Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 4, Issue 5 (2026)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

Assessment of Water Quality Parameters in Fish Ponds Using Physicochemical Analysis and Their Impact on Fish Growth Performance

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ABSTRACT

Water quality is the cornerstone of successful aquaculture, directly governing fish physiology, health, growth performance, and overall pond productivity. This review comprehensively assesses key physicochemical parameters in fish ponds including temperature, dissolved oxygen (DO), pH, alkalinity, hardness, nitrogenous wastes (ammonia, nitrite, nitrate), turbidity, and salinity and their intricate interrelationships. The paper examines thermal dynamics via the Q10 effect, oxygen-carbon dioxide balance, carbonate buffering systems, and the toxicological impacts of nitrogenous compounds on respiratory physiology and osmoregulation. Special emphasis is placed on how deviations from optimal ranges induce stress, suppress immunity, elevate Feed Conversion Ratio (FCR), and reduce Specific Growth Rate (SGR), often leading to disease outbreaks and economic losses. The review also explores modern analytical methodologies, the transformative role of IoT and AI in precision aquaculture, molecular insights from omics studies, and sustainable management strategies such as Integrated Multi-Trophic Aquaculture (IMTA), probiotics, and digital twins. By synthesizing laboratory findings, field observations, and species-specific optima (particularly for tilapia, carp, and catfish), this study underscores the need for continuous monitoring and proactive management to optimize fish growth and ensure sustainable aquaculture production.

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Keywords— Water Quality, Aquaculture, Physicochemical Parameters, Fish Growth Performance, Dissolved Oxygen, Ammonia Toxicity, pH and Alkalinity, Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), Precision Aquaculture, IoT in Aquaculture, Sustainable Pond Management

1. Introduction

The success of any aquaculture operation is fundamentally dependent on the quality of the aquatic medium. Unlike terrestrial livestock, aquatic organisms perform all their vital physiological and metabolic activities breathing, excretion, feeding, maintenance of salt balance, and reproduction within the water (Boyd, 2015). Consequently, the water in a fish pond is not merely a habitat but a complex, dynamic life-support system where every chemical and physical change triggers a corresponding biological response. The overall performance of any aquaculture system is significantly determined by its water quality, and the small size of fish often produced in modern systems is frequently a direct result of chronic exposure to suboptimal physicochemical conditions (Swann, 1997).

Water quality is defined by an intricate matrix of abiotic factors including temperature, dissolved oxygen (DO), transparency, turbidity, water color, pH, alkalinity, hardness, and the concentration of nitrogenous wastes. These factors are interrelated in such a way that a perturbation in one often leads to a cascade of changes in the others. For example, an increase in water temperature reduces the solubility of oxygen while simultaneously increasing the metabolic demand of the fish and the toxicity of ammonia (Ebeling et al., 2006). Maintaining these parameters within their optimum ranges is essential for maximizing fishery productivity, ensuring that the physical, chemical, and biological standards for normal fish health are met. Chronic exposure to suboptimal concentrations of even a single variable can stress the fish, making them more vulnerable to disease outbreaks, reducing growth rates, and ultimately leading to mass mortality (Francis-Floyd, 2011).

