ISSN 2656-8039 (online)
International Journal of Environment, Engineering & Education
Volume 7, Issue 1, April 2025
www.ijeedu.com

Research Article

Environmental Assessment of Fishpond Water: Physicochemical and Microbial Analysis of Water Quality in Aquaculture

Pamila Erica L. Vicencio, Missy Meine C. Dela Cruz, Angelica P. Reyes*

Department of Environmental Science, College of Science, Bulacan State University, Malolos 3000, Bulacan, Philippines

Abstract

This study assesses the water quality of selected fishponds in Barangay Binakod, Bulacan, Philippines, focusing on critical physicochemical and microbiological parameters necessary for sustainable aquaculture. Key parameters, including pH, temperature, turbidity, dissolved oxygen, phosphate, nitrate, fecal coliform, and total coliform, were measured through on-site field monitoring using calibrated water quality meters and laboratory analysis of water samples. To complement the quantitative data, interviews with fishpond owners were conducted to gather qualitative insights into feeding practices, fertilizer application, and other management practices that influence nutrient loads and water quality. The collected data were compared with the standard aquaculture water quality guidelines outlined in the Department of Environment and Natural Resources (DENR) Administrative Order No. 2016-008 for Class C water bodies. This comparison highlights deviations from the recommended standards and identifies factors contributing to potential water quality issues. The study also examines how these parameters impact the growth, survival, and overall health of aquatic organisms in the fishponds, providing a comprehensive understanding of the current water quality status. The findings of the study offer evidence-based recommendations to fishpond owners, focusing on improving water quality and enhancing aquaculture production. These recommendations address nutrient imbalances, optimize management practices, and reduce environmental impacts. The results of this research contribute to the sustainable management of aquaculture in Barangay Binakod and serve as a valuable reference for improving water quality and productivity in similar aquaculture systems. The importance of maintaining optimal water quality to ensure the long-term viability and profitability of aquaculture operations while promoting environmental sustainability.

Keywords: Air Pollution; Aquaculture Systems; Dissolved Oxygen; Environmental Risks; Sustainable Management.

Received: May 27, 2024
Accepted: January 28, 2025
Published: April 9, 2025

Article Citation: P. E. L. Vicencio, M. M. C. Dela Cruz, A. P. Reyes, "Environmental Assessment of Fishpond Water: Physicochemical and Microbial Analysis of Water Quality in Aquaculture," International Journal of Environment, Engineering & Education, Vol. 7, No. 1, pp. 25-34, 2025.
https://doi.org/10.55151/ijeedu.v7i1.164

***Corresponding Author:** Angelica P. Reyes
✉ reyesangelicap8322@gmail.com

1. INTRODUCTION

Water quality plays a crucial role in determining the productivity and sustainability of aquaculture [1], [2], a significant industry in many countries, including the Philippines. As the cultivation of aquatic organisms such as fish, shrimp, and mollusks, aquaculture has become an essential solution to address the growing global demand for seafood [3]. Overfishing has led to a decline in marine fish stocks, making aquaculture a sustainable alternative to ensure food security and economic stability, particularly in fisheries-dependent nations [4]. Aquaculture contributes significantly to the country's fisheries production in the Philippines, accounting for approximately 53% of the national fish supply [5]. This sector supports food security, provides livelihoods, and drives economic growth, particularly in rural coastal communities. Adopting advanced techniques such as supplementary feeding, water quality management, and pond fertilization has enhanced aquaculture productivity by promoting better growth rates and increasing harvest yields [6]. Aquaculture operations' success relies heavily on maintaining optimal water quality. Deteriorating water quality can result in reduced growth rates, increased disease susceptibility, and lower survival rates among cultured species. Thus, consistent monitoring and managing critical water quality parameters are essential to ensure sustainability.

In the Philippines, the Department of Environment and Natural Resources (DENR) classifies water bodies designated for aquaculture under Class C, as Administrative Order No. 2016-008 stipulated. This classification applies to water bodies intended for fish propagation, the growth of aquatic organisms, and Class II recreational activities, such as boating and fishing. Biological Oxygen Demand (BOD), Total Suspended Solids (TSS), ammonia, nitrite, nitrate, and phosphate are integral to maintaining water quality [7]. Elevated concentrations of nutrients like nitrate and phosphate can result in eutrophication, leading to algal blooms and oxygen depletion, which harm aquatic ecosystems and aquaculture productivity. Furthermore, microbiological indicators such as coliform counts are vital for ensuring water safety, as they reflect the potential presence of harmful pathogens that can threaten aquatic and human health [8].

Despite its growth, aquaculture faces several challenges, including water pollution, climate change, and resource competition. The extensive use of supplementary feeds and fertilizers in aquaculture operations has led to nutrient accumulation in ponds, increasing the risk of eutrophication and disrupting aquatic ecosystems [9]. Addressing these challenges requires innovative approaches, such as integrated multi-trophic aquaculture (IMTA) systems and the application of biofilters to reduce environmental impacts while maintaining productivity [10].

