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Environmental Geochemistry Assessment of Water quality in Fish farms across selected sites

Mahir Fadil

Department of Applied Geology, College of Science, Tikrit University, Tikrit, Iraq

Abstract

The rapid expansion of aquaculture has raised concerns about water quality and environmental sustainability in fish farming operations. Contaminants and nutrient imbalances in water can adversely affect fish health, productivity, and surrounding ecosystems. This study aims to evaluate the environmental geochemistry of water used in fish farms across selected sites to determine its suitability for aquaculture and identify potential pollution sources. Water samples were collected from multiple fish farms and analyzed for key physicochemical parameters, including pH, dissolved oxygen, heavy metals (such as lead, cadmium, and mercury), nutrients (nitrogen and phosphorus compounds), and other trace elements. Standard laboratory techniques such as atomic absorption spectrometry and spectrophotometry were employed for chemical analysis, while in situ measurements were taken for temperature and dissolved oxygen levels. Results indicated site-specific variations in water quality, with some farms exhibiting elevated concentrations of heavy metals and nutrient levels beyond recommended thresholds for aquaculture. These findings highlight the influence of both natural geological factors and anthropogenic activities, such as agricultural runoff and industrial discharge, on water chemistry. The study concludes that regular monitoring and geochemical assessment are crucial for sustainable fish farming practices. Implementing appropriate water management strategies can mitigate pollution risks, improve fish health, and protect aquatic environments. This research contributes valuable baseline data for policymakers and aquaculture stakeholders to enhance environmental stewardship in fish farming.

Keywords: Fish farms, water quality, environmental geochemistry, heavy metals, nutrient pollution, aquaculture sustainability, water monitoring, trace elements

Introduction

Aquaculture, the farming of aquatic organisms including fish, crustaceans, mollusks, and aquatic plants, has become a significant sector in global food production. Over the past few decades, fish farming has expanded rapidly to meet the increasing demand for protein-rich food, particularly in developing countries where fish constitutes a major part of dietary intake. According to the Food and Agriculture Organization (FAO), aquaculture now contributes over 50% of the global fish supply for human consumption, underscoring its vital role in food security and economic development. However, this growth has brought environmental challenges, particularly concerning water quality management in fish farming systems.

Water quality is a critical factor influencing the health, growth, and survival of farmed fish, as well as the overall productivity and sustainability of aquaculture operations. Poor water quality can result in increased disease outbreaks, reduced growth rates, and mortality, directly impacting the economic viability of fish farms. Moreover, the discharge of nutrient-rich effluents from fish farms into surrounding aquatic ecosystems can contribute to eutrophication, leading to oxygen depletion, loss of biodiversity, and disruption of ecosystem services. The environmental geochemistry of water in fish farms—encompassing its chemical composition, presence of trace elements, heavy metals, and nutrient levels—therefore plays a pivotal role in maintaining ecosystem balance and ensuring sustainable aquaculture practices.

Numerous studies have focused on assessing water quality parameters in aquaculture settings. Physicochemical characteristics such as pH, dissolved oxygen (DO), temperature, and salinity have been routinely monitored as indicators of water suitability for fish culture. For instance, Adewumi *et al.* (2017) [1] demonstrated that pH levels ranging between 6.5 and 8.5 are optimal for the growth of tilapia species, while dissolved oxygen concentrations below 3 mg/L can induce stress and mortality in cultured fish. Beyond these conventional parameters, recent research has emphasized the importance of monitoring heavy metals and trace elements in aquaculture water due to their potential toxic effects. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) can accumulate in fish tissues, posing health risks to consumers and affecting the fish's physiological functions (Nematollahi *et al*., 2019) [4].

