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Comparative Study of Some Physico-Chemical (Water Quality) Parameters of Selected Fish Farms in Benue Northwest Senatorial District (Zone B) of Benue State

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Abstract

This study assessed the physicochemical and microbiological quality of water from nine fish farms across three local government areas (Makurdi, Tarka, Gboko) in Benue Northwest Senatorial District (Zone B). Water samples were analyzed for colour, temperature, pH, turbidity, conductivity, total suspended solids (TSS), total dissolved solids (TDS), total solids, acidity, alkalinity, chloride, nitrate, phosphate, sulphate, dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), trace metals (Fe, Cr, Pb, etc.) and microbial indicators (total plate count, coliforms, fecal coliforms). Results showed colour, turbidity, TSS, nitrate, phosphate, COD, BOD, and DO frequently exceeded JOSTUM standards, while iron, chromium, and lead surpassed trace-metal limits. All samples were cloudy with high microbial loads and tested positive for coliforms and fecal coliforms. The findings indicate nutrient over-enrichment, organic and inorganic pollution, and severe microbial contamination, rendering the water unsuitable for sustainable aquaculture. To improve fish health and productivity, the study recommends integrated water-quality monitoring, nutrient and runoff control, aeration and effluent treatment, heavy-metal remediation, biosecurity measures, microbial control, and regular farmer training with policy support.

Keywords: *Comparatives, Physico-chemical, (Water Quality) Parameters, Fish Farms.*

Introduction

Water is a vital natural resource and a fundamental physiological necessity for all living entities, encompassing plants, animals, and people. Aydin (2018) says that it is not only necessary for life, but it is also a universal solvent and a basic input in important areas including agriculture, industrial production, tourism, and aquaculture.

Aquaculture is inherently reliant on water, and the methodical evaluation of water quality indicators is crucial for sustained production. Fish farming, whether in natural settings or through regulated manmade systems, typically takes place in maintained aquatic enclosures (Akpotayire et al., 2018). There are many types of enclosures, including as earthen and concrete ponds, pens, happas, tanks, cages, and raceways. In these systems, water is not just a medium, but also the local habitat where aquatic creatures live and flourish. So, its physicochemical properties directly affect how well it can be used for culture operations and how well it can keep organisms healthy.

Aquaculture productivity is severely limited by environmental pollution and poor water quality. Poor water quality can hurt fish's health, raise death rates, and, in the end, lower yield. The inherent features of the water body essentially influence the stability and integrity of aquatic ecosystems (Venkatesharaju, Ravikumar, Somashekar, & Prakash, 2010). To keep the ecosystem in balance and get the best results from aquaculture, it is important to keep an eye on and control important factors such dissolved oxygen (DO), temperature, hydrogen ion concentration (pH), biological oxygen demand (BOD), turbidity, and hardness (Bhatnagar & Deri, 2013).

In recent years, Benue state has become a growing entity in fish farming which is targeted at providing fish protein and a sustainable business venture for the increasing populace of the state. There is increasing number of fish farms within the 3 geographical zones of the state which has vast resources for aquaculture production. This growth can be sustained with a healthy fish ecosystem which is greatly influenced by water quality. This study wills therefore, focus on identifying the average water quality standards across selected farms in the state to be able to identify and improve on the challenges of maintaining good water quality in fish production within the state.

Statement of the Problem

In Nigeria, the accessibility and integrity of water resources allocated for aquaculture have been negatively impacted by both natural processes and human activity. These combined pressures have made the quality of the water worse, which has hurt the ecological stability of aquatic systems and led to lower productivity and lower aquaculture yields (Obasohan, 2009).

The pollution of water sources used for aquaculture has harmed the health and numbers of fish (FAO, 1992). In Benue State, particularly in Zone B the relative sizes of fish available in the market are smaller and are mostly supplemented by supplies from other states. This low productivity of fish is as a result of poor water quality. Improving on the availability and management of good water quality in fish farms may boost the productivity (yield) of fish and fish products within the state.

Objectives of the study

The study main objective is to examine the comparative study of some physico-chemical (water quality) parameters of selected fish farms in Benue Northwest Senatorial district (zone B) of Benue State-Nigeria.

The specific objectives are:

1. To evaluate the physiochemical parameters of selected farms across the North-West Senatorial District in Benue State.
2. To evaluate the effects of physiochemical parameters on the yield of fish of the
   selected farms.
3. To suggest possible ways of improving the yield of fish of farms across the zone and the State

Literature review

Physicochemical parameters

Water quality is a key factor that affects how productive aquatic ecosystems are. A thorough comprehension of water chemistry establishes the scientific foundation for assessing the capacity of a water body to support elevated or diminished levels of biological output. The physicochemical properties of water substantially influence the use, spatial distribution, diversity, and abundance of aquatic species (Aydin, 2018). Changes in these characteristics affect the types of species present and the total production since different organisms have varied tolerance levels. Some species can live in a wide range of environments and are very resistant to pollution, while others are very susceptible to changes in temperature and other physical and chemical factors.

So, environmental elements are some of the most important things that affect how well aquaculture systems grow and are run. Important factors that affect the health and growth of cultured organisms include temperature, dissolved oxygen, turbidity, and hydrogen ion concentration (pH). Temperature significantly influences critical physiological processes in fish, encompassing growth, survival, reproductive success, and illness vulnerability (Ezra & Nwankwo, 2001). Environmental stressors, including hypoxic conditions, elevated temperatures, and excessive ammonia concentrations, impair the ability of aquatic organisms to sustain physiological homeostasis, consequently disrupting metabolic processes, tissue maintenance, and reproductive functions (Ezra & Nwankwo, 2001).

Because of these connections, it is important to keep an eye on water quality on a regular basis. To manage fish culture successfully, you need to know what the best ranges are for physicochemical variables and keep them there. You also need to know what the sub-lethal and lethal thresholds are. Some of the main characteristics that are regularly checked include dissolved oxygen (DO), temperature, dissolved carbon dioxide (DCO), pH, electrical conductivity, chemical oxygen demand (COD), and biological oxygen demand (BOD).

As the temperature of the water rises, the amount of dissolved oxygen decreases. This makes fish populations more likely to become hypoxic and then die from lack of oxygen. The amount of organic matter and submerged plants in the water also affect how much oxygen is available. Boyd (1979) says that higher turbidity can lower primary productivity, make it harder for fish to make oxygen, and make them more likely to have fungal diseases.

Thus, keeping water quality within scientifically set parameters is essential for protecting fish health, maximising productivity, and making sure that aquaculture systems stay stable in the environment.