The interplay between aquaculture practices and water quality underscores the need for comprehensive research and policy interventions to ensure sustainable management of aquatic resources. By addressing these challenges, the aquaculture sector can continue to meet growing demand while minimizing its ecological footprint and contributing to long-term food security and economic development.

Amid the increasing aquaculture activities in the Philippines, several challenges related to water quality demand further attention. Using supplemental feeds and pond fertilization to boost productivity often elevates nutrient concentrations in water, mainly phosphate and nitrate, which can trigger eutrophication. This phenomenon, characterized by excessive algal blooms, disrupts aquatic ecosystem balance and depletes oxygen levels, leading to hypoxia and fish mortality.

Eutrophication not only impacts the health of aquatic organisms but also degrades water quality, threatening the sustainability of the aquaculture industry [11]. Additionally, microbiological parameters such as total and fecal coliform remain critical in ensuring water safety for aquaculture and recreational purposes. Supplemental feeding and fertilization can increase organic matter in water, creating favorable conditions for microbial proliferation. While total coliform is no longer recommended as a primary indicator of water quality, fecal coliform, which originates from warm-blooded animal waste, remains a key parameter for assessing aquaculture and recreational water quality [12].

Physicochemical parameters, including pH, temperature, and turbidity, also play pivotal roles in determining the health of aquaculture systems. For instance, pH levels must remain 6.5 to 9.0 to avoid stress or mortality among aquatic organisms, and optimal water temperatures for aquaculture species typically range from 25°C to 31°C [13]. Although not directly harmful to aquatic organisms, high turbidity caused by suspended particles reduces light penetration, impairs photosynthesis, and facilitates microbial growth by interfering with disinfection processes.

These water quality issues are especially relevant in areas with intensive aquaculture activities, such as Barangay Binakod in Paombong, Bulacan. Poor water quality in such areas compromises aquaculture yields and poses broader environmental risks. Addressing these challenges requires localized data collection and monitoring systems to guide sustainable aquaculture practices.

Several previous studies have examined the relationship between water quality and aquaculture success. These studies highlight the importance of parameters such as pH, temperature, dissolved oxygen levels, and nutrients like phosphate and nitrate in determining the productivity of aquaculture systems [14], [15]. For instance, Boyd and Tucker [16] emphasized that dissolved oxygen is critical for supporting the metabolism of aquaculture organisms, while temperature fluctuations influence fish metabolism and immune responses.

Research by the National Academies of Sciences, Engineering, and Medicine [17] demonstrated that excessive phosphate in water can trigger harmful algal blooms. In contrast, nitrate promotes the growth of aquatic plants but poses a risk of eutrophication when it exceeds threshold levels. Similarly, Camargo and Alonso [18] revealed that high nitrate concentrations in aquatic ecosystems could lead to oxygen depletion and toxicity for aquatic organisms. Despite these findings, there are still limitations in the existing studies, particularly in local contexts such as the Philippines. Specific data on water quality in aquaculture areas like Binakod remain scarce, even though this region holds significant potential for aquaculture development. Aquaculture practices in the Philippines often lack comprehensive water quality data, which hampers optimal management and reduces harvest yields [19], [20].

Additionally, previous studies have predominantly focused on physicochemical aspects while paying little attention to microbiological parameters. Microbiological contamination, such as coliform bacteria, risks human health and aquaculture organisms, especially in areas with intensive aquaculture activities [8], [21], [22]. These microbiological parameters are crucial not only for ensuring the safety of aquaculture products but also for maintaining the stability of aquaculture ecosystems.

This study is crucial for enhancing our understanding of water quality in regions with intensive aquaculture activities, such as Barangay Binakod. The findings are anticipated to inform the development of improved water management policies in aquaculture and promote sustainable practices. Additionally, this research contributes to the theoretical framework concerning the impact of water quality parameters on aquaculture productivity. It serves as a reference for future studies aimed at mitigating the environmental impacts of aquaculture. Despite existing studies on water quality in aquaculture, there is a lack of research tailored to specific contexts like the Philippines. Many studies focus on general aspects without considering local conditions that may present unique challenges. In Barangay Binakod, comprehensive research examining the relationship between aquaculture intensity and changes in physicochemical and microbiological water quality is lacking.

This study aims to analyze water quality in intensive aquaculture areas like Barangay Binakod, focusing on relevant physicochemical and microbiological parameters, including pH, temperature, phosphate, nitrate, total coliform, and fecal coliform. Additionally, the research seeks to identify potential environmental risks resulting from poorly managed aquaculture practices and provide recommendations to enhance the sustainability of aquaculture in the region.

