*Aquaculture Reimagined: Modern Approaches to Sustainable Fish Farming*
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*Chapter* 13

# Water Quality Management: Precision and Practice

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***Abstract***

The term "water quality parameter" refers to the essential conditions that fish need for their normal activities, such as feeding, swimming, spawning, metabolism and growth. Maintaining optimal water quality is crucial for successful fish farming. Monitoring factors like temperature, pH and oxygen levels, as well as implementing effective filtration methods, is essential to prevent harmful buildup and maintain a healthy aquatic environment. Regular monitoring of parameters like ammonia and nitrate levels is recommended to ensure the well-being of aquatic creatures. Understanding and controlling water quality is key to achieving high fish production and quality in aquaculture. Water, a vital element for life, is influenced by physical, biological, chemical and structural properties. Groundwater contamination from various sources like sewage systems, landfills and agricultural practices poses a significant risk to human health. Monitoring water quality parameters such as pH, temperature, dissolved oxygen and nutrient levels is essential for aquaculture farming. By studying water quality, researchers can predict environmental changes, assess human impacts on ecosystems and ensure the health of aquatic habitats.

***Keywords*** Management techniques, pH balance, Temperature, Water quality

## 1. Introduction

A "water quality parameter" refers to the essential material, biological and chemical conditions that fish require for their daily activities, such as swimming, feeding, spawning, metabolism, growth and waste elimination. Fish and other aquatic species are important sources of protein and economic value in many regions worldwide. Experts have identified various physical, chemical and biological factors affecting water quality in both stagnant and flowing water bodies due to the accumulation of pollutants. The characteristics of water quality that support the optimal functioning of all organisms are subject to practical constraints. The well-being of aquatic organisms is affected by rapid changes in water quality parameters. Proper regulation of water quality is essential in fish farming to ensure optimal

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growth and health of aquatic organisms. Monitoring oxygen levels, pH balance and temperature is crucial for fish health. Regular monitoring of water parameters like ammonia and nitrate levels is necessary to maintain a healthy aquatic environment and prevent harmful accumulation. Efficient filtration systems and regulations to reduce trash and fertilizer runoff are important for maintaining water quality standards.

Fish farmers can grow healthy fish populations in a sustainable manner with the least amount of negative environmental effects by putting a high priority on careful management of the water quality. Most countries in the world raise fish in ponds with leached water, but sadly, these farmers are not aware of the necessity of water quality regulations for fisheries and aquaculture. If they have received the right guidance and are kept up to date on water quality management strategies, they may be able to achieve maximum fish production in the ponds while utilizing the least amount of input and producing a high output of fish yield. Temperature, transparency, turbidity, water color, carbon dioxide, pH, alkalinity, hardness, ammonia, nitrite, nitrate, plankton population, primary productivity and biochemical oxygen demand (BOD) are key factors influencing fish production. Ensuring a balanced aquatic environment and cultivating appropriate fish feed species in ponds are essential for enhancing fish yield. The totality of water's physical, chemical and biological properties that affect its usefulness is known as water quality. Fish can develop germs that cause sickness and coexist peacefully with their environment. Fish that encounter unbalanced conditions, such deteriorating water quality or habitat, may become stressed and more prone to disease. For this reason, it is essential to keep an eye on the elements of water quality that have an impact on aquatic life's growth and survival. The physical, chemical and biological properties of water significantly influence fish productivity. Water quality is crucial for successful fish farming, with factors such as temperature, clarity, turbidity, color, carbon dioxide, pH, alkalinity, hardness, ammonia levels, nitrite, nitrate, primary productivity, BOD, plankton population and other parameters playing a key role. Understanding and managing water quality is essential for the success of aquaculture operations (Devi and Bhatnagar, 2013). Therefore, it is essential to make sure that these environmental parameters are suitably managed and maintained to support fish survival and maximum growth.

## 2. The Water Quality Parameters

Water is a crucial substance that greatly influences life. Contaminated water can lead to waterborne illnesses, making it important to regularly test water quality. Figure 1 shows parameters like temperature, pH, turbidity, salinity, nitrates and phosphates that should be monitored.

