Assessing Antimicrobial Usage Practices in Commercial Tilapia Farming: A One Health Cross-sectional Survey in Bangladesh

CGIAR INITIATIVE ON One Health

WorldFish CGIAR

Assessing Antimicrobial Usage Practices in Commercial Tilapia Farming: A One Health Cross-sectional Survey in Bangladesh

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Citation

This publication should be cited as: Rheman S, Khor, Laura, Hossain, S, Delamare-Deboutteville J and Mohan CV. 2023. Assessing antimicrobial usage practices in commercial tilapia farming: a One Health cross-sectional survey in Bangladesh. Penang, Malaysia: WorldFish. Report: 2023

Acknowledgments

This work was conducted as part of the CGIAR Initiative Protecting Human Health through a One Health Approach. This work is being implemented by CGIAR researchers from WorldFish, the International Livestock Research Institute, International Food Policy Research Institute and International Water Management Institute, in close partnership with the Centre for Environment, Fisheries and Aquaculture Science, University of Exeter, Bangladesh Livestock Research Institute, Bangladesh Agricultural University, Fleming Fund Country Grant Bangladesh and International Centre for Diarrhoeal Disease Research Bangladesh. We would like to thank all funders who supported this research through their contributions to the CGIAR Trust Fund: https://www.cgiar.org/funders/. This work aims to enhance educational approach to promote a One Health approach to the aquatic food system in Bangladesh.

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List of Abbreviations

AMR	antimicrobial resistance
AMU	antimicrobial usage
BLRI	Bangladesh Livestock Research Institute
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CGIAR	the Consultative Group on International Agricultural Research
CIAs	critically important antimicrobials
CS	cross-sectional survey
DAP	diammonium phosphate
FFCGB	Fleming Fund Country Grant Bangladesh
HIAs	highly important antimicrobials
ICDDRB	International Centre for Diarrhoeal Disease Research, Bangladesh
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IQR	inter quartile range
IWMI	International Water Management Institute
LS	longitudinal survey
TSP	triammonium phosphate
UOE	University of Exeter
WHO	World Health Organization
WP	Work package

Executive summary

The Initiative on One Health, titled "Protecting Human Health Through a One Health Approach," was launched in January 2022 as part of the Consultative Group on International Agricultural Research (CGIAR) program. It is dedicated to promoting the well-being of humans, animals, and the environment. The initiative's key objectives include the detection, reduction, and control of zoonoses, foodborne diseases, and antimicrobial resistance (AMR) in low- and middle-income countries. It is implemented by four CGIAR research centers: the International Food Policy Research Institute (IFPRI), the International Livestock Research Institute (ILRI), the International Water Management Institute (IWMI), and WorldFish. Currently, the initiative is being carried out in seven countries across Africa and Asia, including Bangladesh.

In Bangladesh, Work Package 3 (WP3): AMR (aquaculture) focuses on collecting evidence on antimicrobial use (AMU) and the prevalence of antimicrobial resistance (AMR) in the aquaculture sector. In partnership with ILRI and IFPRI, WorldFish is leading the implementation of WP3 in the country. The WP3 AMR (Aquaculture) aims to tackle AMU/AMR burden in aquaculture sector in Bangladesh.

Fisheries and aquaculture have grown to become one of the most vital food-producing sectors in Bangladesh, contributing 60% of the population's daily animal protein intake. Among the prominent species, tilapia is extensively cultivated in various waterbodies, particularly in earthen ponds. This species is highly popular among local consumers and has emerged as an affordable source of protein for many in Bangladesh. However, despite its importance, the sustainability of tilapia farming faces significant challenges such as vulnerability to disease outbreaks.

In Bangladesh, disease management in aquaculture farms often relies on the use of treatment products, including antimicrobials. A range of agrochemicals, medicines, and drugs—such as antibiotics intended for both fisheries and livestock treatments—are reportedly used in aquaculture to prevent and treat fish diseases. However, fish diseases in Bangladesh are predominantly diagnosed based on clinical signs. This reliance on presumptive diagnosis can lead to incorrect treatments, potentially contributing to the emergence, transmission, and spread of antimicrobial-resistant pathogens through interconnected food chains.

By analyzing factors such as farm management practices, biosecurity measures, aquamedicines use, and the availability of alternative disease management strategies, the study seeks to identify effective pathways for enhancing farm productivity while minimizing the risks associated with antimicrobial resistance (AMR).

The objective of this study is to assess the current practices in commercial tilapia farming and identify the factors influencing the use of drugs and chemicals including antimicrobials from a One Health perspective. The investigation aims to explore how various factors—such as farming practices, environmental conditions, disease occurrence and farmers behavior—impact the decision-making process related to AMU in tilapia aquaculture. By adopting a One Health approach, which integrates human, animal, and environmental health, the study also seeks to understand how antimicrobial use in aquaculture may contribute to the broader issue of AMR and its potential spillover into human health and the environment. Ultimately, the research aims to promote sustainable aquaculture practices that balance economic viability with responsible AMU, safeguarding both animal and human health as well as the surrounding environment.

This retrospective cross-sectional study was conducted in November 2022 in five Upazilas situated in the Mymensingh district of Bangladesh, a region noteworthy for the rapid and substantial intensification and growth of commercial finfish farming in ponds, both in terms of scale and variety. During the study period, a retrospective cross-sectional (CS) was conducted to evaluate the knowledge, attitudes, perceptions, and practices of 120 tilapia farms.

Introduction

Over time, fisheries and aquaculture have become one of the most significant food-producing sectors in Bangladesh. In the fiscal year 2021-22, the country's total fish production was approximately 4.75 million tons, with 57.39 percent sourced from various aquaculture production systems. This sector supplements 60% of the daily animal protein consumed by the population (DOF, 2022a). The country currently holds the 5th position in the world in terms of aquaculture production (FAO, 2022).

Fish farming in Bangladesh primarily takes place in earthen ponds, commonly employing a polyculture system where multiple fish species are cultivated together (Jahan et al., 2015). Various fish species, including native ones and those imported from other countries due to their faster growth rates and easy propagation techniques, are commercially farmed in different regions of Bangladesh. The top three freshwater finfish species cultivated in these ponds are pangas (*Pangasius hypophthalmus*), tilapia (*Oreochromis* sp.), and rohu (*Labeo rohita*) (DOF 2022a).

Tilapia, a non-native fish species, was initially introduced to Bangladesh from Thailand in 1954 and in subsequent stages, various strains of tilapia, including the genetically improved farmed tilapia have been introduced from different countries (Hussain, 2004; Hussain et al., 2013). This species has emerged as one of the extensively cultivated fish varieties primarily due to its rapid growth rate within a relatively short culture duration (Kumar & Engle, 2016). Its adaptability to various environmental conditions, combined with widespread acceptance among native consumers and relatively low market prices, further contribute to its popularity in aquaculture in Bangladesh (Tran et al., 2019).

In terms of production from ponds, tilapia currently holds the position as the second-highest farmed fish species in Bangladesh, following pangas and the country yielded approximately 329,316 tons of tilapia from ponds in 2021-2022, constituting 15.20% of the total fish production from ponds (DOF 2022b). However, the total aquaculture production of tilapia is believed to be much higher. This is because apart from pond aquaculture, the species is farmed in diverse aquaculture systems such as coastal ghers, seasonal cultured water bodies, floodplains, beels, and haors.

