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Water Quality Monitoring: A Panacea for Sustainable Aquaculture and Economic Development in Nigeria

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Abstract
Regular water quality monitoring is essential to the sustainability and efficiency of aquaculture systems in Nigeria, where the sector significantly boosts the country's GDP. This study explores how effective water quality monitoring could enhance aquaculture operations in order to address the problems facing the sector that threaten the long-term viability of fish farming and economic growth. The study focused on key water parameters like pH, temperature, turbidity, and soluble oxygen that directly affect fish health, growth rates, and total farm productivity. The study argues that sustaining healthy aquatic ecosystems, increasing fish productivity and guaranteeing the long-term sustainability of the aquaculture sector all depend on routine and efficient water quality monitoring. The study comes to the conclusion that modern water quality management techniques, cutting-edge technology, government support, and strong legislative frameworks are all necessary to improve aquaculture's sustainability, which has the potential to greatly increase food security, reduce poverty and boost Nigeria's economy.

Keywords: Water Quality, Monitoring, Aquaculture, Panacea, Economic development

Introduction

Aquaculture is one of the food production industries that is expanding at one of the fastest rates. Food security, ecological health, unrestricted use of natural resources, biodiversity protection, and socioeconomic resilience all depend on its continued growth. Several European and Asian countries, including those in Africa, have embraced aquaculture as a solution to the ongoing reliance on wild fisheries for sustenance (Bene et al. 2016). Aquaculture's explosive rise in recent decades has improved food security in regions where it has been used. According to Adeogun et al. (2015), these variables include population expansion, rising food consumption, technical developments in fish production and the finite and declining availability of catch fisheries. In the face of declining capture fishery resources and rising demand for fish and fisheries products, aquaculture has emerged as the main source of aquatic food and protein supply and contributes to global food security (Boyd et al. 2022; Troell et al. 2023). To maintain sustainable aquaculture operations, Nigerian fish farmers have adopted a variety of aquaculture systems, including semi-intensive and intense systems, as well as closed, semi-open and open systems.

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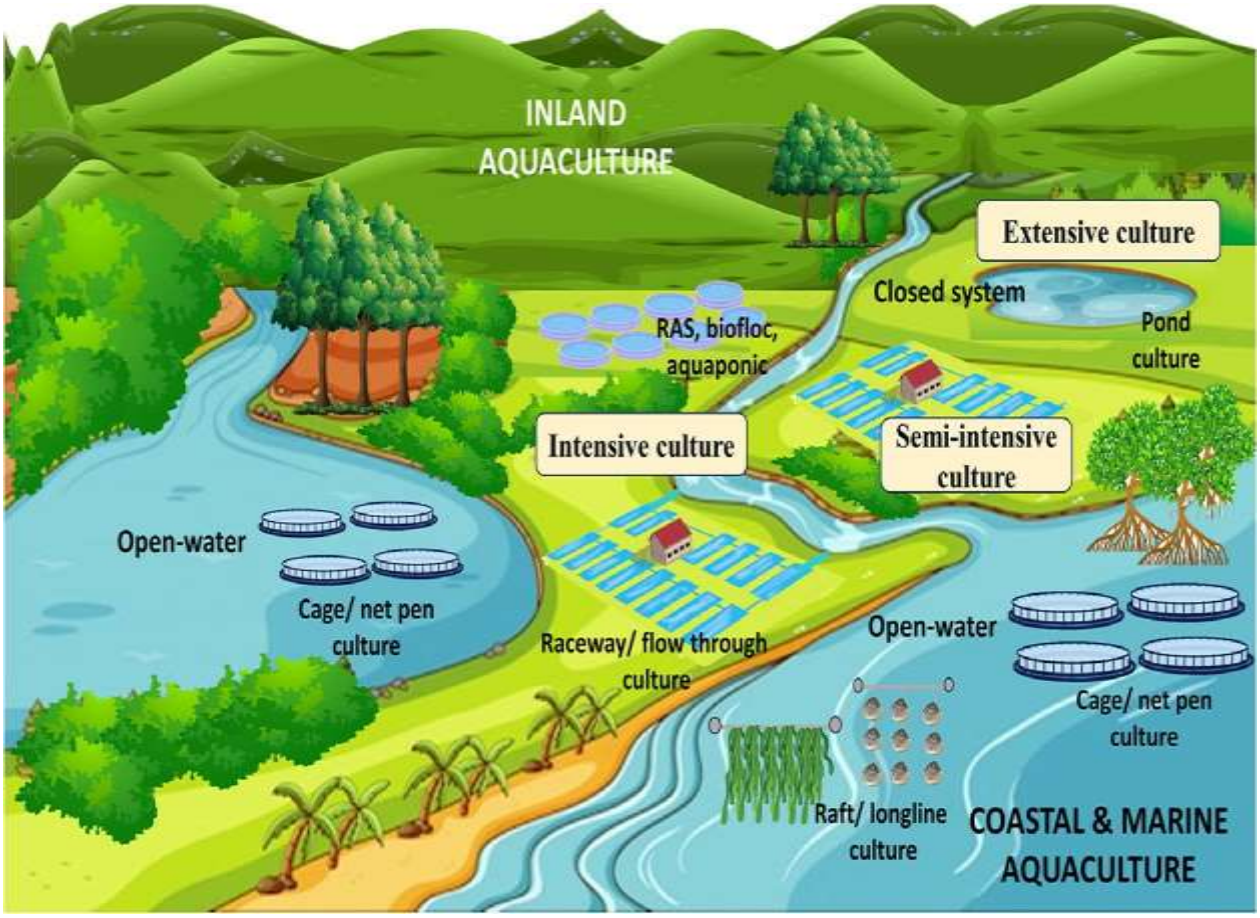
Figure 1. A range of aquaculture production systems in closed environments (tanks, ponds, and raceways) and open



habitats (cages and extractive culture systems in lakes, rivers, and coastal waterways).
Source: [Yusoff et al. 2024**].**