### *2.1. Turbidity*

Turbidity, caused by factors such as organic debris, plankton dispersion, suspended clay particles and decomposition byproducts, hinders photosynthesis by blocking light penetration in water.

*2.2. Dissolved Oxygen (DO)*

The two main sources of oxygen in water are photosynthetic planktons and atmospheric air. For aquatic organisms, obtaining enough oxygen is a greater challenge than it is for terrestrial species because of the low solubility of oxygen in water, which also decreases with increased temperature, increased salinity, low atmospheric pressure, high humidity, high concentration of submerged plants and plankton blooms. Oxygen loss in water can directly or indirectly causes fish malnutrition and feeding, stunted growth and increased fish mortality (Bhatnagar and Garg, 2000). Dissolved oxygen influences the growth, survival, distribution, behavior and physiology of fish and other aquatic animals (Solis, 1988). Low DO meant that fish swam incredibly slowly and were impacted if they came to the water's surface. It also meant that the secchi disc reading fell below 20 cm. Fish gulping at the water's surface is a sign that the pond's DO levels are low.

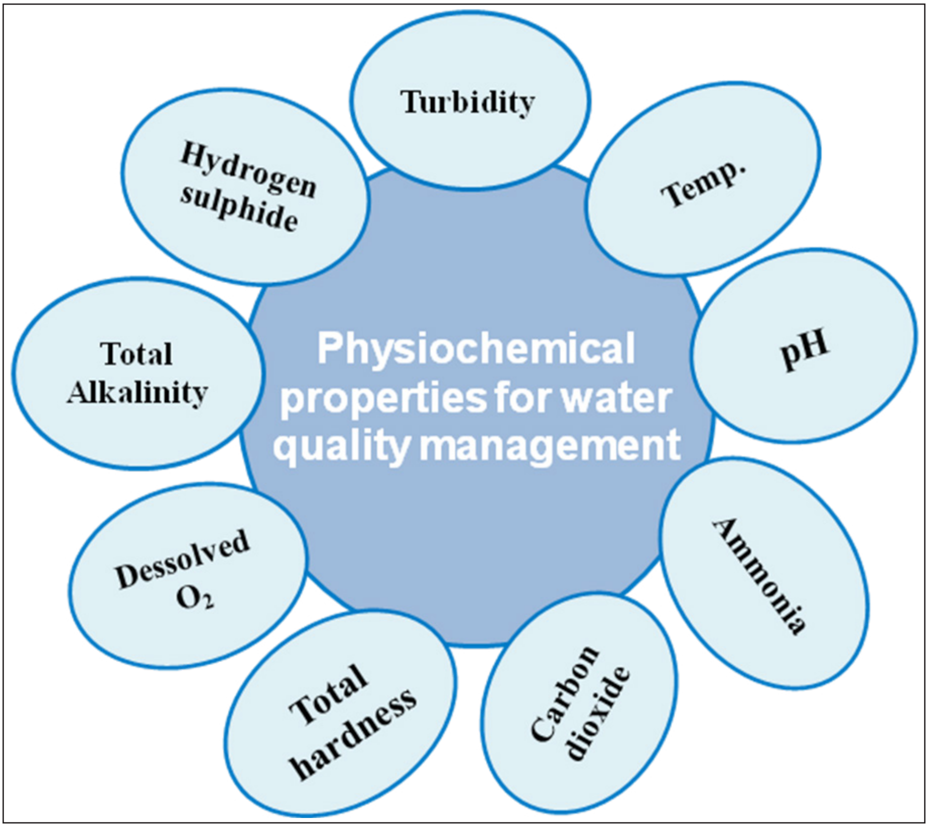


Figure 1: Water quality management parameters

*2.3. Temperature*

Whether an aquatic organism is on land or in the water, its body temperature is determined by its surroundings. Fish, despite having cold blood, experience fluctuations in body temperature based on their environment, which can impact their physiology, metabolism and overall health. Higher temperatures can lead to increased oxygen demand, respiration rate and metabolic activity in fish. However, it can also reduce oxygen solubility and increase ammonia levels in the water. Prolonged ice cover can result in the accumulation of pollutants like carbon dioxide, methane and hydrogen sulfide, posing a threat to fish health.