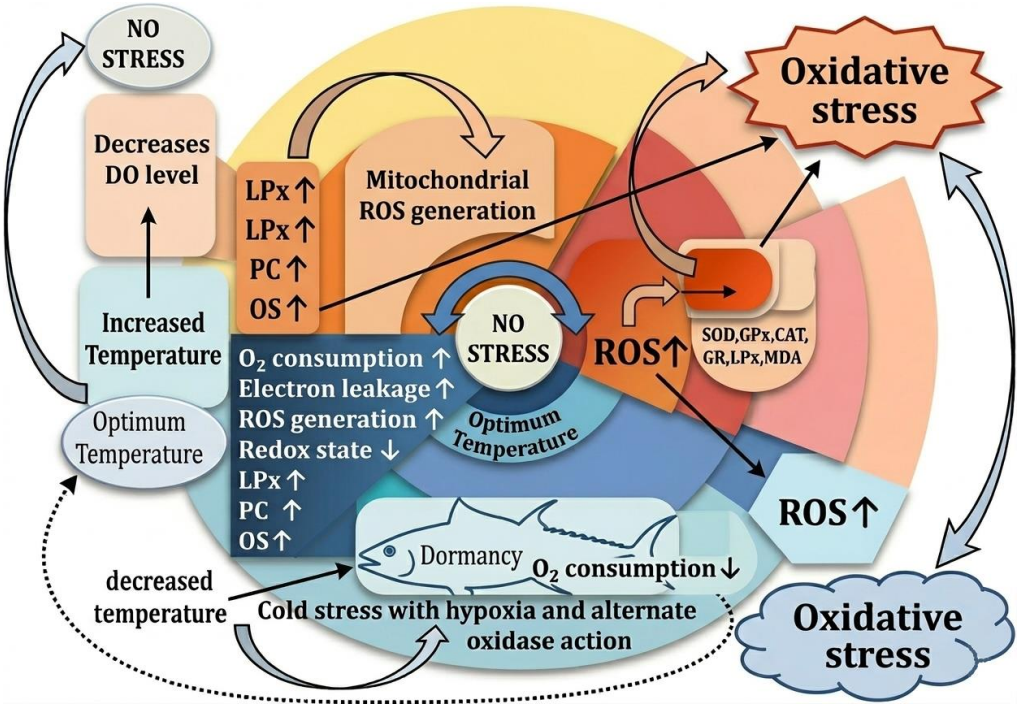
2. Thermal Dynamics and the Q_{10} Effect on Aquatic Metabolism

Water temperature is a primary governing factor in aquaculture because fish are poikilothermic, meaning their internal body temperature fluctuates with the surrounding environment. This thermal dependency dictates the rate of all biochemical reactions within the fish's body. In general, the rates of chemical and biological reactions approximately double for every 10°C increase in temperature a principle known as the Q_{10} effect. This implies that at 30°C, a fish's metabolic rate and consequent oxygen requirement are twice as high as they would be at 20°C (Mallya, 2007).

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Figure:1 Impact of Thermal Stress and Hypoxia on Mitochondrial ROS Generation and Oxidative Stress in Fish



Each species possesses a specific thermal window characterized by an optimal range for growth and survival. For instance, Nile tilapia (*Oreochromis niloticus*) grow best between 26°C and 32°C. While cold-water species like rainbow trout require temperatures between 12°C and 18°C (Piper et al., 1982). Temperatures outside these ranges impair feeding efficiency and lower resistance to infections. Furthermore, temperature influences the speed of chemical changes in both the soil and the water. In warmer ponds, fertilizers dissolve faster, herbicides act more quickly, and the rate of oxygen consumption by decaying organic matter increases (Boyd & Tucker, 1998).

Thermal stratification often occurs in ponds where surface waters heat more rapidly and become less dense than the deeper, cooler layers. This density gradient prevents the mixing of water layers, which can lead to the isolation of the bottom water (hypolimnion) from atmospheric oxygen and photosynthetic production. If the stratification is suddenly disrupted by wind or rain, the sudden mixing of oxygen-depleted bottom water can cause a rapid drop in DO throughout the pond, leading to catastrophic fish kills (Hargreaves & Tucker, 2004).

Table 1: Optimal Temperature Ranges and Critical Limits for Common Aquaculture Species

Species	Optimal Temperature (°C)	Lower Critical/Lethal (°C)	Upper Critical/Lethal (°C)

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Tilapia (Oreochromis spp.)	26 - 32	8 - 12	35 - 38
Common Carp (Cyprinus carpio)	20 - 28	< 10	> 32
Channel Catfish (Ictalurus punctatus)	24 - 30	< 10	> 34
Rainbow Trout (Oncorhynchus mykiss)	12 - 18	< 4	> 22
Indian Major Carps	20 - 37	< 16	> 40

3. The Oxygen-Carbon Dioxide Balance and Respiratory Physiology

Dissolved oxygen (DO) is arguably the most critical water quality parameter in aquaculture. It is essential for the survival of fish and for the aerobic biological processes that break down waste. DO levels in a pond are never static; they fluctuate according to a diurnal cycle driven by the balance between photosynthesis, which produces oxygen during the day, and respiration, which consumes it 24 hours a day (Bowden, 2008).

