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Knowledge, attitude and practices (KAP) of fish farmers regarding water quality management and antimicrobial usage in the Federal Capital Territory, Abuja, Nigeria

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Abstract

Water quality is a critical determinant of success in aquaculture, yet its management often depends on farmers' knowledge, understanding and practices. This study assessed the knowledge, attitude and practices (KAP) of fish farmers regarding water quality management in the Federal Capital Territory (FCT), Abuja, Nigeria. A cross-sectional survey was conducted using a structured questionnaire administered to 102 fish farmers across the six area councils of the FCT. Data were analysed using descriptive statistics. The results revealed a significant gap between attitude and practice: while 68% of farmers believed water quality affected fish health, only 32% actively monitored any water quality parameter. Among those parameters monitored, pH was the most tracked parameter (58%), while crucial parameters like dissolved oxygen, ammonia and nitrite were largely ignored. Farmers primarily relied on visual cues like water colour (11%) and bad smell (10%) for water quality assessment. Management practices were suboptimal: 54% changed water daily, but none used aeration. Boreholes were the primary water source (44%). Disease management was heavily dependent on antibiotics, with 43% using them for treatment and 21% for prevention. Oxytetracycline (33%) and Enrofloxacin (32%) were the most used antibiotics, and 56% of farmers reported antibiotic treatment failures. Mortalities were common, with 37% of farmers experiencing over 21% mortality per production cycle, peaking during the dry season (50%). There is an urgent need for targeted extension programmes, training on practical water quality monitoring and prudent antimicrobial use to enhance sustainable aquaculture.

Keywords: Aquaculture; Knowledge-attitude-practices; Water quality management; Fish farmers; Antibiotic use; FCT, Abuja Nigeria.

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Introduction

Global food security faces an unprecedented challenge of feeding growing populations, with animal protein demand projected to rise significantly in the coming decades. Under this condition, aquaculture has emerged the fastest-growing food production sector worldwide, now supplying over half of all fish for human consumption (FAO, 2022).

The role of aquaculture in global food security is particularly critical in developing nations, where it contributes directly to food security, poverty alleviation and livelihood creation. In Nigeria, Africa's most populous country, aquaculture is not just an economic activity but a vital component of the national food basket. As capture fisheries stagnate due to over-exploitation and environmental degradation, aquaculture has become indispensable in bridging the wide gap between the domestic fish supply and demand, which is estimated at over 2.4 million metric tonnes annually (FAO, 2022; Ogunji and Wuertz, 2023).

The success of aquaculture, however, is essentially tied to the quality of the water in which the fish are reared. Water is the fundamental medium for fish, influencing every aspect of their existence, from respiration, feeding, growth, excretion, to reproduction (Boyd and Tucker, 2012). Unlike terrestrial livestock, fish are poikilothermic and live in an environment where they cannot escape accumulating metabolic wastes and toxins. Key physicochemical parameters such as dissolved oxygen (DO), temperature, pH, and water levels of ammonia, nitrite and heavy metals like iron must be maintained within species-specific tolerance limits to ensure optimal health and productivity (Tumwesigye *et al.,* 2022). Deviations from these optimal ranges induce physiological stress, which suppress the immune system, reduce growth and feed conversion efficiency, and increases susceptibility to infectious diseases, often culminating in mass mortalities and severe economic losses for farmers (Conte, 2004; Tumwesigye et *al.,* 2022).

Recognizing this, the management of water quality is arguably the most crucial technical skill for an aquaculture farmer. Effective management, however, is not merely a function of access to technology but is profoundly influenced by the farmer's knowledge, perceptions and resulting practices. Evidence from various regions suggests a significant disconnect between scientific recommendations and on-farm practices. Earlier reports from Uganda's Rwenzori region showed that approximately 81% of fish farmers demonstrated poor knowledge of water quality principles (Ssekyanzi *et al.,* 2023). Similarly, in Kenya's Lake Victoria, while cage farmers exhibited positive attitudes, their actual biosecurity and management practices often diverged from recommended standards (Mziri, 2023).

In Nigeria, research from states like Ogun and Oyo has consistently highlighted that while farmers are generally aware of the importance of water quality; their monitoring is often limited to visual inspection of water colour and clarity, with little to no routine testing of critical parameters like ammonia, nitrite or dissolved oxygen (Oluwatobi *et al.,* 2021). This reliance on subjective assessment is inadequate, as toxic compounds can accumulate to lethal levels long before any visible clinical signs manifest in fish and the pond (Boyd *et al.,* 2016).