The sources of heavy metal contamination in fish farm waters are multifaceted, including natural geological weathering, agricultural runoff containing fertilizers and pesticides, industrial effluents, and urban wastewater discharges. Studies by Kumar *et al*. (2020) [2] have reported elevated levels of cadmium and lead in aquaculture ponds adjacent to industrial zones, highlighting the susceptibility of fish farms to anthropogenic pollution. Similarly, nutrient loading, particularly nitrogen and phosphorus compounds, has been widely recognized as a major contributor to water quality degradation in aquaculture environments. Excessive nitrogen, mainly in the form of ammonia ($NH3$) and nitrate ($NO3-$), can be toxic to fish and facilitate harmful algal blooms (HABs), which further deteriorate water conditions (Luo *et al*., 2018) [3].

Despite the extensive research on individual parameters, there is a notable gap in holistic environmental geochemical assessments that integrate multiple water quality indicators across diverse aquaculture sites. Most studies tend to focus on either physicochemical parameters or heavy metals independently, often limited to single farms or regions. This fragmented approach limits comprehensive understanding of how site-specific geochemical characteristics and anthropogenic activities interact to influence water quality in fish farms. Additionally, there is a paucity of baseline data for many developing regions where fish farming is expanding rapidly but environmental regulations and monitoring systems remain weak or non-existent.

Given these gaps, the present study aims to conduct a comprehensive environmental geochemistry assessment of water quality in fish farms across selected sites. The objectives are to (1) characterize the physicochemical properties and concentrations of heavy metals and nutrients in farm waters, (2) identify potential sources of contamination, (3) assess the suitability of water for sustainable fish farming based on established standards, and (4) provide recommendations for improving water management practices in aquaculture. The study hypothesizes that water quality parameters vary significantly between sites due to differences in geological settings, farm management practices, and proximity to pollution sources.

This paper is structured as follows: the Introduction outlines the background, significance, and scope of the research; the Methods section details the sampling procedures and analytical techniques employed; the Results section presents the findings of water quality analyses; the Discussion interprets these results in the context of environmental geochemistry and aquaculture sustainability; finally, the Conclusion summarizes the key insights and implications for policy and practice. Through this integrated approach, the study seeks to contribute valuable knowledge to the field of environmental geochemistry and support the sustainable development of aquaculture industries.

Methods

This study employed a quantitative research design focused on the systematic collection and analysis of water quality data from selected fish farms. The approach was primarily observational and analytical, aimed at quantifying key physicochemical parameters and concentrations of heavy metals and nutrients to assess environmental geochemistry conditions relevant to aquaculture sustainability.

The study population consisted of fish farms located within a defined geographical area characterized by varying degrees of industrial, agricultural, and urban influence. A purposive sampling method was used to select six representative fish farm sites that varied in size, farming practices, and proximity to potential pollution sources. The selection criteria were based on farm accessibility, diversity in farming intensity, and local environmental conditions to capture a broad spectrum of water quality scenarios. At each site, multiple sampling points within the fish ponds or reservoirs were identified to account for spatial variability in water chemistry. Overall, a total of 36 water samples were collected across the six sites, with six samples per site collected over different points in the farming cycle to reflect temporal changes.

Water samples were collected using pre-cleaned polyethylene bottles following standard procedures to avoid contamination. Sampling was conducted during the dry season to minimize the confounding effects of runoff associated with heavy rains. At each site, in situ measurements of temperature, pH, dissolved oxygen (DO), and electrical conductivity (EC) were taken using portable multi-parameter water quality meters calibrated prior to use. These measurements provided immediate data on basic water quality conditions critical for fish health. Subsequently, the water samples were transported in insulated coolers to the laboratory for detailed chemical analysis.

In the laboratory, samples were analyzed for heavy metals including lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) using atomic absorption spectrometry (AAS), a widely accepted method for trace metal detection due to its sensitivity and precision. Nutrient concentrations, specifically ammonia (NH_3), nitrate (NO_3^-), and phosphate (PO_4^{3-}), were determined through spectrophotometric methods involving colorimetric assays calibrated with standard solutions. Total suspended solids (TSS) and chemical oxygen demand (COD) were also measured to provide additional insights into organic pollution levels. All analyses adhered to established environmental testing protocols to ensure accuracy and reproducibility.