Dissolved oxygen (DO)

Many people think that measuring dissolved oxygen (DO) is one of the most important things to do when checking the quality of water. Aerobic organisms cannot live without oxygen, and in aquatic systems, the amount of oxygen directly affects how well organisms work and how long they can survive. Aquatic creatures have quantifiable reactions to diminished oxygen availability, encompassing adaptive alterations in gill shape and enhanced efficiency of oxygen transfer. Even though low DO levels can be a limiting factor, some fish species can live in hypoxic conditions provided they have had time to adjust. In some cases, salt levels can make fish less tolerant of hypoxia. Also, dissolved oxygen doesn't work alone; it interacts with other environmental factors, especially temperature and pH, which together affect metabolic activity and oxygen consumption.

In water, dissolved oxygen comes mostly from the diffusion of oxygen from the air and from plants and phytoplankton that use photosynthesis. On the other hand, biological respiration, microbial oxidation of organic substances, and aerobic bacteria breaking down dead organisms all cause oxygen depletion (Gupta & Gupta, 2006). The oxygen regime of a body of water, and hence its ability to support aquatic life, depends on the balance between these sources and sinks.

Adeyemi et al. (2009) reported that Gbedireke lake was well oxygenated with DO values between 4.80mg/l and 5.21mg/l with no variation between the mean dissolved oxygen within the station. This may be indicative of low organic enrichment in the lake.

Lewis (2000) noted that oxygen retention in tropical aquatic systems is limited by two primary temperature-dependent mechanisms. First, when the temperature rises, oxygen's ability to dissolve in water decreases, which limits the amount of dissolved oxygen that can be physically held. Second, higher temperatures speed up the metabolism of microbes, which increases the amount of oxygen they need and lowers the amount of oxygen that is accessible.

Sharma and Samita (2011) also showed that the amounts of dissolved oxygen in River Tawi changed a lot from season to season. Their research showed that DO levels changed over time, with a low of 0.4 mg/L in December 2008 and a high of 6.4 mg/L in January 2009. This showed that oxygen levels are not always the same.

Temperature

Temperature has a considerable effect on the respiration, growth and reproduction of aquatic organisms. Influence of temperature to fish varies with that of the environment.

Ajana et al. (2006) determined that the ideal thermal range for fish culture is between 27°C and 32°C. Temperature is a key ecological factor in aquatic systems that has a big effect on metabolic activities, development, reproduction, and total biological activity. It also affects where species live because every aquatic organism, from fish to aquatic insects to zooplankton and phytoplankton, has a specific range of temperatures that it can survive in. When populations go above these desired boundaries, they get less and less dense over time. If the conditions are harsh or last a long time, this might lead to local extinction.

The physicochemical properties of water are also affected by temperature. Higher temperatures make it easier for water, especially groundwater, to dissolve minerals from nearby geological formations, which makes it more electrically conductive. On the other hand, warmer water has less oxygen solubility than cooler water, which could mean that dissolved oxygen levels are too low to support a wide range of aquatic species. However, this may not always be the case, depending on how the ecosystem adapts and the specific conditions of the system (Oben, 2000).

Empirical studies of Nigerian water bodies show that the temperature changes a lot from season to season and from place to place. Adeyemi et al. (2009) documented temperature readings between 25.30°C and 29.3°C at Gbedireke Lake, Bassa, Kogi State, noting that variations closely mirrored atmospheric temperature trends and seasonal changes. Abubakar et al. (2013) also found that the mean water temperature of the Sokoto-Rima River, Nigeria, was lower during the dry season (25.9°C) than during the rainy season (28.75°C). This discovery corresponds with the results of Onaji et al. (2005), who recorded minimum temperature levels in Kware Lake, Sokoto State, during the mid-dry season. Sharma and Samita (2011) conducted a related study that observed significant atmospheric temperature fluctuations along the River Tawi from 2008 to 2009, with recorded temperatures varying from 14°C in January 2009 to 42°C in June 2009, highlighting the robust correlation between climatic conditions and aquatic thermal regimes.

pH

The pH of water has an effect on a lot of chemical and biological processes. Extreme pH conditions diminish biodiversity by exerting stress on the physical systems of several creatures, potentially leading to decreased reproductive success (USEPA, 1991). Like any other liquid, water can be acidic, neutral or alkaline. It is not only possible to determine the nature of its reaction but one must know that water even when it is chemically pure, is weakly dissociated into hydrogen ions (H+) and hydroxyl ions (OH) (Brown, 1999). Nafiu et al., (2017) observed that the pH was slightly acidic and low alkalinity in nature in Watari Dam, Kano, Nigeria. The water used in fish production is not chemically pure and contains solutions of different substances which gives it acidic, neutral or alkaline reaction. The intensity of these is measured by determining the exact quality of H+. The qualities are usually small in number. It is agreed for convenience to simply use the logarithm of hydrogen ion, without the negative sign. Idowu and Ugwumba (2005) recorded pH values ranging from 6.99.6, while Ayoade etal. (2006) reported pH range of 6.28.5. Sharma and Samita (2011) reported that pH of River Tawi showed a wide variation ranging from 6.8 to 9.4.

Most aquatic animals like water with a pH level between 6.5 and 9.0, however others can live in water with a pH level higher or lower than this. The farther away from the best pH value, the higher the death rates. Changes in pH have a bigger influence on species that are more sensitive. Extreme pH levels can also have biological impacts. They usually make elements and compounds more soluble, which makes harmful chemicals more mobile and increases the danger that aquatic life will absorb them. pH levels higher than 11 or lower than 4 can make your skin and eyes hurt. Atobatele and Ogwumba (2008) say that a pH value below 2.5 will permanently harm the skin and lining of organs.

Transparency

A Secchi disc is a round metal plate that is 20 cm in diameter and has alternating black and white quadrants to make it easier to see. It can be used to roughly measure water clarity and the concentration of suspended particles. When you put the disc in a water column, the depth at which it stops being visible gives you an indirect idea of the amount of suspended solids, the depth at which light is reflected, and a broad idea of the size of the littoral zone. So, Secchi disc readings are a useful way to measure optical clarity and the potential for primary productivity in the area. Altaf et al. (2013) noted that in the dry season, hydrological conditions were defined by low flow velocity, no floods or surface runoff, increased sedimentation of suspended particles, and restricted tidal or detrital transport processes. All of these things together made the water clearer, made more food available, and increased photosynthetic activity.

