

Microbiological Characterization of Irrigation Water and Risk Assessment for Rice Production: Application of the Biological Quality Index (IBQ6) in the M'Bahiakro Irrigated Agricultural Perimeter (Central-Eastern Côte d'Ivoire)

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How to cite this paper: Bai, R., Konan, S.K., N'Cho, H.A., Oga, M.S., Kouassi, L.K. and Kouame, I.K. (2025) Microbiological Characterization of Irrigation Water and Risk Assessment for Rice Production: Application of the Biological Quality Index (IBQ6) in the M'Bahiakro Irrigated Agricultural Perimeter (Central-Eastern Côte d'Ivoire). *Open Journal of Modern Hydrology*, 15, 294-307. <https://doi.org/10.4236/ojmh.2025.154018>

Received: March 22, 2025

Accepted: August 25, 2025

Published: August 28, 2025

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Abstract

Assessing the microbiological quality of irrigation water is essential for ensuring the proper functioning of irrigated agricultural areas and securing optimal rice production yields. This study aims to evaluate the microbiological quality of irrigation water and the potential risks it poses to rice cultivation in M'Bahiakro. The adopted methodology involved identifying microbial pollution indicators such as total coliforms, fecal coliforms, *Escherichia coli*, and fecal streptococci. Water samples were collected from three (03) monitoring stations during both the dry and rainy seasons. The qualitative and quantitative identification of these microorganisms was performed by filtering 100 mL of water through a cellulose membrane filter (MF) with a uniform pore diameter of 0.45 µm. The risk to rice production was assessed using the IBQ6 index method. Results revealed high contamination levels in the irrigation water, characterized by elevated loads of total and fecal coliforms, fecal streptococci, and *E. coli*, both upstream and downstream of the dam, thereby exposing rice farming to significant health and agronomic risks. This microbial pollution is exacerbated during the dry season, when the IBQ6 scores indicate poor water quality (34 - 35/100), threatening both

crop yields and farmers' health. A slight improvement is observed during the rainy season due to dilution effects (IBQ6: 54 - 63/100), although the water quality remains insufficient to ensure sustainable irrigation. Furthermore, high concentrations of nutrients such as phosphorus and ammonia intensify anthropogenic pressure and the risks of eutrophication. These findings underscore the need for integrated water resource management, including pollution source control, community awareness initiatives, and the implementation of ecological or physical barriers to limit the spread of pathogens.

Keywords

Microbial Water Quality, Irrigated Rice Farming, IBQ6 Index, M'Bahiakro, Côte d'Ivoire

1. Introduction

Water is a vital natural resource for human survival, but it is also a powerful tool for socio-economic development. In agriculture, it plays a critical role particularly in rice paddies. Increased availability of nutrients in water promotes high grain yields, while the presence of standing surface water helps suppress weed growth and moderate soil temperature fluctuations. However, the rise in water stress due to climate change and increasing pressure on conventional water resources has led to unregulated and excessive water use, exacerbating imbalances in water distribution especially in agricultural zones. As a result, many farmers have turned to so-called unconventional water sources to meet their irrigation needs [1] [2]. These waters, often drawn from rivers, urban discharges, or partially treated wastewater, are used because of their accessibility, despite posing significant health and environmental risks.

According to [3], the presence of pathogenic bacteria in irrigation water is a major risk factor for the sanitary quality of agricultural produce. Globally, over 10% of the population is estimated to consume crops irrigated with contaminated water, raising serious public health concerns [4]. In West Africa, the rise of irrigated agriculture has been accompanied by increasing reliance on non-conventional water sources, which are often subject to fecal or chemical contamination. Several studies have confirmed the presence of fecal coliforms, *Escherichia coli*, and other pathogens in irrigation water, particularly in peri-urban areas where sanitary controls are limited [2] [5] [6]. This situation represents a major health risk for producers, consumers, and agricultural ecosystems.