### *2.4. Biochemical Oxygen Demand (BOD)*

The BOD measures the amount of dissolved oxygen consumed by bacteria during the biodegradation of organic materials in water, such as food particles or sewage. Factors like excess phosphate, residential and cow sewage from non-point sources and high organic loads can lead to elevated BOD levels in rural ponds.

### *2.5. Water Colour*

The color of the water is visible to the human eye and the visible light wavelengths that an object reflects define its color. Plankton, highly dense stocking fish, minerals, organic and inorganic fertilizers, algae blooms, *etc.* are the culprits behind the color shift in the water.

### *2.6. Alkalinity*

Alkalinity, which is a measure of the total concentration of bases in pond water and includes carbonates, bicarbonates, hydroxides, phosphates and borates in addition to dissolved calcium, magnesium and other chemicals, is the ability of water to absorb pH changes. While alkalinity is reduced or consumed by respiration, nitrification and sulphide oxidation Cook *et al.* (1986) and to a lesser extent by evaporation and decomposing organic matter, alkalinity is primarily increased by lime leaching from cement ponds or calcareous rocks, photosynthesis, denitrification and sulphate reduction. If the alkalinity is low, a small amount of acid can greatly affect our pH.

### *2.7. pH*

The pH is determined by the negative logarithm of the hydrogen ion concentration. The presence of carbon dioxide in natural streams affects their pH significantly. While the typical blood pH of fish is 7.4, a slightly wider range of 7.0 to 8.5 may be more beneficial for fish growth and reproduction. Fish mortality is practically certain at pH values below 4.0 or even higher than 11.0. Fish can become stressed in water with pH ranges of 4.0 to 6.5 and 9.0 to 11.0.

### *2.8. Carbon-dioxide ($CO_2$)*

Free carbon dioxide, a gas produced by animal respiration and highly soluble in water, is the main source of carbon in the atmosphere. It is found in limestone, coral reefs and the earth's crust in dissolved or bound forms such as bicarbonate or carbonates. When carbonic acid dissolves in water, it can lower the pH of a system, which can be harmful to aquatic life, especially in systems with inadequate buffering.

*2.9. Salinity*

Electrically charged ions such as cations ($Ca^{++}$, $Mg^{++}$, $K^+$, $Na^+$) and anions ($CO_3^-$, $HCO_3^-$, $SO_4^-$, $Cl^-$) along with other components like $NO_3^-$, $NH_4^+$ and $PO_4^-$ collectively determine the salinity level. The main contributing factor that influences fish development, density and the expansion of the aquatic population is salinity.

*2.10. Conductivity*

Conductivity is a measure of the overall ionic content of a solution and can indicate the freshness of water. It is also used to assess fish productivity by measuring primary production. Water conductivity is affected by factors such as temperature, dissolved particles and ionic concentrations ($Ca^{2+}$, $Mg^{2+}$, $HCO_3^-$, $CO_3^-$, $NO_3^-$ and $PO_4^-$). Natural water conductivity ranges from 20-1500 mhos $cm^{-1}$, while distilled water has a conductivity of about 1 mhos $cm^{-1}$. Freshwater conductivity can increase to 10,000 hs $cm^{-1}$ in contaminated conditions but typically falls between 50 to 1500 hs $cm^{-1}$. Seawater conductivity is around 35,000 hs $cm^{-1}$ and higher.

*2.11. Hardness*

The term "hardness" describes the concentration of several ions in a body of water, such as hydrogen, iron, manganese, strontium, calcium, magnesium and zinc, along with many other alkaline earth elements. Fish need calcium and magnesium for metabolic reactions including the formation of scales and bones.

*2.12. Calcium*

Significantly important for the environment, calcium is present in fish culture water as a divalent salt and as carbonate in soil. Fish can take calcium from the water as well as from the food they consume.

*2.13. Chloride*

Chloride, often known as chlorine ($Cl^-$), is an element that may be added to water to disinfect it and lessen harmful bacteria and deadly germs. It is also a gas that is available as salt. However, the chemical properties of the two elements are very different. Most water bodies have chloride as a significant variable, which helps fish maintain osmotic balance.