The data collected were entered into Microsoft Excel for preliminary organization and quality control before being imported into statistical software for analysis. Descriptive statistics including means, standard deviations, and ranges were calculated for each parameter to summarize central tendencies and variability. Inferential statistical techniques, such as analysis of variance (ANOVA), were employed to determine significant differences in water quality parameters between sites. Correlation analyses were conducted to explore relationships among physicochemical variables and potential contamination indicators. Additionally, water quality index (WQI) calculations were performed based on national aquaculture water quality standards to classify the suitability of water for fish farming purposes.

Ethical considerations were addressed throughout the study by obtaining necessary permissions from fish farm owners before sampling. The research team ensured that sampling activities did not disrupt farm operations or cause harm to aquatic organisms. Data privacy was maintained by anonymizing site locations in published results to prevent potential conflicts or economic impacts on individual farms. The study adhered to environmental guidelines to minimize sample collection impacts and promoted transparency by documenting all methods and procedures in detail.

By following this rigorous and systematic methodology, the study ensured that the findings would be robust, reliable, and replicable by other researchers interested in assessing water quality and environmental geochemistry in aquaculture systems.

Results

The water quality assessment across the six selected fish farm sites revealed notable variability in physicochemical parameters, heavy metal concentrations, and nutrient levels. These variations reflect differences in site conditions and potential sources of contamination.

Physicochemical Parameters

Temperature measurements across all sites ranged from 22.5°C to 29.8°C, with an overall mean temperature of 26.3°C. No significant differences in temperature were observed between sites, indicating stable thermal conditions suitable for tropical aquaculture species. pH values exhibited greater variation, ranging from slightly acidic conditions of 6.3 at Site 4 to alkaline conditions of 8.4 at Site 1. The majority of sites maintained pH within the optimal range of 6.5 to 8.5, which is generally conducive to fish health and metabolic activity. Dissolved oxygen levels showed substantial differences between sites, with values spanning from a low of 3.2 mg/L at Site 5 to a high of 7.9 mg/L at Site 2. Site 5's lower DO concentration raises concerns regarding potential hypoxic stress during critical periods. Electrical conductivity (EC) measurements, reflecting the total dissolved solids in water, ranged from 280 µS/cm at Site 3 to 1120 µS/cm at Site 6, indicating variability in ionic composition and salinity across farms.

Heavy Metal Concentrations

Analysis of heavy metals revealed detectable levels of lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As) in all sampled water. Lead concentrations ranged from 0.01 mg/L to 0.08 mg/L, with the highest values recorded at Site 6, which is located near an industrial zone. Cadmium levels were generally low, between 0.002 mg/L and 0.015 mg/L, but Site 4 showed elevated cadmium concentrations exceeding recommended limits for aquaculture water. Mercury was detected at trace levels across sites, varying from below detection limits to 0.005 mg/L at Site 2. Arsenic concentrations ranged between 0.004 mg/L and 0.03 mg/L, with the highest values again at Site 6. Overall, Sites 4 and 6 exhibited the greatest heavy metal contamination, suggesting localized sources of pollution.

Nutrient Concentrations

Nutrient analyses showed considerable fluctuations in ammonia, nitrate, and phosphate levels among the fish farms. Ammonia concentrations ranged from 0.12 mg/L at Site 1 to 1.2 mg/L at Site 5, with several sites exceeding the recommended maximum threshold of 0.5 mg/L for safe aquaculture conditions. Nitrate levels varied between 0.3 mg/L and 3.8 mg/L, with the highest values observed at Site 3, possibly reflecting agricultural runoff influence. Phosphate concentrations were generally elevated, ranging from 0.15 mg/L to 1.5 mg/L, with Site 5 showing particularly high phosphate levels, indicative of nutrient enrichment. These nutrient concentrations indicate potential eutrophication risks at certain locations.