This dearth in technical knowledge is inextricably linked to the rising crisis of antimicrobial resistance (AMR). When water quality is suboptimal, fish experience chronic stress, leading to immunosuppression and increased susceptibility to opportunistic bacterial pathogens such as *Aeromonas spp.*, *Pseudomonas spp.*, and *Vibrio spp. (*Clols-Fuentes *et al.*, 2023*)*. Farmers, faced with the threat of mass mortality, often resort to the

indiscriminate use of antimicrobials. In many low-income countries (LICs), the use of antibiotics in aquaculture is largely unregulated, with producers frequently applying antibiotics such as oxytetracycline, enrofloxacin and ampicillin for prophylaxis, growth promotion and treatment without professional diagnosis or veterinary prescription (Alhaji *et al.,* 2024).

The consequences of this misuse extend beyond the farm gate. Antibiotics and their metabolites, which are often poorly biodegradable, are excreted into the aquatic environment, where they exert selective pressure on environmental microbiota (Alhaji *et al.,* 2024). This facilitates the emergence and dissemination of antibiotic resistance genes (ARGs) through horizontal gene transfer (HGT) mechanisms (conjugation, transduction and transformation), creating a reservoir of multidrug-resistant (MDR) bacteria (Milijasevic *et al.,* 2024). These pathogens can reach human populations via the consumption of contaminated fish products or direct contact with aquaculture runoff, representing a significant public health threat.

In the Federal Capital Territory (FCT), Abuja, the aquaculture sector has experienced rapid growth, driven by urban demand for fresh fish. This growth is characterized by a proliferation of small to medium-scale, intensive operations often utilizing concrete and tarpaulin tanks (Oyetola *et al.,* 2022). These systems are highly efficient but also highly vulnerable to rapid water quality deterioration if not managed meticulously. The predominant use of African catfish (*Clarias gariepinus*), while prized for its resilience, can lead to complacency, masking underlying water quality issues until they reach a critical point. Furthermore, many farmers in the FCT Abuja rely on borehole water, which can introduce specific challenges such as high iron content and low initial dissolved oxygen (Abejide *et al.,* 2023). Despite these unique contextual challenges, a comprehensive assessment of the knowledge, attitude and practices (KAP) of fish farmers specifically in the FCT Abuja regarding water quality management and AMR in aquaculture is lacking. The present study evaluated the knowledge, attitudes and practices (KAP) of aquaculture farmers in FCT regarding water quality management and antimicrobial usage, offered insights into the behavioural and technical drivers of risk and proposed a framework for sustainable growth and profitability of the aquaculture sector in Nigeria and One Health-oriented intervention.

Materials and Methods

Study Area: This study was conducted in the Federal Capital Territory (FCT), Abuja, Nigeria. The FCT Abuja is located in the central region of the country and comprises six Area Councils: Abuja Municipal Area Council (AMAC), Bwari, Kuje, Gwagwalada, Kwali and Abaji. The territory falls within the southern Guinea savannah zone and has witnessed significant growth in peri-urban aquaculture, driven by high demand for fish from its large urban population (Figure 1).

Study Design: A descriptive cross-sectional study was conducted between June and August 2025 to evaluate the knowledge, attitudes and practices (KAP) of fish farmers across the six Area Councils of the Federal Capital Territory (FCT). Using a multi-stage sampling technique, all six councils were purposively selected for full geographical coverage, followed by the random selection of 17 active farmers per council to achieve a representative sample of 102 respondents. Data were gathered via a pre-tested, expert-validated structured questionnaire adapted from established aquaculture literature (Ssekyanzi *et al.,* 2023). The instrument assessed five key domains: years of experience of farmers and farm profiles, production practices, knowledge and attitudes towards water quality, water management protocols, and fish health and antibiotic usage. Inclusion

was restricted to active farmers with standing stock who provided informed consent.

Data Analysis: Data from the completed questionnaires were coded, entered and cleaned using Microsoft Excel 2019. Data were then analysed using descriptive statistics including frequencies and percentages, and tables and charts were used to summarize the farmers years of experience, farm profiles and their KAP responses.

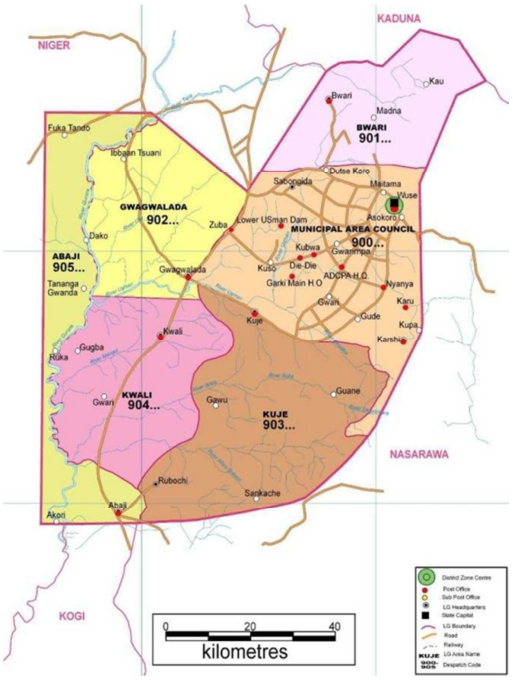

Figure 1. Map showing the study location, Federal Capital Territory (FCT), Abuja Nigeria. [Source: Obi-Anike *et al.,* 2017]