Côte d'Ivoire is no exception to this trend. Studies conducted in the peri-urban areas of Abidjan, Yamoussoukro, Bingerville, and within the Bandama watershed have revealed alarming levels of fecal contamination in well, borehole, and surface waters [7]-[10]. These findings reflect the lack of systematic monitoring of water microbiological quality, despite its crucial role in agricultural productivity and sanitary safety. The irrigated agricultural area of M'Bahiakro, located in the Cen-

tral-Eastern region of Côte d'Ivoire and the focus of this study, is a strategic site for national rice production [11]-[13]. Developed as part of food security policies, this perimeter relies on an irrigation system fed by the N'Zi River. Despite its importance, data on the microbiological quality of irrigation water in this area remains scarce, even though the potential risks to public health and crop performance are considerable. Thus, this study aims to analyze the microbiological quality of irrigation water and assess associated health risks using the IBQ6 index, a standardized evaluation tool widely recognized for its ability to reflect the microbiological status of aquatic or agricultural environments. The relevance of this index in various agro-environmental contexts, particularly for assessing health risks related to irrigation, has been demonstrated by several authors [14].

2. Materials and Methods

2.1. Study Area Description

The irrigated agricultural perimeter of M'Bahiakro is located 6 km from the town itself, specifically on the right bank of the N'Zi River. The town of M'Bahiakro lies in the Iffou region, in the Central-Eastern part of Côte d'Ivoire, within Zone 30 N E. Covering an area of 450 hectares, the irrigated perimeter stretches 9 km in length with a width ranging from 300 to 1000 meters. It includes the first inflatable irrigation dam in Côte d'Ivoire [11]. The inflatable dam at M'Bahiakro stands 5 meters high, with the normal water level at an altitude of 118 meters. The topography of the N'Zi River basin particularly in the irrigated area of M'Bahiakro is characterized by flat terrain [15]. Monthly precipitation ranges from 0 to 160 mm, with an annual rainfall of approximately 1000 mm. The average temperature varies between 25.6°C and 29.1°C throughout the year. The primary economic activity of the local population is agriculture (Figure 1).

2.2. Water Sampling

Water samples were collected at three (03) monitoring stations: E1 (upstream), E2 (at the dam), and E3 (downstream) (Figure 1). The samples were taken using 250 mL glass bottles, which were labeled and stored at temperatures below 4°C in a cooler for subsequent laboratory analysis. Prior to sampling, the bottles were thoroughly washed and rinsed several times with deionized water. Sampling, transportation, and storage were carried out in accordance with the protocol defined by AFNOR standards. The sampling campaigns took place during the dry season (March 2023) and the rainy season (May 2024). The parameters analyzed included total coliforms, fecal coliforms, *Escherichia coli*, and fecal streptococci. These analyses were conducted in compliance with the French standards currently applicable in Côte d'Ivoire.

2.3. Method for Analyzing Bacteriological Parameters

The microbiological analysis of the water samples involved counting total coliforms, fecal coliforms, *Escherichia coli*, and fecal streptococci using the dilution method

combined with the membrane filtration technique (MFT). The qualitative and quantitative identification of microorganisms present in the water samples was carried out by filtering 100 mL of water through a cellulose membrane filter (MF) with uniformly sized pores measuring 0.45 μm in diameter. The membrane filtration technique (MFT) used in this selective medium is simple, faster, and more reliable [3]. A PROLABO adjustable water bath was used to regenerate the nutrient agar media in 90 mm Petri dishes. Incubation of the various bacterial strains at their respective temperatures was carried out using a P SELECTA-type incubator for 24 hours. Colony enumeration was performed with a WTW KEIMZÄHLGERÄT BZG 28 colony counter. The parameters analyzed were conducted in accordance with the French standards currently enforced in Côte d'Ivoire, as summarized in **Table 1**. Due to the high organic load (notably high turbidity and color intensity), samples were diluted to the 10th decimal dilution using sterilized water and subsequently reduced back to 100%. Prior to filtration, the liquid was fixed using lactose agar containing TTC (Triphenyl-tetrazolium chloride) and Tergitol 7.