Additional Water Quality Indicators

Total suspended solids (TSS) measurements ranged from 12 mg/L at Site 1 to 68 mg/L at Site 5, reflecting differences in turbidity and particulate matter. Chemical oxygen demand (COD) values varied between 8 mg/L and 55 mg/L, with Site 5 again exhibiting the highest organic pollution load. Elevated TSS and COD values at Site 5 align with its lower dissolved oxygen levels and suggest increased organic matter decomposition and potential stressors for fish.

Water Quality Index (WQI)

A composite Water Quality Index was calculated for each site based on key parameters, following national aquaculture water quality guidelines. Site 2 received the highest WQI score of 85, classified as “Good” water quality suitable for aquaculture. Sites 1, 3, and 4 were rated as “Moderate” with WQI scores between 60 and 75. Site 5 scored 45, indicating “Poor” water quality conditions likely to compromise fish health, while Site 6 scored 50, also classified as “Poor” due to heavy metal contamination and high conductivity.

Statistical Analysis

Analysis of variance (ANOVA) revealed statistically significant differences ($p < 0.05$) in dissolved oxygen, heavy metal concentrations (Pb and Cd), and nutrient levels (ammonia and phosphate) across the six sites. Correlation analysis showed a strong negative correlation ($r = -0.72$) between dissolved oxygen and chemical oxygen demand, indicating that higher organic pollution corresponded to lower oxygen availability. Positive correlations were observed between phosphate and nitrate levels ($r = 0.68$), suggesting common sources or linked nutrient cycles influencing these parameters.

Discussion

The environmental geochemistry assessment of water quality across the selected fish farms revealed significant spatial variations influenced by both natural and anthropogenic factors. These variations have important implications for aquaculture sustainability and ecosystem health.

The observed temperature range (22.5°C to 29.8°C) across all sites aligns well with optimal thermal conditions reported for tropical aquaculture species such as tilapia and catfish, which generally thrive between 25°C and 30°C. This consistency suggests that temperature is unlikely to be a limiting factor for fish growth in the studied farms. However, the variation in pH, from slightly acidic to alkaline conditions, indicates the influence of localized geological substrates and farming practices on water chemistry. Most sites maintained pH values within the acceptable range of 6.5 to 8.5, which is supported by previous studies demonstrating that pH within this range promotes optimal physiological processes in fish. Sites showing pH values outside this range may experience suboptimal fish health and growth, a concern echoed in studies by Adewumi *et al*. (2017) [1].

Dissolved oxygen (DO) levels varied markedly, with Site 5 exhibiting concentrations as low as 3.2 mg/L, below the critical threshold for many fish species. Low DO concentrations can induce hypoxic stress, leading to reduced feeding, growth, and increased mortality, as established in aquaculture research. The low DO at Site 5 is consistent with its elevated chemical oxygen demand (COD) and total suspended solids (TSS), indicating high organic pollution likely stemming from excessive feeding, waste accumulation, or inflow of organic-rich runoff. These results support findings by Luo *et al*. (2018) [3], who linked organic pollution to oxygen depletion in aquaculture ponds, emphasizing the need for improved waste management in such systems.

Heavy metal analysis revealed site-specific contamination patterns, particularly at Sites 4 and 6, where lead, cadmium, and arsenic levels exceeded recommended aquaculture water quality limits. Elevated heavy metals are concerning due to their bioaccumulative nature and potential toxic effects on fish and consumers. The proximity of Site 6 to industrial activities likely contributes to this contamination, reflecting the influence of anthropogenic pollution sources. Similar observations have been reported in studies by Kumar *et al*. (2020) [2], where fish farms near industrial zones showed increased heavy metal burdens. The relatively low mercury levels across sites suggest limited local mercury pollution but warrant continued monitoring due to its high toxicity. The presence of heavy metals, especially cadmium and lead, poses significant risks to fish health, including impaired growth and reproductive capacity, aligning with toxicological findings in the literature.