There are several methods for raising fish. Fish farming can be done with freshwater (inland rivers, streams, and lakes), brackish water (a mix of fresh and salty, like lagoons) and marine water (seawater). Freshwater fish culture is more common than brackish water fish culture in Nigeria. Fish can be grown in concrete tanks, earthen ponds, cages, pens, runways, water diverted from rivers, streams, lakes, wells, borehole water, spring water and treated pipe-borne water, depending on the structures intended to act as enclosures during rearing. The aquaculture operator should ensure that the water used for fish culture is free of impurities including oil, industrial waste, and residential effluents that are bad for fish and could end up costing them money. Only about 0.03% of the world's aquaculture production takes place in Sub-Saharan Africa (SSA), despite the fact that aquaculture is crucial for livelihoods, regional food security, and national economic growth in Africa (Quagrainie et al. 2009; FAO, 2014). Nigeria and Egypt are the producers of more than 55% of all fish grown in Africa. The ability of the fish farmer to precisely monitor the physical, chemical, and biological characteristics of the aquaculture water is essential to the success of any fish farming enterprise (NAERLS, 1996). Fish culture is impacted by the water source's quality. The water used for fish farming will not yield the best results if the conditions are not suitable for fish and other aquatic species (NAERLS, 1996). Water is essential to aquaculture and a major barrier to commercial fish production. The amount and quality of a particular water source determine its viability for long-term aquaculture operations. For aquaculture to thrive, there must be a sufficient supply of high-quality water.

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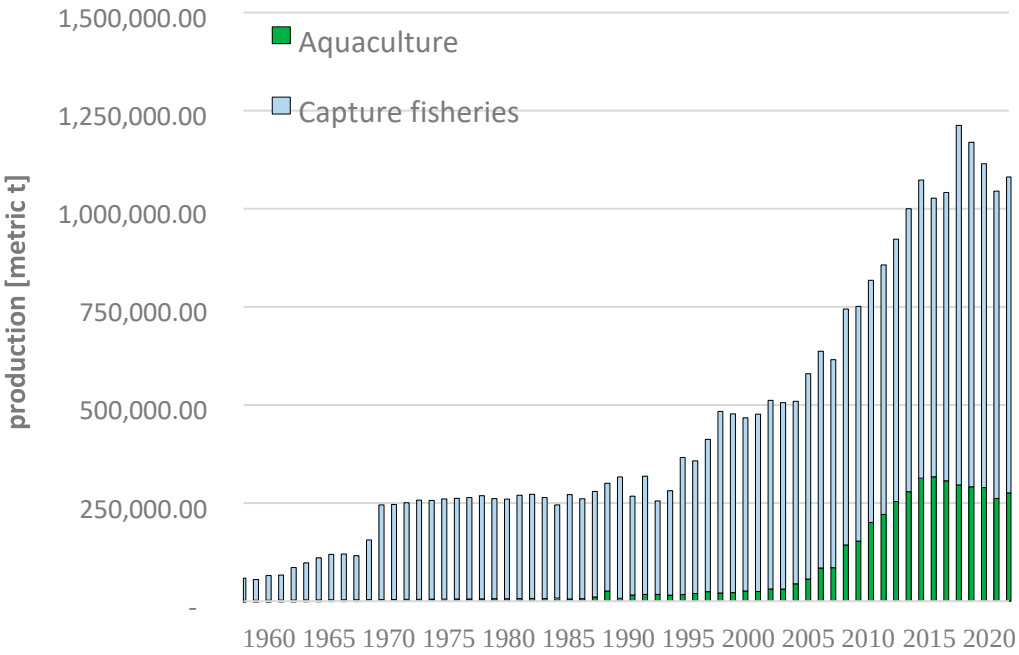
Globally, there are several complex issues with water quality monitoring that need immediate attention (Breaban et al. 2012). The foundation of water quality monitoring is the methodical assessment of the physicochemical and biological indicators of aquaculture water, including critical elements such as water temperature, dissolve oxygen, pH, ammonia, and nitrogen. The life habitat of aquatic organisms is directly impacted by these markers. For example, the amount of dissolved oxygen in the water directly affects fish respiration, while ammonia nitrogen accumulation can damage aquatic life and degrade the water's quality. Farmers can maintain optimal breeding conditions by spotting problems with water quality early on and taking the appropriate steps, such as changing the water, increasing oxygen levels, or altering feed intake. A consistent, plentiful, and high-quality supply of water is necessary for fish farming. Together with high-quality feed, water is one of the most important components of fish production for a sustainable aquaculture operation. Fish rely entirely on water for respiration, feeding, development, waste removal, salt balance and reproduction. Thus, monitoring and understanding the water's physical, chemical, and biological properties is crucial to aquaculture's success. Water quality affects fish survival and growth in aquaculture operations. All of the physiological functions of fish are performed in the water. As a result, the water has a major impact on whether an aquaculture business succeeds or fails. Interestingly, in many nations and locations around the world, aquaculture the production of fish, contributes significantly to household meals, livelihoods, and economic development. It is also a major source of animal protein (FAO, 2020). Nigeria is not excluded. Aquaculture has been found to be growing at the quickest rate among Nigeria's agricultural sectors. According to Ogunji and Wuertz (2023), it has been rising at a rate of 13.6% since year 2000, notwithstanding a recent standstill and has made a substantial contribution to economic development (Figure 1). Nigerians consume between 11.2 and 13.3 kg of fish annually, which accounts for about 40% of their protein intake (Ajayi et al. 2022; O. F. Omamuyovwe et al., 2024; Adeleke et al. 2020). However, Nigeria's per capita protein intake is lower than the average for Sub-Saharan Africa. Importantly, fish is less expensive than other animal protein sources (Babatunde et al. 2021). The annual production of fish has grown to one million metric tons. Fisheries account for 805,210 metric tons, while aquaculture accounts for 275,645 metric tons (Figure 1).



Data: https://data.worldbank.org/

Figure 2. Production from aquaculture and captured fisheries, 1960–2020.