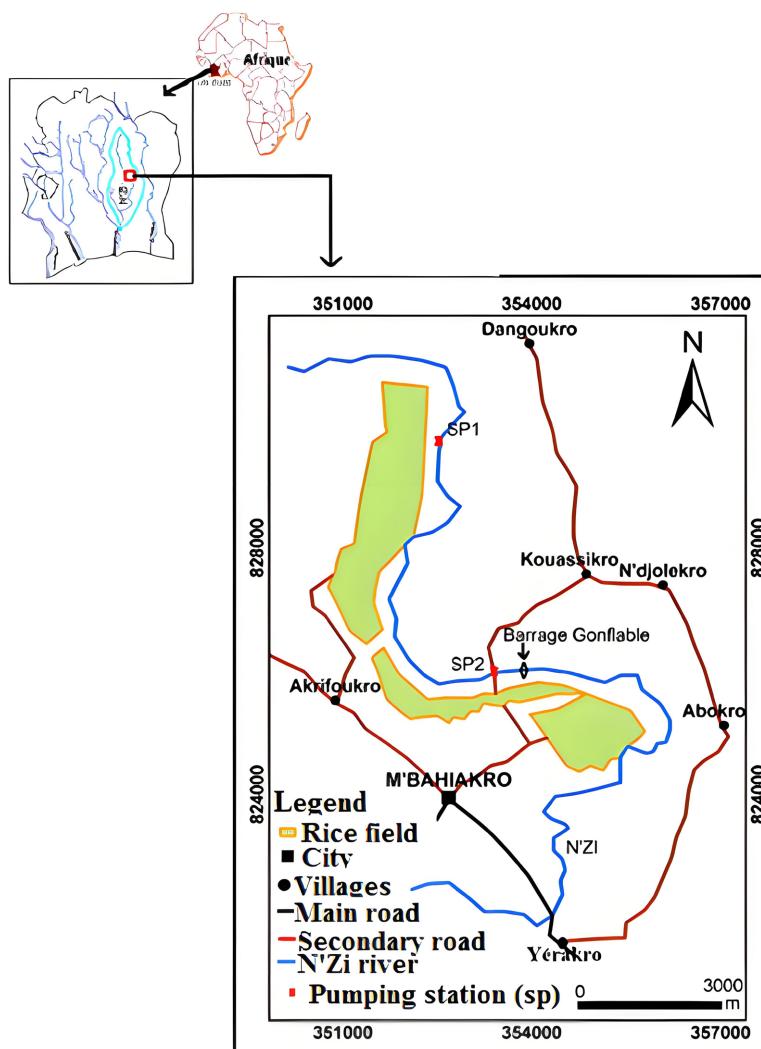


Figure 1. Location of the irrigated perimeter of M'Bahiakro [11].

Table 1. Microbiological water analysis methods.

Microbiological Parameters	Culture Medium	Reference Standard	T (°C)	Analytical method
Escherichia coli	Tryptone-Bile Glucuronate Agar	NF ISO 9308-1	44	
Fecal streptococci	Slanetz agar	NF ISO7899-2	37	Millipore membrane filtration
Fecal coliforms (FC)	Tergitol 7 and TTC agar	NF ISO 9308-1	44	
Total coliforms (TC)	Tergitol 7 agar and TTC	NF ISO9308-1	30	

2.4. Method for Assessing Microbiological Quality Risk in Rice Production

2.4.1. IQB5 and IQB6 Indices

The IQB5 and IQB6 indices, sometimes referred to as IQBP5 and IQBP6, are tools for assessing the overall quality of fresh water, particularly that of rivers and lakes. They are based on a combination of physicochemical and bacteriological parameters that allow an overall rating to be assigned to the water on a scale from 0 (very poor quality) to 100 (excellent quality). Each parameter is converted into a sub-index according to a quality scale (from 0 to 100), and the sub-indices are then combined to produce an overall score. The final score is interpreted according to a qualitative grid (excellent, good, fair, poor, very poor). This standardized and comprehensive assessment system is a valuable decision-making tool for integrated water resource management and environmental quality monitoring [16] [17]. The IQB5 index is based on five essential parameters:

- Total phosphorus (P): a key element in eutrophication processes.
- Fecal coliforms (or *Escherichia coli*): indicator of fecal pollution
- Ammoniacal nitrogen (NH_4^+) indicator of domestic or agricultural discharges.
- Nitrites-nitrates: indicators of nitrogen pollution.
- Active chlorophyll a: chlorophyll a is an excellent indicator of algal biomass.
- The IQB6 is an extension that generally includes a sixth parameter:
- Suspended solids: indicator of water mineralization or the presence of fertilizers.

2.4.2. Method for Calculating the IQB6 Index

Two methods for calculating the Bacteriological Quality Index (IBQ) or IQB5/IQB6 are used to assess water quality, particularly in irrigation or environmental contexts:

- Method 1: conversion of concentrations into sub-indices (analytical approach)
This method is the most detailed and is based on a multi-step approach [16]:

1) Method 1: conversion of concentrations into sub-indices (analytical approach)

Example: *Coliformes totaux*, *Coliformes fécaux*, *E. coli*, *Streptocoques fécaux*. The data are expressed in CFU/100 mL (colony-forming units).

- **Conversion into sub-indices (0 to 100)**

- Each parameter is compared to predefined thresholds.
- A transformation function (table or curve) associates a concentration with a quality score.
- The lower the concentration, the higher the score (and vice versa).

- **Calculation of the overall IBQ index**

In order to ensure that the results are representative, the IQBP must be assessed using samples taken between May and October inclusive, preferably spread over a period of three consecutive years [17]. At this level, there are two options:

- Average of sb-indices (flexible method)

The arithmetic means of the sub-indices obtained for each microbiological parameter (e.g., fecal coliforms, *E. coli*, fecal streptococci) are calculated:

$$\text{IBQ} = (\text{Sub-index1} + \text{Sub-index2} + \dots + \text{Sub-indexN})/N$$

- **Lowest values (strict method, known as the “minimum” method)**

The parameter with the poorest quality is considered to determine the overall quality of the water. The overall index is therefore the lowest of the sub-indices (Table 2):

$$\text{IBQ} = \text{MIN} (\text{Sub-index1}, \text{Sub-index2}, \dots, \text{Sub-indexN})$$

Table 2. Illustrative example of the overall IBQ calculation.

Parameters	Concentrations (CFU/100 mL)	Sub-index
Fecal coliforms	2500	60
<i>Escherichia coli</i>	450	85
Fecal streptococci	1200	55

Note: The overall assessment varies depending on the chosen method, and the final result is expressed on a scale from 0 to 100. It is associated with a quality class (excellent, good, fair, poor, very poor) (Table 3).

Table 3. Official interpretation scale for IQB5 and IQB6 indices [16].

IQB5/6	Class	Water Quality	Interpretation
80 to 100	A	Excellent	Very good quality water, suitable for all uses including swimming
60 to 79	B	Good	Good quality water, generally suitable for most uses
40 to 59	C	Doubtful	Questionable water quality, some uses may be compromised
20 to 39	D	Poor	Poor quality water, most uses may be compromised
0 to 19	E	Very Poor	Very poor water quality, all uses may be compromised

2) Method 2: Using an automated tool (Excel file)

The Quebec Ministry of the Environment provides a downloadable Excel file (IQBP Quebec Government Guide and Tools):

- Enter measured data (e.g., fecal coliforms = 3500 CFU/100 mL);
- The file automatically applies the transformation into sub-indices;
- It calculates the overall IQB6 or IQB5 index;
- It generates a qualitative interpretation;
- Advantage: fast, no manual conversion errors.