Results

Farm Characteristics and Farmers Years of Experience: The aquaculture sector in the FCT has seen fluctuating growth, with a peak of 32 farms established between 2020 – 2021, followed by 21 farms in the 2024 – 2025, 15 in 2022 – 2023, 2 in 2014 – 2015, 9 in 2016 – 2017, and 23 in 2018 – 2019. Farmer experience was distributed as follows : 33 farmers (32%) had 1 – 3 years of experience, 25 farmers (24.5%) had over 6 years of experience, 27(26.5%) 4 – 6 years of experience, and 17 (16.7%) less than one year. Regarding culture systems, mixed systems were the most common (37/102 = 36.3%), followed by concrete ponds (21/102 = 20.6%), tarpaulin tanks (20/102 = 9.6%), plastic tanks (19/102 = 18.6%, and earthen ponds (5/102 = 4.9%).

African catfish was the dominant species, cultured by 84 farms (82.3 %), followed by the mixed culture of African catfish and Tilapia (12/102 = 11.8 %), and only 6/102 = 5.9% farmed Tilapia alone. Regarding the procurement of stock, the vast majority of farmers 62.7% (64/102) rely on external hatcheries for their fingerlings, while 30.4% (31/102) farmers operated their own on-farm hatcheries, and 6.9% (7/102) utilized a mixed source.

Management Practices – Feed and Water: Management of critical inputs such as feed and water showed varying degrees of standardization among the surveyed farmers. Nutritional management was highly consistent across the surveyed population, with a predominant reliance on floating feed, utilized by 80 farmers (78.4%). In contrast, only 7 farmers (6.9%) use strictly non-floating feed, while 15 farmers (14.7%) employed a mixture of both floating and non-floating types.

Water sources for aquaculture activities were diverse (Figure 2). The primary source was borehole water, utilized by 45 farmers (44.1%). Other sources and combinations are shown in Figure 2.

Majority of the fish farmers (67.6%) reported that they do not monitor water quality parameters, while only 32.3% engage in any form of monitoring. Among the 32.3% who do monitor (Figure 3), pH is the most frequently tested parameter (19/102 = 18.6% farmers), followed by temperature (3/102 = 2.9% farmers) and a combination of pH and temperature (6/102 = 5.9% farmers). Temperature, pH and advanced parameters

such as dissolved oxygen, ammonia and nitrite were monitored by only 5 out of the 102 (4.9%) fish farmers surveyed (Figure 3).

Responses received showed that maintenance of water quality was primarily achieved through water exchange. Twenty- seven (27) farmers (26.5%) perform weekly water changes, while 55 farmers (53.9%) change water daily, and 20 farmers (19.6%) changed water occasionally. To further improve water quality, farmers employed regular water changes as the primary method (54/102 = 52.9%), water treatment (12/102 = 11.8%), regular water recirculation (11/102 = 10.9%), the use of chemical additives (11/102 = 10.9% farmers), followed by a combination of regular water changes and treatment (8/102 = 7.8% farmers), water change and circulation (6/102 = 5.9%).

