. Among the most concerning contributors are untreated or inadequately treated wastewater and plastic pollution. The discharge of untreated or poorly treated domestic and industrial effluents introduces pathogenic microorganisms, organic matter, and nutrients into marine environments, fostering the proliferation of harmful microbes (**Manini et al., 2022**). Additionally, plastic pollution, particularly microplastics, exacerbates the problem by acting as vectors for microbial colonization, allowing pathogenic bacteria to persist in the aquatic ecosystem (**Koelmans et al., 2019**).

Plastics in aquatic environments significantly impact microorganisms by altering habitats and supporting the formation of the "plastisphere," where microbes colonize plastic surfaces. The study in the Xiangjiang River found that microplastics influenced both prokaryotic and eukaryotic microbial communities. Notably, Proteobacteria, Actinobacteria, and Firmicutes were dominant prokaryotes, while Chloroplastida, SAR, Ascomycota, and Rotifera were common eukaryotes. Smaller microplastics (50–100 μm), particularly transparent and black ones, showed stronger correlations with these microorganisms. For example, transparent microplastics were positively correlated with Chlorophyta and Planctomycetota, while black microplastics correlated with Proteobacteria. In sediments, microplastics showed significant relationships with Gemmatimonadota, Myxococcota, and Acidobacteriota. These interactions suggest that plastics can change microbial community structure, enhance colonization by specific taxa, promote potential pathogenicity or antibiotic resistance, and alter metabolic processes—posing ecological risks to aquatic systems (**Zhao et al., 2024**).

In western Algeria, beaches such as Stidia, Sablettes, and Mersat-El-Hadjadj recorded a mean microplastic abundance of 55.47 ± 48.01 items/ m^2 , with fragments constituting nearly 80% of all microplastic debris (**Bentaallah et al., 2023**). Another study in Annaba highlighted that beaches such as Joannonville and Sidi Salem face severe pollution, primarily due to inadequate waste management, with plastics making up 31% of the total litter (**Djebar et al., 2024**). These statistics underscore the pressing need for water quality monitoring programs to mitigate public health risks and protect marine ecosystems in Algeria.

The quality of coastal waters in the Mediterranean, particularly in Algeria, has become a significant concern due to its impact on public health and the environment. This has led to the establishment of specific legislation, notably Executive Decree No. 93-164, which regulates the sanitary conditions of recreational waters in accordance with the guidelines issued by the International Office for Water in July 2002. These guidelines define two levels of microbial water quality: guide values, which represent optimal conditions, and imperative values, which are the maximum permissible limits to ensure safety. The key microbiological parameters include total coliforms (500/100 ml guide, 10,000/100 ml imperative), faecal coliforms (100/100 ml guide, 2,000/100 ml imperative), faecal streptococci (100/100 ml guide, no imperative value), and the complete absence of both Salmonella and enteroviruses as imperative requirements. These standards are essential for assessing whether bathing water is safe and aim to reduce the risk of infections and waterborne diseases, thus ensuring the protection of public health and supporting sustainable use of coastal environments (**Kerfouf et al., 2010**).

This study focuses on the bacteriological assessment of Terga Beach to evaluate the extent of microbial contamination and its implications

for public health. Bacteriological analyses were performed to enumerate key microbial indicators: total coliforms, faecal coliforms (*Escherichia coli*), faecal streptococci, and Clostridia (*Clostridium perfringens*). These indicators were chosen for their reliability in reflecting the presence of faecal pollution and their established use in water quality monitoring programs worldwide.

Total coliforms and faecal coliforms, particularly *E. coli*, are primary indicators of faecal contamination, signaling recent inputs of human or animal waste and the potential presence of enteric pathogens (Ashbolt et al., 2001). Faecal streptococci, including Enterococcus

species, are highly resistant to environmental stress and have been closely linked to gastrointestinal illnesses in swimmers (Harwood et al., 2014). *Clostridium perfringens*, a spore-forming bacterium, serves as a conservative indicator of long-term pollution and provides valuable insights into the historical contamination of water bodies (Stelma, 2018).