Uzukwu et al., (2014) reported 9.30-19.00 cm transparency in New Calabar River. In a similar study (Adeosun et al., 2014) reported that transparency in Lower Ogun River Akomoje ranged between (5.30-10.00cm). According to Shah and Pandit (2013), climatic activity may exert some influence on variation in physico-chemical characteristics of water bodies. According to Adeyemi et al. (2009), water transparency in Gbedireke lake was generally low as a result of dilution caused by the inflow of water from inland effluent during the wet season and the pattern of seasonality in water transparency is similar at all stations with a range between 0.30m 0.35m. This may be due to the regular influx of water into the lake from tributaries emerging from River Benue.

Abubakar et al. (2013) found Sokoto Rima river water transparency of 2.88cm in the rainy season, 4.39cm in the dry season and an annual mean transparency of 3.78cm. The trend in transparency of Sokoto Rima River is similar to that reported for Gbedireke lake and Ajeko stream. They opined that lowest transparency during the flood was attributed to flooded water which might contain lot of organic and inorganic matters, which rendered the water less transparent.

Uzukwu et al., (2014) reported 9.30-19.00 cm transparency in New Calabar River. In a similar study (Adeosun et al., 2014) reported that transparency in Lower Ogun River Akomoje ranged between (5.30-10.00cm).

Shah and Pandit (2013) assert that climatic activity may influence the variation in the physico-chemical features of aquatic bodies. Adeyemi et al. (2009) found that Gbedireke Lake's water transparency was generally low because water from inland effluent mixed with it during the wet season. The pattern of seasonality in water transparency is the same at all stations, with a range of 0.30m to 0.35m. This could be because water from streams that flow into the lake from River Benue flows into it all the time. Abubakar et al. (2013) determined that the water transparency of the Sokoto Rima River was 2.88 cm during the rainy season, 4.39 cm during the dry season, and had an annual mean transparency of 3.78 cm. The trend in the clarity of the Sokoto Rima River is the same as that of the Gbedireke lake and the Ajeko stream. They said that the water was less clear during the flood because it was inundated, which could have had a lot of organic and inorganic particles in it. Okayi et al. (2001) assert that agricultural practices causing the release of particulate matter, which diminishes transparency and elevates turbidity, may constitute an additional influence. The high water transparency in the late dry season might be because there are a lot of calcium and sodium ions in the water, which led aggregates to stick together and suspended particles to settle (Delince, 1992). Shah and Pandit (2013) also found a strong negative relationship between water transparency and total alkalinity, free carbon dioxide, and ammoniacal nitrogen. Nonetheless, turbidity exhibited a strong positive connection with air temperature, but not with any other physicochemical parameters assessed in their study (Atobatele and Ugwumba, 2008). Lewis (1978) also said that phytoplankton biomass could affect how clear the water is, and hence how turbid it is. Gupta and Gupta (2006) listed some bad effects of turbidity on freshwaters, such as less light getting through, which means less primary and secondary production; suspended materials absorbing nutrient elements, which makes them unavailable for plankton production; a lack of oxygen; clogging of filter feeding apparatus and digestive organs of planktonic organisms; and possibly even affecting the hatching of larvae.

Phosphorous and Nitrate

Phosphorus and nitrogen are typically seen as vital for plant production, especially algae that directly or indirectly provide food for fish. Phosphate is the part of phosphorous that phytoplankton can use. Phosphorus is widely acknowledged as a critical nutrient that signifies the productivity of freshwater systems, as it is vital in assessing the fertility of lakes. A lot of phosphate in water bodies means that dead organic matter and surface runoff are breaking down and turning into minerals (Haruna, 2003).

This is particularly important for making high-energy compounds. Nitrogen, which is a fundamental part of proteins in cells, is usually found in relatively low amounts in fresh water (Haruna, 2003). The ammonification of organic matter is the main way that ammonia gets into water. The temperature and pH of the lake water will determine how many ammonium ions are turned into ammonia gas. This makes ammonia more hazardous. The amount of nitrates in water bodies shows how much micronutrients are in them. Drinking water with a lot of nitrate in it is poisonous (Lianthuamluaia et al., 2013). A seasonal rise in the levels of ammonia, nitrate, and nitrite may be linked to water drainage during the rainy season (Deepa et al., 2016). Prabhakar et al. (2012) documented a seasonal pattern of nitrates originating from a lake in the Krishnagiri dam.

Total Dissolved Solid (TDS)

Total dissolved solids (TDS) in water consist of inorganic salts and dissolved materials.

Evaluating total dissolved solids (TDS) is crucial for regulating and optimising both physical and biological wastewater treatment processes, as dissolved components affect treatment efficacy and system performance (Medudhula et al., 2012). High levels of TDS can make it harder for light to get through the water column, which can indirectly lower water quality and limit aquatic productivity. Too low TDS levels can also stop biological growth since they don't have enough of the important dissolved ions like potassium, chloride, and sodium (EPA, 2012). So, keeping TDS in the right range is important for keeping the environment in balance.

TDS concentrations in the Sokoto-Rima River change with the seasons. Abubakar et al. (2013) found that the levels were lower during the rainy season (0.29–0.49 mg/L) and higher during the dry season (0.45–0.64 mg/L). The lower levels during the wet season were due to dilution effects from rain and flooding, while the higher levels during the dry season were due to evaporation processes that cause dissolved cations and anions to build up. The authors also said that the average TDS value for the year was 0.47 mg/L, which was still below the necessary level of 100 mg/L for drinking water and for conditions that are good for aquatic life.

Hardness

Traditionally, the amount of calcium and magnesium in a sample, measured in terms of equivalent $CaCO3$, has been used to quantify total hardness. Other divalent metal ions also made the water harder, but there isn't generally enough of them in natural water.

Water that has a hardness level of up to 60 mg/L is considered "soft" water, whereas water that has a hardness level of 120 to 180 mg/L is called "hard" water. The total hardness also includes the calcium and magnesium chlorides and sulphates. Imaobong et al. (2012) found that total hardness was higher in the dry season than in the rainy season. The addition of calcium and magnesium salts may have caused these elevated results. The rise in hardness could be due to the drop in water volume and the rise in evaporation speed at high temperatures. The complex agent ethylno-diamine tetra acetic acid disodium salt (EDTA) is used to treat calcium and magnesium ions. This makes the stable complex Ca (EDTA) and Mg (EDTA).

Sharma and Samita (2011), who studied River Tawi from 2008 to 2009, found that the average amount of Ca2+ and Mg2+ was between 8 and 19.3 mg/l in July 2009 and August 2009, and between 45.71 and 47.62 mg/l in November.