*2.14. Ammonia ($NH_3$)*

Fish emit ammonia as a consequence of their metabolism of proteins and bacteria break down organic waste materials such dead planktons, leftover food, sewage and so forth to produce ammonia. When ammonia is unionized ($NH_3$), it is extremely dangerous; yet, when ammonia is ionized ($NH_4^+$), it is not; both forms are known as "total ammonia."

*2.15. Effect of $NH_3$*

Common effects of ammonia in the range > 0.02 mg $l^{-1}$ include gill damage, destruction of mucous-producing membranes, "sub-lethal" effects like reduced growth, poor feed conversion and reduced disease resistance at concentrations lower than lethal concentrations, osmoregulatory imbalance and kidney failure. Fish suffering from ammonia toxicity often become lethargic and surface near the surface, panting for air.

### *2.16. Nitrite ($NO_2^-$)*

The autotrophic Nitrosomonas bacteria produce nitrite as a byproduct of the aerobic nitrification process when oxygen and ammonia react.

### *2.17. Effect of $NH_3$*

Nitrite is often referred to as the "silent killer" of fish due to its ability to convert hemoglobin in the blood to methemoglobin, resulting in brownish discoloration of the blood and gills, which impairs oxygen uptake. It also adversely affects the fish's neurological system, liver, spleen and kidneys.

### *2.18. Nitrate ($NO_3$)*

The autotrophic Nitrobacter bacteria produces nitrate by combining nitrite and oxygen to create ammonia and nitrite, both of which are toxic to fish. Usually, nitrate concentrations hover between 50 and 100 parts per million.

### *2.19. Phosphorus*

The majority of phosphorus (P) in water is found in the form of phosphate ($PO_4$), which, unless conditions are severely acidic, is often found in surface water as connected to live or dead particulate matter and in the soil as insoluble $Ca_3(PO_4)_2$ and precipitated phosphates on colloids. Due to its frequent shortage, ability to promote plant (algae) development and role in augmenting aquatic production, it is an essential plant nutrient.

### *2.20. Hydrogen Sulphide*

The odor of hydrogen sulfide ($H_2S$) is similar to that of rotten eggs. It is highly soluble in water, with a solubility of 4000 mg $L^{-1}$ at 20 °C (Barton *et al.*, 2014). Hydrogen sulfide gas is colorless, flammable and slightly denser than air, with a density of 1.19 at 15 °C (Rubright *et al.*, 2017). Sulfide ($S_2^-$) and bisulfide ($HS^-$) in water are in equilibrium with $H_2S$. $H_2S$ and $S_2^-$ are toxic, while $HS^-$ is not (Barton *et al.*, 2014). The dissociation of $H_2S$ is pH-dependent, with $HS^-$ production starting at pH 5. A pH below 6.8 in marine water systems can lead to the production of $H_2S$ from sulfides (Rojas-Tirado, 2018).

$$H_2S\ (g) \Leftrightarrow H_2S\ (aq) \Leftrightarrow HS^- + H^+ \Leftrightarrow S_2^- + 2H^+$$