The concentration of DO is influenced by temperature, salinity, altitude, and organic waste load. Warmer water holds less oxygen than cooler water, and brackish water holds less than freshwater. In intensive systems, the demand for oxygen often exceeds the natural supply, necessitating mechanical aeration to prevent deficits. Levels below 3 mg/L because significant stress, and prolonged exposure to levels below 2 mg/L is often fatal for most tropical species (El-Sayed, 2019).

Table 2: Biological Implications of Dissolved Oxygen Concentrations

Parameter Status	DO Concentration (mg/L)	Biological Implications
Optimal	5.0 - 10.0	High feeding efficiency, rapid growth, robust immunity.
Suboptimal/Stress	3.0 - 5.0	Reduced appetite, lethargy, increased susceptibility to parasites.
Critical	2.0 - 3.0	Gasping at surface, potential for mass mortality during pre-dawn.
Lethal	< 2.0	Sudden mass mortality, collapse of the pond ecosystem.

Inversely related to DO is the concentration of carbon dioxide (CO2), which results primarily from the respiration of aquatic organisms and the decomposition of organic matter. While low levels of CO2 are normal, concentrations exceeding 10 mg/L require corrective actions, and levels above 25 mg/L are common in intensive biofloc systems, where they can cause significant health issues. CO2 has an antagonistic effect on oxygen; high environmental CO2 elevates blood CO2 (hypercapnia), which reduces the oxygen-binding capacity of hemoglobin the Bohr effect. This effectively means that even if DO levels are technically adequate, the fish may still suffer from hypoxia if

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CO2 levels are too high. Exposure to high CO2 (15 - 30 mg/L) can reduce growth by up to 38% and worsen the feed conversion ratio (FCR) by 30% (Schmidt-Nielsen, 1997) (Rajendiran et al., 2023).

4. pH, Alkalinity, and the Carbonate Buffering System

The pH of pond water, a measure of its hydrogen ion concentration, is a critical indicator of its chemical stability. Most freshwater species thrive in a pH range of 6.5 to 8.5. Like DO, pH exhibits a diurnal cycle: it rises during the day as photosynthesis removes CO2 (forming less carbonic acid) and falls at night as respiration adds CO2. Ponds with high algal concentrations experience more dramatic pH swings, which can stress the fish and harm their protective mucous membranes (Boyd, 2019)

Alkalinity and hardness are the primary components of the water buffering system (WBS). Total alkalinity measures the concentration of titratable bases, mainly bicarbonates and carbonates, which neutralize acids and stabilize pH. A pond with low alkalinity (below 20 mg/L as CaCO3) is prone to rapid pH crashes, while an alkalinity of 50 - 300 mg/L is considered ideal for buffering. Hardness, representing the concentration of calcium and magnesium ions, is essential for osmoregulation and the formation of bone and scale tissues (Wetzel, 2001).

Table 3: Impact of pH Levels on Fish Health and Physiology

pH Range	Classification	Impact on Fish Health
< 4.0	Highly Acidic	Acid stress, blood acidosis, osmoregulatory failure, mortality.
4.0 - 6.5	Acidic	Reduced growth, skin erosion, excess mucus secretion.
6.5 - 8.5	Optimal	Maximum growth performance and metabolic efficiency.
8.5 - 9.5	Alkaline	Increased risk of ammonia toxicity, potential gill irritation.
> 11.0	Highly Alkaline	Lethal due to damage to tissues and high un-ionized ammonia.

The relationship between pH and ammonia is particularly dangerous. Ammonia exists in two forms: un-ionized (NH3) and ionized (NH4+). The toxic NH3 form increases as pH and temperature rise. For instance, at a pH of 7.0, only a tiny fraction of total ammonia is toxic, but at a pH of 9.0, over a third of the ammonia becomes toxic. This synergy means that a pH spike in a pond with moderate ammonia levels can lead to a sudden toxic event (Stickney, 2017).