Bangladesh's commercial pond aquaculture system including tilapia farming is undergoing through substantial expansion and transformation, many widely practiced farming systems are now transitioning from extensive to semi-intensive/ intensive operational practices (Belton et al., 2011; Belton & Azad, 2012; Palash et al., 2018). Especially in the last decade the country has experienced tremendous growth in the sector partly because of the intensification of the culture systems (DOF 2022b).

The use of high stocking densities in intensified production systems may increase the likelihood of disease outbreaks in aquaculture farms (Krkosek, 2010), resulting in the emergence of potent pathogens and elevated transmission rates both within and between farms (Subasinghe et al., 2019). The industry faces a significant threat to its sustainability due to the prevalence of various fish diseases (Faruk et al., 2017; Hasan et al., 2014; Hinchliffe et al., 2021). Based on baseline and unusual mortality rates in tilapia, an estimated hidden annual loss of 875.7 million USD was calculated in the context of Bangladesh's aquaculture (Debnath et al., 2022).

One of the main approaches to disease management in aquaculture farm in Bangladesh often involves the use of chemicals (Heal et al., 2021; Uddin et al., 2016). In fact the utilization of antimicrobials in the country's fish production systems has been classified as "problematic" (Grace et al., 2015). Similar to many low- or middle-income countries , a verity of agrochemicals and aquamedicines such as antibiotics are commonly deployed for the prevention and treatment of fish diseases (Ali et al., 2016; Faruk & Azad, 2021; Faruk et al., 2021; Kawsar et al., 2022; Rheman et al., 2023). The use of antibiotics in Bangladesh's aquaculture farms is primarily guided by feed/drug sellers, local service providers, or the farmers themselves, rather than registered veterinarians (Chowdhury et al., 2022).

A recent study estimated that the country is now the third-highest user among the world’s top major aquaculture-producing countries regarding the number of antibiotic brands used (Lulijwa et al., 2020). A nationwide literature review on aquamedicines, drugs, and chemicals identified 58 antibiotic brands that have been employed in Bangladesh's aquaculture sector (Asif et al., 2021). Oxytetracycline, chloro-tetracycline, amoxicillin, erythromycin, ciprofloxacin, co-trimoxazole, sulfadiazine, sulfamethoxazole, chloramphenicol and prefuran are some of the reported antibiotics commonly used in Bangladesh aquaculture (Akter et al., 2022; Ali et al., 2014; Chowdhury et al., 2022; Das et al., 2020; Haque et al., 2021; Jahan et al., 2021). World Health Organization (WHO) has categorized many of these antibiotics as critically important antimicrobials (CIAs) and highly important antimicrobials (HIAs) for human medicine (WHO, 2019).

In Bangladesh, fish diseases are primarily identified based on clinical signs, and the precise causes or etiological agents of many of these diseases remain unconfirmed by laboratory diagnostic methods. Incorrect disease diagnosis can lead to the inappropriate use of antimicrobials, contributing to the emergence, transmission, and dissemination of AMR pathogens (Knobler et al., 2003).

Limited information exists regarding the prevalence of antimicrobial-resistant pathogens in aquaculture in Bangladesh, primarily because most studies focus on antimicrobial usage (AMU) rather than AMR (Rheman et al., 2023). Few studies have confirmed the presence of human significance AMR pathogens including *E.coli*, *Salmonella* and *Vibrio* species in aquaculture farms and settings (Foysal et al., 2012; Hossain & Rahman, 2018; Siddique et al., 2021).

The current study aims to assess fish farmer knowledge, attitudes, perceptions and practices regarding AMU and One Health in commercial tilapia food production systems in Bangladesh with an argumentation that understanding of behavior and practices is necessary for experimental testing of the impact of reduced reliance of AMU on production and profit of fish farming.

Methodology

Study area

The research took place in November 2022 in five Upazilas located in the Mymensingh district of Bangladesh, namely Mymensingh Sadar, Tarakanda, Phulpur, Fulbaria, and Trishal Upazilas (Figure 1). It is one of the regions of the country where commercial finfish farming in ponds has rapidly expanded both horizontally and vertically. At present, Mymensingh is one of the top freshwater pond finfish production hubs of the country. Besides pangas and tilapia, several cyprinids and catfish species are commercially farmed, mainly following a polyculture system. Finfish farmers in this area are considered as experienced practitioners (Heal et al., 2022).

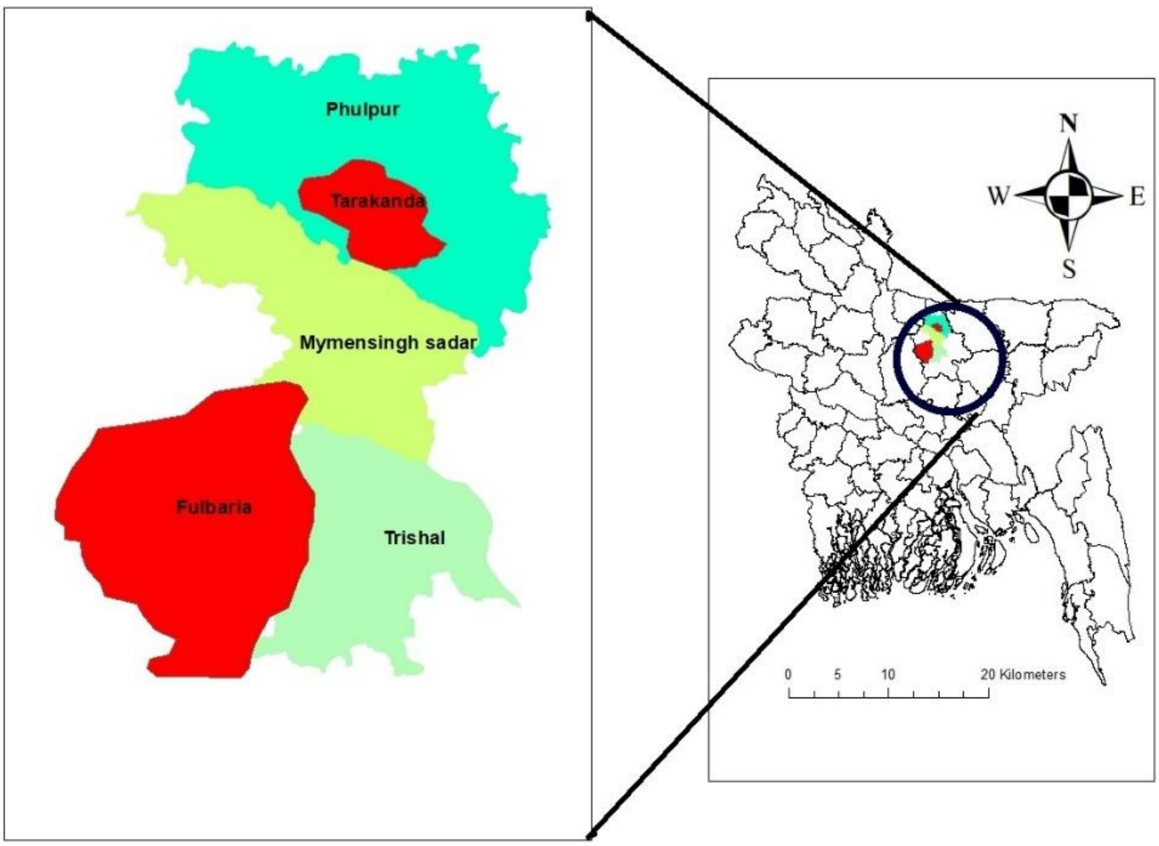

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Figure 1. Study area.