Aquatic organisms are highly vulnerable to low levels of $H_2S$. Prolonged exposure can lead to reduced growth and severe stress in fish due to cellular anoxia and respiratory system disruption. The sulfate levels in seawater are approximately 1000 times higher than in freshwater, potentially leading to $H_2S$ production (Lien *et al.*, 2022). As a result, $H_2S$ outbreaks can affect marine RAS. $H_2S$ poisoning has led to significant fish deaths and significant financial losses in recent years. Despite the fact that $H_2S$ is known to be harmful, no official toxicity threshold has been established. However, it is not advised to use more than 2 µg $L^{-1}$ for freshwater species and more than 5 µg $L^{-1}$ for marine species (Sommerset *et al.*, 2020). $H_2S$ has a 96-hour fatal concentration range of 20 to 50 µg $L^{-1}$ in freshwater and 50 to 500 µg $L^{-1}$ in a marine environment. Fish that suffer from $H_2S$ toxicity succumb to it rapidly (Lien *et al.*, 2022). As a result, regular measurements are necessary to gather precise data on $H_2S$ production. Unfortunately, monitoring $H_2S$ levels alone may not be sufficient to prevent issues. Anticipating potential situations is crucial to avoid problems. Factors that can lead to $H_2S$ formation include the presence of carbon-based compounds in water, the concentration of sulphate in freshwater (5-50 mg $L^{-1}$, seawater 2700 mg $L^{-1}$) and biodegradation reactions with organic material and bacteria like methane-reducing or sulphate-reducing bacteria in oxygen-deprived conditions (Letelier-Gordo *et al.*, 2020). Physical factors like low water flow, organic matter buildup and high turbidity can lead to the formation of $H_2S$. Additionally, the combination of carbon-based materials and sulfate from leftover feed or waste can produce $HS^-$ and eventually $H_2S$. Organic matter can also contribute to $H_2S$ production through biodegradation, involving oxidation and reduction processes that transfer electrons from organic carbon donors to electron acceptors (Lien *et al.*, 2022).

### *2.21. Primary Productivity*

The rate of photosynthesis is determined by the dissolved oxygen (DO) concentration in water, which is a common indicator of productivity. It can be measured as gross primary productivity or net primary productivity. Net primary productivity is the total amount of organic matter produced through photosynthesis minus the amount used for respiration. This metric helps assess phytoplankton abundance in light and dark bottles.

### *2.22. Plankton*

Planktons are aquatic pelagic organisms that are not driven by their own swimming ability, but rather by the current of the sea. Fish eat organisms known as phytoplankton and zooplanktons, which are components of plants and animals, respectively. To collect them for identification, plankton nets are utilized. Since plankton is at the base of the food chain, there is a relationship between the amount of plankton and fish production.

### *2.23. Plankton Blooms and Fish Kill*

Other than fertilization, a pond's surface might become eutrophicated due to an overabundance of planktons. In surface waters, some blue green algae species grow to form dense scums that hinder light penetration for photosynthesis below 1 m, causing shallow thermal stratification, less soluble phosphate availability in the top layer and anoxic conditions (high concentrations of free carbon dioxide and little oxygen) in the deep areas that cause fish kills.

### *2.24. Ozone*

Hansen *et al.* (2016) suggest that ozone is a safe disinfectant that enhances water quality in RAS by oxidizing organic materials, nitrite, color, chemical oxygen demand and suspended particles. Summerfelt *et al.* (2009) also note that ozone can combat bacterial flavors, geosmin and fish diseases. However, excess ozone in a fish tank can be harmful to aquatic animals. There are numerous ozone sensors available for purchase. Nevertheless, they can be exceedingly costly, untrustworthy, or fail to display variations in ozone levels. For this reason, ORP is frequently employed to track the addition of ozone (Powell and Scolding, 2018). The ORP logs a substance's ability to transfer or receive electrons while it is in solution. An ORP sensor should be positioned downstream of the ozone injection point and where all ozone has been utilized to protect RAS sensors from ozone damage (Bullock *et al.*, 1997). Alternative methods like UV absorbance changes at 254 nm or 272 nm and enhanced electrochemical oxidation have been proposed. However, ORP provides only indirect conclusions when comparing data before and after ozone treatment. A recent study by Pettersson *et al.* (2022) found that dissolved ozone in water can be measured using the standard colorimetric indigo method (IOA Standardization Committee - Europe, 006/89 (F), 1989). The ozone production outcome can be determined through titration using an iodometric standard method (IOA Standardization Committee Europe, 001/87 (F), 1987).

## 3. Water Quality and Fish Behaviour

Fish stress response is correlated with the quality of the water. Fish under stress may exhibit altered behavior, weakened immune systems and stunted growth (Hjeltnes *et al.*, 2018). These adjustments may be significant, particularly given that ideal growth is highly desired. For instance, elevated body temperature (2-4 °C) in stressed zebrafish (*Danio rerio*) can be interpreted as a fever reaction. According to Rey *et al.* (2015), fish awareness is linked to the emotional fever that has been seen. The relationship between consciousness and emotional fever in zebrafish remains unclear, despite the fish's obvious ability to exhibit it. However, fish growth and the identification of genetic sex based on temperature can be impacted by water parameters, including temperature (Santi *et al.*, 2017).