5. Nitrogenous Wastes: The Ammonia and Nitrite Pathways

Nitrogenous compounds are the primary chemical stressors in intensive aquaculture. They originate from the catabolism of proteins in fish feed and the subsequent excretion of ammonia through the gills, as well as the decomposition of uneaten food and feces. Ammonia is highly toxic in its un-ionized form (NH3), capable of causing gill irritation, respiratory problems, and chronic stress at concentrations as low as 0.05 mg/L. High ammonia levels impair the fish's ability to excrete its own metabolic waste, leading to

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a buildup of ammonia in the blood and tissues, which can result in neurological damage and death (Tucker & D'Abramo, 2008).

Nitrite (NO_2^-) is the intermediate product of the nitrification process, where ammonia is converted into nitrate (NO_3^-). Nitrite is toxic because it enters the bloodstream and converts hemoglobin into methemoglobin, which is incapable of transporting oxygen. This "brown blood disease" induces functional hypoxia. While nitrate is significantly less toxic and can be tolerated at higher levels, excessive concentrations still promote algal blooms and indicate a high organic load that may eventually lead to oxygen depletion (Bhatnagar & Devi, 2013).

Table 4: Recommended Limits and Toxic Mechanisms of Nitrogenous Compounds

Compound	Recommended Limit (mg/L)	Toxic Mechanism
Ammonia (NH_3)	< 0.05	Direct tissue damage, metabolic interference.
Nitrite (NO_2^-)	< 0.1	Methemoglobinemia (Brown Blood Disease).
Nitrate (NO_3^-)	< 50	Eutrophication, chronic stress at very high levels.

6. Physical Parameters: Turbidity, Depth, and Color

Turbidity refers to the cloudiness of water caused by suspended particles, and its impact depends on the nature of the particles. Planktonic turbidity is often a sign of a fertile, productive pond, providing natural food for species like tilapia. However, turbidity caused by suspended clay or silt is undesirable. Excessive inorganic turbidity (beyond 4% by volume) can clog fish gills, leading to respiratory distress, and reduces light penetration, which inhibits the photosynthesis necessary for oxygen production (Wurts & Durborow, 1992).

Water depth and color are also significant physical indicators. A depth of 1 - 2 meters is generally considered optimal; shallow ponds overheat easily, while excessively deep ponds may suffer from poor circulation and anaerobic bottom conditions. Water color provides a visual diagnostic of the pond's biological state: light green or blue indicates a healthy phytoplankton community, while dark brown or red may signal high zooplankton levels, excessive iron, or the death of an algal bloom, which can lead to rapid oxygen depletion (Sallenave, 2019).

7. Osmoregulation and the Role of Salinity and Hardness

Osmoregulation is the physiological process by which fish maintain a constant internal concentration of salts and water despite the external environment. This process is energy-intensive and is heavily influenced by the salinity and hardness of the water (Larsen et al., 2014).

Salinity fluctuations trigger a series of complex responses. For example, in Genetically Improved Farmed Tilapia (GIFT), high salinity environments force the fish to redirect energy away from anabolic processes like fatty acid synthesis toward the maintenance

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of osmotic balance. This metabolic reprogramming involves the down-regulation of genes such as Fasn (fatty acid synthase) and the up-regulation of transporters involved in ion regulation (Zhang et al., 2026).

Similarly, water hardness, specifically the presence of calcium, is vital for stabilizing the permeability of the gills. In soft water, fish lose ions more rapidly and must expend more energy to recover them. Conversely, excessive hardness can lead to hypercalcemia and premature bone ossification. Research on Koi carp suggests an optimal hardness of approximately 225 mg CaCO3/L for balancing tissue physiology and antioxidant protection (Agarwal et al., 2024).

8. Impact on Growth Performance: SGR and FCR Dynamics

The ultimate measure of water quality management is the growth performance of the fish, typically quantified through the Specific Growth Rate (SGR) and the Feed Conversion Ratio (FCR). SGR represents the daily percentage increase in fish weight, while FCR measures the efficiency of feed utilization (Riberio et al., 2024).