Population census and farm selection

A series of consultations were made with local aquaculture experts, academics, fisheries officers, and leaders of fish farmer cooperatives to identify the main tilapia producing upazilas in Mymensingh district. With the support of the local key informants, following a process of rapid appraisal, one community interview was conducted in each identified upazila to record currently practicing commercial tilapia culture farms. Initial farm records were further verified through physical visits and phone surveys to produce the census list of the farms. A total of three hundred and seventy-four currently practicing commercial tilapia farms were mapped in this way. From the population census list, one hundred and twenty farms were randomly selected for the study and the remaining farms were included in the replacement list. If any farm from the main list refused to participate in the study, alternative farms were randomly selected from the replacement list and included in the main list once consent was received (Figure 2). This way, 120 farms were recruited from five Upazilas of Mymensingh district for the study. Reported data showed that four farms did not do any tilapia farming during the last production cycle, therefore, these four farms were excluded from final analysis.

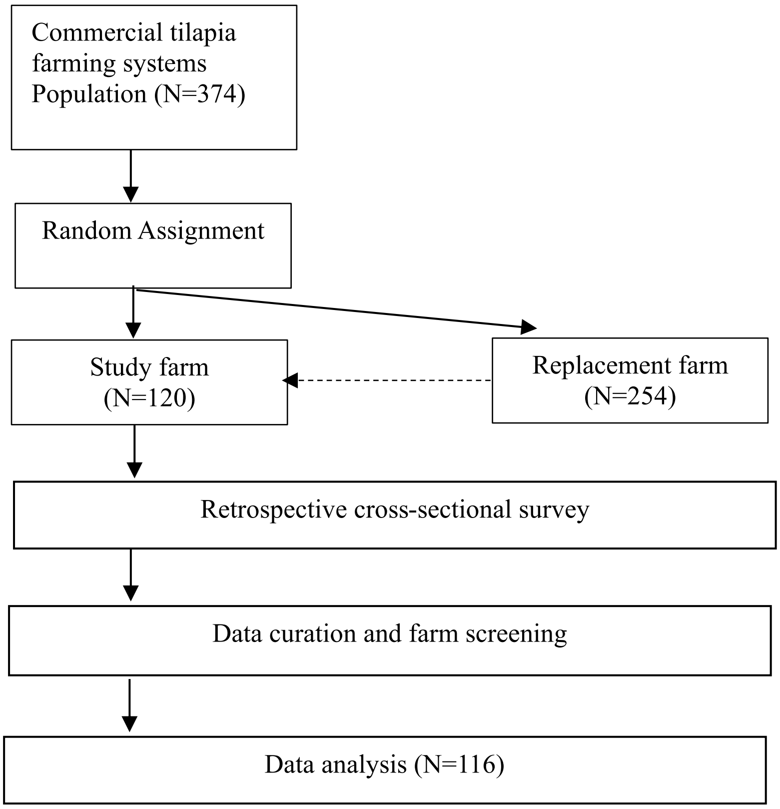

Figure 2. Study design

Upazila-wise distribution of recruited tilapia-dominant farms for the CS and LS study are shown in Figure 3.

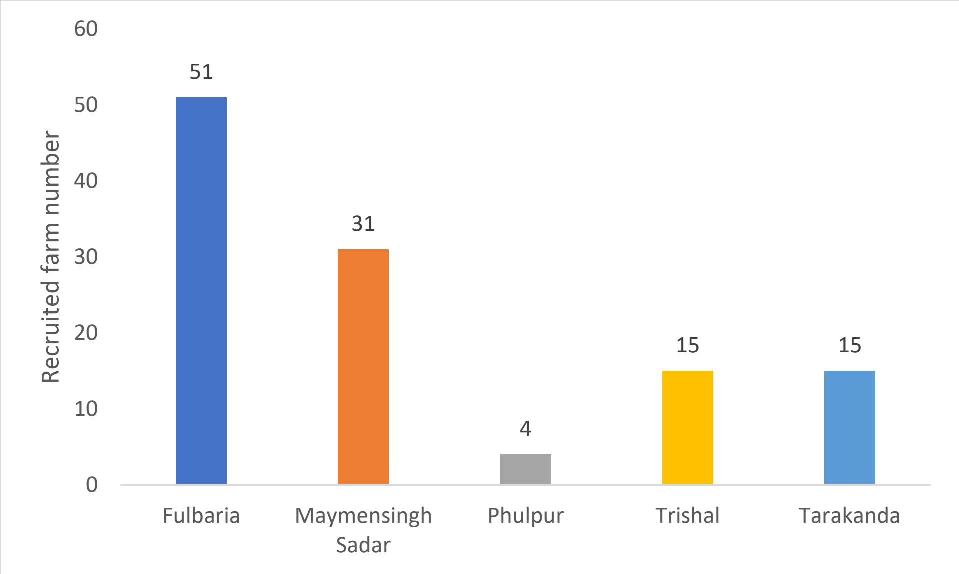

Figure 3. Upazila-wise distribution of the recruited tilapia-dominant farms.

Survey pond selection

From each recruited farm, a single unit of tilapia pond was randomly selected for the study. The respondent was asked to point out all the tilapia ponds on the farm that were used in the previous production cycle. All the eligible ponds were listed and sketched by enumerators. The survey tool was programmed to randomly select one pond from the list of eligible ponds for the study.

Survey tools development

A survey tool was developed (Table 1), pretested, and validated for assessment of farming practices, aquamedicines use, knowledge, attitudes, perceptions and practices regarding AMU. The survey was conducted using SurveyCTO® mobile data collection platform on Android mobile tablet devices.

Survey tools	Description
CS tool	Farm-level information: Socioeconomic/demographic information, AMR awareness and attitudes, farm layout and worker information, general farming practice and biosecurity. Pond-level information from previous completed production cycle: Farming practices e.g., stocking, feeding, fertilization and harvesting, disease, mortality, response to mortality, prevention, treatments, production economics.
Owner information	Only used if owner was absent during cross-sectional (CS) survey

Table 1. Survey tools developed for One Health assessment of commercial tilapia farms.

Aquaculture input products from farms and shop surveys

Prior to conducting the retrospective study, an extensive web search was carried out using various search engines to compile an inventory of commonly used input materials in aquaculture. Simultaneously, surveys of input shops (n=50) were conducted across six upazilas in the Mymensingh district (Figure 4). The input materials identified through both the web search and shop surveys were documented, including images and detailed information on various brands of feeds, fertilizers, aquamedicines, antimicrobial products, growth promoters, and feed supplements.

Figure 4. Input shop surveys to catalogue commonly used aquamedicines in fish farm

The inventory of products was later developed into a reference photobook (Figure 5) which was further enriched with images and product information. The photobook was then used to assist farmers in identifying aquaculture input products applied in the pond during last production cycle.

Figure 5. Photobook of aquamedicines, feeds, and fertilizers.

Enumerator recruitment and training

Three postgraduate lead-enumerators and seven graduate data-enumerators who had prior experience of conducting fisheries surveys in the study area were recruited through a competitive recruitment process. Lead- and data-enumerators underwent 1 day of virtual training on the survey tools using Learn.ink platform. A week later, the training of the 10 enumerators was carried out in-person at the Aspada Training Academy in Mymensingh on 23-24th October 2022, aiming to enhance their knowledge on One Health, AMU, and antimicrobial (AMR) issues, understanding of survey techniques and questions and time required to complete the survey (Figure 6). Every enumerator was given abundant opportunity to practice on a mock survey, enabling them to raise questions and prepare for situations they might encounter during the actual survey.