3. Results and Discussion

3.1. Results

Analysis of the Microbiological Quality of Irrigation Water in M'Bahiakro

The microbiological study revealed moderate to significant bacterial contamination of human and/or animal origin.

1) Total coliform bacteria and fecal coliform bacteria

Seasonal analysis of total coliform bacteria (TC) and fecal coliform bacteria (FC) in irrigation water (**Figure 2**) shows consistently high concentrations throughout the study area. Analysis of total coliform concentrations in irrigation water in the study area reveals that all measured values greatly exceed the standard of 1000 CFU/100 mL, as defined by the guidelines in [18] and [19]. The highest average values were recorded during the dry season. Furthermore, fecal coliform values indicate variable levels depending on the season and sampling site. The concentrations measured ranged from 1010 to 11,460 CFU/100 mL in the dry season and from 864 to 11,030 CFU/100 mL in the rainy season. Overall, the values recorded upstream and down-stream of the dam exceed the regulatory threshold of 1000 CFU/100 mL, confirming significant fecal contamination in these areas. However, the levels observed at the dam for both seasons remain below the critical thresholds. Finally, seasonal comparisons show that fecal coliform concentrations are generally higher during the dry season.

2) Fecal streptococci and Escherichia coli

Analysis of the data presented in **Figure 3**, concerning the concentrations of fecal streptococci and Escherichia coli in irrigation water from the N'Zi River in

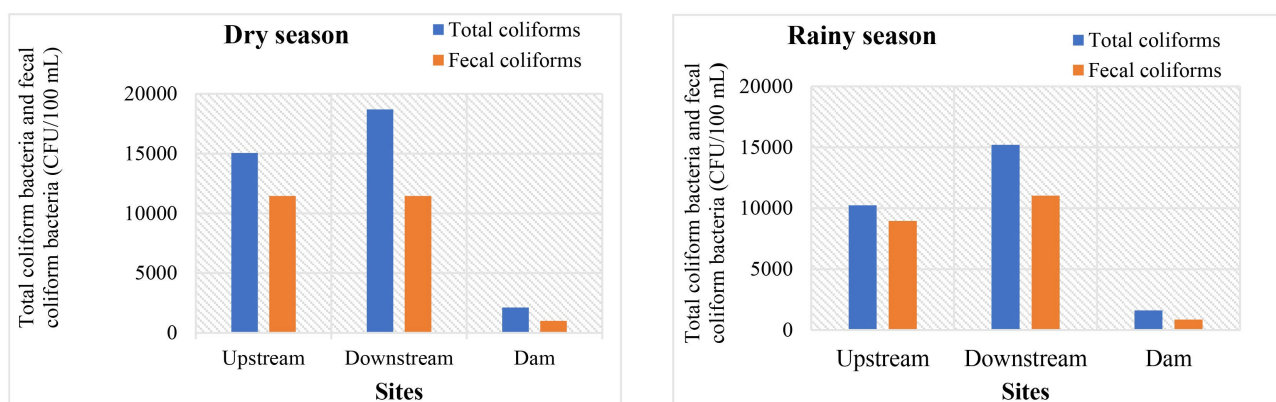


Figure 2. Coliform values in the N'Zi River at M'Bahiakro during the dry and rainy seasons.