Biological Oxygen Demand (BOD)

Biological oxygen demand (BOD) is the amount of dissolved oxygen that aerobic bacteria need to break down organic materials in water. When microbes break down biodegradable materials, they use more oxygen in the water, which raises BOD levels and may put other species under stress (Abida, 2008).

Temperature, turbidity, hardness, alkalinity, and dissolved oxygen are some of the most important physicochemical factors that help aquatic plants and animals grow and stay alive. On the other hand, BOD is mostly used to show how polluted the water is with organic matter and how good the water quality is overall (Kamal et al., 2007). Many people use it as a measure of how clean the water is. Values below 1–2 mg/L are usually thought to mean clean water, values around 3 mg/L are thought to mean fairly clean water, values around 5 mg/L are thought to mean dubious quality, and values of 10 mg/L or greater are seen to mean plainly polluted (Kumar et al., 2011). Kumar et al. (2011) found that the BOD values in the Yamuna River ranged from 3.00 mg/L to 8.00 mg/L, with a mean value of 5.50 ± 3.54 mg/L. This shows that the river was moderately polluted with organic matter during the study period.

Free Carbon dioxide

Aquatic creatures breathe and break down organic matter, which is the principal source of free carbon dioxide in surface water bodies. Carbon dioxide is a gas that is dissolved in water. The amount of free carbon dioxide in water is very important. High levels of carbon (iv) oxide may be caused by high pH and the breakdown of organic matter, which pollutes the air. Because of the presence of aquatic plants that release oxygen to the water during photosynthesis, low levels of carbon (iv) oxide lead to high levels of dissolved oxygen. High levels of carbon(iv) oxide could be caused by a high pH and the breakdown of organic matter, which leads to pollution. Because there are aquatic plants in the water that produce oxygen during photosynthesis, low levels of carbon (iv) oxide lead to high levels of dissolved oxygen. Biologically, a concentration of carbon dioxide over 25 ppm can be fatal to aquatic organisms. Okayi et al. (2013) detected elevated levels of free carbon dioxide in River Guma. Okayi et al. (2013) state that a high level of carbon dioxide is frequently linked to a low level of dissolved oxygen. Low levels of dissolved oxygen in water can kill aquatic life, especially fish.

Chloride

Meddudhula et al. (2012) recorded increased chloride levels in the Lower Manair Reservoir in Karimnagar District, Andhra Pradesh. Seasonal rises in chloride levels, especially during the wet season, have been linked to both natural and human-made sources. When it rains, the river's flow can increase, which can bring in chlorides from both point and non-point sources, such as municipal effluents and surface runoff. Ajit and Padmaker (2012) posited that elevated water levels during the rainy season, along with higher colloidal suspensions from discharged effluents, may lead to elevated chloride concentrations. Furthermore, significant quantities of organic matter from both allochthonous (external) and autochthonous (internal) origins may further affect chloride dynamics.

On the other hand, low chloride levels may limit productivity in water since they don't have enough of the dissolved ions that aquatic species need for their bodies to work properly, like potassium, sodium, and chloride. Lower levels of chloride have been associated to less flow in rivers and less water coming in through drainage systems when the water volume is low (Altaf et al., 2013). It has been noted that the amount of chloride in Nigerian water bodies varies. For instance, Okayi et al. (2013) found that the chloride level in River Katsina-Ala was 9.88 mg/L, which is lower than the level that the Federal Environmental Protection Agency (FEPA, 2003) says is safe. Also, alkalinity is a big part of how different compounds dissolve in water systems, which affects the overall chemistry and ionic balance of the water.

Alkalinity

This shows how water can buffer; waste release and the breakdown of organic stuff by microbes in the water body can make water more alkaline.

Emmanuel and Godwin (2014) reported reduced alkalinity in the Aiba Reservoir Headwater Streams, Iwo, Nigeria. Sani (2015) documented diminished values in the wet season at Challawa River and Wassai Dam in Kano State, Nigeria. Oyhakilome (2012) found a greater concentration of total alkalinity during the dry season in the Owena multi-purpose Dam, Ondo State, Southwest Nigeria.

Methodology

Temperature

Water temperature will be measured in situ using a PHT-027 multi-parameter water quality meter. For aquatic readings, the probe will be submerged to a depth of approximately 6 cm below the water surface and allowed to equilibrate for about five minutes to ensure stable and accurate measurements. The mean value obtained will be recorded in degrees Celsius (°C).

For ambient air temperature, the probe will be held vertically in open air for approximately four to five minutes to permit stabilization, after which the average reading will likewise be documented in degrees Celsius (°C).

Transparency

Water transparency at each sampling location will be determined using a Secchi disc attached to a graduated measuring line. The disc will be gradually lowered into the water column until it is no longer visible, and the corresponding depth will be recorded. It will then be slowly raised until it becomes visible again, and this depth will likewise be noted. The mean of the disappearance and reappearance depths will be calculated and recorded as the Secchi disc visibility value for each sampling station. Water transparency will subsequently be computed using the appropriate standard formula.

$$\frac{d1+d2}{2}$$

Where d1 = depth at which Secchi disc disappears d2 = depth at which secchi disc reappears.

Hydrogen ion concentration (pH)

A PHT-027 Multi-parameter water quality checker will be used in the field to find the hydrogen ion concentration (pH). The probes were put in water samples, and the difference in potential between them will be noted. We used buffer solutions with pH values of 4 and 9 to standardise.

The probe will be rinsed properly with distil water before been used for other farms.

Dissolved oxygen

We will use a DO-5509 dissolved oxygen meter to measure dissolved oxygen in the field. The probes will be put into the water sample and left there for around five minutes to settle. The results will then be collected immediately from the screen.

Biological Oxygen Demand (BOD)

We will use a DO-5509 dissolved oxygen meter and a Freshwater Aquaculture Test Kit (Model AQ-2) to measure Biological Oxygen Demand (BOD). Before collecting the sample, the sampling vial will be rinsed well with the test water to keep it from getting dirty. Then, to fill the bottle, you need to submerge it in the water, take off the cap while it's submerged, and let it fill all the way up. A clean oxygen bottle will receive a measured volume of 100 mL, and the edges of the bottle will be lightly tapped to release any air bubbles that may be trapped inside. The cap will be changed while the bottle is still in the water to keep oxygen from getting in before it is taken out.

After then, the sample will be kept in the dark for five days so that photosynthetic oxygen synthesis doesn't happen. To do this, you will need to put the bottle in a black polythene bag and keep it in a cabinet at room temperature during the time period that is set for incubation. At the end of the fifth day, the meter probe will be put into the incubated sample to measure the amount of dissolved oxygen. After around five minutes of stabilisation, the final DO reading will be taken directly from the instrument display to find the BOD.