When exposed to high temperatures (36 °C) 6-8 days after hatching, African catfish (*Clarias gariepinus*) became more masculine. Ninety to one hundred percent of the exposed individuals were male (Santi *et al.*, 2017). Fish movement patterns can be altered by specific contaminants and the strength of these changes can be used to determine the pollutant concentration. Pollution models can indicate water contamination but cannot pinpoint specific concentrations. Ongoing research focuses on more intricate relationships. Water quality assessment includes factors such as fish movement speed, height, distance traveled and position distribution (Bernatowicz *et al.*, 2009). Fen (2014) utilized group behavior metrics such as swimming speed and distance to the nearest neighbor to assess normal and abnormal water quality. All of these methods, meanwhile, are only useful under specific circumstances and very few studies have documented relationships between various water quality parameters and fish behavioral traits. Changes in water quality can be determined and predicted based on fish behavior. Video imaging can be used to detect fish behavior, which includes traits including shape, texture, backdrop, color, swimming direction and speed, frequency of fin thumping, feeding state and metabolic rate (Cook *et al.*, 2014). Video imaging, however, might not be appropriate in an aquaculture environment, for instance, if turbidity is significant.

Fish can be identified based on their backgrounds using background modeling, the temporal difference method and the optical flow method. For instance, Zhang *et al.* (2015) employed a computer vision system to accurately detect fish by quantifying pectoral fins and filtering out background information. Variations in swimming behavior, depth and acceleration serve as indicators of how fish react to their environment (Kolevic *et al.*, 2021). It is essential to consider the impact of conditions in Recirculating Aquaculture Systems (RAS) on the welfare and performance of the fish species being raised, despite regular water quality monitoring (Kolarevic *et al.*, 2021). Fish behavior is not normally an intrinsic part of the systems. Fish swimming behavior can be impacted by a range of feeding schedules and water quality parameters, including DO, $CO_2$, nitrate and pH. The behavior of individual farmed and wild fish has been observed using biotelemetry techniques (Sinisalo, 2022). According to Martins *et al.* (2012), tags allow for the precise measurement of acceleration and gravity force algorithms, which can then be sent to acoustic receivers (AccelTag; Thelma Biotel, Norway). The technique has been utilized to monitor swimming activity in sea cages, as reported by Cook *et al.* (2014). Fish behavior can be tracked in real time with the use of an acoustic acceleration tag called AccelTag (Kolarevic *et al.*, 2016). They are nevertheless constrained by the tag sizes that are offered (7 and 11 g). Approximately 2% of body mass should be the tag size.