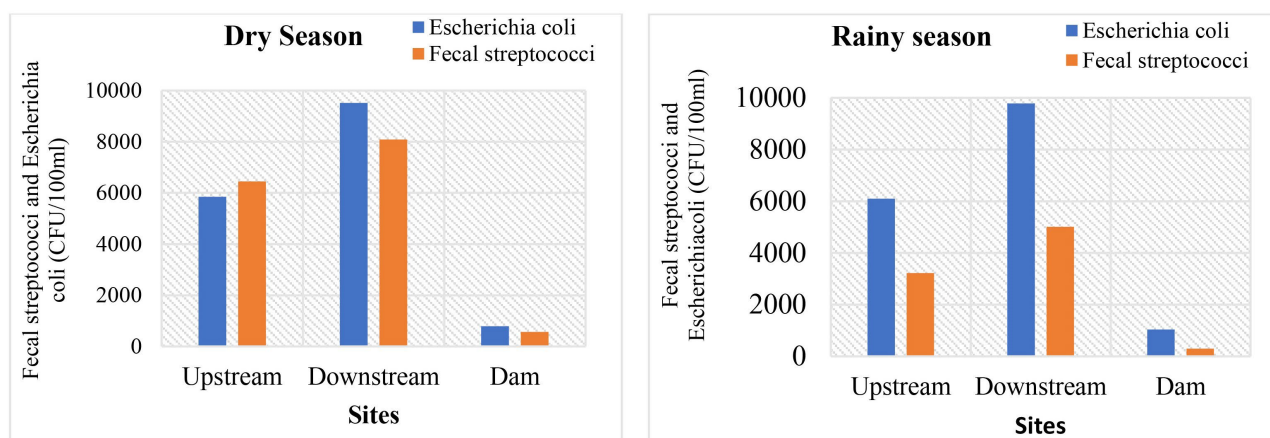


Figure 3. Values for fecal coliforms, streptococci, and *Escherichia coli* in irrigation water at M'Bahiakro.

M'Bahiakro, reveals a differentiated spatial and seasonal distribution. In general, *Escherichia coli* levels are higher than fecal streptococci levels at all sampling sites, with the notable exception of the upstream area during the dry season, where fecal streptococci concentrations are slightly higher. The highest average *E. coli* values were recorded downstream of the irrigated perimeter, regardless of the season, suggesting continuous and recent fecal pollution of human or animal origin. In contrast, significant decreases in *E. coli* levels were observed at the dam, with concentrations ranging from 790 to 1039 CFU/100 mL.

As for fecal streptococci, the highest values were also observed downstream, across all seasons. Upstream, the average concentrations of fecal streptococci do not differ significantly from those of *E. coli* during the dry season, but they remain above the threshold of 1,000 CFU/100 mL recommended by the guidelines in [18] and [19]. This situation indicates long-standing and persistent fecal contamination.

3.2. Discussion

3.2.1. Microbiological Characterization of Irrigation Water

Total coliform bacteria (TC) are a group of microorganisms found in various environments and commonly used as indicators of microbiological contamination in water. In the study area, results show that sampled irrigation waters exhibit TC concentrations significantly above the accepted threshold (>1000 CFU/100 mL) in all seasons. Although this indicator is relevant for assessing overall microbiological quality, TC cannot directly determine fecal origin. Therefore, fecal coliforms (FC) are often used to more accurately characterize contamination of human or animal origin, as they are abundantly present in feces and closely associated with untreated domestic wastewater, which often carries pathogenic agents. During this study, FC concentrations ranged from 1010 to 11,460 CFU/100 mL in the dry season and from 864 to 11,030 CFU/100 mL in the rainy season. These values reveal microbiological contamination, likely from fecal or environmental sources at the monitored sites.

Additionally, concentrations observed upstream and downstream of the dam were significantly higher than those recorded at the dam site itself, indicating marked spatial variations in water quality along the N'Zi River. These findings align with previous studies in Côte d'Ivoire [7] [20] that reported systematic fecal contamination (100%) in irrigation water from peri-urban areas of Abidjan and Korhogo. The particularly high levels of TC and FC recorded downstream may be due to the site's proximity to Yerakro village, at the entrance to M'Bahiakro, a zone under strong anthropogenic pressure (e.g., laundry, dishwashing, bathing), introducing various human-derived microbial agents. These results are consistent with the work of [21] [22], who pointed out that bacterial contamination of surface water is often linked to point sources such as latrines, septic tanks, animal pens, stables, or direct discharges of untreated wastewater. The high presence of FC in this area is further reinforced by the proximity of numerous domestic animals (cattle, goats, sheep) and household waste from nearby dwellings. Upstream, contamination appears to stem from industrial effluents, household waste from neighboring villages, and agricultural runoff entering the N'Zi River and contributing to a high microbial load. Similar situations were reported by [23] in the Lis Valley, Portugal, where high microbiological contamination was observed both upstream and downstream of a rice production system due to sources outside the irrigated perimeter. In contrast, the water in the dam shows lower coliform levels, though still exceeding regulatory thresholds. This could be attributed to the ecological nature of the rice paddies (low-intensity systems) surrounded by native vegetation that serves as habitat for diverse birdlife. Aquatic birds, common in wetlands, may also contribute to fecal contamination of the reservoirs [23]. Additionally, the presence of grazing livestock, especially cattle around the dam could explain the noticeable levels of FC. Similar findings were reported by [24] in Virginia (USA), where stream contamination from livestock decreased by 94% after installing fences to prevent direct access to surface water. In the same vein, [25] and [26] emphasized that domestic animals in agricultural areas are a major source of pathogenic microorganisms capable of contaminating both soil and surrounding water systems.