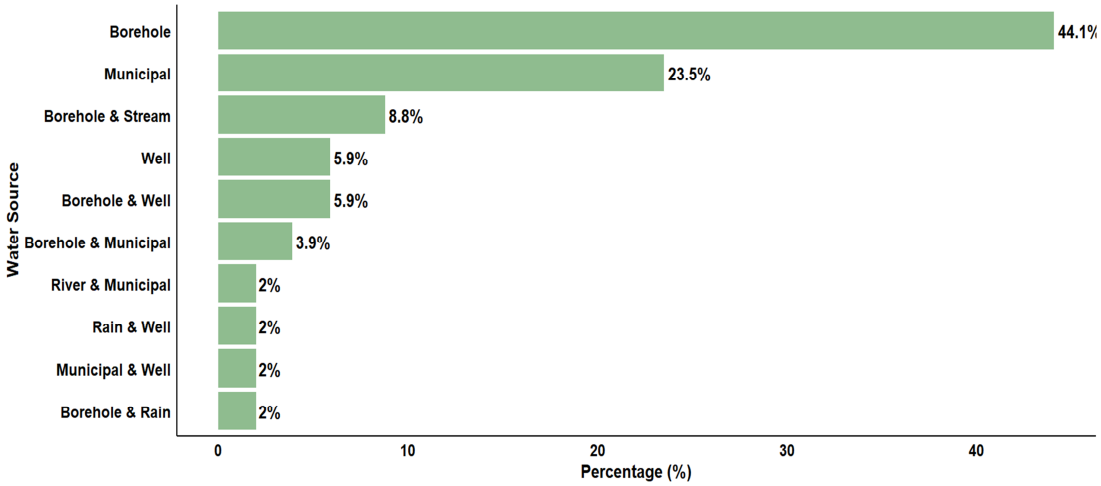

Figure 2. Distribution of water sources for aquaculture activities in the Federal Capital Territory (FCT), Abuja, Nigeria.

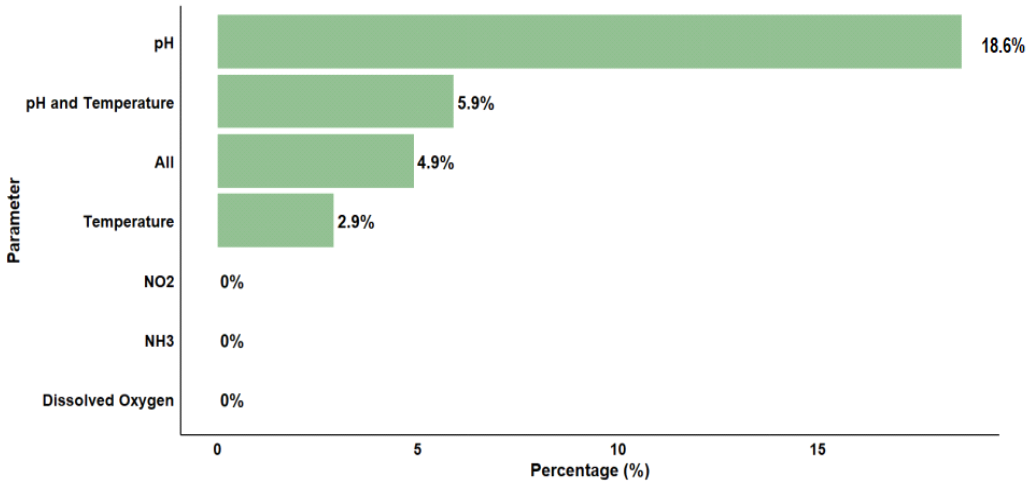

Figure 3. Distribution of water quality parameters monitored by fish farmers in the Federal Capital Territory (FCT), Abuja, Nigeria.

Perceptions of Water Quality and Observational Indicators: A significant majority of the surveyed farmers (69/102 = 67.6%) acknowledged the direct impact of water quality on fish health and productivity. When identifying specific indicators of deteriorating water conditions, respondents reported a variety of physical and chemical signs (Table 1). The most prevalent observation was the combination of bad smell and green water (20.6%), suggesting that eutrophication and organic decomposition are the primary visible concerns for farmers. Notably, none of the farmers identified low dissolved oxygen as a standalone sign, though it was recognized when coupled with other physical indicators like foaming or bad smells.

Table 1. Distribution of signs of poor aquaculture water quality as reported by fish farmers in in the Federal Capital Territory (FCT), Abuja, Nigeria.

Signs of poor quality aquaculture water, as reported by respondents.	Number of farmers	Percentage of the farmers
Foaming.	3	2.9%
Bad smell.	10	9.8%
Green water.	11	10.8%
Hot or cold water.	3	2.9%
Chemical contamination.	10	9.8%
High carbon dioxide.	3	2.9%
Low dissolved oxygen.	0	0%
Bad smell and green water.	21	20.6%
Foaming and green water.	4	3.9%
Foaming and bad smell.	7	6.9%
Bad smell and hot or cold.	2	2.0%
Bad smell and chemical.	2	2.0%
Bad smell and low dissolved oxygen.	2	2.0%
Foaming, bad smell, green water.	12	11.8%
Foaming bad smell low oxygen.	7	6.9%
Foaming, high $C0_2$, low oxygen.	2	2.0%
Foaming, green water, chemical contamination.	3	2.9%
Total	**102**	**100%**

Fish Health and Mortality Observations: In terms of symptomatic ill health, 17 farmers (16.6%) reported direct mortality, while 16 (15.7%) observed gasping as a sign of respiratory distress. Other symptoms of ill health reported included swollen bellies (12/102 = 11.8%), erratic swimming (6/102 = 5.9%), and fin rot (4/102 = 3.9%).