Figure 6. Capacity building of enumerators on One Health survey techniques.

Statistical analysis

Survey data were downloaded from SurveyCTO as a CSV file and subsequently converted into an Excel spreadsheet. The data in Excel were double-checked for accuracy before being transferred to the Statistical Package for the Social Sciences (SPSS, IBM, Chicago, IL, USA) for analysis. Analyses primarily involved cross-tabulation with Chi-square tests, multiple response tabulation, and one-way analysis of variance for continuous variables.

Results

Farm layout and general information

Basic demographics and surveyed farm characteristics are shown in Table 2. Most respondents (96.6%) were farm owners, and all participants were male. Only 30.2% of the respondents received formal training on fish farming. Most of the respondents had 6-10 years of experience in fish farming (35.3%). Of the total worker only 31.0% and 0.9% were reported male and female paid workers respectively, however 13.8% reported farm reported to had unpaid female worker (Table 2).

Demographic characteristics	**Farms (N)**	**Responses (%)**
Position of the respondents		
Owner	112	96.6
Manager	4	3.4
Gender		
Female	0	0
Male	116	100.0
Number of years' experience in aquaculture (range)		
1-5	23	19.8
6-10	41	35.3
11-15	29	25.0
16-20	14	12.1
20-25	7	6.0
>25	2	1.7
Training		
Yes	35	30.2
No	81	69.8
Worker information		
Male paid workers	36	31.0
Female paid workers	1	0.9
Female unpaid workers	16	13.8

Table 2. Basic demographics characteristics of the studied farms.

Cross-sectional farm level practices

Culture techniques

The predominant farming type among the respondents was growing tilapia with other fish species (91.4%), a polyculture system (Table 3). Only a few farmers (2.6%) reported following exclusively tilapia monoculture systems on their farms.

Continuous farming was the most prevalent culture technique (72.4%), whereby fish is constantly farmed (in any one of the ponds) without a clear break in between cycles, being stocked in mixed batches and harvested at varying intervals. Only 27% of the respondents reported to follow all-in-all-out management practice, whereby all the fish are stocked and harvested as separate batches during the same period during which no multiple stocking and harvesting was conducted. Farming two crops per year was most common, approximately 80.2% of the farmers practicing this. Besides tilapia, carps are the most common group of species grown on farms.

Farming techniques	Farms (N)	Responses (%)
Culture type		
Polyculture	106	91.38
Monoculture	3	2.59
Both	7	6.03
Stocking practice		
All-in-all out	32	27.59
Continuous	84	72.41
Production cycle (per year)		
One production cycle	14	12.07
Two production cycles	93	80.17
Three production cycles	9	7.76
Type of other fish cultured in the farm		
Carp	108	93.10
Catfish	52	44.83

Table 3. Characteristics of farming techniques.

Water source and management

Pond water was sourced from various sources, including ground, rain, river, and municipal water (Table 4). Filling out the pond with groundwater (borewell water) was the primary source of water for commercial tilapia-dominant farms, followed by rainwater in the study area. Approximately 97.41% of the farms rely on borewell water. Rainwater was the second most common source of water in the studied farm, and approximately 50.00% of farms depended on rainwater. Only a few farms use municipal (1.67%) and river water (0.83%). None used water from irrigation, nearby farms, lakes, or any other sources.

Water exchange during the production operation was very common (87.07%) in the studied fish farms, and only 12.93% reported not conducting any water exchange. The practice of recording water quality parameters of the culture pond was very scarce, most of the farmers (69.83%) did not record any water quality variables.

Water management	Farms (N)	Responses (%)
Source of water		
Supply water (municipal town water)	2	1.72
Ground water (via bore)	113	97.41
Irrigation canal	0	0
Nearby farm	0	0
River	1	0.86
Rain	58	50
Lake	0	0
Other (specify)	0	0
Is there water exchange in ponds?		
No	15	12.93
Yes	101	87.07
Are water parameters recorded?		
No	81	69.83
Yes	35	30.17

Table 4: Water source and management practices.

Effluent release

Fram effluent release practices is shown in Table 5. Approximately 59.48% of farms were found to discharge effluents into the environment. Among these, the majority (88.41%) did so without any form of treatment. Releasing effluents after each production cycle is most common (42.24%), followed by once every few months (25.86%). Farm effluents were mainly released directly into a canal (42.24%) or into surrounding agricultural land adjacent to the farm (39.66%) and in majority case effluent released without treatment (77.59%).

Effluent release practices	Farms (N)	Responses (%)
Do your farm release any effluents		
No	47	40.52
Yes	69	59.48
If yes, how the effluents released?		
Treated with chemicals before discharge through outlet	1	1.45
Directed to a settlement pond before discharge through outlet	0	0
Discharged through outlet without treatment	61	88.41
Discharged through outlet leading to shared settlement pond	8	11.59
Other (specify)	0	0
How often is the water discharged from the farm?		
After every cycle	49	42.24
2-3x a week	2	1.72
1-2x a month	29	25
1x every few months	30	25.86
No discharge	6	5.17
Where are the effluents are discharged?		

Upstream directly into a river	0	0
Downstream directly into a river	7	6.03
Directly into a canal	49	42.24
Directly into a lake	8	6.9
mangrove/wetland	15	12.93
To a wastewater treatment plant/system	0	0
To an open agricultural land outside the farm	46	39.66
How often do you carry out treatment on farm effluents before discharge?		
All the time	1	0.86
Sometimes	25	21.55
Never	90	77.59

Table 5: Effluent discharge practices.

Pond sludge removal

Most of the farmers (95.69%) removed sludge from their culture ponds. Removing sludge after each production cycle was most practiced (38.74%). Approximately 28.83% of farmers reported to remove sludges one to two times per year. The removed sludges were mostly used to repair the pond dyke (Table 6).

Sludge removal	**Farms (N)**	**Responses (%)**
Does your farm carry out pond sludge removal?		
No	5	4.31
Yes	111	95.69
If yes, how frequently is pond sludge is removed?		
In between every cycle	43	38.74
1-2x a year	32	28.83
3-4x a year	14	12.61
After more than a year	22	19.82
Where is the pond sludge disposed?		
Dike	111	95.69
Vegetable garden	7	6.03
Used as agricultural feed	4	3.45
In closest water body	8	6.9
Other (specify)	11	9.48

Table 6. Pond sludge removal practice in the studied farms.

Presence of livestock in the farm

About 86.21% of farms did not have livestock. Approximately 13.79% used their farms to rear livestock including cattle, poultry, and goats. Cattle were the predominant livestock type and kept on 8.62% of the surveyed farms (Table 7).

Livestock	Farms (N)	Responses (%)
Poultry (chicken and ducks)	7	6.03
Cattle	10	8.62
Sheep	0	0
Goats	1	0.86
None	100	86.21

Table 7. Presence of livestock in the studied farms.