Seasonal analysis shows that FC concentrations are generally higher during the dry season, which may be explained by a concentration effect due to lower dilution of microbial loads during periods of low flow. In general, the concentrations of TC bacteria observed in this study are higher than those of FC in samples from the N'Zi River at M'Bahiakro. These results are consistent with findings by [27] [28], which noted that TC levels frequently exceed those of FC in river waters. As such, these waters may be deemed unsuitable for irrigation based on certain microbiological criteria (TC and FC), potentially posing health risks and compromising rice production in the M'Bahiakro region. In addition to coliform analysis, investigations also focused on fecal streptococci and *Escherichia coli*, two microbial indicators also recognized for their relevance in assessing fecal contamination. The results show that concentrations of both bacterial groups were signifi-

cantly higher upstream and downstream of the dam, exceeding the guideline thresholds defined by [18] and [19] in all seasons. This situation is likely due to both direct wastewater discharges and soil runoff, which can carry large amounts of fecal bacteria into the river. Specifically, downstream *E. coli* concentrations were higher than those of fecal streptococci, suggesting recent contamination likely linked to human or animal activity. *Escherichia coli* is indeed considered an excellent indicator of recent fecal pollution, as it is always present in the feces of warm-blooded humans and animals but typically absent in clean water [29] [30]. In contrast, upstream samples showed higher concentrations of fecal streptococci than *E. coli*, reflecting older fecal contamination, mostly of animal origin. These bacteria are known for their greater survival in aquatic environments, especially under high salinity conditions. Thus, all sites upstream and downstream of the dam reveal a dual origin of fecal contamination-both human and animal-which could deteriorate the quality of irrigation water and become a limiting factor for local rice production. At the dam site, concentrations of fecal streptococci and *Escherichia coli* indicate water quality that is considered passable but remains fragile according to established criteria. This situation raises concerns about the sustainability of intensive agricultural use, particularly rice cultivation, which requires relatively clean water to ensure optimal yields. This observation highlights the need to strengthen water quality monitoring and management measures, in order to preserve its agronomic potential while minimizing health risks for local communities.

3.2.2. Assessment of Microbiological Risk to Rice Production

Assessment of water quality using the IQB6 index, as defined by [16], reveals significant deterioration during the dry season, with very low scores (34 - 35/100) indicating poor quality. This situation is mainly the result of acute microbiological pollution, marked by fecal coliform concentrations exceeding 11,000 CFU/100 mL upstream and downstream, well above acceptable thresholds for irrigation. At the same time, total phosphorus (≈ 0.46 mg/L) and ammoniacal nitrogen (≈ 1.1 mg/L) levels indicate significant anthropogenic pressure, of domestic or agricultural origin, which may promote eutrophication. However, the work of [11] in M'Bahiakro showed that high levels of phosphorus, potassium, and ammonia do not necessarily pose a threat to rice cultivation, due to the high flow rate of the river, which limits algal proliferation. Nevertheless, in the context studied, the parameters analyzed reveal water quality that is unsuitable for rice production, due to major health risks for both producers and consumers. Indeed, water contaminated with fecal coliforms, ammonium, or phosphates can alter soil structure, promote the development of anoxic conditions in rice fields, and thus disrupt the physiological processes essential for rice growth. This disruption results in a significant reduction in yields. As [31], persistent anoxic conditions during sensitive stages of rice development, such as tillering or flowering, can lead to root asphyxia and compromise nutrient uptake, permanently affecting the agronomic performance of the plants. In addition, studies have shown that irrigation with polluted water