By analyzing these bacteriological parameters, this study aims to provide an evidence-based evaluation of the water quality at Terga Beach, highlight the potential risks associated with pollution sources, and inform strategies for environmental management and public health protection in the region

MATERIALS AND METHODS

1. Study Area

This study was conducted in August 2024, a period characterized by high temperatures and intense sunshine. The research focused on the bacteriological analysis of water at Terga Beach (Figure 1), located in the commune of Terga,

within the wilaya of Ain Temouchent, in northwestern Algeria. These environmental conditions are particularly significant as they can influence bacterial growth and the overall microbiological quality of coastal waters.

Figure 1: Satellite Image of Terga Beach.



Note: Satellite image of Terga Beach, Ain Temouchent, Algeria, from Google Maps. Copyright 2024 Google.

2. Sampling for Bacteriological Analysis

Water samples ($n = 5$) were collected at 11:00 AM using 900 mL sterile glass bottles from the same sampling location shown in Figure 2. The bottles had been previously washed, autoclaved, and dried in the laboratory to ensure

sterility. To obtain representative samples and minimize contamination, each bottle was submerged approximately 30 cm below the water surface, with the cap removed immediately before collection. The neck of each bottle and its cap were briefly flamed using an alcohol-soaked

cotton swab both before and after sampling. Bottles were filled to approximately three-quarters of their volume to allow for adequate oxygen exchange and proper agitation prior to

analysis. After collection, the samples were transported to the laboratory in an insulated cooler maintained at 4 °C and were analyzed within six hours to preserve microbial integrity.

Figure 2: Satellite Image of the Sampling Point.



Note: Adapted from a satellite image of Terga Beach, from Google Maps. The red point indicates the sampling location. Copyright 2025 Google.

3. Bacteriological Analysis

The bacteriological analyses were performed in a quality control laboratory in Ain Temouchent and focused on detecting and enumerating the following microbial indicators:

- Total coliforms
- Faecal coliforms (*Escherichia coli*)
- Faecal streptococci
- Clostridia (*Clostridium perfringens*)

3.1. Detection and Enumeration of Total Coliforms

The detection and enumeration of total coliforms were performed using the membrane filtration method, following the ISO 9308-1 standard. A 100 mL water sample was aseptically filtered through a 0.45 µm nitrocellulose membrane and incubated on

Lactose TTC Agar with Tergitol 7 at 37°C for 24 hours. Positive colonies were identified based on their yellow-orange pigmentation and characteristic morphology (ISO, 2014).

3.2. Detection and Enumeration of Faecal Coliforms (*Escherichia coli*)

The detection and enumeration of faecal coliforms (*Escherichia coli*) were carried out using the membrane filtration method in accordance with ISO 9308-1:2014. A 100 mL water sample was filtered through a 0.45 µm membrane and cultured on Lactose TTC Agar with Tergitol 7. The medium was incubated at 36 °C ± 2 °C for 24 hours, and positive colonies appeared as small, smooth, slightly raised, yellow-orange colonies due to lactose

fermentation (ISO, 2014; Sigma-Aldrich, 2019).

3.3. Detection and Enumeration of Faecal Streptococci

The detection and enumeration of faecal streptococci were conducted using the membrane filtration method as outlined in ISO 7899-2:1984. A 100 mL water sample was filtered through a 0.45 μm membrane and cultured on Slanetz and Bartley agar. The medium was incubated at 37°C for 44 ± 4 hours, and positive colonies appeared black due to esculin hydrolysis (ISO, 2000; Slanetz & Bartley, 1957).

3.4. Detection and Enumeration of Clostridia (*Clostridium perfringens*)

The detection and enumeration of the spores of sulfite-reducing anaerobes (clostridia), including *Clostridium perfringens*, were performed using a heat treatment and membrane filtration method in accordance with ISO 6461-2:1986. A 100 mL water sample was filtered through a membrane. To eliminate non-spore-forming bacteria, the water sample was subjected to heat treatment at 75°C to 80°C for 10 minutes. After cooling, the membrane was cultured on Sulfite-Polymyxin-Sulfadiazine (SPS) agar. Incubation was carried out at 37°C for 20 ± 4 hours under anaerobic conditions.