Biosecurity practices

The biosecurity practices implemented in the studied farms are presented in Table 8. Drying (91.38%), liming (94.83%) and maintaining a fallow period were quite a common practice for pond preparation. Only 1.78% farms did not practice any fallow period. Use of organic fertilizer in the studied farms was quite low, only 9 farms (7.76%) farms reported to use organic fertilizers of any kind. Alarmingly, approximately 64.66% of farms neither did fish and equipment disinfection nor did they safely discard the transport water. However, it was common practice (87.93%) to visually check health of the incoming fry/fingerling during introduction. For important aspects of internal biosecurity viz vehicle, equipment, foot and hand distinction practice were almost all absent; approximately 98.28% reported they did not follow them at all. Cleaning/disinfecting was the primary measure farmers took to prevent farms from happening disease. Only 8 farms (6.9%) reported using veterinary drugs viz antibiotics, antivirals, antifungals and antiparasitics. Treatment of the sick fish was the most common measures (75.86) taken by the respondents upon seeing clinical signs/mortality in their farms, sending samples for lab testing was almost nonexistent, only two farmers (1.72%) sent samples to the lab for confirmatory diagnosis.

Biosecurity practices	Farms (N)	Responses (%)
Which of the following do you do for the pond preparation?		
Drying pond	106	91.38
Liming pond	110	94.83
Cleaning nets	40	34.48
Organic fertilization	9	7.76
Inorganic fertilization	20	17.24
None	6	5.17
Other (specify)	10	8.62
Fallow period		
1-7 days	24	20.69
1-2 weeks	37	31.9
3-4 weeks	47	40.52
5-10 weeks	6	5.17

None	2	1.72
Biosecurity followed at the time of bringing the seed?		
Fish disinfection	32	27.59
Equipment disinfection	2	1.72
Disposal of transport water away from ponds	10	8.62
None	75	64.66
Other (specify)	0	0
Do you stock clean/healthy/genetically improved seed?		
No	14	12.07
Yes	102	87.93
Share equipment or staff with another farm?		
No	90	77.59
Yes	26	22.41
Use of on farm internal biosecurity measures?		
Vehicle disinfection	0	0
Footbath	0	0
Hand disinfection	1	0.86
Equipment disinfection	2	1.72
None	114	98.28
Other	1	0.86
What preventive measures do you take to avoid disease in your pond?		
Clean/disinfect	85	73.28
Veterinary drugs (excluding vaccines)	8	6.9
Vaccines	0	0
Feed them well	16	13.79
Special diet (including supplements)	0	0
Avoid mixing with other fish	1	0.86
Other (specify)	19	16.38
If veterinary drugs are selected		
Antibiotics	5	62.5
Antivirals	1	12.5
Antiparasitics	2	25
Antifungals	0	0
Other (specify)	2	25
What measures do you take upon seeing clinical signs or mortality?		
Report the incident	35	30.17
Collect samples for lab testing	2	1.72
Stop sales of fish	33	28.45
Stop incoming fish	12	10.34
Fish disposal	17	14.66
Fish treatment	88	75.86
Fish harvest	12	10.34
Other (specify)	10	8.62
What do you do when the fish continue to die despite your treatment?		
Increase the dose of the drug	26	22.41
Find a specialist	67	57.76

Nothing	4	3.45
Emergency harvest of pond	26	22.41
Harvest & sell moribund/dead fish	17	14.66
Change medication	61	52.59
Isolation of infected pond(s)	1	0.86
Removal and disposal of moribund fish (not sold)	20	17.24
Treat water before discharge	2	1.72
Shutting down water inflow/outflow to/from affected pond(s)	0	0
Restricted onsite movement of staff/visitors, equipment, and animals	0	0
Cancellation of fish sales	5	4.31
Cancellation of fish movement to/from outside farm sites	0	0
Disinfection of equipment before use between pond(s)	1	0.86
Installation of netting/fencing to prevent scavengers, predators and other unwanted animals	0	0
Use separate nets, and other small equipment for different pond(s)	0	0
Other (specify)	7	6.03

Table 8. Bio-security practices implemented in the studied farms.

Farmers awareness on AMR

farmer awareness details regarding AMR are outlined in Table 9. Majority of the respondents (50.00%) reported that the main purpose of using antibiotics in farms was for treatment of fish while 11.21% respondents said preventing disease was the main purpose of using antibiotic (Table 9). Around 56.03% of the respondents did not see any problems using antibiotics in aquaculture production.

Majority of the surveyed farmers (75.00%) learned about the health consequences of antibiotic use, such as unhealthy fish, negative impacts on human health, and antimicrobial resistance, through informal channels like other farmers, friends, or relatives. Only two farms (12.50%) gained awareness through media sources such as radio, newspapers, or television.

The majority (78.45%) of farmers declared that they did not consume fish that were recently treated with medicines.

Most farmers (44.83%) were unaware of the withdrawal period required before consuming fish treated with medication. While most farmers (87.07%) refrained from selling sick fish in the market, a significant proportion (39.66%) did not know how long they should wait before selling treated fish.

Furthermore, the majority (88.79%) of farmers had never heard of antimicrobial resistance (AMR), and 87.07% did not understand what it is. Only 12.93% correctly defined AMR as the overuse of antibiotics or antivirals, leading to these drugs becoming ineffective.

Awareness on AMR	**Farms (N)**	**Responses (%)**
Main purpose of using antibiotics		
Prevent disease	13	11.21
Treat disease	58	50.00
Improve growth	1	0.86
Other	1	0.86
None	43	37.07
Do you see any problems with using antibiotics in aquaculture production?		
Yes	51	43.97
No	65	56.03
If yes (n=51), downsides of using antibiotics in aquaculture production		
High cost	24	47.06
Low quality/ drugs don't work well	31	60.78
Don't know which drug to use	21	41.18
Could make fish unhealthy	6	11.76
Could be dangerous for my health	9	17.65
Could lead to resistance/AMR	1	1.96
Reduced fish growth	2	3.92
If known (n=16), where did you hear adverse health implication of antibiotic use?		
Veterinary officer	0	0.00
NGO/charity	0	0.00
Farmer cooperative	0	0.00
Drug/feed company	1	6.25
Radio/newspaper/TV	2	12.50
Social media	0	0.00
Other farmer/friend/relative	12	75.00
Other	1	6.25
Do you consume fish that have just been treated with medicines?		
Yes	25	21.55
No	91	78.45
How many days should you wait before consuming the fish that has just been treated?		
Don't know/No answer	52	44.83
0 day	1	0.86
1 Week	9	7.76
2 weeks	11	9.48
3 weeks	21	18.10
1 month	14	12.07
2 months	2	1.72
3 months	3	2.59
>3 months	4	3.45
Do you sell sick fish?		
Yes	15	12.93
No	101	87.07
How many days should you wait before selling the fish that has just been treated?		
No answer	46	39.66
1 week	8	6.90
2 weeks	2	1.72
3 weeks	14	12.07
1 months	28	24.14
2 months	15	12.93
Over 2 months	3	2.59

Have you ever heard of antimicrobial resistance (AMR)?		
Yes	13	10.83
No	103	88.79
Could you please explain what antimicrobial resistance is?		
Over-use of antibiotic / antivirals	15	**12.93**
Toxins in the meat of fish	0	0.00
Don't know	101	87.07

Table 9. Farmers' awareness on AMR.

Cross-sectional pond level practices

Characteristics of the selected ponds

Differences in the pond sizes were observed among the randomly selected ponds (Figure 7). The mean size was 0.33 ha with min 0.04 ha and max 1.21 ha. The inter quartile range (IQR) was 0.28 ha (p25 = 0.14, p75 = 0.42).