When water quality is suboptimal, the fish's metabolic energy is diverted from somatic growth to stress compensation a phenomenon known as the General Adaptation Syndrome. Under conditions of low dissolved oxygen (DO) or high ammonia, the fish's appetite decreases, and the energy that is consumed is used for "metabolic firefighting" rather than building muscle (University of Florida, 2021). This results in a significant decline in SGR and an increase in FCR, meaning the farmer must provide more feed to achieve the same weight gain, thus increasing costs and further deteriorating water quality through uneaten feed and increased waste (Erunwas, 2025).

In a study of tilapia growth, it was found that diurnal fluctuations in DO and \text{CO}_2 typical of "green water" ponds can reduce weight gain by over 60% compared to fish kept in stable, clear-water environments. Furthermore, the type of feed used can interact with water quality; for instance, sinking feed may have a lower FCR in certain stages because it is not properly utilized if it falls into anaerobic bottom layers, whereas floating feed allows for better observation but can lead to waste if oversupplied (Abdelhamid et al., 2019).

Table 5: Growth Metric Impacts and Physiological Mechanisms of Suboptimal Water Parameters

Parameter Constraint	Growth Metric Impact	Physiological Mechanism
Hypoxia (< 3 mg/L)	High FCR, Low SGR	Reduced metabolic capacity, anaerobic stress.
High CO2 (> 20 mg/L)	30% worse FCR	Bohr effect, blood acidosis.
Thermal Stress	Low SGR	Altered enzyme kinetics, reduced appetite.
Suboptimal pH	Increased FCR	Osmoregulatory drain, gill mucus buildup.

9. Pathological Consequences of Physicochemical Stress

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Poor water quality is a primary precursor to disease outbreaks in aquaculture. Chronic exposure to stressors like low DO, high ammonia, or extreme pH suppresses the fish's immune system, making them susceptible to opportunistic pathogens such as fungi and bacteria (Abdel-Tawwab et al., 2015).

Environmental pollution from residual bait and feces accumulates at the pond bottom, decomposing to release toxins that hamper growth and can lead to mass mortality. The use of water quality regulators like Bacillus subtilis (BS) has shown promise in mitigating these effects. BS promotes growth by secreting digestive enzymes and improves the intestinal flora, while also quickly decomposing organic matter in the water to reduce ammonia and nitrite levels. This dual action enhances both growth performance (SGR/FCR) and the non-specific immunity of the fish, as evidenced by increased serum levels of total protein and albumin (Koudijs, 2025).

10. Analytical Methodologies: Laboratory vs. Field Techniques

Assessing water quality requires a combination of physical and chemical tests, traditionally guided by protocols such as the "Standard Methods for the Examination of Water and Wastewater" (Schreck, 1981).

Laboratory analysis (APHA standards) remains the gold standard for accuracy and regulatory compliance. Techniques like titrimetric analysis for alkalinity, the Winkler method for DO, and Atomic Absorption Spectrophotometry (AAS) for mineral analysis (zinc, copper, calcium, iron) provide highly reliable data. However, these methods are labor-intensive and provide only a "snapshot" of water quality at the moment of sampling, often missing the critical diurnal fluctuations that drive fish stress (Selye, 1950).

Field monitoring has evolved from simple thermometers and Secchi discs to advanced digital multiparameter meters. Modern handheld and benchtop meters from brands like YSI, Hanna Instruments, and Horiba allow for rapid, on-site measurement of pH, DO, conductivity, and turbidity. While convenient, these field sensors require frequent calibration and are susceptible to "drift," particularly DO probes (Bambi Langa et al., 2026).