2. LITERATURE REVIEW

2.1. Water Quality in Aquaculture

Water quality plays a critical role in the health and productivity of aquatic organisms, particularly in controlled environments like aquaculture systems. The survival, growth, and overall well-being of marine species are directly influenced by key physicochemical parameters of the water, such as temperature, pH, dissolved oxygen (DO), and nutrient levels (nitrates and phosphates). According to Boyd and Tucker [23], water quality management is a cornerstone of successful aquaculture, as it ensures the habitat remains conducive to the physiological needs of fish and other cultured species. Optimal water quality not only enhances growth rates but also minimizes stress and reduces the susceptibility of fish to diseases and mortality.

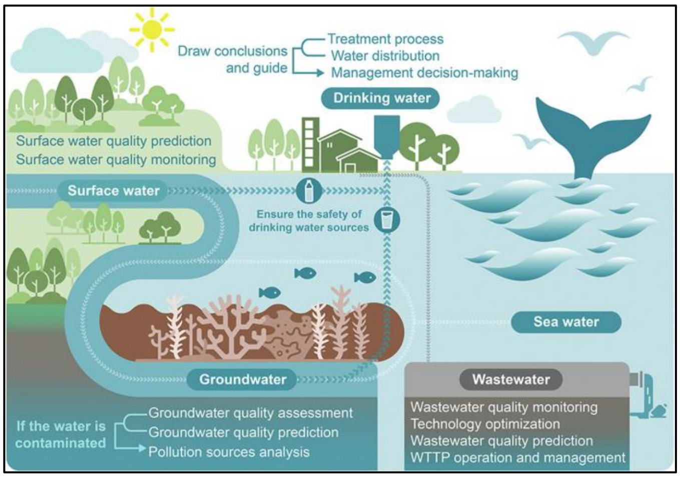

Figure 1. Machine Learning Approaches to Water Environments [24].

Ture is one of the most significant factors influencing metabolic rates in aquatic organisms. Fish species' growth and feeding efficiency, like tilapia, were maximized when temperatures remained within 25–30°C. Deviations from this range, either too high or too low, can disrupt metabolic functions and hinder growth [25]–[28]. Simulations are critical; excessive acidity or alkalinity in aquaculture ponds can affect the physiological processes of fish, potentially leading to poor health outcomes. pH values outside the optimal range of 6.5–9.0 could impair gill function, alter blood chemistry, and increase mortality [29].

Dissolved oxygen is another essential parameter. Adequate oxygen levels are necessary for respiration and energy production in aquatic species. Research conducted by Bhatnagar and Devi [30] highlights that DO concentrations below five mg/L can severely limit fish growth and may cause hypoxia, leading to mass fish kills. Conversely, over-saturation with oxygen can also cause complications, such as gas bubble disease in fish, underscoring the importance of maintaining balanced oxygen levels. High consents like nitrates and phosphates can also promote excessive algae growth, leading to eutrophication and oxygen depletion. This is particularly concerning in intensive aquaculture systems where nutrient inputs are high. Research by Van Rijn [31] emphasizes the need for regular monitoring and management of nutrient levels to prevent these harmful effects. Therefore, the successful management of why in aquaculture involves continuous monitoring of these parameters to ensure they remain within the optimal ranges. According to Pillay and Kutty [32], proactive water quality management practices, such as aeration systems, water recirculation technologies, and regular testing, are essential to mitigate the risks associated with suboptimal water conditions.

2.2. Water Pollution and Microbial Contamination

Access to clean and safe water remains a global challenge, with millions affected by water-borne pathogens such as bacteria, viruses, and parasites [33]–[35]. Polluted water impacts human health, the environment, and industries like aquaculture, which rely heavily on high water quality. Industrial discharges, agricultural runoff, and untreated sewage significantly contribute to water pollution. Agrarian runoff is significant in deteriorating aquaculture water quality, negatively affecting fish growth and increasing disease susceptibility, especially in tropical regions [36].

Microbial contamination, particularly from coliform bacteria, is a primary concern in water safety. Escherichia coli (E. coli) and other fecal coliforms are often used as indicators of microbial contamination, signaling the presence of pathogens that pose risks to both human health and aquatic life. Naddeo et al. [37] found that E. coli contamination levels in aquaculture waters in developing countries often exceed safe limits, resulting in significant economic losses. Mondal et al. [38] also noted a strong correlation between bacterial loads in commercial fish ponds and disease outbreaks, which can reduce harvest yields.