can affect the sanitary quality of rice by promoting post-harvest contamination or altering the organoleptic properties of the grain. This can compromise the marketability of the product, especially in demanding markets. Furthermore, the use of contaminated water exposes rice farmers to waterborne pathogens (salmonella, *E. coli*, etc.), increasing the incidence of skin, parasitic, or digestive infections, particularly during transplanting or manual weeding. This health risk, which is often overlooked, nevertheless constitutes a real threat in rural areas.

Furthermore, during the rainy season, a relative improvement in IQB6 scores (54 to 63/100) is observed, due to a hydrological dilution effect and natural renewal of water bodies. The dam site, with a higher score ($\approx 63/100$), appears to benefit from better regulation or a settling effect. However, this improvement remains fragile and insufficient, as fecal coliform concentrations remain high (up to 11,030 CFU/100 mL downstream), and nutrient loads remain above ecologically acceptable thresholds. Although increased water volumes during the rainy season can support rice growth, the questionable to fair quality of this water could affect rice productivity. The biological imbalances induced by this situation compromise plant health and jeopardize the sustainability of irrigated systems. As [11] pointed out, physico-chemically adequate water alone does not guarantee the viability of irrigated developments; rigorous microbiological control is essential. Similarly, [1] pointed out that microbiologically compromised irrigation water may contain enteric pathogens, which can be transferred to irrigated food crops and cause human disease. These results confirm that the overall ecological status of water remains a concern, as does the need for integrated water resource management, based on continuous microbiological monitoring, reduction of pollution sources, and the adoption of appropriate cultural practices such as resilient varietal selection, adjusted crop calendars, and controlled drainage management.

4. Conclusion

Irrigated rice cultivation is of considerable economic and social importance in Côte d'Ivoire, particularly in the M'Bahiakro region. As a strategic crop for national food security, it requires in-depth knowledge of certain abiotic factors, notably the microbiological quality of irrigation water, which is a key element of its sustainability. This study focused on assessing the microbiological quality of water used for agricultural irrigation and its impact on rice production. The results obtained reveal high water contamination, characterized by high concentrations of fecal and total coliforms, fecal streptococci, and *Escherichia coli*, detected upstream, downstream, and at the dam in the study area. This microbiological pollution, exacerbated during the dry season, compromises agronomic performance and exposes rice farmers to significant health risks, as confirmed by the IBQ6 index indicating poor water quality. A relative improvement in quality is observed during the rainy season due to the dilution effect (IBQ6: 54 - 63/100), but it remains insufficient to guarantee sustainable irrigation. In addition, high concentrations of nutrients such as phosphorus and ammonia increase anthropogenic

pressure on the aquatic environment and increase the risk of eutrophication. These results highlight the urgent need to implement integrated water resource management, including control of pollution sources, raising awareness among local communities of health and environmental issues, and adopting ecological or physical measures to limit the spread of pathogens. However, this study has certain limitations in that it is based on a primarily descriptive approach, without the use of quantitative modeling or multifactorial analyses that could establish precise correlations between water quality and rice yields. As a result, future research could further explore the impact of local agricultural practices, incorporate spatial modeling of microbiological risk, or explore the cumulative effects of water quality on rice physiology and food security in rural communities.

Acknowledgements

Avoid the stilted expression, “One of us (R. B. G.) thanks...” Instead, try “R. B. G. thanks”. Do NOT put sponsor acknowledgements in the unnumbered footnote on the first page, but here.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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