Table 6: Comparison of Analytical Methodologies for Water Quality Monitoring

Analytical Method	Parameters Covered	Advantages	Limitations
Laboratory (Standard Methods)	Heavy metals, BOD, Nutrients	Uncompromising accuracy	Time-consuming, costly
Digital Handheld Meters	pH, DO, Temp, TDS	Fast results, portable	Requires frequent calibration
IoT/Automated Systems	Continuous DO, pH, Temp	24/7 monitoring, alerts	High initial investment

11. Precision Aquaculture and the IoT Revolution

The shift toward "Aquaculture 4.0" is characterized by the integration of the Internet of

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Things (IoT) and Artificial Intelligence (AI) to create smart monitoring systems. These systems utilize arrays of sensors to continuously track critical parameters, providing a "high-resolution temporal map" of the pond's dynamics (Ahmed et al., 2024).

The IoT-AI synergy allows for proactive rather than reactive management. Machine learning models like Random Forest and Long Short-Term Memory (LSTM) networks can analyze historical data to forecast oxygen depletion or ammonia spikes days in advance (Shi et al., 2026). These systems can also automate life-support equipment, such as turning on aerators when DO drops below a set threshold, thereby reducing human error and labor costs (ITU, 2025). In field trials, AI-driven optimization tools have demonstrated up to 30% savings in feed costs and double-digit reductions in mortality rates (Martins as cited in Blue Food Innovation, 2026).

12. Molecular Insights: Omics and Metabolic Reprogramming

Advances in transcriptomics and proteomics have allowed researchers to peer into the molecular mechanisms behind water quality stress. RNA-seq analysis of fish exposed to high currents or saline-alkaline stress shows a clear downregulation of genes involved in mitochondrial energy production (oxidative phosphorylation) and the upregulation of stress-response genes related to antioxidant defense and cellular protection (e.g., UCP3, cygb1, Selenop) (Rather et al., 2024).

This molecular "reprogramming" is a survival strategy. By shifting energy production away from muscle building and toward cellular repair and osmoregulation, the fish adapts to the hydrodynamic or chemical stress at the cost of its growth. Understanding these pathways such as the FoxO and PI3K-Akt signaling pathways provides a basis for selective breeding of more resilient fish strains and the development of targeted nutritional interventions (Abdillah, 2025).

13. Management Strategies and Future Directions

The sustainable growth of the aquaculture sector depends on the implementation of holistic management strategies that prioritize water quality.

Key strategies include:

1. **Integrated Multi-Trophic Aquaculture (IMTA):** Farming diverse species (e.g., fish, bivalves, and seaweed) in a single system where the waste of one species becomes the nutrient source for another, thereby naturally filtering the water.
2. **Circular Economy Frameworks:** Reusing water and nutrients within the farm, and using by-products like fish excrement to generate bioenergy or organic fertilizers.
3. **Sustainable Feed Alternatives:** Reducing the reliance on wild-caught fishmeal by incorporating plant proteins and insect meals, which can also help reduce the environmental repercussions of pond waste.
4. **Water Quality Regulators:** Utilizing probiotics and organic sediment enhancers to stabilize the microbial community and reduce the buildup of toxic nitrogenous compounds (Fini et al., 2025).

As the industry moves toward 2030, the adoption of "digital twins" virtual models of the pond that simulate real-world conditions will allow farmers to test different

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management scenarios and optimize production in a risk-free environment. Despite challenges such as sensor durability and the high upfront costs of automation, the transition toward data-driven, predictive aquaculture is essential for ensuring food security in a climate-uncertain world (Mahesh, 2024).

14. Summary of Physicochemical Parameters and Growth Impacts

The relationship between a fish and its environment is a delicate balance of chemical and physical forces. The following table summarizes the key parameters and their ultimate impact on the economic and biological success of a pond operation (Horodysky et al., 2015).

Table 7: Summary of Key Physicochemical Parameters and Their Growth/Economic Impacts

Parameter	Ideal Range	Critical Threshold	Growth/Economic Impact
Temperature	25 - 32°C (Warm)	< 15 or > 35°C	Metabolism control, Q10 effect on feed efficiency.
Dissolved Oxygen	5.0 - 10.0 mg/L	< 2.0 mg/L	Primary driver of SGR; mortality at low levels.
Ammonia (NH3)	< 0.02 mg/L	> 0.05 mg/L	Chronic stress, gill damage, immune suppression.
pH	7.0 - 8.5	< 4 or > 11	Regulates ammonia toxicity and osmo-balance.
Alkalinity	50 - 300 mg/L	< 20 mg/L	Prevents pH crashes; supports nitrification.
Hardness	50 - 400 mg/L	< 20 mg/L	Crucial for Ca/Mg uptake and bone formation.
Salinity	0 - 10 ppt (Tilapia)	> 16 ppt	Energy diversion to osmoregulation; reduced SGR.
Turbidity	30 - 60 cm (Secchi)	< 20 cm	Limits photosynthesis; high silt clogs gills.