Despite the fact that production figures have not increased much over the past ten years, the National Aquaculture Strategy was developed in 2008 (NAS, 2008) with the goal of boosting domestic fish output and planning for future

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growth. Like the economies of other African countries, Nigeria's aquaculture subsector is essential to generating income and jobs (Simus et al. 2022; Mulokozi et al. 2020). Due to the availability of land for aquaculture, the project has proven to be very successful, with an anticipated increase in production of 2.5 million tonnes (Babatunde et al. 2021). Nigeria has been recognized as one of the top aquaculture destinations in the world. This is because of the ideal climate, sought-after aquatic resources, and superior soil. However, there has been a great deal of worry about the safety of Nigeria's surface and underground waters due to the country's fast increasing water contamination and inefficient waste management system. For aquaculture operations to be sustainable and have the potential to advance Nigeria's economic development, water quality monitoring is therefore essential.

The State of Aquaculture in Nigeria

Nigerians are consuming more fish, but there is not enough to meet demand. Because of this, the nation imports a considerable quantity of fish every year. One strategy to close this gap is aquaculture, which provides chances for rural development, food security and job creation.

Aquaculture can be practiced on more than 1.75 million hectares of freshwater. An additional half a million hectares along the canals are thought to be suitable for mariculture. Nigerian aquaculture seems to have stagnated lately. However, with aquaculture making up 52% of the region's total farmed fish production, the nation continues to be the greatest fish producer in sub-Saharan Africa (FAO, 2025).

Freshwater fish are the primary focus of Nigerian aquaculture, with catfish species making up more than half of total production, or over 260 000 tonnes annually. Tilapia, nile perch, and carp are important fish grown for food.

At about 7.3%, the South Zone had the highest proportion of households involved in fish farming, per a 2019 survey (FAO, 2025). The lowest percentages were found in the Southwest and Southeast. Slightly more than 3% of Nigerian families engaged in fish farming, mostly in rural areas.

Importance of Water Quality Monitoring in Sustainable Aquaculture Operation in Nigeria

Aquaculture, an essential component of contemporary agriculture, bears a heavy load in supplying the world's expanding protein needs. Aquaculture has been growing and using intensive farming methods as a result of rising market demand and technological advancements. However, the resulting issue with water quality has turned into a barrier to the aquaculture industry's ability to grow sustainably in Nigeria. In addition to being crucial for the welfare and production of farmed aquatic species, effective water quality monitoring is necessary for the long-term resilience, environmental sustainability and economic growth of Nigeria's aquaculture business. Since aquatic water quality is directly related to the safety and quality of aquatic products as well as the preservation of the natural environment, monitoring it has become essential. Water quality monitoring is based on a systematic evaluation of the physicochemical and biological characteristics of aquaculture water. Water quality monitoring is essential for Nigerian aquaculture operations to be sustainable in the following ways.

i) **Enhancing Aquatic Development and Health:** To promote aquaculture species' growth and wellbeing, specific ranges of water quality parameters, such as oxygen levels, pH, temperature, salinity, and ammonia concentrations, must be maintained. When these variables are kept in check, fish and shellfish have the best conditions for feeding, reproduction, and survival. Higher harvests and better financial returns are also produced by species that are healthy and well-grown.

ii) **Preventing Stress and Disease:** Poor water quality can lead to stress, weaker immune systems, and increased susceptibility to sickness. By seeing early signs of contaminants or imbalances in the water, routine monitoring allows for timely treatment. This helps ecosystems and reduces the likelihood of disease outbreaks by reducing the demand for antibiotics and other chemicals.

iii) **Improving Feed Efficiency and Conversion:** For fish and shellfish to convert feed into growth, stable, healthy conditions are ideal. Aquaculture operators can increase feed conversion ratios, increase production efficiency, and decrease waste by adjusting feeding techniques, water circulation and aeration in response to water quality monitoring.

iv) **Reducing Environmental Impact:** Because of the buildup of contaminants, uneaten food, and fish waste, aquaculture can contribute to water contamination. Monitoring water quality helps identify nutrient excesses, like excess nitrogen and phosphorus, which can lead to harmful algal blooms and oxygen depletion in surrounding ecosystems. When water quality issues are identified early, operators can take the necessary steps to prevent environmental degradation and safeguard adjacent water bodies.

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v) **Optimizing Resource Use:** Effective water quality monitoring can help aquaculture businesses save water and energy. By understanding the needs of the system, operators may optimize water flow, aeration, and filtration systems, reducing operational costs and the farm's environmental effect.
vi) **Maintaining Regulatory Compliance:** Aquaculture operations are often subject to environmental limitations related to water quality. Monitoring ensures compliance with national, international or regional standards. This enhances the farm's standing for moral behavior and protects the company from lawsuits.
vii) **Sustaining Ecosystem Health:** Systems for aquaculture are a part of broader ecosystems. Water quality monitoring ensures that agricultural operations do not negatively impact adjacent wetlands, water bodies, or coastal areas. By preventing issues like pollution and eutrophication, water quality monitoring helps to maintain biodiversity and ecosystem health.
viii) **Data-Driven Decision Making:** Aquaculture companies may make educated decisions about stocking numbers, feeding schedules and water management by using data from continuous monitoring and data collection. In the end, this increases productivity while lessening the impact on the environment, which helps the farm remain sustainable over the long run.

In essence, the social, environmental and economic aspects of sustainable aquaculture all depend on water quality monitoring. It ensures that aquaculture may thrive without harming or depleting the resources it depends on by enabling ethical farming practices to achieve a balance between ecological preservation and productivity.

Key Physico-Chemical/Biological Indicators of Aquaculture and Their Impacts

Water Temperature: According to Lucinda and Martin (1999), temperature is the degree of heat or coolness in a live organism's body, whether it is on land or in water. Since fish have cold blood, their body temperature fluctuates in response to their surroundings, which impacts their physiology and metabolism and ultimately, their output. A higher temperature raises the microbiota's rate of biochemical activity, the rate at which plants breathe and consequently, the need for oxygen. It also raises the amount of ammonia in water and decreases the solubility of oxygen.

pH: In the aquatic environment, the pH of the water plays a crucial role in controlling chemical processes (Himmel et al. 2010). The blood pH of fish is 7.4 on average; a small variation from this value, usually between 6.5 and 8.5, is more ideal and supportive of fish life in water. In water with a pH between 4.0 and 6.5 and 9.0 and 11.0, fish can get stressed; at a pH below 4.0 or higher than 11.0, death is all but guaranteed (Ekubo and Abowei, 2011). According to Bhatnagar et al. (2004), fish and shellfish culture is killed by temperatures below 4 or above 10.5.