Positive colonies appeared black due to the reduction of sulfite to iron sulfide (ISO, 1986; Bio-Rad, 2011).

4. Quality Control and Reliability of Results

To ensure the reliability and accuracy of the bacteriological analyses, several quality control measures were implemented in the laboratory. All glassware, membranes, and culture media were sterilized prior to use, either by autoclaving or dry heat, to eliminate any risk of contamination. Sterile blanks were processed alongside the water samples to verify procedural sterility. The performance and selectivity of each batch of culture media were confirmed using known reference bacterial strains. To enhance the repeatability of the results, all analyses were conducted in triplicate, and the average of the three replicates was used for data interpretation. Additionally, incubation equipment was regularly calibrated to maintain the required temperature ranges specified in the ISO standards. Colony identification and enumeration were verified by two independent laboratory technicians to minimize subjectivity and analytical error. These rigorous quality assurance procedures ensured the generation of reliable and reproducible microbiological data.

RESULTS AND DISCUSSION

1. Bacteriological Contamination at Terga Beach

The results of the bacteriological analyses are summarized in **Table 1**, based on five replicate water samples collected from the same location and time at Terga Beach, as detailed in **Table 2**. **Figure 3** illustrates the hierarchical relationship between total coliforms, faecal coliforms, and *Escherichia coli*, which is essential for understanding the microbial indicators assessed in this study.

The data show uncountable concentrations of both total coliforms and faecal

coliforms (*E. coli*) across all samples, with each exceeding the upper detection limit of 2400 CFU/100 mL. These consistently elevated values point to severe microbial contamination, likely originating from untreated domestic wastewater discharges and surface runoff containing organic material. When benchmarked against established coastal water quality standards (**Table 3**), these levels represent a clear case of non-compliance. Specifically, the WHO guideline for *E. coli* is <500 CFU/100 mL, the EU "excellent" threshold is ≤ 250 CFU/100 mL, and the

Algerian indicative range is 200–500 CFU/100 mL—all of which are greatly exceeded. Such substantial deviations underscore the magnitude of faecal pollution and the associated public health risk. Similar levels have been observed in other coastal regions affected by anthropogenic pressures (**Megchún-García, 2015**). The persistent presence of *E. coli* specifically confirms recent faecal pollution, given its short environmental lifespan outside of the host organism (**Zubcov & Ene, 2021, p. 61**).

In contrast, faecal streptococci levels were relatively low, averaging 5 CFU/100 mL (SD = 1.58). This is well within the WHO guideline (<100 CFU/100 mL) and EU limits for both "excellent" (≤ 100 CFU/100 mL) and "sufficient" (≤ 330 CFU/100 mL) water quality (**Table 3**). This indicates intermittent contamination, as streptococci—especially *Enterococcus* species—are more resistant to environmental stress and serve as indicators of persistent pollution (**Gotkowska-Plachta & Gołaś, 2023**). Their limited presence suggests that faecal inputs are not continuous but rather episodic.

Clostridia (*Clostridium perfringens*) concentrations ranged from 10 to 13 CFU/100 mL, with an average of 11.2 CFU/100 mL (SD

= 1.30). These results fall within Algeria's indicative guideline of <100 CFU/100 mL or absence (**Table 3**), indicating moderate contamination potentially from past faecal pollution. Clostridia are known for their spore-forming capability, allowing them to survive in the environment long after contamination events (**Some et al., 2021**). The low variability across replicates further supports the notion of consistent, low-level historical pollution rather than recent acute discharges. Compared with similar coastal studies, these concentrations are moderate, suggesting recurrent but not chronic pollution events (**Sánchez Moreno et al., 2019**).