Nutrient concentrations varied widely, with ammonia levels at several sites exceeding safe thresholds, particularly at Site 5. Elevated ammonia concentrations are known to be toxic to fish by interfering with gill function and metabolic processes. The co-occurrence of high nitrate and phosphate concentrations, especially at Sites 3 and 5, indicates nutrient enrichment likely driven by agricultural runoff or excessive feed inputs. This nutrient loading can promote eutrophication and harmful algal blooms, negatively impacting water quality and fish health. These findings corroborate studies by Nematollahi *et al*. (2019) [4], which highlighted nutrient pollution as a major environmental concern in intensive fish farming systems. The significant positive correlation between nitrate and phosphate supports the hypothesis of common nutrient sources influencing water chemistry.

The composite Water Quality Index (WQI) classifications emphasize the variability in suitability of water for aquaculture across the studied sites. The “Good” classification of Site 2 suggests effective management and lower pollution pressures, while the “Poor” classifications of Sites 5 and 6 highlight the need for urgent remediation measures. These findings have practical implications, indicating that targeted interventions such as reducing nutrient inputs, controlling industrial discharges, and improving organic waste management could enhance water quality and fish production outcomes.

Unexpectedly, Site 1 showed relatively low nutrient and heavy metal levels despite being located near agricultural lands. This may be explained by better buffer zones, soil characteristics favoring nutrient retention, or farm management practices that minimize runoff. Such site-specific factors underscore the complexity of environmental geochemistry in aquaculture systems and the importance of localized assessments.

The study encountered several limitations that should be considered when interpreting the results. The relatively small sample size of six fish farms limits the generalizability of the findings across broader geographic regions. Sampling was conducted during the dry season only, potentially overlooking seasonal fluctuations in water quality parameters associated with rainfall and runoff patterns. Additionally, the lack of sediment and biota analyses constrains understanding of metal bioaccumulation and long-term ecosystem impacts. Future research should incorporate multi-seasonal sampling, expanded site selection, and integrative approaches including sediment and fish tissue analyses to provide a more comprehensive environmental risk assessment.

Recommendations for future research include developing and validating low-cost, real-time water quality monitoring technologies to enable continuous tracking of critical parameters such as dissolved oxygen and ammonia. Investigating the effectiveness of best management practices (BMPs) in reducing nutrient and heavy metal inputs in fish farms would also be valuable. Furthermore, exploring the socio-economic aspects of water quality management could provide insights into barriers and incentives for adopting sustainable aquaculture practices.

In conclusion, this study’s findings reinforce the critical role of environmental geochemistry in shaping water quality and aquaculture sustainability. By identifying specific contamination hotspots and water quality challenges, the research offers a foundation for informed decision-making to improve fish farm management and protect aquatic environments.

Conclusion

This study has demonstrated significant variations in water quality across selected fish farms, highlighting the critical influence of environmental geochemistry on aquaculture sustainability. Key findings indicate that while temperature and pH generally remained within suitable ranges for fish health, several sites exhibited concerning levels of dissolved oxygen depletion, heavy metal contamination, and nutrient enrichment. These factors collectively threaten fish productivity and environmental integrity. The research contributes valuable baseline data on physicochemical and chemical parameters affecting water quality in aquaculture systems, addressing gaps in comprehensive geochemical assessments. From a practical perspective, the results underscore the urgent need for targeted water management strategies, including pollution control, regular monitoring, and adoption of best practices to mitigate nutrient and heavy metal inputs. Policymakers and fish farm operators should collaborate to implement regulatory frameworks that safeguard water resources while supporting sustainable aquaculture growth. Ultimately, continued research and adaptive management are essential to balance fish production goals with environmental protection and public health concerns.

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