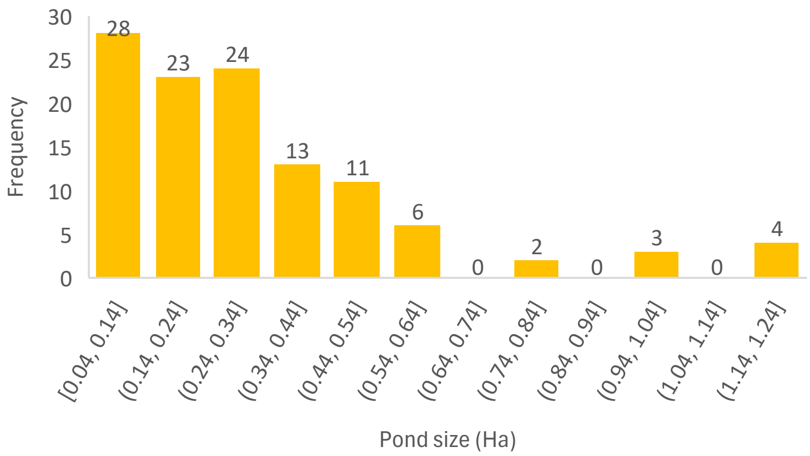

Figure 7. Size frequency distribution of the tilapia ponds.

Pond practices: Stocking and sourcing of seeds

Farming tilapia alongside other species was the most common production technique observed in the selected ponds. Only 11.21% of the selected ponds practiced monoculture of tilapia (Table 10). The most prevalent practice was farming tilapia with carps, which accounted for 60.34% of the ponds. Stocked tilapia seeds were mostly sourced directly from hatchery or nursery (75.00%). Obtaining tilapia seeds from middleman was the second most favored source of tilapia seeds (25.00%) among the respondents.

Stocking and source of seeds	Farms (N)	Responses (%)
Fish species composition in the selected ponds		
Only tilapia	13	11.21
Tilapia and carp	70	60.34
Tilapia, carp, catfish	28	24.14
Tilapia, carp, catfish and other fish	1	0.86
Tilapia and catfish	4	3.45
Sources of tilapia seeds		
Hatchery/nursery	87	75.00
Own stock	13	11.21
Middleman	29	25.00
Other (specify)	1	0.86

Table 10. Fish stocking composition and seed sources in the tilapia ponds.

Pond practices: Feeding

Commercial tilapia farms in earthen ponds rely extensively on commercial feed. All the surveyed farms used commercial feed in the selected ponds, whereas only 3.45% of farms reported using homemade feed; no farmers reported using domestic scraps in the selected ponds (Table 11).

Types of feeds	Farms (N)	Responses (%)
Do you use home made feed?		
No	112	96.55
Yes	4	3.45
Do you feed domestic scrap?		
No	116	100
Yes	0	0
Do you feed commercial feed?		
No	0	0
Yes	100	100

Table 11. Types of feeds used in the tilapia ponds.

Pond practice: Use of fertilizers

The majority of farmers (86.21%) did not use any fertilizers in the selected ponds. Among those who did, inorganic fertilizers were more commonly used (12.07%) compared to organic fertilizers (2.59%). Organic fertilizer use was reported in only three instances: twice with compost manure and once with cured cattle manure (Table 12). Among the farms that applied inorganic fertilizers, 85.71% used urea, 78.57% used triple superphosphate (TSP), and 35.71% used diammonium phosphate (DAP).

Use of fertilizer	Farms (N)	Responses (%)
Are fertilizers being used in the selected ponds?		
Organic fertilizers	3	2.59
Inorganic fertilizers	14	12.07
None	100	86.21
What type of organic fertilizers are being used?		
Compost	2	66.67
Cured cattle manure	1	33.33
What type of inorganic fertilizers are being used?		
Urea - CO(NH2)2	12	85.71
Triammonium phosphate (TSP)	11	78.57
Diammonium phosphate (DAP)	5	35.71

Table 12. Reported use of fertilizers in the tilapia ponds.

Pond practices: Harvesting and consumption.

Harvested tilapia fish were mostly sold in the wholesale markets (50.00%). Around 36. 21% of the respondents sold the harvested tilapia fish to middlemen (Table 8). Majority of farmers (97.41%) consumed a portion of the produced fish.

Harvesting	Farms (N)	Responses (%)
Who did you sell the tilapia?		
Larger stores	7	6.03
Own outlets	0	0
Middlemen	42	36.21
Wholesales	58	50
Auction markets	29	25
Which of the following quality checks do buyers carry out on sale of fish?		
Freshness	115	99.14
Size	111	95.69
Tissue content	8	6.9
Antimicrobial residues	0	0
Pathogen testing	0	0
None	0	0
Did your household consumed harvested fish?		
No	3	2.59
Yes	113	97.41

Table 13. Marketing of harvested tilapia produced from the tilapia ponds.

Diseases and treatments

Pond practices: Clinical signs of diseases and mortalities

Around half of the surveyed farms (50.86%, 59/116) observed clinical signs of diseases in the selected pond. The affected fish species exhibited various clinical signs (Figure 8). The top three clinical signs reported were eye exophthalmia (34.78%, 16/46), skin erosion (30.43%, 14/46) and gasping air at the water surface (26.09%, 12/46) in tilapia, swollen anus (50.00%, 13/26), gasping at the surface (38.46%, 10/26) and skin erosion (34.62%, 9/26) in carps, and abdominal distension/swelling (60.00%, 3/5), appetite loss and swollen anus (40.00%, 2/5 each) in catfish.

About 46.55% (54/116) farms encountered fish mortality in the ponds and among the mortality affected ponds, approximately half of them (48.08%, 25/52) observed multiple mortality incidence in the ponds. Approximately 31.90%, (37/116) of respondents also encountered fish mortality in other ponds during the last completed production cycle.

Most of the fish mortality occurred suddenly (77.78%, 42/54) and most of the mortality events (61.11%, 33/54) typically lasted for 1 week (Figures 9 and 10). Some of the main reasons of fish mortality reported by the interviewed farmers in the selected ponds were bacterial disease (37.04%, 20/54), transportation stress (20.37%, 11/54), sudden temperature fluctuation and water quality stress (16.67% each, 9/54)), high ammonia and low dissolved oxygen (14.81% each, 8/54). Approximately 16.67% (9/54) reported “no suspected cause” of mortality. Categorically, the respondents identified water quality, pathogens, and climatic conditions as the top three reasons for fish mortality in the ponds (Figure 11).