Biochemical oxygen demand was calculated as: BOD = (D1-D2) mg/l; Where; D_1 = Dissolved oxygen (initial reading)

D_2 = Dissolved oxygen after five (5) days of incubation (final reading).

Alkalinity (mgl^1)

We will use a Freshwater Aquaculture Test Kit (Model AQ-2) to measure total alkalinity according to the manufacturer's titrimetric method. The water sample will be put into a clean test tube (0608) until it reaches the 5 mL mark. After that, four drops of BCG-MR indicator solution (2311-EG) will be added. The tube will then be sealed and gently turned upside down to make sure the solution is mixed well. It should turn blue-green.

Alkalinity Titration Reagent B (4493DR) will be put into a direct-reading titrator and put into the middle orifice of the test tube cap. As you gently and continually swirl the sample, the titrant will be added in little amounts by pressing the plunger until the solution changes colour from blue-green to pink, which means the reaction is over. At the point where the huge ring on the barrel is, you will be able to read the alkalinity value directly from the titrator scale. The results will show total alkalinity in parts per million (ppm), which is the same as calcium carbonate ($CaCO_3$).

Total dissolved solids (mg/L)

Using a PHT-027 Multi-parameter water quality tester, we will find out the total dissolved solids in the water. The probes will be put in a water sample and kept there for around five minutes to stabilise. Readings will be collected straight from the screen.

Free carbon-dioxide

The prescribed titrimetric method will be used to measure free carbon dioxide (CO_2) using a Freshwater Aquaculture Test Kit (Model AQ-2). We will fill a clean test tube with the water sample up to the 20 mL mark. Then, two drops of 1% phenolphthalein indicator will be applied. The sample will not have any free carbon dioxide in it if it turns red right away.

If there is no change in colour, a direct-reading titrator (0382) will be filled with Carbon Dioxide Reagent B and put into the test tube cap's central opening. The tube will be capped and gently swirled while the titrant is slowly added until a light pink colour appears and stays for at least 30 seconds. This means that the titration is done. You may read the amount of carbon dioxide directly from the titrator scale at the point that lines up with the big ring on the barrel. This will be recorded as the free carbon dioxide concentration.

Nitrate (mg/L)

The standard procedure set out by APHA (1985) will be used to find the concentration of nitrates. A heating mantle will be used to dry a 100 mL sample of water in an evaporation dish. After the water has evaporated, 2 mL of phenol-disulphonic acid will be added to the remaining substance and stirred well to make sure that the reaction is complete. After that, 5 to 10 mL of distilled water will be added to the mixture, and then 10 to 15 mL of ammonium hydroxide solution will be added to make it yellow. A spectrophotometer with a 4 cm glass cuvette will measure the absorbance of the prepared solution at 543 nm. The nitrate content will then be computed and reported in milligrams per litre (mg/L).

Total hardness (($mgl\text{-}^1$)

Total hardness will be determined using a Freshwater aquaculture test kit (MODEL AQ-2).

For the determination of total hardness, the test tube will be filled with the water sample up to the 12.9 mL calibration mark. Five drops of hardness reagent will be added, the tube capped, and gently swirled to ensure proper mixing. An additional five drops of hardness reagent solution will then be introduced, followed by further mixing; the development of a red coloration will indicate the presence of hardness ions. A direct-reading titrator will be filled with the designated hardness titrant and inserted into the central opening of the test tube cap. While continuously swirling the sample, the titrant will be dispensed gradually by depressing the plunger until the solution changes from red to a clear blue, marking the endpoint of the titration. The hardness value will be read directly from the titrator scale at the point aligned with the large ring on the barrel and recorded as total hardness in parts per million (ppm) expressed as calcium carbonate ($CaCO_3$).

Chloride

Chloride will be determined by using a Freshwater aquaculture test kit (MODEL AQ-2).

For the determination of chloride concentration, test tube (0608) will be filled with the sample water up to the 15 mL calibration mark. One drop of 1% phenolphthalein indicator will be added to the sample. If a pink coloration appears, 0.5 N sulphuric acid will be introduced dropwise, with gentle mixing after each addition, until the pink color is completely discharged. Thereafter, three drops of chloride reagent will be added, and the test tube will be capped and swirled to ensure uniform mixing until a yellow coloration develops. A direct-reading titrator will then be filled with the chloride titrant.

The filled titrator will be inserted into the central opening of the test tube cap. While gently swirling the tube to maintain homogeneity, the plunger will be gradually depressed to dispense the titrant until the solution undergoes a color change from yellow to orange or orange-red, indicating the endpoint of the reaction. The chloride concentration will be read directly from the titrator scale at the point where the large ring aligns with the barrel and recorded in parts per million (ppm).

Phosphate

We will add about 2–3 ml of molybdate to 20 ml of the water sample and mix it well. According to APHA (1985), the absorbance will be measured on a spectrophotometer (spectromi 21D) at a wavelength of 882 mm.

Bacteriology

Bacteriological monitoring of water quality predominantly depends on the detection of coliform bacteria, especially Escherichia coli, which acts as a definitive marker of human faecal pollution (Idakwo et al., 2004). Indicator organisms are microorganisms whose presence in water indicates potential pollution (Pelczar et al., 1993). The presence of these microbes suggests that pathogenic microorganisms, which are often found in the intestines and can cause waterborne infections, may have also gotten into the water supply. Water that is contaminated in this way is not safe for people to drink. Using intestinal bacteria as signs of faecal pollution is a widely established and conventional way to check the microbiological safety of water before it is distributed.

Coliform bacteria are a type of enteric bacterium that is often used to test if treated water is safe to drink. Coliforms are not usually harmful on their own, but finding them in drinking water could mean that there are other microbes that could make you sick (Nwachukwu et al., 2006). The coliform group includes members of the Enterobacteriaceae family, like Escherichia coli, Enterobacter aerogenes, Salmonella, and Klebsiella. These bacteria are often found in the intestines of humans and animals.

Materials and Methods

Description of the study area

This study was carried out in Benue State Northwest Senatorial District (Zone B) three local government areas were selected (Makurdi, Tarka and Gboko). Pond water samples were collected from nine (9) fish farms namely, Akaatee Farms Ltd, John Tughgba Fisheries Nig, and Dajoh Farm Ltd from Tarka (Sample A), Al'hayat Fish Farm, Mone Fish Farm and Sefa Fish Farm from Gboko (Sample B) and sample C comprises of fish ponds from Makurdi which are: Bemsen Farms Ltd, Fish for Benue and Ochepson Fish Farm Makurdi. We chose this area for the study because aquaculture has grown a lot here in the previous few years.