Dissolve Oxygen: Fish, shrimp and other aquatic species' growth, survival, distribution, behavior and physiology are all impacted by dissolved oxygen (Solis, 2008). Photosynthetic planktons and atmospheric air are the main sources of oxygen in water. Due to the low solubility of oxygen in water which decreases with increasing temperature, salinity, low atmospheric pressure, high humidity, high concentration of submerged plants, and plankton blooms, aquatic organisms have a harder time getting enough oxygen than terrestrial ones. Fish malnutrition, poor feeding, stunted growthand increased mortality are all directly or indirectly caused by oxygen depletion in water (Bhatnagar and Garg, 2000).

Biochemical Oxygen Demand (BOD): The oxygen consumption rate brought on by metabolic processes is measured by BOD. It serves as a gauge of the degree of stress experienced by the fish population. The ideal BOD level for aquaculture, according to Santhosh and Singh (2007), should be less than 10 mg/L; however, water with BOD levels between 10 and 15 mg L-1 may be suitable for fish culture. Ekubo and Abowei (2011) state that an aquatic system is deemed clean if its BOD levels are between 1.0 and 2.0 mg/L, reasonably clean if they are 3.0 mg/L, questionable if they are 5.0 mg/L, and bad and contaminated if they are 10.0 mg/L.

Alkalinity: The overall concentration of bases in aquatic systems, such as carbonates, bicarbonates, hydroxides, phosphates and borates, dissolved calcium, magnesium, and other substances in the water, is measured by alkalinity, which is the water's resistance to pH changes. While respiration, nitrification, and sulphide oxidation reduce or consume alkalinity, and to a lesser extent, it increases due to evaporation and decomposing organic matter, the main causes of alkalinity increase are lime leaching out of calcareous rocks, photosynthesis, de-nitrification, and sulphate reduction (Stumn and Morgan, 2001: Anna et al., 2025: Cook et al., 2006). A low alkalinity, however, suggests that even a tiny quantity of acid might significantly alter our pH.

Ammonia Nitrogen: Ammonium, the ionized form of ammonia (NH_4^+), has been shown to be a substantial contributor to "acute ammonia intoxication" and signs of neurological disturbance, including loss of equilibrium,

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hyperexcitability, convulsions, and coma, in fish with decreased pH and dissolved oxygen levels (Randall and Tsui, 2002). Excessive concentration can lead to eutrophication of the body of water and damage aquatic organisms.

Microorganisms: The level of water contamination for aquaculture that may result in disease infection can be determined by the presence of microorganisms like bacteria (e.g., coliforms) and other markers of biological pollution, such as pathogens.

By monitoring these key variables, farmers may ensure that aquatic products may grow rapidly and healthily, improve output and quality, and reduce losses. This enables them to identify and promptly treat water quality problems.

Table 1: Standard Water Quality Criteria for fishery

Parameter	Standard Water Quality Criteria for Fisheries (NESRA, 2011)
Water temperature ^{0}C	15−30^{0}C
pH	6.5−8.5
EC(μS/cm)	400 μS/cm
Turbidity (NTU)	< 20 NTU
TSS (mg/l)	0.25 mg/L
DO (mg/l)	≥6.0 mg/L
BOD_5 (mg/l)	≤3.0 mg/L
Calcium (mg/l)	180 mg/L
Nitrate (mg/l)	≤9.1 mg/L
Chloride (mg/l)	300 mg/L
Ammonium (mg/l)	≤0.05 mg/L
Iron (mg/l)	0.05 mg/L
Zinc (mg/l)	0.01 mg/L
Copper	0.001−0.01 mg/L

Table 2. Physico-Chemical Parameters/Standard Limits for Fish Culture

Parameters	**WHO**	**FEPA**	**SON**	**BD**
pH	6.5 - 8.5	6 – 9	6.5 - 8.5	7.0-9.5
Conductivity (uS/cm)	300	-	1000	-
Temperature (°C)	< 35	27	Ambient	15-35
DO (mg/L)	4 – 6	8-10	-	3-5
BOD (mg/L)	6	10	-	3-6
TDS (mg/L)	500	500	-	-
Transparency (cm/L)	10	<7	5	-
Alkalinity (mg/L)	600	-	-	50-200
Nitrate (mg/L)	50	20	-	-
Sulphate (mg/L)	500	500	-	-
Magnesium (mg/L)	-	-	-	-
Calcium (mg/L)	200	-	-	4-160
Potassium (mg/L)	-	-	-	-

WHO=World Health Organization (2009); FEPA= Federal Environmental Protection Agency (1991); SON= Standard Organization of Nigeria (1970); BD = Bhatnargar and Devi (2013).

Methods of Water Quality Monitoring for Aquaculture

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Traditional Monitoring Methods for Aquaculture

Water quality monitoring in aquaculture systems has traditionally been accomplished by time-consuming manual sampling. Water samples are frequently collected and analyzed in a lab as part of conventional methods. These methods are time-consuming, labor-intensive, and may not provide real-time data, despite their widespread use. They could also fail to notice short-term variations in the water's quality.

Modern Methods/ Technology in Water Quality Monitoring for Aquaculture

Artificial intelligence (AI) and water quality monitoring technologies are revolutionizing aquaculture by enhancing aquatic environment health, sustainability, and efficiency. Some of the most important contemporary technologies utilized in the aquaculture sector are listed below:

i) IoT Technologies and Models

As technology develops, intelligent monitoring systems (IMS) and internet of things (IoT)-based real-time monitoring and early warning systems could be developed to increase the efficacy and efficiency of water quality monitoring and management. The Internet of Things (IoT), a collective network of communication devices integrated with artificial intelligence (AI), water quality sensors, and modeling, can help monitor and manage key water quality parameters in aquaculture systems, such as dissolved oxygen, pH, turbidity, and temperature. Wireless sensor networks have been widely used in water quality monitoring (Shi et al. 2018; Wei et al. 2023).