From a public health perspective, microbial contamination of recreational waters poses serious risks, including gastrointestinal illness, skin infections, and respiratory issues among beachgoers (**Leonard & Eaton, 2021**). Environmentally, such contamination can degrade water quality, disrupt aquatic ecosystems, and contribute to harmful algal blooms due to nutrient overloading (**Heisler et al., 2008**). Economically, it can lead to a decline in tourism, increased water treatment costs, and negative impacts on local fisheries (**Rangel-Buitrago et al., 2024**).

Table 1 : Results of Bacteriological Analysis of Coastal Waters from Terga Beach.

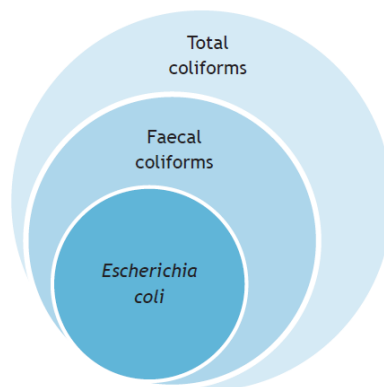
Bacterial Indicator	Measured Concentration (CFU/100 mL)	Interpretation	Environmental Significance
Total Coliforms	Uncountable	High contamination	Indicator of organic pollution from domestic sources
Faecal Coliforms (<i>E. coli</i>)	Uncountable	Recent faecal contamination	Strong indicator of human/animal waste in water
Faecal Streptococci	5	Low contamination	Resistant to environmental stress, suggests intermittent pollution
Clostridia (<i>Clostridium perfringens</i>)	11.2	Moderate contamination	Indicator of past faecal pollution due to spore persistence

Table 2: Bacteriological Analysis of Replicate Water Samples from Terga Beach.

Sample ID	Total Coliforms (CFU/100 mL)	Faecal Coliforms (<i>E.coli</i>) (CFU/100 mL)	Faecal Streptococci (CFU/100 mL)	Clostridia (<i>Clostridium perfringens</i>) (CFU/100 mL)
Sample 1	>2400	>2400	6	10
Sample 2	>2400	>2400	4	12
Sample 3	>2400	>2400	5	11
Sample 4	>2400	>2400	7	10
Sample 5	>2400	>2400	3	13
Average	>2400	>2400	5	11.2
Standard Deviation	(Not calculable, but indicates consistent 'uncountable' status)	(Not calculable, but indicates consistent 'uncountable' status)	1.58	1.30

Note: Values indicated as >2400 represent concentrations exceeding the maximum quantifiable limit of the Most Probable Number (MPN) method (i.e., too numerous to count - TNTC). The exact concentration is unknown but is confirmed to be greater than 2400 CFU/100 mL.

Figure 3: Representation of the Coliform Bacteria Group.



Note: From *Ecotoxicological methodological guide for environmental monitoring : problematics, laboratory techniques and health risk investigation* (p. 61), by E. Zubcov & A. Ene, 2021, Tipografia Centrală.

Table 3: Coastal Water Quality Standards.

Bacterial Indicator	WHO Guideline (CFU/100 mL)	EU (Excellent) (CFU/100 mL)	EU (Sufficient) (CFU/100 mL)	Algeria (Indicative) (CFU/100 mL)
Faecal Coliforms (<i>E.coli</i>)	< 500	≤ 250	≤ 500	200 - 500
Faecal Streptococci	< 100	≤ 100	≤ 330	100 - 200
Total Coliforms	-	-	-	1000 - 2000
Clostridia (<i>Clostridium perfringens</i>)	-	-	-	< 100 or absent

Note: Data adapted from WHO (2003), European Commission (2006), Ministère de l'Aménagement du Territoire et de l'Environnement (1996).

2. Relationships Between Environmental Parameters and Microbial Contaminants

Environmental parameters such as temperature, salinity, and sunlight exposure significantly influence the survival and proliferation of microbial indicators in coastal waters. Among these, temperature is one of the most critical factors affecting bacterial dynamics.

Although temperature measurements were not the primary focus of this study, the literature clearly establishes that warmer water temperatures can enhance the growth and persistence of faecal bacteria, including *Escherichia coli* and faecal streptococci (**Solo-Gabriele et al., 2015**). Elevated temperatures increase bacterial metabolic rates, decrease die-off rates, and support the growth of autochthonous bacteria, which may interfere with the detection of faecal indicators. This is particularly relevant in Mediterranean coastal environments, where summer water temperatures often exceed 25 °C, creating favorable conditions for microbial survival.