Microbial contamination in aquaculture is a significant issue as it can lead to substantial economic losses and pose public health risks. Traditional methods like multiple tube fermentation (MTF) have been used for a long time due to their reliability in measuring microbial contamination [39]. However, these methods are quite time-consuming and laborintensive, which has driven the adoption of more advanced techniques such as Polymerase Chain Reaction (PCR). PCR-based methods offer significant advantages with their ability to detect specific bacterial DNA sequences quickly and accurately. PCR can effectively detect E. coli, a standard indicator of fecal contamination, in aquaculture environments [40]–[42]. This early detection capability allows aquaculture operators to take corrective actions to prevent the spread of pathogens quickly.

Environmental factors such as heavy rainfall increase microbial loads in coastal aquaculture areas in regions like the Philippines. Rain can carry pollutants and bacteria from the land into aquaculture systems, exacerbating contamination risks [19], [43]. This necessitates strict water management practices and pollution control measures, such as improving wastewater treatment infrastructure and implementing buffer zones to filter runoff before it reaches aquaculture sites. Strengthening these practices helps maintain product quality and safety and sustains the productivity and viability of aquaculture operations in these vulnerable regions.

2.3. Physicochemical and Microbial Interactions

The interplay between physicochemical properties and microbial loads in water is critical in determining aquatic ecosystems' health, biodiversity, and functioning. Temperature, pH, dissolved oxygen (DO), and nutrient concentrations influence microbial activity and aquatic organisms' morphology, physiology, and behavior. Deviations in these parameters from their optimal ranges can lead to stress in marine life, reduced biodiversity, and increased disease vulnerability [44].

Temperature significantly affects microbial growth and metabolic activity. Higher water temperatures can accelerate microbial decomposition rates, lowering dissolved oxygen levels and adversely affecting oxygen-dependent species. For instance, a study in Lake Tanganyika found that rising water temperatures, driven by climate change, caused oxygen depletion, disrupting microbial nutrient cycling and damaging fish populations critical for local fisheries [45]. Similarly, maintaining water temperatures within optimal ranges is essential for controlling microbial populations and preventing harmful algal blooms in aquaculture systems [6].

pH is another crucial factor influencing microbial dynamics. Most aquatic organisms and microbes' function within a narrow pH range, and deviations can disrupt microbial processes, particularly nutrient cycling. Research conducted in Lake Naivasha, Kenya, showed that shifts in pH affected the balance of nitrifying and denitrifying bacteria, altering nitrogen availability, which impacted aquatic productivity [46]. Therefore, the interaction between pH and microbial communities directly affects nutrient cycling and overall water quality.

Dissolved Oxygen (DO) levels are essential for aquatic respiration, particularly for aerobic organisms. Low DO concentrations, or hypoxia, often result from nutrient overloading and eutrophication, stimulating microbial oxygen consumption. A study by the Chesapeake Bay [47] demonstrated that nutrient pollution from agricultural runoff increased microbial oxygen demand, leading to seasonal hypoxic zones that severely affected fish and benthic communities. Hypoxia disrupts the balance of aquatic ecosystems, often leading to "dead zones" where life struggles to survive.

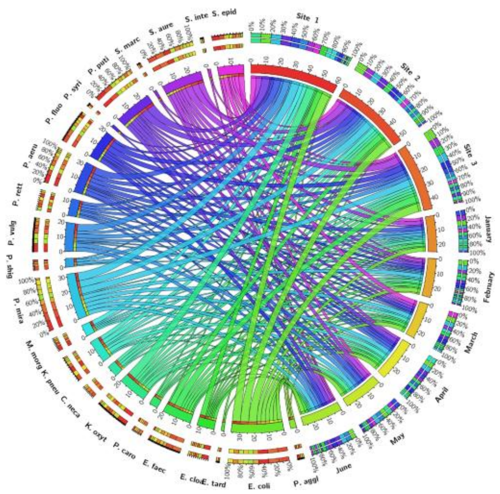

Figure 2. Cord Diagram Displaying the Distribution of Occurrence Frequencies (%) and Abundances of Bacterial Species [48].

The redundancy analysis (RDA) revealed key physicochemical factors shaping the microbial community composition (Figure 2). Specifically, elevated Water Quality Index (WQI) scores were strongly associated with declining water quality, as indicated by clustering sites with higher concentrations of fecal indicator bacterial groups. The analysis highlights those parameters such as dissolved oxygen (DO), pH, and nutrient levels (e.g., nitrate and phosphate) are critical in driving microbial community shifts. The increasing WQI scores correspond to a rise in the total fecal bacterial load, emphasizing the compounding impact of deteriorating water conditions on microbial dynamics.

Nutrient concentrations, especially nitrogen and phosphorus, further underscore the complex relationship between physicochemical parameters and microbial loads. Excessive nutrient inputs, commonly from agricultural runoff, promote the growth of opportunistic microorganisms, including harmful cyanobacteria. In Lake Okeechobee, Florida, phosphorus runoff led to recurring cyanobacterial blooms, which degraded water quality and posed significant health risks to nearby communities [49]. These blooms deplete oxygen and produce toxins that harm aquatic life and human health [50]–[53].