Fig. 4. Temperature Sensor

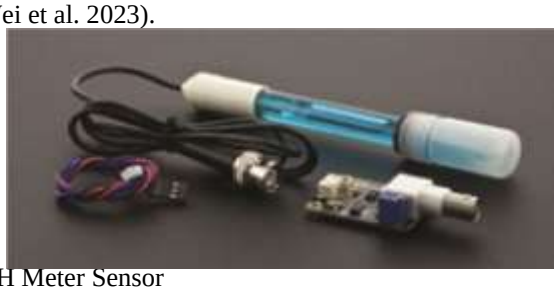

Fig. 3. pH Meter Sensor

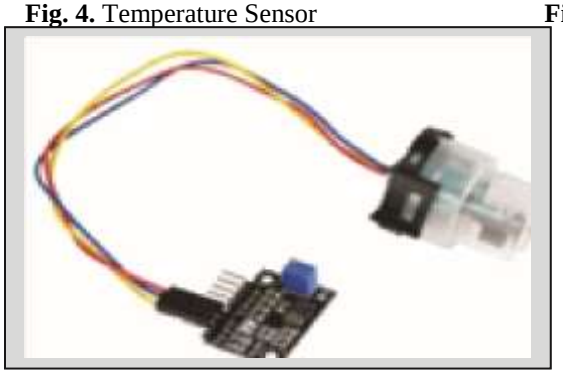

Fig. 5. Turbidity Sensors

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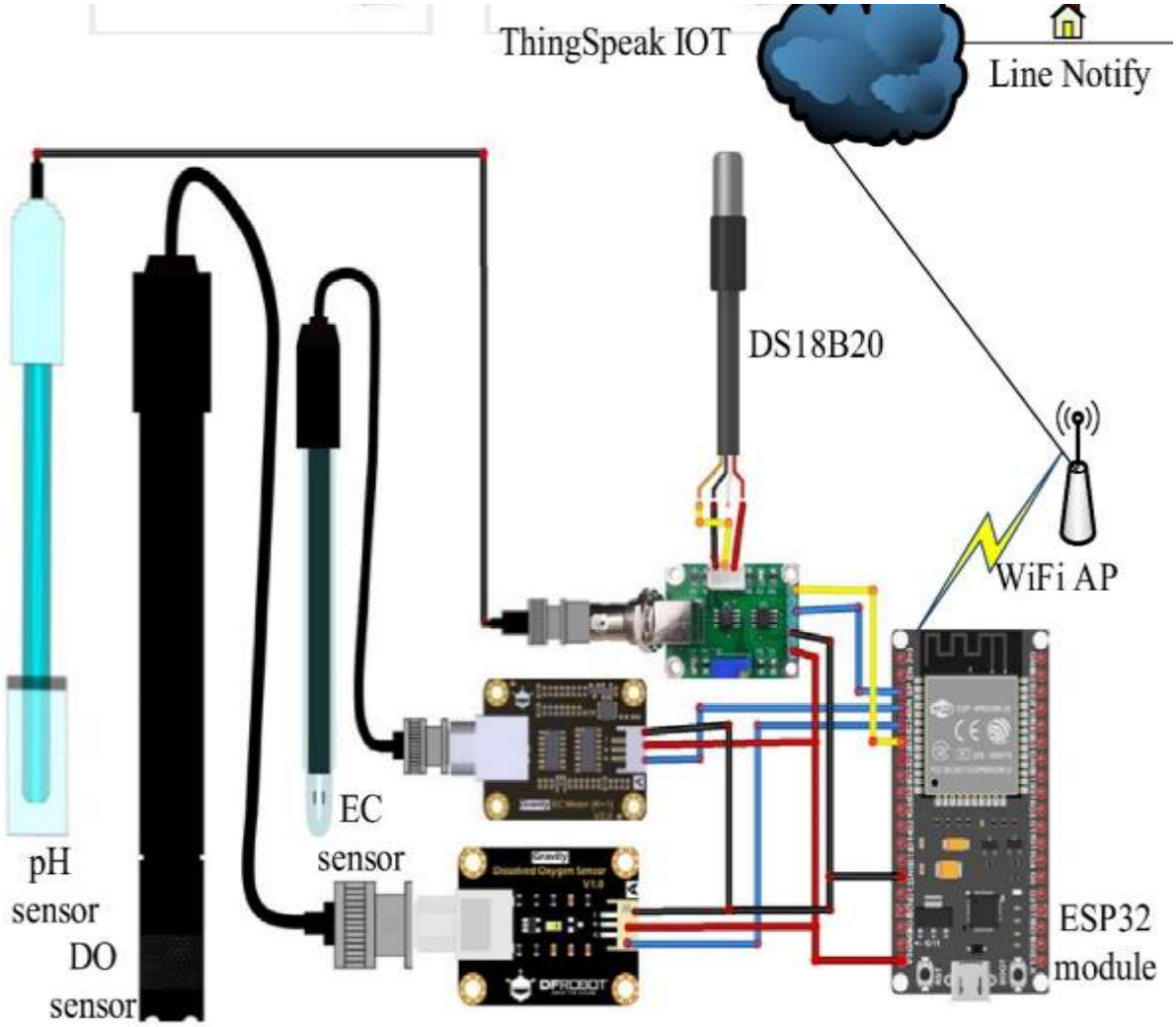

Fig. 6. System schematic of wireless multi-sensor water quality monitoring system
Source: Lin, J.Y. et al. (2021).

ii) Wireless Sensor Network

Since the advent of sophisticated communication methods, wireless sensor networks (WSN) have gained interest as a way to improve water quality monitoring systems (Rashid Abdul Haq and Harigovindan, 2020). WSNs excel at remotely gathering and sending data without the need for an established network. Additionally, WSN is a very attractive technology due to its very low communication power consumption, which increases the power efficiency of the sensor nodes. Since WSNs offer a solution for a variety of control and monitoring applications, they are becoming an essential component of WQM (Rasheed Abdul Haq and Harigovindan, 2020). These are straightforward, inexpensive networks that require little human involvement and are remotely monitored in real time. Base stations and sensor nodes make up a WSN network. Typically, a node with sensing and data transmission capabilities is in charge of monitoring the parameters. On the other hand, the base station acts as a gateway and connects all nodes, enabling remote node management and data transfer. They carry data using low-power technologies including IEEE 802.15.4, Bluetooth, and ZigBee.