Mortality rates varied across the surveyed population. While 63.7% of farmers reported losses below 20%, 17.6% (18/102) experienced mortality rates exceeding 30%. Seasonal trends were stark, with 50% (51/102) of farmers identifying the dry season as the period of highest fish mortality, compared to 18.6% in the rainy season. Furthermore, 69.6% (71/102) of farmers have never taken water samples to a laboratory for professional analysis.

Antimicrobial Use and Pharmacotherapy Practices: The occurrence of farmers treating their fish themselves was high: 41.2% (42/102) of farmers treat sick fish themselves, and 34.3% do so in combination with a veterinarian's prescription. Antibiotics were used by 24 (23.5%) farmers as a primary treatment method, often in combination with salt baths (10/102 = 9.8%) or herbal remedies (10/102 = 9.8%). The reasons for antibiotic use extended beyond therapeutic needs: while 44 farmers (43.1%) used them for treatment, 21 (20.6%) used them mainly for prevention, and 11 (10.8%) used them as growth enhancers.

Oxytetracycline and Enrofloxacin were the most common antibiotics used, by 34 (33.3%) and 33 (32.4%) farmers, respectively, while 15 farmers (14.7%) utilized a cocktail of various medications. Most antibiotic applications occurred for treatment of ill health (39/102 = 38.2%) or upon receiving new stock (23/102 = 22.5%). Disturbingly, 55.9% (57/102) of farmers reported that antibiotics have failed to work in their aquaculture systems.

Discussion and Conclusion

The findings from this study reveal several important trends that reflect both progress and persisting deficiencies in water quality management among fish farmers in the Federal Capital Territory (FCT), Abuja, Nigeria.

The fact that the majority of farms (31%) were established between 2020 and 2021, and 21% between 2024 and 2025, implied an accelerated growth in aquaculture following the pandemic. Similar expansions have been reported in other urban centres, such as Ibadan and Lagos, where growing demand for affordable animal protein and government support stimulated establishment of new farms (Jose, 2024).

The dominance of farmers with only 1 – 5 years of experience (58%) suggested that many producers are learning through trial and error rather than established Best Management Practices (BMPs). Similar findings in Uganda and Ghana have shown that younger, less experienced farmers often possess weaker knowledge of water quality dynamics and higher rates of production failure (Mohammed *et al.,* 2025; Ssekyanzi *et al.,* 2023).

The findings in the present study that majority of farmers practice mixed culture systems (36%), followed by tarpaulin (20%) and concrete ponds (21%), suggests adaptability and resource optimization among farmers. The low use of earthen ponds (5%) reflects the urban and peri-urban setting of Abuja, where space constraints discourage large earthen constructions.

Catfish (*Clarias gariepinus*) accounted for 82% of cultured species, consistent with nationwide trends due to its reported rapid growth and tolerance of suboptimal conditions (Ogunji and Wuertz, 2023; FAO, 2022).

Though our study did not determine carrying capacity of the respondents' farm, however

misunderstanding of the carrying capacity of their systems may have contributed to mortalities recorded in the farm in this study. Carrying capacity, which is the maximum weight of fish a tank can successfully contain without crisis is a function of water management and oxygen supply (Taslimi, 2020). In a static pond or tank system, the carrying capacity is primarily limited by the rate of natural oxygen diffusion and the volume of water. For catfish in a static pond, the maximum carrying capacity is typically 1.8 kg of fish per square meter (Taslimi, 2020). When this limit is exceeded, the environment reaches its elastic limit, characterized by depleted oxygen and skyrocketing ammonia (Boyd and Tucker, 2012).

In the FCT, the absence of aeration (0%) means that any intensification beyond this base limits relies solely on the dilution effect of water changes. While 53.9% of farmers change water daily, this practice is water-inefficient and fails to address the underlying issue of exceeding the system's biological assimilative capacity. Adopting simple models of carrying capacity based on feeding rate where approximately 3% of the feed weight is converted to ammonia nitrogen, would allow farmers to predict water change requirements more accurately.

Borehole water (44.1%) was the dominant source recorded in this study, followed by municipal (23.5%) and borehole + stream (8.8%) sources. While borehole water offers availability advantages, it often contains high iron concentrations in the Abuja region (Muogbo *et al.,* 2023), possibly contributing to chronic gill irritation and hypoxia (Francis-Floyd *et al.,* 2022). Despite this, only 32.3% of farmers in the present study reported monitoring any water-quality parameter, consistent with national observations that regular water monitoring remains uncommon among small-scale fish farmers in Nigeria (Oluwatobi *et al.,* 2021)

Among the water parameters monitored by respondents in the present study, pH was the most common (58%), followed by temperature (9%), while none monitored ammonia, nitrite, or dissolved oxygen individually. The lack of ammonia and nitrite monitoring (0%) is a critical omission and will have negative implications for fish farming in FCT Abuja farms. Toxic ammonia exists in two forms: ionized (NH_4^+) and the more lethal unionized (NH_3). The concentration of the toxic NH_3 form increases by a factor of ten for every unit increase in pH (Wynne, n.d.). Since 58% of farmers only monitored pH, they may be unaware that a slight pH shift can turn a manageable ammonia concentration into a lethal event (Hargreaves *et al.,* 2004).