In aquaculture settings, monitoring these physicochemical parameters is vital. A study of water quality in mussel farms in Samar, Philippines, found that while temperature and pH levels were generally within acceptable ranges, turbidity and total solids exceeded safe limits, raising concerns about sedimentation and water clarity [54]. Elevated turbidity reduces light penetration, affecting photosynthesis and disrupting the aquatic food web. Furthermore, sedimentation may provide surfaces for microbial colonization, influencing nutrient dynamics and contributing to eutrophication.

3. MATERIAL AND METHODS

3.1. Research Design

The study employs an experimental, mixed-methods design, integrating quantitative and qualitative approaches [55], [56]. The quantitative aspect is emphasized through precise experimental procedures for collecting and analyzing water samples. These samples will be systematically obtained from two fishponds in Binakod, Paombong, Bulacan, ensuring a diverse and representative dataset.

To capture the aquatic environment's heterogeneity, samples will be collected from various depths and locations within each pond. For parameters sensitive to rapid changes, on-site testing will be conducted immediately, while other samples will be carefully preserved and transported to the laboratory for more detailed analysis. This approach ensures comprehensive and reliable data for evaluating water quality.

3.2. Research Location

The samples were collected and assessed from selected Binakod, Paombong, Bulacan fishponds. These fishponds were chosen as representative sites to evaluate the area's physicochemical and microbial parameters of water quality. Water testing for each station, conducted on 8 May 2024 in the selected fishpond in Binakod, Paombong, Bulacan, reveals several vital environmental conditions.

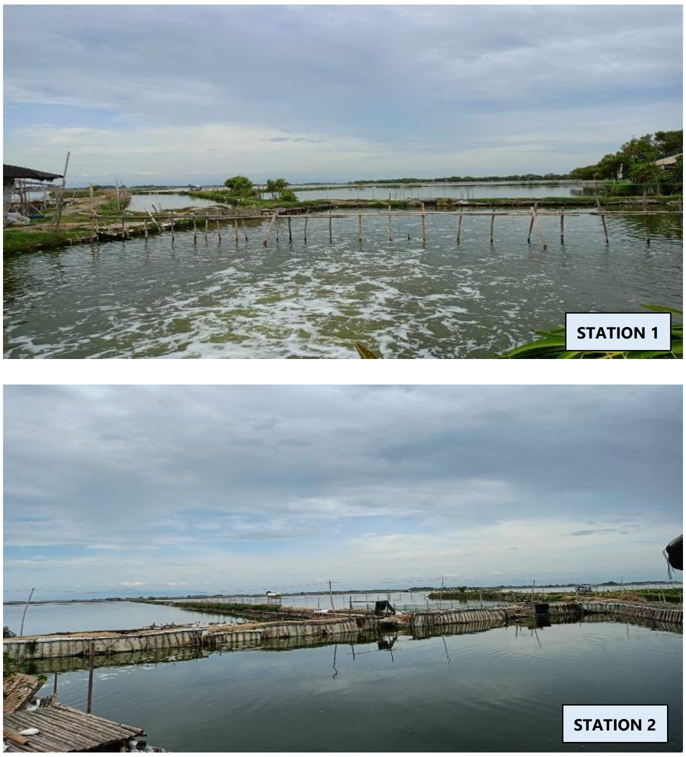

Figure 3. Research Location (STA 1 & STA 2)

The location was selected due to its significance in local aquaculture activities, where water quality plays a crucial role in the health and productivity of fish farming operations. The environmental conditions, including water sources and surrounding agricultural practices, were also considered to ensure comprehensive data collection and analysis relevant to aquaculture sustainability.

3.3. Research Equipment

To accurately assess the water quality in the selected fishponds, the researchers utilized specialized tools for on-site measurements of various physicochemical parameters. In real-time, a multi-parameter water quality meter was employed to measure temperature, pH, dissolved oxygen (DO), and salinity. The water quality meter was regularly calibrated following internationally recognized standards, ensuring the reliability and accuracy of the measurements [57]–[59]. Calibration is crucial, as even minor discrepancies in the instrument's readings could lead to significant errors in assessing water quality, particularly for sensitive parameters like dissolved oxygen, which directly influence the metabolism and survival of aquatic species [6], [23].

In addition to field equipment, chemical reagents were used to examine specific components of the water samples more thoroughly. These reagents were chosen based on their compatibility with nitrate and phosphate detection methods, which require susceptible and particular reactions [60]. Ensuring that the reagents and instruments met stringent quality standards helped maintain the scientific rigor of the research [61].