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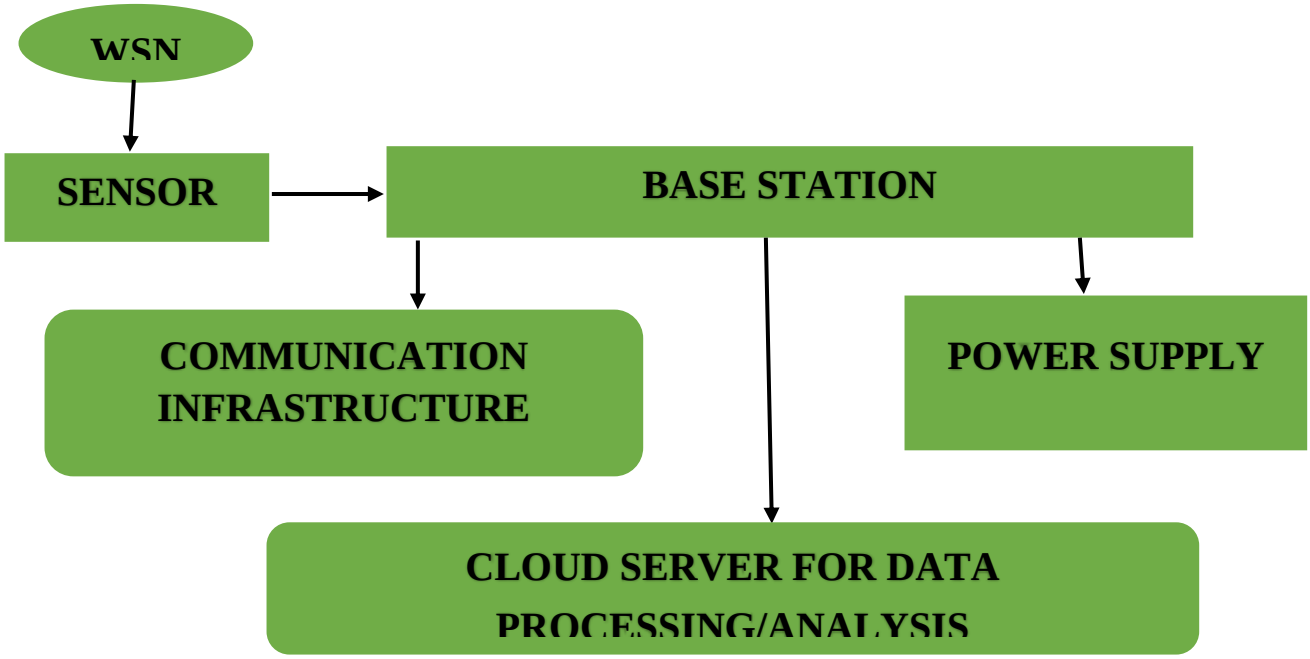

Fig. 7. Wireless Sensor System

iii) Automated Water Quality Monitoring System

Automated systems for aquaculture water quality monitoring continuously monitor and regulate critical water parameters that affect the health of aquatic animals using state-of-the-art sensors, software, and technology. These technologies help to minimize the need for manual monitoring, ensure the sustainability of aquaculture operations, and maintain optimal conditions. The system uses sensors and probes immersed in the water to monitor temperature, pH, dissolved oxygen, ammonia, nitrite, and other factors. Sensor data is collected and stored by data recorders so that it may be viewed and examined from a distance. By modifying water flow, filtration, and aeration in response to sensor data, automated control systems can improve the environment. By connecting the system to wireless networks or the Internet of Things, aquaculture operators can access it from a distance and send data in real time. The gathered data is analyzed by software to provide reports, identify patterns, and sound an alert or make adjustments if water quality parameters depart from allowable limits.

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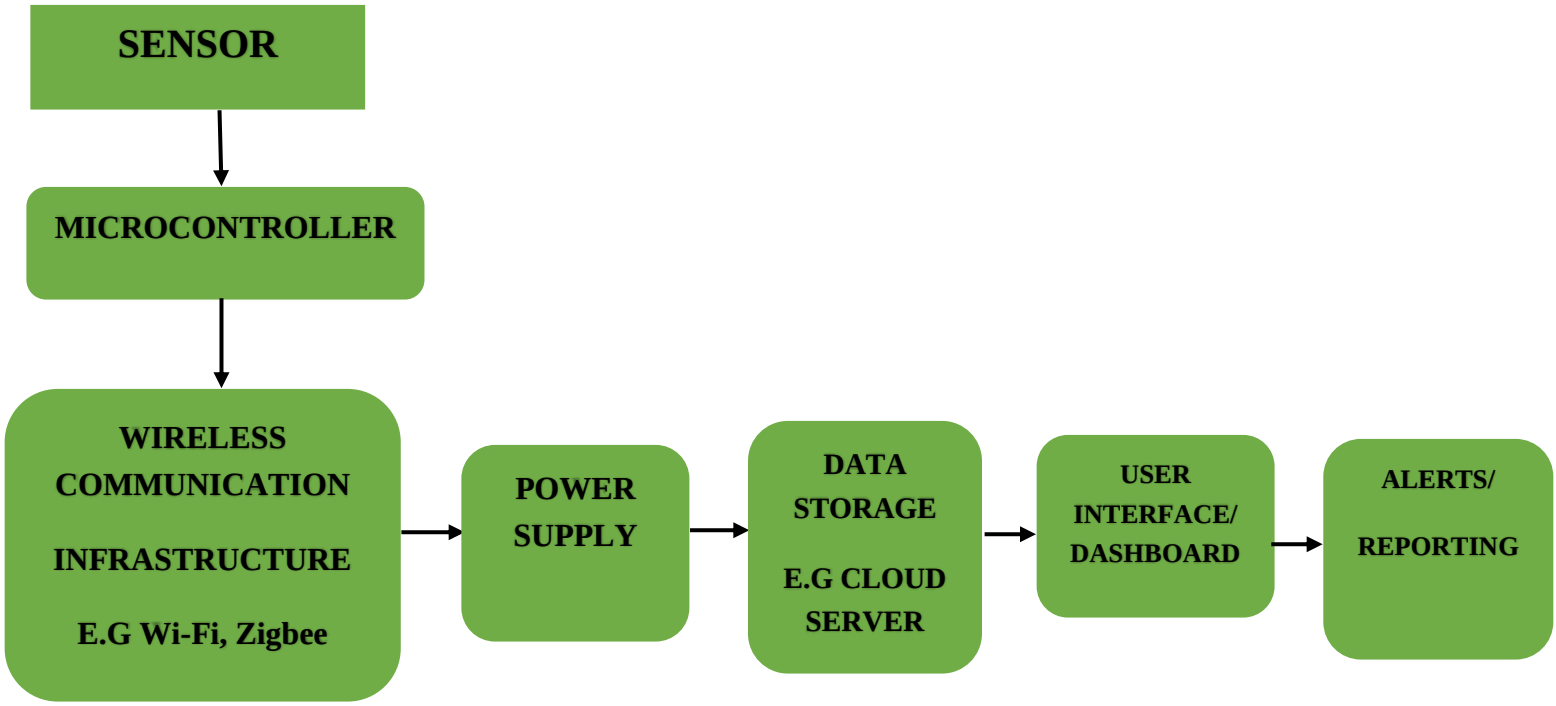