15. Conclusion

Effective management of water quality parameters is fundamental to achieving high growth performance, low mortality, and economic viability in aquaculture systems. This review demonstrates that maintaining optimal ranges of temperature (25–32°C), dissolved oxygen (5–10 mg/L), pH (7.0–8.5), alkalinity (50–300 mg/L), and minimizing nitrogenous wastes (especially un-ionized ammonia <0.02–0.05 mg/L) is essential for supporting fish metabolism, respiration, osmoregulation, and immune function. Suboptimal conditions trigger cascading physiological stresses including the Q10-driven increase in metabolic demand, Bohr effect from elevated CO_2, ammonia toxicity, and energy diversion toward stress responses resulting in reduced SGR, deteriorated FCR, higher disease susceptibility, and potential mass mortalities. Advancements in digital technologies, IoT-enabled real-time monitoring, AI predictive analytics, and molecular-level understanding through omics approaches now enable a

Online ISSN 3007-3197
Print ISSN 3007-3189

shift from reactive to precision, data-driven aquaculture management. Strategies such as Integrated Multi-Trophic Aquaculture (IMTA), probiotic application, sustainable feeds, and digital twin modeling offer promising pathways toward climate-resilient and resource-efficient production systems. Ultimately, investing in robust water quality management is not merely a technical necessity but a strategic imperative for sustainable aquaculture. As global demand for fish protein continues to rise, proactive physicochemical monitoring and holistic environmental stewardship will be critical to enhancing productivity, minimizing environmental impact, and ensuring long-term food security in the sector.

References

Bhatnagar, A., & Devi, P. (2013). Water quality guidelines for the management of pond fish culture. International Journal of Environmental Sciences, 3(6), 1980–2009.

Boyd, C. E. (2015). Water quality: An introduction. Springer International Publishing.

Ebeling, J. M., Timmons, M. B., & Bisogni, J. J. (2006). Engineering analysis of the stoichiometry of photoautotrophic, autotrophic nitrifying and heterotrophic removal of ammonia-nitrogen in aquaculture systems. Aquaculture, 257(1-4), 346–358.

Francis-Floyd, R. (2011). Stress its role in fish disease. University of Florida IFAS Extension, CIR919, 1–5.

Stickney, R. R. (2017). Principles of aquaculture. John Wiley & Sons.

Swann, L. D. (1997). A fish farmer's guide to understanding water quality. Purdue University Cooperative Extension Service.

Tucker, C. S., & D'Abramo, L. R. (2008). Managing high pH in freshwater fish ponds. Southern Regional Aquaculture Center (SRAC), Publication No. 4604.

Wurts, W. A., & Durborow, R. M. (1992). Interactions of pH, carbon dioxide, alkalinity and hardness in fish ponds. Southern Regional Aquaculture Center (SRAC), Publication No. 464.

Bowden, T. J. (2008). Modulation of the immune system of fish by their environment. Fish & Shellfish Immunology, 25(4), 373-383.

Boyd, C. E. (2019). Water Quality: An Introduction. Springer Nature

Boyd, C. E., & Tucker, C. S. (1998). Pond Aquaculture Water Quality Management. Kluwer Academic Publishers.

El-Sayed, A. F. M. (2019). Tilapia Culture. Academic Press.

Hargreaves, J. A., & Tucker, C. S. (2004). Managing ammonia in fish ponds. Southern Regional Aquaculture Center (SRAC) Publication No. 4603.

Mallya, Y. J. (2007). The effects of dissolved oxygen on fish growth in aquaculture. United Nations University Fisheries Training Programme.