The reported clinical signs: gasping, erratic swimming and swollen bellies are evidence of biochemical poisoning or microbial infection triggered by poor environment. Gasping is often misinterpreted simply as "breathing," but in many cases, it signifies that the gills are compromised by high ammonia or that the blood is unable to carry oxygen due to high nitrite concentrations (Zhang *et al.,* 2025). Chronic exposure to these pollutants induces a stress response that elevates corticosteroid levels and modulates proteins such as heat shock protein 70 (HSP70) and metallothionein 1 (MT1), which are biomarkers for oxidative stress and heavy metal toxicity (Udume *et al.,* 2022). This stress cascade suppresses the immune system, allowing opportunistic and zoonotic pathogens such as *Aeromonas hydrophila*, *Vibrio cholerae*, and *Pseudomonas aeruginosa* to invade (Okon *et al.,* 2022). The total lack of ammonia monitoring among Abuja farmers (0%) suggests that fish reared in the study area may frequently be subjected to chronic high ammonia concentrations that may possibly suppress growth and damage respiratory surfaces.

While 68% of farmers believed that water quality affects fish performance, 32% did not, indicating a knowledge gap. Reported signs of

poor water quality such as green water (11%), bad smell (10%) and foaming (3%) correspond closely with high organic loading and algal blooms (Boyd and Tucker, 2012). Interestingly, none reported low dissolved oxygen, suggesting either lack of detection ability or underestimation of its significance. The reliance on sensory cues, such as bad smell and green water, is reactive rather than proactive. By the time a pond smells of ammonia or exhibits foaming, the fish have already been exposed to chronic toxic levels that may have compromised their growth and immune systems (Xu *et al.,* 2021). This management by observation is particularly dangerous for *Clarias gariepinus*, which can survive high stress but with a significant loss in productivity – a phenomenon where fish only feed to survive and not to grow (Taslimi, 2020).

Results of mortality analysis which showed that 29% of farmers experienced less than 10% mortality per cycle, while 34% lost 10 – 20% and 19% suffered losses above 30%, are disturbing, for commercial viability. The seasonal patterns which showed that 50% of farmers experienced higher mortality during the dry season, is consistent with previous reports that high temperature and reduced water volume which commonly occur in dry season increase ammonia toxicity and lower oxygen solubility (Oresegun and Tanko 2007; Ssekyanzi *et al.,* 2023).

Seventy per cent (70%) of farmers in this study never took water samples to the laboratory, and only 20% did so when fish became sick. This reactive approach reflects a low culture of preventive management among small-scale aquaculture producers, where adoption of recommended management practices (including routine water testing) is often low and many farmers rarely test water unless disease appears (Wanja *et al*., 2020; Adelodun *et al.,* 2021; Ssekyanzi *et al.,* 2023). Diagnostic testing is critical for identifying specific stressors and preventing recurrent mortality, underscoring the need to strengthen laboratory outreach programmes.

Results of fish treatment practices indicated that 41% of farmers treat their own fish, 25% rely on veterinarians, and 34% combine both. Farmers treating their own fish is common among resource-limited farmers, but it increases the likelihood of misdiagnosis and misuse of medicines. The fact that the most frequently used treatment was antibiotic treatment (24%) raise concern about antibiotic misuse. Antibiotic misuse/overuse remains a major concern, as 56% of the respondents reported treatment failure, pointing towards possibly antimicrobial resistance (Cabello *et al.,* 2016; Moffo *et al.,* 2024).

Oxytetracycline and Enrofloxacin were among the most widely used antibiotics in fish farms in the study area, reflecting the trend towards broad-spectrum antibiotic misuse in the absence of veterinary supervision (Adelowo and Okunlola, 2019; Alhaji *et al.,* 2024). The finding in the present study that 43% used antibiotics therapeutically, 21% did so preventively and 11% for growth promotion, are trends discouraged by the FAO and World Health Organization due to resistance risks (FAO, 2022). The minimal veterinary supervision in most cases highlights a critical policy gap in fish health governance.