Fig. 8. Water Quality Monitoring System

Role of Aquaculture in Economic Development in Nigeria

Nigeria's economy, like that of the majority of African nations, is largely dependent on aquaculture for employment and income (Mulokozi et al., 2020). Nigeria's economy depends on aquaculture because it creates jobs, corporate earnings, and taxes. It also reduces poverty, attracts new investment, and stimulates economic growth. Amuneke et al. (2017) state that there are two ways in which aquaculture in Nigeria is related to other local economic sectors: directly and indirectly. It supports other industries and promotes economic growth by the buying and selling of goods and services, as well as investments in foreign exchange, human capital, and infrastructure development. Primary jobs (such as pond laborers, aquaculture hatchery workers, aquaculture technicians, and feed production workers, among others) and secondary employment (such as workers at fish processing plants, legal and illegal fish traders, etc.) are at the top of the food chain. Full-time, part-time, and intermittent work as a worker in hatcheries, nurseries, and grow-out production facilities are examples of farm-level aquaculture occupations. later vocations at later levels along aquaculture value chains include those in input supply, intermediate trade, and the distribution, processing, exporting, and vending of domestic fish. These all contribute to Nigeria's economic expansion.

Challenges Inhibiting Sustainable Aquaculture Development in Nigeria/Solutions

Numerous problems hinder the expansion and environmental impacts of sustainable aquaculture development in Nigeria. These difficulties include:

Climate Change

Climate change has been given top priority in global governance and development policies (Onada and Ogunola 2016). The repercussions include significant changes in weather extremes, changes to inland water hydrological regimes, and an increase in drought and flooding (Dike et al. 2020, Oparinde, 2021; IPCC, 2023). Fish productivity is clearly impacted by these factors (Oparinde, 2021; Oparinde, 2023). An increase in fish disease infestation has led to a decline in aquaculture productivity (Onada and Ogunola 2016).

Ipinjolu et al. (2014) provided additional empirical evidence of how climate change is affecting Nigerian fisheries and aquaculture. Both Nigeria's food security and local livelihoods are being significantly impacted by these incidences. The physiology of fish and rearing water is affected by temperature increases, and alter feed metabolism, respiration rates, feeding rates, enzyme activity, and oxygen consumption (Ipinjolu et al. 2014; Islam et al. 2022). These issues affect fish development, reproduction, and product shelf life. Most importantly, high temperatures cause oxygen to become much less soluble in water. Furthermore, this promotes the growth and survival of parasites and pathogens.

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These conditions certainly reduce fish survival and have an impact on the items that fish normally consume. Less rainfall has also been a problem for fish aquaculture in some areas. Anticipated income will be depleted to cover the cost of water required for fish production. However, aquaculture companies would lose money if culture enclosures overflowed due to floods caused by excessive rain.

Ipinjolu et al. (2014) suggested that the consequences of climate change on Nigerian fisheries and aquaculture still mostly rely on observation, forecasts, and other countries' experiences due to a lack of quantitative data. Several scholars claim that Nigeria does not now prioritize addressing the issues of climate change and aquaculture (Onada and Ogunola, 2016; Olutumise, 2023). According to Areola and Fakoya (2020), the aquaculture industry is not receiving enough national attention in terms of national policy and strategic planning on climate change, which clearly threatens the potential of these subsectors

More attention from the government and the public is desperately needed. We suggest encouraging the sale of smaller fish and shortening the production cycle in arid areas to help fight the water shortage. As a result, aquaculture production could be focused on times when there is an adequate water supply. To reduce the risk of flooding and fish mortality, aquaculture activities in areas that are vulnerable to floods should concentrate more on the dry season.

Poor feed Availability and Quality

Imported fish feed, which can be costly and of variable quality, is frequently used. There is little fish feed produced locally, and many small-scale farmers find it difficult to obtain premium feed at affordable costs. One of the biggest obstacles preventing aquaculture from expanding is definitely the cost of high-quality feed (Udoh and Dickson 2017). According to Udoh and Dickson (2017), feed costs currently account for 40–60% of total expenses and 60–80% of operating costs (Hasan, 2006). Aquaculture needs to cut expenses without sacrificing feed quality in order to be sustainable. To lessen reliance on imports, a significant effort is needed to professionalize feed manufacturing. Even though small businesses control the market and account for about 60% of local production, Nigeria has the largest feed mills in sub-Saharan Africa (Fagbenro and Adebayo 2005). Consequently, a significant amount of fishmeal used in Nigeria's aquaculture industry is imported. Furthermore, the capacity to produce fishmeal is insufficient to meet the growing aquaculture output. As a result, a significant amount of fish feed has been imported. We suggest enhancing feed formulation and processing as well as promoting public-private partnerships in the creation of sustainable feed solutions, such as new feed technologies and more effective production techniques, in order to address the problem of inadequate feed availability and quality.