3.4. Data Collection

Water samples were collected from the field using sterile sampling bottles provided by an accredited laboratory. These samples were stored in an icebox at 4°C to prevent contamination and preserve their integrity during transport [62]. Upon arrival at the laboratory, advanced techniques such as spectrophotometry were used to measure nitrate and phosphate levels [63]. At the same time, colony-counting methods were applied to analyze total coliform and fecal coliform concentrations [60].

On-site, key parameters such as temperature, pH, dissolved oxygen, and turbidity were measured using portable instruments, as these can vary quickly based on environmental factors [6]. This dual method of real-time field data and detailed laboratory analysis provided a comprehensive assessment of the water quality in the fishponds, ensuring both accurate and contextual insights into their chemical and microbial conditions for effective aquaculture management [64]–[66].

4. RESULT AND DISCUSSION

4.1. Physicochemical Parameters

Physicochemical water testing is crucial for assessing water quality in aquatic environments. These parameters reflect physical and chemical conditions that can impact ecosystems and human health if the water is used for daily purposes. This study conducted testing at two locations, Station 1 and 2. The results are presented in tables to facilitate further interpretation of water quality at these sites.

Table 1. Water Testing Physicochemical Parameters (STA. 1).

Parameters	Results	Units	Limits
Temperature	25.0	Celsius	25-31
pH	9.91	-	6.5-9.0
Dissolved Oxygen (DO)	43.4	mg/L	5.0
Nitrates	<0.05	mg/L	7.0
Phosphates	0.27	mg/L	0.025

The results of the physicochemical water testing for Station 1, conducted on 8 May 2024, in the fishpond in Binakod, Paombong, Bulacan, indicate various environmental conditions. The water temperature was recorded at 25°C, within the acceptable range of 25–31°C, showing suitable thermal conditions for aquaculture. However, the pH value of 9.91 exceeded the recommended range of 6.5–9.0, indicating an alkaline environment that may affect aquatic life. The Dissolved Oxygen (DO) concentration was 43.40 mg/L, significantly higher than the acceptable limit of 5 mg/L, suggesting an imbalance in oxygen levels, which might stress the aquatic ecosystem.

The nitrate concentration was measured at <0.05 mg/L, remaining well below the permissible limit of 7 mg/L. On the other hand, the phosphate level was recorded at 0.27 mg/L, surpassing the allowable limit of 0.025 mg/L, which could contribute to nutrient pollution and potentially lead to eutrophication. Observations also revealed that the water had low turbidity and a yellowish hue, which is ideal for aquaculture practices.

Table 2. Water Testing Physicochemical Parameters (STA. 2).

Parameters	Results	Units	Limits
Temperature	25.0	Celsius	25-31
pH	9.21	-	6.5-9.0
Dissolved Oxygen (DO)	-	mg/L	5.0
Nitrates	<0.05	mg/L	7.0
Phosphates	0.52	mg/L	0.025

The results of the physicochemical water testing for Station 2, conducted on 8 May 2024, in the selected fishpond located in Binakod, Paombong, Bulacan, reveal several vital environmental conditions. The temperature was recorded at 25°C, within the acceptable range of 25–31°C, indicating that the thermal conditions are appropriate for aquaculture. However, the pH level of 9.21 exceeds the recommended limit of 6.5–9.0, indicating an alkaline environment similar to Station 1. This elevated pH may negatively affect aquatic organisms if it remains too high. Dissolved Oxygen (DO) was recorded at 0 mg/L, significantly below the acceptable limit of 5 mg/L, indicating a critical oxygen deficiency that could endanger aquatic life.

The nitrate concentration in Station 2 was <0.05 mg/L, well below the permissible limit of 7 mg/L, suggesting minimal nitrate pollution. However, the phosphate concentration was measured at 0.52 mg/L, far exceeding the allowable limit of 0.025 mg/L, raising concerns about nutrient pollution and potential eutrophication. Water quality observations showed high turbidity and dark yellow coloration, indicating poor water clarity. These conditions suggest that Station 2 water quality is less suitable for aquaculture than Station 1.

4.2. Microbial Parameters

Microbial water testing aims to assess the presence of microorganisms, particularly those from fecal contamination, which can affect human health if the water is used for daily purposes. In this study, testing was conducted at two locations (Station 01 and Station 02) to determine microbial contamination levels through Fecal Coliform and Total Coliform parameters.

Table 3 presents the microbial water testing results for Station 1, with samples collected from a fishpond in Binakod, Paombong, Bulacan. The Fecal Coliform level was recorded at <1.8 MPN/100mL, well below the permissible limit of 200 MPN/100mL, indicating a low risk of fecal contamination. The analysis was conducted using Multiple Tube Fermentation Techniques, a standard method for detecting coliform bacteria in water.

Table 3. Water Testing Microbial Parameters (STA. 1).