Overall, the results indicate that although fish farmers in the FCT Abuja Nigeria recognize the importance of water quality, practices remain rudimentary. High dependence on borehole water, limited monitoring, lack of aeration and unsupervised antibiotic use collectively hinder sustainable production. These findings align with regional KAP assessments (Ssekyanzi *et al.,* 2023) and reinforce the urgent need for targeted extension services.

Extension programs should emphasize low-cost water-quality testing (simple pH and ammonia strips), adoption of aeration and filtration technologies and improved understanding of nitrogen cycling.

Additionally, government and development partners should support community-based diagnostic centres offering subsidized water testing. Finally, integration of veterinarians and aquatic health professionals into aquaculture advisory systems will be crucial to mitigate antimicrobial misuse.

Conflict of Interest

Authors declare that there was no conflict of interest

References

Abejide O, Ibrahim U and Yusuf SD (2023). Determination of heavy metals concentration in some sachet water commonly in Abuja Municipal Council, Nigeria. *EDUCATUM Journal of Science, Mathematics and Technology,* 10(1): 28 – 34. https://doi.org/10.37134/ejsmt.vol10.1.4.2023

Adelodun BO, Adekola OA, Rafiu AR and Ailele SI (2021). Assessment of fish farmers' use of recommended management practices in Oyo State, Nigeria. *Asian Journal of Fisheries and Aquatic Research*, 11(6): 14 – 20.

Adelowo OO, and Okunlola I (2019). Field assessment of antibiotic use in fish farms in southwestern Nigeria. *Revue d'Élevage et de Médecine Vétérinaire des Pays Tropicaux*, 72(4): 187 – 191.

Alhaji NB, Odetokun IA, Jibrin MS, Lawan MK and Kwaga J (2024). Antibiotic resistance and mitigation using One Health lens in aquaculture of Northern Nigeria. *Onderstepoort Journal of Veterinary Research*, 91(2): a2165. https://doi.org/10.4102/ojvr.v91i2.2165

Boyd CE and Tucker CS (2012) Pond Aquaculture Water Quality Management. *Springer Science and Business Media*, New York.

Boyd CE, Tucker CS and Somridhivej B (2016), Alkalinity and Hardness: Critical but Elusive Concepts in Aquaculture. *Journal of the World Aquaculture Society*, 47: 6 – 41. https://doi.org/10.1111/jwas.12241

Cabello FC, Godfrey HP, Buschmann AH and Dölz HJ (2016). Aquaculture as an environmental gateway to antimicrobial resistance. *Environmental Microbiology*, 15(7): 1917 – 1945.

Clols-Fuentes J, Nguinkal JA, Unger P, Kreikemeyer B and Palm HW (2023). Bacterial community in African catfish (*Clarias gariepinus*) recirculating aquaculture systems under different stocking densities. *Frontiers in Marine Science*, 10: 1073250. https://doi.org/10.3389/fmars.2023.1073250

Conte FS (2004). Stress and welfare of cultured fish. *Applied Animal Behaviour Science*, 86(3–4): 205 – 223.

FAO (Food and Agriculture Organization). (2022). FAO Yearbook: Fishery and Aquaculture Statistics 2022. FAO, Rome.

Francis-Floyd R, Watson C, Petty D and Pouder D (2022). Ammonia in Aquatic Systems: FA-16/FA031, 06/2022. *EDIS*, *2022*(4). https://doi.org/10.32473/edis-fa031-2022

Hargreaves JA, and Tucker CS (2004). Managing Ammonia in Fish Ponds (SRAC Publication No. 4603). Southern Regional Aquaculture Center (SRAC).

Jose C (2024, November 19). An Overview of the Aquaculture Industry in Nigeria - International Aquafeed. https://www.aquafeed.co.uk/an-overview-of-the-aquaculture-industry-in-nigeria/

Milijasevic M, Veskovic-Moracanin S, Babic Milijasevic J, Petrovic J and Nastasijevic I (2024). Antimicrobial resistance in aquaculture: Risk mitigation within the One Health context. *Foods*, 13(15): 2448. https://doi.org/10.3390/foods13152448

Moffo F, Ndebé MMF, Tangu MN, Noumedem RNG, Awah-Ndukum J and Mouiche MMM (2024). Antimicrobial use, residues and resistance in fish production in Africa: systematic review and meta-analysis. *BMC veterinary research*, 20(1): 307. https://doi.org/10.1186/s12917-024-04158-w

Mohammed A, Manson B and Amponsah S (2025). Assessing the effects of farming on water quality of fish farms in Ghana: the case study of Sunyani Municipality. *International Journal of Agriculture Environment and Food Sciences*, 9(2): 446 – 451. https://doi.org/10.31015/2025.2.18

Muogbo NB, Makut MD, and Ishaleku D (2023). Assessment of bacteriological quality and heavy metals concentrations of borehole water tanks in Wuse 1 District of Abuja, Nigeria. *Microbiology Research Journal International*, 33(5): 35 – 42. https://doi.org/10.9734/mrji/2023/v33i51384

Mziri VM (2023). A knowledge, attitude, and practices (KAP) analysis of biosecurity and water quality effects in Nile tilapia (*Oreochromis niloticus*) cage aquaculture in Lake Victoria, Kenya [Final Project]. GRÓ Fisheries Training Programme under the auspices of UNESCO.