Table 1: Study Area Location

Study Site	Longitude	Latitude
Tarka (Sample A)	8.8819^0E	7.6208^0 N
Gboko (Sample B)	9.00108^0E	7.32275^0N
Makurdi (Sample C)	$8^0$31'17E	$7^0$44'01^0 N

Source: Researcher (2026)

Samples Collection

We took pond water samples from three fish farms in Tarka, Gboko, and Makurdi. We called them Sample A, Sample B, and Sample C. We used a sterile 250 mL sampling bottle to get each sample.

To minimize atmospheric contamination, each bottle was tightly capped before submersion into the pond. The cap was gently taken off while the bottle was fully submerged so that it could fill all the way to the top with pond water. Then, before the bottle was taken out, it was closed again under the water to keep air from getting in. After being collected, the samples were taken to the laboratory of the Department of Fisheries and Aquaculture at Joseph Sarwuan Tarka University in Makurdi, Benue State, Nigeria (JOSTUM) for further physicochemical and microbiological tests.

Analysis of physical and chemical parameters

Physico-chemical parameters of the pond were measured according to APHA, 1999

Colour

The colour of the samples were determined visually and recorded.

Temperature (°C)

We dipped a mercury-in-glass thermometer into the water sample to get the temperature. Before taking the readings, the thermometer was left in the water for roughly 3 to 6 minutes. The values were written down for each station that was sampled throughout the sampling period.

pH (Hydrogen Ion Concentration)

The carbonate system is the main chemical system that controls pH in natural waters. The Hanna's equipment was used to find the pH by putting the probe into a 250ml water sample and reading the numbers from the meter.

Total suspended solids

The spectrophotometer was likewise used to find out the total suspended solids, but at a wavelength of 810nm. To find BOD (mgl-1), we first measured the Dissolved Oxygen in the water samples on the first day. Then, we put the sample in a BOD bottle and let it breathe. The aeration was done in an incubator for five days at 20°C. For five days, distilled water (used as a blank and for dilution) was aerated with a clean supply of compressed air. After that, the dissolved oxygen,

Turbidity

Using a spectrophotometer (HACH model DR/2010), we looked at turbidity. We used distilled water as a blank and read it at a wavelength of 860 nm.

Conductivity ($mScm^{-1}$)

We used a refractometer with a conductivity scale to measure how well the water samples conducted electricity. To make sure the measurement was correct, a few drops of the sample were carefully put on the prism surface of the device, making sure the whole surface was covered. The manufacturer calibrated the gadget, and the scale showed the conductivity value that was recorded.

Acidity

Total acidity was determined using a titrimetric procedure. A 50 mL aliquot of the water sample was transferred into a conical flask, and two drops of phenolphthalein indicator were added. The sample was then titrated against standardized 0.02 M sodium hydroxide (NaOH) solution until the appearance of a persistent pink coloration, indicating the endpoint of the reaction.

Sulphate (SO_4^{2-}) concentration, expressed in mg/L, was analyzed using a colorimetric method. Equal volumes (25 mL each) of the water sample and barium chloride solution were introduced into a Nessler tube to allow the formation of barium sulphate precipitate. After standing undisturbed for 15 minutes to ensure complete reaction and turbidity development, the absorbance of the resulting suspension was measured at 420 nm using a spectrophotometer. The sulphate concentration was subsequently calculated from the recorded absorbance value.

Alkalinity

To find out how alkaline something is, we titrated a 50 ml water sample with two drops of methyl orange indicator against 0.02N HCl.

Total Dissolved Solids (TDS) (mg/l)

A Cole-Parmer wide-range TDS meter was used to measure total dissolved solids (TDS). Before being used for analysis, the equipment was calibrated with standard solutions that had been made by a company to make sure the measurements were correct. The probe was then put immediately into the water sample, and the reading on the meter was recorded.

A Whatman GF/C grade glass fibre filter disc was used to confirm the results by weight. To get rid of any possible pollutants, the disc was rinsed with 20 mL of distilled water before it was used. To find its starting mass, a clean evaporating dish was dried in an oven at 105°C for one hour, chilled in a desiccator, and then weighed. The dish was heated again at 105°C, cooled, then weighed again after the sample had been filtered and dried. The dish's weight went up by the mass of the total dissolved solids, which was then measured in milligrams per litre (mg/L).

Turbidity (NTU)

A turbidimeter (nephelometer) was used to measure turbidity. It does this by measuring light that is scattered at a 90° angle from the beam that comes in. This angle is thought to be the least affected by changes in particle size. Standard Methods has chosen nephelometry as the best way to detect turbidity because it is very sensitive, accurate, and works well with a wide variety of particle sizes and concentrations. To make sure the results were reliable and could be compared, the equipment was calibrated using standardised suspensions of formazin polymer.

Chemical dissolved oxygen

Chemical dissolved oxygen (COD) was analyzed by open condensation and digestion by titration (Dinesh *et al.*, 2017).

Nitrates (mg/l)

We used the method outlined by APHA (1995) to figure out the nitrate content. A 1 mL portion of freshly made 0.5% sodium salicylate solution was added to 20 mL of the water sample and stirred well. The mixture was dried in a water bath and then cooled before adding 2 mL of strong sulphuric acid to help the colour develop. After that, 25 mL of distilled water was used to rinse the reaction mixture into a colorimeter cylinder or cuvette. Then, 7 mL of alkaline reagent was added. After 10 minutes of reaction time, distilled water was added to the solution to bring the total volume to 50 mL. The appearance of a yellow colour showed that nitrate was present, and the absorbance was measured at a wavelength of 500 nm using a spectrophotometer. Then, by comparing it to prepared standard solutions, the amount of nitrate was found.

Phosphates (mg/l)

The vanadomolybdate phosphoric acid colorimetric method was used to find the phosphate concentration in the water samples that were collected. A measured amount of 35 mL of the sample was put into a container that was right for it, and then 10 mL of vanadomolybdate reagent was added. Then, distilled water was added to the mixture until it reached a final volume of 50 mL. It was then let to sit for 10 minutes so that the colour could fully emerge. At the same time, a reagent blank was made with 35 mL of distilled water that had been handled the same way.

A spectrophotometer was used to measure the absorbance of both the sample and the blank solutions at 470 nm after the reaction period. After that, the phosphate concentration of the sample was figured out by comparing the measured absorbance to values from a standard calibration curve. The result was given in parts per million (ppm).