## 4. Monitoring and Management Techniques: Ensuring Optimal Conditions

### *4.1. Measurements of Water Quality*

In order for intensive aquaculture to be successful, it is essential to monitor key water quality indicators such as dissolved oxygen (DO), salinity, temperature, pH and electrical conductivity (EC). Water quality metrics have traditionally been tested using handheld sensors at predetermined intervals. But this needs workers, takes time and can only be done during business hours. Many of the fundamental measurements may now be performed using online instrumentation thanks to advancements in automation, monitoring and instrumentation in recent years (Lekang, 2013). With the advancement of affordable sensors and information technologies, wireless sensor networks (WSN) have become a more convenient option for monitoring. During designing and implementing instruments for aquaculture, it is essential to consider the unique conditions present in this industry (Lekang, 2013). In addition to the instrument's cost, there are other expenses including calibration, upkeep and operational costs. Sensors may also need to be changed at predetermined intervals. To ensure cost-effective RAS management, regular and effective monitoring of water quality is essential. For instance, Zhu *et al.* (2010) introduced an online water monitoring system capable of measuring temperature, EC, pH and DO. Zhang *et al.* (2011) utilized an Orion5-Star Portable pH/ORP/DO/EC Multimeter to assess these parameters in an RAS. Additionally, Odey and Li (2013) employed an AquaMesh wireless mesh sensor network to monitor pH, DO, temperature and EC in their study. Numerous researches have described how to assess these factors in aquaculture online, but they have all just measured the fundamental water quality indicators. Portable equipment like the Multi 3410 (WTW GmbH) can test the most common basic water quality parameters, like temperature, pH and DO. While there are portable alternatives, ion-exchange chromatography and suppressed conductivity detectors, *e.g.*, Dionex DX-500, Dionex ICS1600, Dionex Integrion HPIC (Lindholm-Lehto *et al.*, 2021); are frequently used in laboratories to quantify nitrite, nitrate and phosphate more precisely. Equipment used in lab settings has been adapted for use in aquaculture operations. A spectrophotometer, which gauges a sample's absorption of light, is a common type of detector. Intelligent data management and monitoring equipment integration is now commercially available from companies such as Greenspan and Fleck in Australia, Gimat in Germany and Isco, Hydrolab and Emnet in the USA (Lv, 2015). Siemens has developed a monitoring system called the YSI5200 for aquaculture. The YSI5200 includes advanced alarm modes and can monitor and log parameters such as dissolved oxygen (DO), pH, conductivity, oxidation-reduction potential (ORP), salinity and temperature. The Model 5200A can continuously monitor these parameters, while the Model 5400 can handle up to four DO probes and four additional inputs, including temperature, pH and ORP.

### *4.2. Measurement Frequency*

Numerous factors should be monitored when it comes to water quality. To prevent harmful disruptions in RAS, some of them (such DO, $CO_2$ and pH) must be continuously watched, while others (including off flavors, trace elements and metals) can be checked less regularly. Effective online monitoring solutions, however, are not accessible for all parameters and they are especially not affordable. Regular collection of quality parameter data is necessary to maintain water quality within an ideal range. Water quality has traditionally been checked by hand sampling and sending samples to a laboratory for analysis (Pasika and Gandla, 2020). This doesn't provide real-time data, but it does take time, demand labor-intensive labor and require analytical equipment (Pasika and Gandla, 2020). The frequency of measuring water quality parameters is a matter of debate. Ferreira *et al.* (2011), for instance, recommended weekly monitoring of pH and turbidity but daily monitoring of DO, temperature and salinity. Nevertheless, significant alterations in the quality of the water may go unnoticed, resulting in significant fish losses and monetary damages. Real-time remote monitoring with new sensor technology and wireless connection is feasible. Real-time monitoring of specific water quality parameters is essential for farmers to detect and address low water quality issues promptly. Aquaculture poses various challenges for farmers, including limited funding, high labor costs and the need for real-time monitoring of key water quality indicators. Rashid *et al.* (2021) highlighted the importance of using intelligent systems to maintain optimal water quality by continuously monitoring water quality metrics. Implementing a water quality prediction model can help anticipate fluctuations in water quality. A smart aquaculture system can not only reduce labor expenses but also improve fish health. pH, turbidity, water level, temperature and humidity can all be tracked using a monitoring system that consists of sensors and a microcontroller. The monitoring station received the wirelessly transmitted data in real time and on a continual basis. A micro-controller unit with a sensor network was included of the system, which allowed for water tank sampling every 10 seconds (Pasika and Gandla, 2020). Furthermore, an algorithm was employed to track variations in the parameters related to water quality.