Piper, R. G., McElwain, I. B., Orme, L. E., McCraren, J. P., Fowler, L. G., & Leonard, J. R. (1982). Fish Hatchery Management. U.S. Department of the Interior, Fish and Wildlife Service.

Schmidt-Nielsen, K. (1997). Animal Physiology: Adaptation and Environment. Cambridge University Press.

Wetzel, R. G. (2001). Limnology: Lake and River Ecosystems. Academic Press.

Online ISSN 3007-3197
Print ISSN 3007-3189

Sallenave, R. (2019). *Understanding water quality parameters to better manage your pond*.

Larsen, E. H., Deaton, L. E., Onken, H., O'Donnell, M., Grosell, M., Dantzler, W. H., & Weihrauch, D. (2014). Osmoregulation and excretion. *Comprehensive physiology*, *4*(2), 405-573.

Zhang, Y., Chen, B., Li, D., Zou, Z., Zhu, J., Yu, J., ... & Xiao, W. (2026). Multi-Omics Analysis Provides Insights into the Key Regulatory Pathways of Energy Metabolism in GIFT Under Salinity Stress. *Veterinary Sciences*, *13*(1), 105.

Agarwal, D., Shanmugam, S. A., Kathirvelpandian, A., Eswaran, S., Rather, M. A., & Rakkannan, G. (2024). Unraveling the impact of climate change on fish physiology: a focus on temperature and salinity dynamics. *Journal of Applied Ichthyology*, *2024*(1), 5782274.

Abdelhamid, A. M., Magouz, F. I., & El-Kashawy, M. E. (2019). Comparison between effects of sinking and floating diets on growth performance of the Nile tilapia (Oreochromis niloticus). *Journal of Animal and Poultry Production*, *10*(6), 183–188. https://doi.org/10.21608/jappmu.2019.46747

Abdel-Tawwab, M., Hagras, A. E., El-Naggar, G. O., & Gomaah, M. S. (2015). Effect of dissolved oxygen and carbon dioxide on the growth and feed utilization of Nile tilapia, Oreochromis niloticus (L.). *International Journal of Aquatic Science*, *6*(1), 12–25.

Bambi Langa, A., et al. (2026). Optimization of growth performance of Nile Tilapia (Oreochromis niloticus) in biofloc farming: Evaluating growth performance and system stability under reduced feeding regimes. *Aquaculture Research*, *2026*, 1–12. https://doi.org/10.1155/2026/341768

Erunwas. (2025). *Effect of water quality on fish growth: Why it matters for every aquaculture farm*. https://www.erunwas.com/news-detail/id-292.html

Koudijs Ethiopia. (2025). *Choosing the right feed for your fish: Floating vs sinking feed*. https://www.alemakoudijs.com/explore-and-learn/insights/choosing-the-right-feed-for-your-fish-floating-vs-sinking-feed

Riberio, J. P., Carvalho, L. V., & Fonseco, A. L. (2024). Growth performance, survival rate, and water quality in an aquaculture system using different feeding strategies for juveniles of Nile tilapia (Oreochromis niloticus). *Aquatic Sciences and Engineering*, *39*(1), 17–23. https://doi.org/10.26650/ASE20231362453

Schreck, C. B. (1981). Stress and compensation in teleostean fishes: Response to social and physical factors. In A. D. Pickering (Ed.), *Stress and Fish* (pp. 295–321). Academic Press.

Selye, H. (1950). *The Physiology and Pathology of Exposure to Stress*. Acta Inc.

University of Florida (Ask IFAS). (2021). *Ammonia in aquatic systems*. https://ask.ifas.ufl.edu/publication/FA031

Horodysky, A. Z., Cooke, S. J., & Brill, R. W. (2015). Physiology in the service of fisheries science: why thinking mechanistically matters. *Reviews in Fish Biology and Fisheries*, *25*(3), 425-447.

Rajendiran, T., Sabarathinam, C., Panda, B., & Elumalai, V. (2023). Influence of dissolved oxygen, water level and temperature on dissolved organic carbon in coastal groundwater. *Hydrology*, *10*(4), 85.