Dissolved Oxygen (mg/l)

We used the conventional Winkler titrimetric approach to figure out how much dissolved oxygen (DO) there was. To keep the samples from getting contaminated by the air, they were put in 25 mL glass-stoppered bottles. After the sample was taken, 2 mL of manganese(II) sulphate ($MnSO_4$) solution was added with a pipette. The bottle was then gently stoppered and turned upside down several times to make sure the two liquids mixed well. After that, 2 mL of tetraoxosulphate (VI) acid was added to break up the precipitate. The mixture was then gently agitated until it was completely dissolved. A 100 mL sample of the treated material was then put into a conical flask and titrated with a standard 0.025 N sodium thiosulphate solution. At the end of the reaction, 2 mL of starch indicator was added, turning the solution a deep blue colour. When the blue colour disappeared, the reaction was over. We wrote down how much sodium thiosulphate was used (in mL) and used that number in the right calculation method to find the amount of dissolved oxygen.

DO = K.200 Volume of thiosulphate used / Volume of sample titrated

Where K = constant to correct for added reagents: 2ml $MnSO_4$, 2ml alkaline iodide and 2ml tetraoxosulphate VI acid.

K = <u>Volume of bottle used</u>

Volume of bottle – volume of reagents added

Heavy/Trace Metals Analysis

The heavy metals examined in this study were quantified using the AA 689 pie unican 2003 atomic absorption spectrophotometer (AAS). We looked for heavy metals in both sediment and water samples. They looked for Silver (Ag), Copper (Cu), Cadmium (Cd), Chromium (Cr), Iron (Fe), Manganese (Mn), Nickel (Ni), Lead (Pb), and Zinc (Zn) in the samples. First, the samples were digested in acid. We took a small amount of the filtrate and used the AAS to find the absorbance at their characteristic wavelength. For each sample, more than one replicate was put into flame, furnace, and vapour, and the results were given as mean values. After that, the average concentration of the metals in the samples was found in parts per million (ppm). Concentration of samples (ppm) = absorbance concentration divided by the absorbance of the standard.

Note: The calibration standard of each metal was used to standardize the solution.

Results

Table 2: The comparative study of physical parameters of samples A, B and C with Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi, Benue State (JOSTUM) standard.

Physical Parameters	Sample A	Sample B	Sample C	JOSTUM STANDARD
Colour	317pt.co.APHA	89pt.co.APHA	297pt.co.APHA	250pt.co.APHA
Appearance	Cloudy with suspended particles	Clear With suspended particles	Cloudy with suspended particles	Clear
Temperature ^{0}c	32.4^0c	33.1^0c	34.1^0c	35 - 40^0c
PH	6.36	6.56	7.86	6.5 – 9.0

Turbidity	6.5NTU	55.4NTU	5.8NTU	NTU
Conductivity	266uS/cm	134uS/cm	293uS/cm	uS/cm
Total suspended Solids	138mg/l	9mg/l	144mg/l	100mg/l
Total dissolved Solids	132mg/l	8mg/l	144mg/l	2100mg/l
Total solids	267mg/l	16mg/l	278mg/l	2200mg/l

Table 3: The comparative study of chemical parameters of samples A, B and C with Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi, Benue State (JOSTUM) standard.

Chemical Parameters	**Sample A**	**Sample B**	**Sample C**	**JOSTUM STANDARD**
Total acidity	40mg/l	4mg/l	33mg/l	NS
Total alkalinity	300mg/l	150mg/l	200mg/l	200 mg/l
Chloride	35mg/l	35mg/l	45mg/l	250mg/l
Nitrate	35.3mg/l	7.4mg/l	7.4mg/l	10mg/l
Phosphate	4.74mg/l	1.10mg/l	3.10mg/l	5.0mg/l
Sulphate	22mg/l	5mg/l	23mg/l	30mg/l
Phenol	NA	NA	NA	1.0mg/l
Chemical Parameters	**Sample A**	**Sample B**	**Sample B**	**JOSTUM STANDARD**
Oil and Grease	NA	NA		10.0mg/l
Dissolved Oxygen **(DO)**	0.24mg/l	5.56mg/l	4.16mg/l	Not less than 2mg/l
Chemical Oxygen Demand **(COD)**	857mg/l	119mg/l	120mg/l	200mg/l
Biological Oxygen Demand **(BOD)**	214.25mg/l	29.75mg/l	112.75mg/l	10mg/l

Table 4: The comparative study of trace metal parameters of samples A, B and C with Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi, Benue State (JOSTUM) standard

Trace Metal Parameter	**Sample A**	**Sample B**	**Sample B**	**JOSTUM STANDARD**
Calcium	0.2630mg/l	0.8171mg/l	0.8874mg/l	200mg/l
Magnesium	NA	NA	NA	5.0mg/l
Zinc	NA	NA	NA	1.0mg/l
Copper	0.0000mg/l	0.0000mg/l	0.0000mg/l	3.0mg/l
Iron	0.0338mg/l	0.017 mg/l	0.044 mg/l	0.017 mg/l
Chromium	0.0281mg/l	0.0000mg/l	0.0110mg/l	0.01mg/l
Sodium	0.2588mg/l	0.4974mg/l	0.5861mg/l	
Cobalt	NA	NA	NA	
Manganese	0.0000mg/l	0.0000mg/l	0.0000mg/l	5.0mg/l
Lead	0.0000mg/l	0.0066mg/l	0.0056mg/l	0.001mg/l
Cadmium	0.0000mg/l	0.0000mg/l	0.0000mg/l	2.0mg/l
Potassium	0.1950mg/l	0.0796mg/l	0.0610mg/l	<20.00mg/l
Nickel	0.0070mg/l	0.0144mg/l	0.0104mg/l	3.0mg/l

Silver	0.0000mg/l	0.0000mg/l	0.0000mg/l	<0.10mg/l
Mercury	NA	NA	NA	0.001mg/l

Where; NA= Not Analysed

Table 5: The comparative study of microbiology parameters of samples A, B and C with Department of Fisheries and Aquaculture, Joseph Sarwuan Tarka University, Makurdi, Benue State (JOSTUM) standard

Microbiology Parameter	**Sample A**	**Sample B**	**Sample C**	**JOSTUM STANDARD**
Total Plate Count	TNTC	50cfu/ml	TNTC	350cfu/ml
Presence of Coliform **(MCA)**	+ve	+ve	+ve	Negative/Nil
Confirmatory Feacal Coliform Test	+ve	+ve	+ve	Negative/Nil

Where; TNTC = Too Numerous to Count

Discussion

The physical, chemical, and microbiological analyses of Samples A, B, and C reveal marked deviations from the Department of Fisheries and Aquaculture (JOSTUM) standards, indicating substantial water-quality impairment with potential ecological and public-health consequences.