Obi-Anike HO, Ofobruku SA and Okafor CN (2017). Manpower developmemt and employees performance: Qualitative assessment of small and medium scale businesses in Abuja Nigeria. *Journal of Economics, Management and Trade*, 18(3): 1 – 6.

Ogunji JO and Wuertz S (2023). Aquaculture development in Nigeria: The second biggest aquaculture producer in Africa. *Water,* 15(24): 4224. https://doi.org/10.3390/w15244224

Okon EM, Okocha RC, Adesina BT, Ehigie JO, Alabi OO, Bolanle AM, Matekwe N, Falana BM, Tiamiyu AM, Olatoye IO, and Adedeji OB (2022). Antimicrobial resistance in fish and poultry: Public health implications for animal source food production in Nigeria, Egypt, and South Africa. *Frontiers in Antibiotics*, *1*: 1043302. https://doi.org/10.3389/frabi.2022.1043302

Oluwatobi BA, Festus OA, Rasheedat AR and Ailele SI (2021). Assessment of fish farmers use of recommended management practices in Oyo State, Nigeria. *Asian Journal of Fisheries and Aquatic Research*, 11(6): 14 – 20.

Oresegun A, and Tanko A (2007). Urban aquaculture: Producer perceptions and practices in Lagos State, Nigeria. *Middle-East Journal of Scientific Research*, 2(1): 21 – 27.

Oyetola IA, Sennuga SO, Bako H and Wilberforce AG (2022). Exploring the adoption of fish production using concrete tank in the Municipal Area Council, Abuja. *South Asian Research Journal of Agriculture and Fisheries,* 4(2): 40 – 46.

Ssekyanzi A, Nevejan N, Kabbiri R, Wesana J, and Van Stappen G (2023). Knowledge, attitudes, and practices of fish farmers regarding water quality and its management in the Rwenzori region of Uganda. *WATER, 15(1).* https://doi.org/10.3390/w15010042

Taslimi S (2020). How to Calculate Fish Stocking Density. Cavendish International. https://www.cavendish.ac/fish-stocking-density/

Tumwesigye Z, Tumwesigye W, Opio F, Kemigabo C and Mujuni B (2022). The effect of water quality on aquaculture productivity in Ibanda District, Uganda. *Aquaculture Journal*, 2(1): 23 – 36. https://doi.org/10.3390/aquacj2010003

Udume BU, Ota HO, Yan Z and Chikeziri OC (2022). Evaluating the effect of acute ammonia toxicity in a freshwater ecological environment on the growth and hematological functioning of *Clarias gariepinus*. *AQUA - Water Infrastructure, Ecosystems and Society*, 71(3): 464 – 477. https://doi.org/10.2166/aqua.2022.138

Wanja DW, Mbuthia PG, Waruiru RM, Mwadime JM, Bebora LC, Nyaga PN and Ngowi HA (2020). Fish husbandry practices and water quality in Central Kenya: Potential risk factors for fish mortality and infectious diseases. *Veterinary Medicine International*, 2020: 6839354. https://doi.org/10.1155/2020/6839354

Wynne F (n.d.). Desirable Water Quality Parameters for Catfish Ponds. Kentucky State University Aquaculture Extension. Retrieved December 24, 2025, from https://aquaculture.mgcafe.uky.edu/sites/aquaculture.ca.uky.edu/files/desirable-water-quality-parameters-for-catfish-ponds.pdf

Xu Z, Cao J, Qin X, Qiu W, Mei J and Xie J (2021). Toxic effects on bioaccumulation, hematological parameters, oxidative stress, immune responses and tissue structure in fish exposed to ammonia nitrogen: A review. *Animals*, 11(11): 3304. https://doi.org/10.3390/ani11113304

Zhang Y, Qiao H, Peng L, Meng Y, Song G, Luo C, and Long Y (2025). Influence of high temperature and ammonia and nitrite accumulation on the physiological, structural and genetic aspects of the biology of Largemouth Bass (*Micropterus salmoides*). *Antioxidants*, *14*(4): 495. https://doi.o/10.3390/antiox14040495