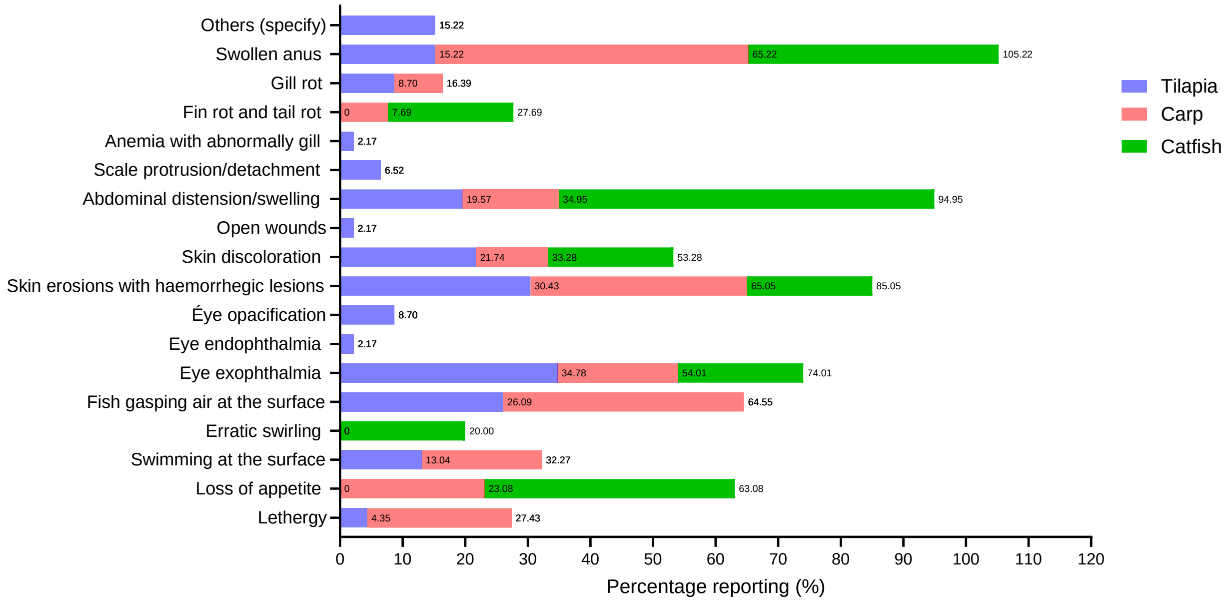

Figure 8. Clinical signs of illness in farmed fish in the tilapia ponds.

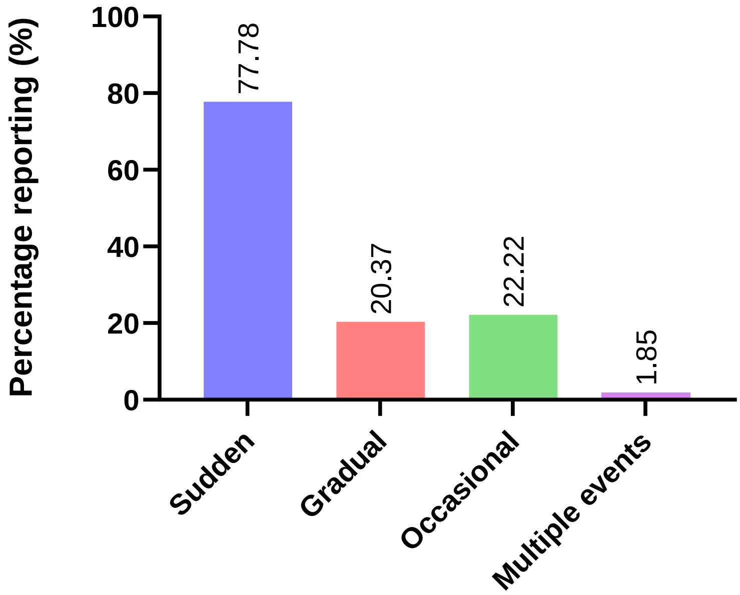

Figure 9. Nature of fish mortality in the tilapia ponds.

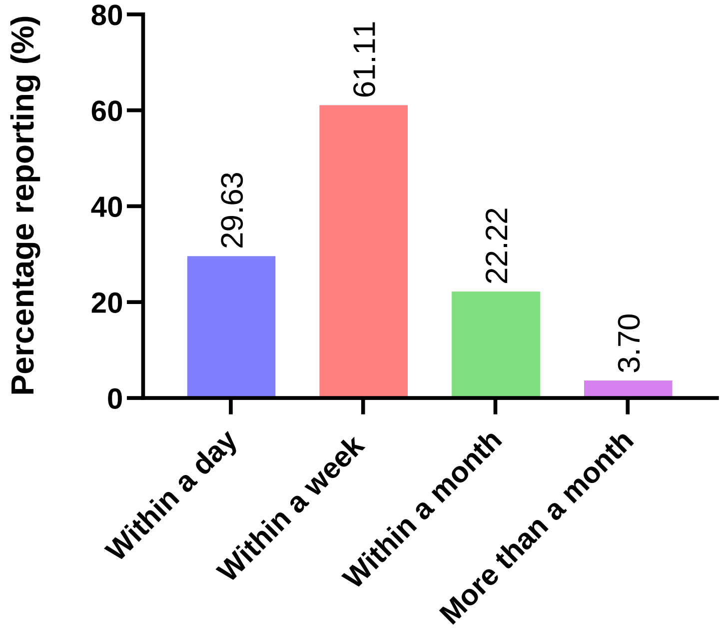

Figure 10. Duration of fish mortality in the tilapia ponds.

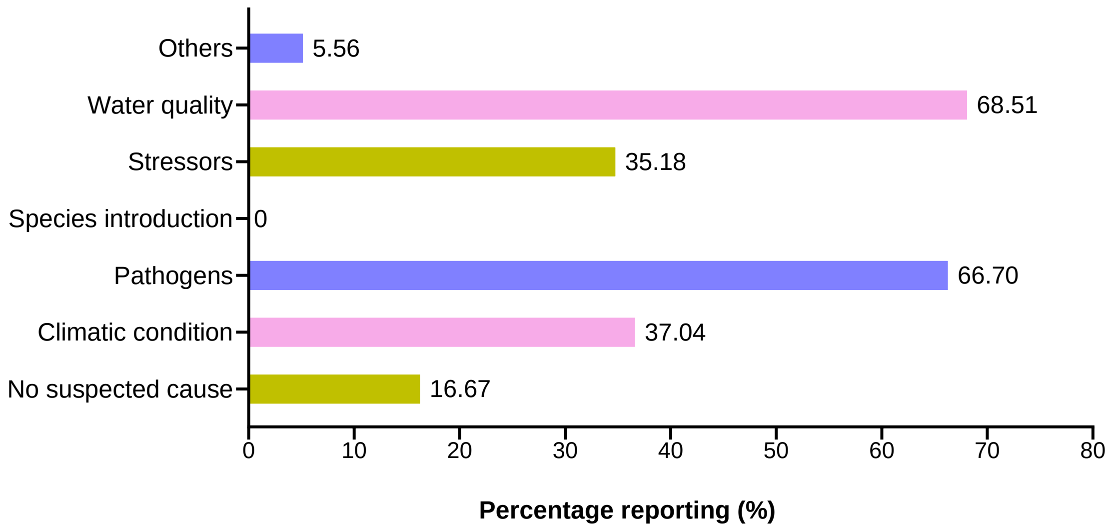

Figure 11. Categorical causes of fish mortality in the tilapia ponds (n=54).

None of the farms reported maintaining mortality records in paper or any other form of documentation. Most of the respondents buried dead fish in the ground (72.41%, 84/116), while 31.9%, (37/116) of respondents indicated discarding dead fish on land (Table 14).

Fish disposal methods	Farms (N)	Responses (%)
Disposal practices		
Consumption	3	2.59
Burying	84	72.41
Burning on farm	0.00	0.00
Burning off farm	0.00	0.00
Collecting for discarding on land	37	31.90
Discarding in water body	5	4.31
Selling for animal feed	1	0.86
Feeding to other animals on farm	8	6.90
Not removing fish from pond (s)	2	1.72
Other	4	3.45

Table 14. Practices for disposing dead fish.