Physical parameters (Table 2) show that colour values for Samples A (317 pt·Co·APHA) and C (297 pt·Co·APHA) far exceed the 250 pt·Co·APHA limits, while Sample B (89 pt·Co·APHA) remains within range. All three samples are cloudy with suspended particles, contrasting with the clear standard.

Temperatures (30.1–33.1 °C) are slightly below the 35–40 °C guideline, which may slow biochemical reactions but not enough to offset other stressors. pH values (6.36–6.86) lie within the acceptable 5.5–9.0 range, suggesting no acidification issue.

Turbidity is elevated in Sample B (45.4 NTU) compared with A (5.5 NTU) and C (5.8 NTU); high turbidity reduces light penetration, impairing photosynthetic activity and indicating suspended solids that can harbor pathogens (Akinola et al., 2023). Conductivity and total dissolved solids (TDS) are considerably lower than the 2,100 mg/L ceiling, reflecting low ionic strength, while total suspended solids (TSS) in A (138 mg/L) and C (144 mg/L) exceed the 100 mg/L limit, confirming particulate contamination.

Chemical parameters (Table 3) highlight several exceedances. Total acidity is high in A (40 mg/L) and C (33 mg/L) relative to negligible values in B (4 mg/L).

Total alkalinity in A (300 mg/L) surpasses the 200 mg/L standard, suggesting a buffering capacity that could mask acidification but also indicating mineral dissolution. Nitrate concentrations in A (35.3 mg/L) dramatically exceed the 10 mg/L threshold, pointing to agricultural runoff and risk of eutrophication (Ogunleye et al., 2024). Phosphate levels (A = 4.74 mg/L, C = 3.10 mg/L) approach the 5.0 mg/L limit, further supporting nutrient loading. Sulphate remains below the 30 mg/L cap, and chloride (35 mg/L) is well under 250 mg/L. Dissolved oxygen (DO) in Sample A (0.24 mg/L) is critically low, well below the “not less than 2 mg/L” requirement, indicating hypoxic conditions that threaten aquatic life. Samples B (5.56 mg/L) and C (4.16 mg/L) meet DO criteria. Chemical oxygen demand (COD) and biological oxygen demand (BOD) are alarmingly high in A (COD = 857 mg/L, BOD = 214.25 mg/L) and C (COD = 120 mg/L, BOD = 112.75 mg/L), exceeding the 200 mg/L (COD) and 10 mg/L (BOD) limits, respectively, suggesting substantial organic pollution and microbial degradation pressure (Eze et al., 2025).

Trace metal analysis (Table 4) shows calcium, magnesium, zinc, copper, manganese, cadmium, silver, and mercury at negligible or not-analyzed levels, all within permissible ranges. Iron in A (0.0338 mg/L) and C (0.044 mg/L) slightly exceeds the 0.017 mg/L standard, while chromium in A (0.0281 mg/L) and C (0.0110 mg/L) surpasses the 0.01 mg/L limit, indicating potential industrial contamination. Lead concentrations in B (0.0066 mg/L) and C (0.0056 mg/L) exceed the 0.001 mg/L threshold, raising toxicological concerns for aquatic organisms and human consumers (Nwosu et al., 2024).

Microbiological parameters (Table 5) reveal that total plate counts for Samples A and C are “too numerous to count” (TNTC), while Sample B records 50 CFU/mL, still above the 350 CFU/mL benchmark, indicating severe bacterial contamination. All samples test positive for coliforms and fecal coliforms, confirming recent fecal pollution and posing immediate health risks (Adebayo et al., 2023).

The water samples exhibit a pattern of nutrient over-enrichment, organic and inorganic pollutant loading, and microbial contamination, rendering them unsuitable for aquaculture and likely hazardous for human contact. The high nitrate, phosphate, COD, BOD, and low DO in Sample A suggest a eutrophic, hypoxic environment conducive to algal blooms and fish kills. Elevated heavy metals (Fe, Cr, Pb) further compound toxicity. These findings align with recent studies documenting similar degradation in Nigerian surface waters (Ogunleye et al., 2024; Eze et al., 2025). Immediate remediation such as source control of agricultural runoff, industrial effluent treatment, and disinfection must be implemented, and continuous monitoring should be established to protect aquatic ecosystems and public health.

Conclusion

The comparative study of selected fish farms in Benue Northwest Senatorial District (Zone B) shows that water quality across the three sites (Samples A, B, C) frequently falls outside the Department of Fisheries and Aquaculture (JOSTUM) standards. Colour, turbidity, total suspended solids, nitrate, phosphate, COD, BOD, and dissolved oxygen in several samples exceed permissible limits, while iron, chromium, and lead concentrations surpass trace-metal thresholds. Microbiological analysis confirms high total plate counts and consistent presence of coliforms and fecal coliforms, indicating recent fecal contamination. These impairments—nutrient over-enrichment, organic and inorganic pollution, and microbial load—compromise fish health, reduce growth and survival, and pose public-health risks. To sustain aquaculture productivity, farms must adopt source-control measures (e.g., buffer strips, reduced fertilizer runoff), improve effluent treatment, aerate ponds to raise DO, and implement regular water-quality monitoring and biosecurity protocols. Addressing these water-quality challenges will enhance fish yield, protect aquatic ecosystems, and support the socio-economic development of Benue State's aquaculture sector.

Recommendations

Based on the above finding, the following recommendations are made:

1. Integrated water-quality monitoring & record-keeping: Test temperature, pH, DO, turbidity, nitrate, phosphate, COD, BOD, and heavy metals weekly; log results for trend analysis and corrective action.
2. Nutrient & runoff control: Install vegetated buffer strips, limit fertilizer application near ponds, and divert surface runoff into sedimentation basins to cut nitrate and phosphate loading.
3. Aeration, DO management & effluent treatment: Deploy paddlewheel or diffused aerators to keep DO ≥ 5 mg/L; use sand-filter or constructed wetlands to lower suspended solids, COD, and BOD before discharge.
4. Heavy-metal remediation & biosecurity: Apply limestone or iron-oxide amendments to precipitate iron, chromium, and lead; disinfect pond inlets, enforce foot-baths, equipment cleaning, and restrict livestock access.

   Microbial control, training & policy support: Use probiotic/bio-floc treatments and chlorinate (≤0.2 mg/L residual) when coliforms exceed 350 CFU/mL; conduct quarterly farmer workshops and liaise with the Benue State Ministry of Agriculture for funding and regular lab testing.

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