However, higher temperatures can also accelerate UV-induced bacterial decay in surface waters, especially under intense sunlight, potentially leading to diurnal fluctuations in bacterial counts (**Anderson et al., 1997**).

In summary, temperature plays a dual role: biologically, by influencing bacterial survival, and anthropogenically, by affecting pollution inputs. Future monitoring efforts at Terga Beach should incorporate continuous tracking of environmental parameters to better understand the interactions between climatic conditions and microbial contamination dynamics.

3. Recommendations for Water Quality Management

To reduce the risks associated with faecal contamination at Terga Beach, a combination of preventive and corrective measures is essential.

First, routine water quality monitoring should be implemented with increased frequency and spatial coverage, allowing for early detection and rapid response to contamination events. This should include microbiological testing (e.g., *E. coli*, *Enterococcus spp.*), as well as molecular methods such as qPCR for more accurate and rapid detection of pathogens (**U.S. EPA, 2012; Ahmed et al., 2021**).

Improving wastewater treatment infrastructure, especially in nearby urban or semi-urban settlements, remains critical. This includes upgrading existing treatment plants to ensure tertiary treatment, implementing decentralized systems for isolated communities, and preventing illegal or accidental discharges into the marine environment. The integration of real-time monitoring systems in treatment facilities can help detect failures early and avoid contamination (**WWAP, 2017**).

Nature-based solutions, such as constructed wetlands, vegetated buffer strips, and bioswales, can be strategically implemented to intercept and treat stormwater and runoff before it reaches coastal waters. These systems are cost-effective, environmentally friendly, and can enhance biodiversity while reducing pollution loads (**Masi et al., 2018**).

Public education campaigns and community engagement initiatives play a crucial role in raising awareness about the environmental and health impacts of improper sewage disposal. Promoting responsible behaviors through local outreach, signage, and school-based programs can foster a culture of environmental stewardship (**Nourredine et al., 2023**).

Furthermore, regulatory enforcement must be strengthened. This includes stricter controls on industrial and municipal effluents, regular inspections, and penalties for violations. Support for integrated coastal zone management (ICZM) should also be prioritized, ensuring that water quality goals are embedded into broader environmental, tourism, and urban development policies (**Cicin-Sain & Belfiore, 2005**).

To advance the identification of contamination sources, future approaches should incorporate microbial source tracking (MST) techniques. These use genetic markers to differentiate between human, livestock, avian, and other sources of faecal pollution (**Harwood et al., 2014**). Coupling MST with GIS-based

spatial analysis, land use mapping, and hydrological modeling can help pinpoint pollution hotspots and guide targeted interventions.

Additionally, the use of remote sensing and drones to monitor land runoff patterns, combined with in-situ sampling, can enhance surveillance capacity and improve the precision of contamination source attribution (**Kokolakis et al., 2025**).

By integrating these advanced tools with community-led monitoring and robust institutional support, Terga Beach can benefit from a comprehensive, science-based strategy for long-term water quality protection and public health safety.

CONCLUSIONS

The results of this study confirm that Terga Beach is significantly contaminated with faecal bacteria, posing a potential risk to public health and the environment. The presence of uncountable levels of total coliforms and faecal coliforms (*E. coli*) indicates recent faecal pollution, most likely resulting from domestic wastewater discharges and seasonal temperature effects that promote bacterial growth. The low detection of faecal streptococci and moderate presence of clostridia suggest that pollution is not persistent but rather occurs intermittently. Given

the importance of coastal waters for tourism and local economies, urgent measures should be taken to improve water quality. Strengthening wastewater treatment infrastructure, enforcing stricter environmental regulations, and conducting regular microbial monitoring are essential steps to mitigate contamination risks. Future studies should incorporate long-term monitoring and molecular techniques to trace pollution sources more precisely and develop targeted remediation strategies.

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