Parameters	Results	Units	Limits
Fecal Coliform	<1.8	MPN/100mL	200
Total Coliform	240	MPN/100mL	-

The Total Coliform count was measured at 240 MPN/100mL, although no specific limit was provided for this parameter. The same Multiple Tube Fermentation Techniques were employed for this measurement. While the Total Coliform levels suggest the presence of non-fecal microorganisms, further investigation may be needed to assess the potential sources and implications of this contamination, especially considering the importance of maintaining water quality in aquaculture settings.

Table 4 presents the microbial water testing results for Station 2, with samples collected from a fishpond in Binakod, Paombong, Bulacan. The Fecal Coliform level was recorded at 4.5 MPN/100mL, well below the permissible limit of 200 MPN/100mL, indicating a low risk of fecal contamination. This measurement was conducted using Multiple Tube Fermentation Techniques, a standard method for detecting coliform bacteria in water.

Table 4. Water Testing Microbial Parameters (STA. 2)

Parameters	Results	Units	Limits
Fecal Coliform	<4.5	MPN/100mL	200
Total Coliform	240	MPN/100mL	-

The Total Coliform count for Station 2 was measured at 240 MPN/100mL, although no specific limit is provided for this parameter. The same Multiple Tube Fermentation Techniques were employed for this analysis. While the low Fecal Coliform levels suggest minimal fecal contamination, the presence of Total Coliform at this level indicates that non-fecal microorganisms are present, which may require further investigation to identify potential sources and assess their implications for water quality in aquaculture environments.

4.3. Water Quality Assessment

The results from the water quality assessment at Stations 1 and 2 offer critical insights into the physicochemical and microbial conditions that influence the health and viability of these aquatic environments, particularly for aquaculture purposes. The temperature readings at both stations, recorded at 25°C, fall within the recommended range of 25-31°C, which supports a suitable thermal environment for most fish species. Maintaining the correct temperature is essential for the metabolic processes of aquatic organisms. However, temperature alone is insufficient for determining the overall water quality, as it interacts with other factors such as pH, dissolved oxygen (DO), and nutrient levels. These interactions often drive the health and stability of aquatic ecosystems.

The elevated pH levels at both stations highlight a potential risk for the aquatic life in the ponds. Station 1 exhibited a pH of 9.91, significantly exceeding the recommended range of 6.5-9.0, while Station 2 had a pH of 9.21, which exceeded the acceptable upper limit. Such high pH levels can cause several ecological issues, including ammonia toxicity, which poses serious risks to fish health, leading to reduced growth rates and reproductive failure. Moreover, these alkaline conditions can alter the bioavailability of nutrients and trace metals, which may have cascading effects on the ecosystem, particularly affecting the primary productivity and the food web. Previous studies, such as the research conducted in high-pH environments like the lakes, have documented that persistent alkaline conditions can severely disrupt the ecological balance by promoting the growth of harmful algae and cyanobacteria, leading to hypoxic conditions that stress aquatic organisms [67].

One of the most concerning results from the assessment is the significant difference in dissolved oxygen (DO) levels between the two stations. While Station 1 exhibited extremely high DO levels (43.4 mg/L), which may indicate supersaturation and excessive photosynthetic activity possibly related to algal blooms, the absence of DO at Station 2 (0 mg/L) points to an anoxic environment. Anoxia is a severe condition that results from excessive nutrient enrichment, leading to the rapid decomposition of organic matter by aerobic bacteria, which depletes the oxygen in the water. Such conditions are highly detrimental to aquatic life, mainly fish, which depend on adequate oxygen levels for respiration. The complete absence of oxygen at Station 2 suggests that the pond may be experiencing eutrophication, a phenomenon where nutrient overloading, particularly from phosphates and nitrates, fuels the overgrowth of algae, followed by their decomposition, resulting in oxygen depletion. This scenario resembles the formation of "dead zones" observed in large water bodies like the Gulf of Mexico, where nutrient runoff from agricultural lands causes widespread hypoxia, threatening marine life and reducing biodiversity [68].

The nutrient concentrations measured at both stations provide further evidence of nutrient loading, particularly phosphate levels, which exceeded acceptable limits at both locations. Station 1 recorded a phosphate concentration of 0.27 mg/L, while Station 2 had an even higher concentration of 0.52 mg/L, exceeding the recommended limit of 0.025 mg/L. Phosphates are a primary contributor to eutrophication, and their presence at elevated levels typically indicates runoff from fertilizers, wastewater, or industrial discharges. This issue is well-documented in the scientific literature, with studies demonstrating that even slight increases in phosphate levels can accelerate algal blooms, leading to oxygen depletion and the subsequent death of fish and other aquatic organisms [69]. In contrast, nitrate levels at both stations were below the detection limit (<0.05 mg/L), suggesting that nitrogen-based pollution may not be as severe. However, the disproportionately high phosphate concentrations remain a significant concern for long-term water quality and the health of the aquatic ecosystem.