Disease Management

High death rates in farmed fish are caused by disease and inadequate management techniques, which lowers output. In aquaculture, disease outbreaks are a major issue. Globally, they are to blame for enormous financial losses. It is anticipated that mortality rates in Nigerian catfish aquaculture will range from 1.9 to 19.7% for every production cycle (Mukaila, 2023). Aquaculture hygiene management has been identified as a significant obstacle to sickness control, second only to the accessibility of pharmaceuticals and the high price of premium feed (Mukaila, 2023). The primary cause of aquaculture deaths, especially in hatcheries, is disease. Temperature increases brought on by climate change have been connected to an increase in breakouts. Regretfully, a number of studies have revealed that Nigerians are not well-informed about the effects of sickness, as well as how to avoid and treat its symptoms (Mukaila, 2023). As a result, the government ought to take a proactive approach to addressing aquaculture disease. The following suggestions ought to be implemented:

- There should be massive investment in professionals, researchers, and extension workers in water quality management, disease prevention, and hygiene and diagnostics.
- The Ministry of Agriculture, being responsible for the development of aquaculture activities, should provide specialized training courses for farmers, increasing their awareness and providing necessary information on the respective measures established for hygiene in aquaculture.
- Centralized and well-equipped laboratories should be set up in different regions of the country, integrating existing expertise from the universities.

Access to Finance

Aquaculture farmers find it challenging to scale their operations, enhance their production methods, or invest in contemporary equipment due to limited access to loans and financial support. Aquaculture operators' access to financing is a result of the government's erratic financial policies. In addition to loans for capital investment and

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startup operating costs, fish farmers often need recurring loans. According to Odoye et al. (2005), short-term loans are intended for yearly supply of seed, feed, new equipment, and expansion; these are absent from our system and are impeding aquaculture's growth. Therefore, in order to support a profitable and sustained aquaculture business, the government should be willing to give fish farmers recurring loans.

Inadequate Training and Technical knowledge

Fish production is impacted by a lack of technical knowledge and experience in hatchery, propagation, and management. In order to increase fish productivity in Nigeria, fish farmers should be given efficient equipment and thorough information about the instruments that are available. Fish deteriorates as soon as it is harvested, thus processing and preservation are critical. To avoid significant financial losses, fish must be processed using top-notch equipment and preserved after collection (Davies and Davies, 2009).

The Role of Government in Water Quality Monitoring in Aquaculture

In Nigeria, the government plays a significant role in ensuring water quality monitoring in aquaculture as this is crucial for the sustainability of the sector. Below are some of the key ways the government is involved:

- **Regulation and policy Development:** To guide aquaculture's maintenance of water quality, the government drafts laws and regulations. Organizations such as the Federal Ministry of Agriculture and Rural Development (FMARD) and the National Agricultural Quarantine Service (NAQS) oversee policies that ensure proper water use, sanitation, and waste management in aquaculture operations. Permissible indicators of water quality, such as pH, temperature, dissolved oxygen concentration, and the presence of dangerous compounds, may be included in these requirements.
- **Water Quality Standards:** The government establishes water quality requirements for aquaculture operations through regulatory agencies. In order to protect aquatic life, human health, and the environment, it is important to make sure that the water used in fish farming is free of pollutants, toxins, and infections.
- **Monitoring and Enforcement:** Water bodies, particularly those utilized for aquaculture, are monitored by a number of government organizations, including the National Environmental Standards and Regulations Enforcement Agency (NESREA). They make sure that water quality regulations are being followed, and when they are not, they take enforcement action. This could entail routine aquaculture farm inspections, water quality testing, and making sure waste disposal systems are properly maintained.
- **Research and Data Collection:** Water quality monitoring in aquaculture areas is carried out by the government through organizations such as the Nigerian Institute for Oceanography and Marine Research (NIOMR) and other universities. By offering evidence-based suggestions for improvement, this study aids in understanding how various farming methods affect the quality of the water.
- **Training and Capacity Building:** Training farmers and other aquaculture industry stakeholders on the best techniques for preserving water quality is frequently funded by the government. This involves teaching people how to monitor important water quality measures and how to properly manage waste and treat water.
- **Funding and Support for Technology:** The government may facilitate the introduction and adoption of modern water quality monitoring technologies by providing subsidies, grants or loans. This helps aquaculture operators adopt efficient systems for real-time monitoring of water quality and maintaining optimal conditions for aquatic health.
- **Environmental Protection:** Additionally, the government works to avoid water contamination from other sources, such agricultural or industrial runoff, which might have an impact on aquaculture. Integrated environmental management techniques, such as pollution control laws and policies protecting water bodies, are used to achieve this.

Conclusion

Without a doubt, water quality monitoring is essential to the survival and success of Nigerian aquaculture. Maintaining optimal water quality is crucial for the health of aquatic organisms, boosting productivity, and lessening environmental impacts, as the text highlights. Given Nigeria's growing aquaculture sector and growing demand for fish, putting in place comprehensive water quality monitoring protocols will help address problems including pollution, disease outbreaks, and resource depletion. Additionally, it will assist the long-term success of the industry and promote better management practices. To achieve sustainable aquaculture development and economic growth, all stakeholders, including government agencies, aquaculture farmers and researchers must work collaboratively to adopt and promote efficient water quality monitoring systems. Ultimately, a commitment to safeguarding water resources will secure a brighter, more prosperous future for Nigeria’s aquaculture sector.

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Recommendation

1. It is there for recommended that water quality monitoring should be strengthened in Nigeria through policy integration, use of bioindicators and technology, capacity building, economic incentives and sustainable watershed-based practices for promoting sustainable aquaculture and economic development.

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