### *4.3. Real-Time Measurements*

There have been reports of several techniques for measuring the quality of water (Lin *et al.*, 2021). They can typically assess essential water quality factors like temperature, pH and dissolved oxygen, which greatly impact the survival of the cultivated species. In recent years, various monitoring systems have been developed, including Wireless Sensor Networks (WSN), a remote aquaculture monitoring system (Wang *et al.*, 2012) and a WSN automatic fisheries monitoring system that utilizes WiFi and ZigBee technologies (Chen *et al.*, 2016). Zigbee is designed for control and sensor networks in wireless personal area networks (WPANs) and operates at frequencies of 2.4 GHz, 900 MHz and 868 MHz. A WSN comprises self-organizing sensors that collect, measure, transmit and analyze data in real-time. The data is sent for remote monitoring or shown on a computer Chen *et al.*, (2016). Aquaculture has made extensive use of WSN for the past ten years. Odey and Li (2013) measured pH, DO and EC using an AquaMesh wireless mesh sensor network. Subsequently, feed consumption and water quality parameters were remotely monitored through the use of WSN and GPRS. Lin *et al.* (2021) employed online monitoring of temperature, pH, dissolved oxygen (DO) and electrical conductivity (EC) in a high-density culture system. They utilized a portable pH/ORP/DO/EC meter to measure these parameters in a recirculating aquaculture system (RAS) connected to an artificial wetland. Applications have been employed in fish farms as well as a range of other sectors. Real-time measurements of basic water quality parameters such as temperature, dissolved oxygen (DO), pH and water level were recorded and stored in a database. An email or SMS alerted a responsible person to an issue. Real-time data could be shown graphically and power sources such as solar and lithium cells were also available.

With 4G technology, it is possible to achieve high transmission distance quality, quick communication and long transmission distance. 5G technology will be used in the future to improve data transfer even further. The quality of data can be increased by adding data processing to enable further analysis. Data reduction, integration, transformation and cleaning are its components. Usually, this entails noise reduction and data correction. Omiwade and Zheng (2012) explored the distributed storage systems, request retransmission mechanisms and multi-path discontinuous data transmission. Data redundancy backup and data repair techniques proposed by Li *et al.* (2014) are among the methods discussed. Additionally, a compression sensing algorithm, as suggested by Zhao (2015), can be utilized. Various noise reduction methods, including the least squares method, quadratic bilinear time-frequency analysis, Fourier transform and wavelet transform, have been developed to minimize noise interference in measurements. According to Wickersham *et al.* (2014), wavelet analysis can be used to separate and extract frequencies for water quality signals. It is a useful technique that has been applied, for instance, to the prediction of water quality and hydrology (Yu *et al.*, 2014). Tolentino *et al.* (2021) demonstrated a system that automatically tracked and adjusted water quality parameters in an intensive Nile tilapia (*O. niloticus*) farming system. They developed a method to measure temperature, salinity, dissolved oxygen (DO), turbidity, pH and oxidation-reduction potential (ORP) of the water. The system featured internet connectivity and online apps for monitoring system status and parameters. Components of the system included a water pump, heater, water bottle, drum, sensors, microcontrollers, correction devices and Long Range Wide Area Network (LoRaWAN) connectivity. While sodium bicarbonate solution was used to adjust pH, fresh replacement water was added to increase the quality of the water.

## 5. Conclusion

To comprehend the aquatic conditions in aquaculture, a number of water quality measures need to be examined. Farmers have different perspectives and options when it comes to measuring water quality and there are currently no regulations dictating which characteristics to measure. Guidelines for permissible ranges and fluctuations do not yet exist. This chapter has enumerated them. While appropriate ranges varied for various species, a few general criteria would be a useful resource for planning and managing a RAS facility.

- Historically, laboratory tests and handheld sensors have been used to evaluate water quality parameters at specific intervals. This procedure is only available during business hours and may take some time to complete.

- Predicting issues in advance based on variations in water quality is one possible use for intelligent systems. Farmers can identify irregularities and take appropriate action before more serious problems arise by using early warning indications. Nonetheless, a lot of the contemporary sensors and monitoring systems require skilled operators, as well as routine calibration and maintenance. Monitoring fish behaviors, such as swimming activity, depth, acceleration and eating, can also reveal the effects of water quality. For instance, computer vision and acoustic acceleration tags can be used to track fish behavior. When combined with the more conventional monitoring measures, this can be a very beneficial addition.

- New IoT-based monitoring devices can track basic water quality indicators such as dissolved oxygen (DO), pH, temperature, turbidity and salinity, which are adequate for routine monitoring. However, more complex tests like cortisol levels and off tastes still need to be conducted in a laboratory and cannot be done in real-time. These can also call for more sophisticated analysis tools and only qualified individuals should be able to complete them. Future research will focus on developing new methods that enable real-time monitoring of increasingly complex water quality data.

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