Microbial contamination, particularly total coliforms, further compounds the potential risks to human and aquatic health. At both stations, total coliforms were detected at 240 MPN/100mL levels, indicating potential microbial contamination despite not exceeding regulatory thresholds. Coliform bacteria are indicators of water contamination, often associated with fecal pollution from human, animal, or industrial sources. While fecal coliforms at both stations were within acceptable limits (<1.8 MPN/100mL at Station 1 and <4.5 MPN/100mL at Station 2), the presence of total coliforms raises concerns about the overall microbial health of the water. Contamination from coliform bacteria not only affects the suitability of the water for aquaculture but also poses public health risks, mainly if the water is used for irrigation or consumption. Research from similar aquaculture environments has shown that elevated coliform levels often correlate with pathogenic microorganisms, leading to outbreaks of diseases such as cholera or typhoid fever [70], [71]. This is particularly concerning in aquaculture, where fish can act as vectors for disease transmission, emphasizing the need for regular monitoring and effective waste management strategies.

The physical characteristics of the water, including turbidity and color, provide additional evidence of water quality degradation. At Station 2, the water's high turbidity and dark yellow color indicate increased suspended solids, which can harm fish and other aquatic organisms. High turbidity reduces light penetration, limiting photosynthesis for aquatic plants and algae. It also contributes to smothering fish eggs and benthic organisms, leading to decreased reproductive success and lower survival rates. Studies on turbid environments, such as those impacted by sedimentation in the Mekong River Basin, have shown that high turbidity is often associated with increased nutrient and pollutant loads, further exacerbating eutrophication and reducing water clarity [72].

This study's combined physicochemical and microbial results underscore the complexity of managing aquaculture environments, where multiple interacting factors contribute to the ecosystem's overall health. Addressing the elevated pH, phosphate levels, and anoxic conditions will require a multi-faceted approach that includes reducing nutrient inputs, improving water aeration, and implementing more robust waste management practices. Moreover, the presence of microbial contaminants, particularly total coliforms, highlights the need for better sanitation and pollution control measures to prevent the introduction of pathogens into the water system. Future studies should focus on longitudinal monitoring to track changes in water quality over time and assess the effectiveness of intervention strategies in mitigating the identified risks.

5. CONCLUSION

The water quality assessments at Stations 1 and 2 highlight several critical challenges for sustainable aquaculture. Both stations exhibit elevated pH levels, with Station 1 exceeding acceptable limits, which could disrupt aquatic life. Phosphate concentrations at both locations were significantly higher than the recommended threshold, signaling nutrient overloading that could lead to eutrophication, promoting harmful algal blooms. Additionally, the dissolved oxygen levels, particularly at Station 2, were critically low, with anoxic conditions observed, raising concerns about the capacity of these waters to support healthy fish populations.

Microbial contamination is another pressing issue, with both stations recording high total coliform counts, suggesting potential fecal pollution. This contamination threatens the aquatic ecosystem and risks human health, especially in aquaculture operations that may rely on water quality for fish farming. These findings call for a comprehensive, integrated approach to water quality management, focusing on reducing nutrient inputs, improving oxygenation, and mitigating microbial contamination through regular monitoring and sustainable practices.

6. RECOMMENDATION

Several water quality parameters in the selected fishponds were within the acceptable limits outlined in the Water Quality Guidelines and General Effluent Standards 2016. However, turbidity, color, pH, and nitrate levels were identified as parameters of concern, requiring immediate attention from researchers and fishpond owners. High pH levels can be mitigated by adding carbon dioxide, a safe and long-lasting method to lower pH. One practical approach is introducing organic matter, such as crushed corn, which enhances carbon dioxide levels during decomposition. The resulting carbon dioxide helps stabilize pH, creating a more suitable environment for aquatic organisms.

Maintaining a vegetation buffer around the fishpond is recommended to address issues related to turbidity and color. Vegetative buffers can reduce soil erosion and runoff, effectively preventing clay turbidity. For nitrate removal, enhancing woodchip bioreactors by adding sulfur granules and seashells can optimize nitrate reduction in aquaculture effluents. These strategies improve the efficiency of bioreactors while minimizing environmental impacts. By implementing these recommendations, fishpond owners can address the identified water quality issues, maintain optimal conditions for aquaculture, and ensure sustainable fish production.

Acknowledgments

The authors of this research study extend their deepest gratitude to the fishpond owners, whose cooperation and valuable insights were instrumental in completing this work. Heartfelt appreciation is also extended to the university faculty for their unwavering guidance and expertise and to the laboratory technicians for their dedicated data collection and analysis assistance. Finally, the authors acknowledge the support and contributions of all individuals who provided invaluable advice, encouragement, and assistance throughout this research endeavor. Their collective efforts were essential to the success of this study.

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