Most respondents did not report and did not seek any professional assistance following the outbreak of disease in the pond (75.00% each, 87/116). Among those who reported and sought professional help (n=29), most respondents reported 51.72%, (15/29) and sought assistance 68.97% (20/29) from chemical/drug suppliers (Figures 12 and 13). Professional assistance was primarily offered free of charge; only one respondent reported paying for the guidance. Only two respondents (1.72%, 2/116) sent samples to the laboratory for the diagnosis of the disease responsible for the clinical signs, however only one respondent received results from the laboratory.

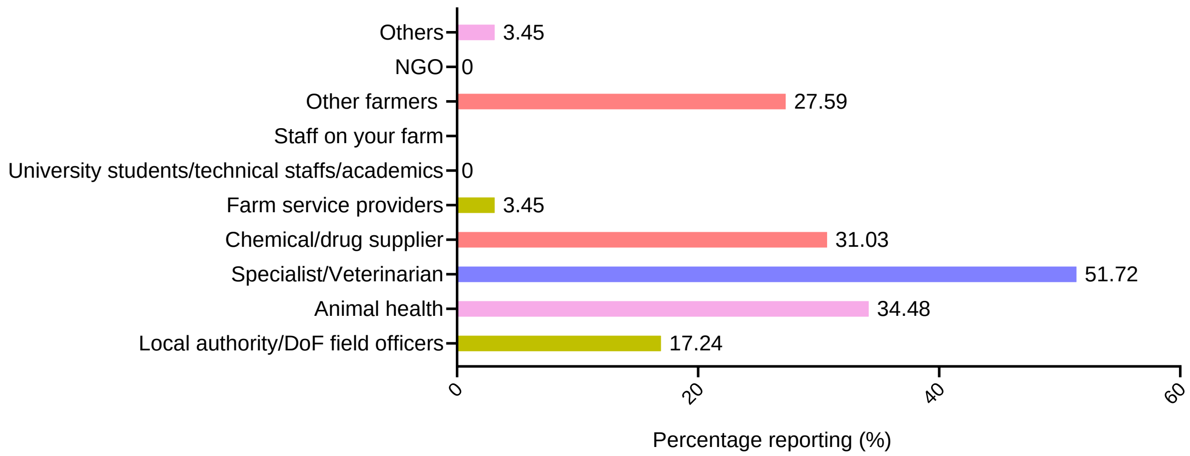

Figure 12. Mortality incidents in the tilapia ponds.

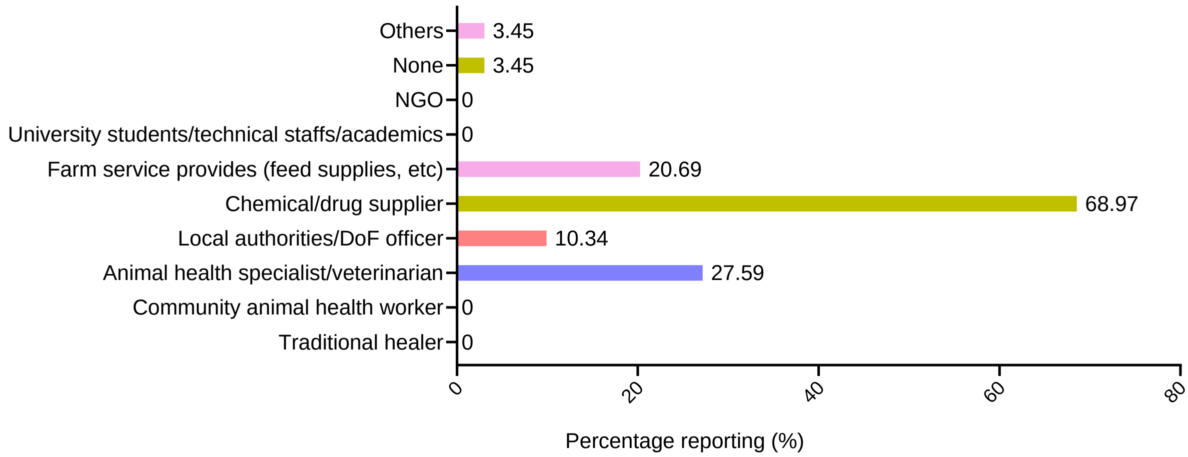

Figure 13. Help seeking behaviors of the respondents during disease outbreaks.

Medicinal products used in the selected tilapia ponds

Approximately half of the respondents (52.59%, 61/116) reported deploying aqua-medicine products specifically for treatment purposes in the pond during the last completed production cycle. In most cases, these products were generally applied when problems in fish health had already surfaced, such as clinical signs of illness (39.3%, 24/61) or low mortality (44.3%, 27/61) (Figure 14).

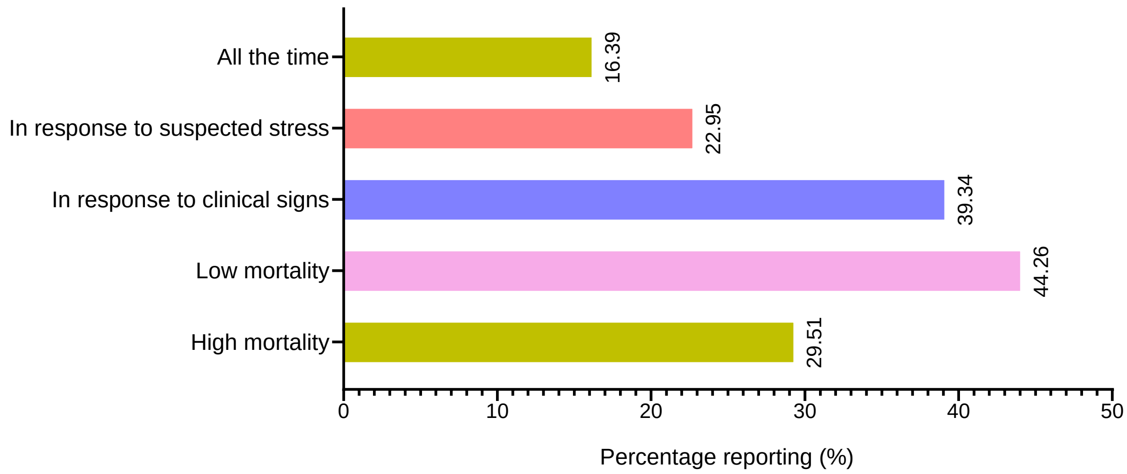

Figure 14. Situations promoting treatment product deployment in the tilapia ponds.

Farmers reported a total of 251 events of various aqua-medicine administration during the most recently completed production cycle in the selected tilapia ponds (Annex 1). Of these administrations, collectively, the highest proportion—approximately 29.9% (75/251)—involved the application of commercial branded antimicrobial agents (antibiotics, Antibiotics as feed additive, antiparasitics, disinfectants and biocides), while 8.0% (20/251) specifically pertained to antibiotic administration only. Nearly half of the farms (45.7%, 53/116) under the study administered one of the antimicrobial treatments at least once in the selected tilapia ponds during the most recent completed production cycle, whereas 14.7% (17/116) farms used antibiotics specifically in the studied ponds. Among the other administrated aquamedicines, 40.5% (47/116) and 25.9% (30/116) farms applied obnoxious gas reducing and oxygen enhancing commercial products respectively (Table 15).

Products	**Administration events n (%)**	**Farms reported n (%)**
Antibiotics	20 (8.0)	17 (14.7)
Antibiotics as feed additive	1 (0.4)	1 (0.9)
Antiparasitics	19 (7.6)	18 (15.5)
Disinfectants	33 (13.1)	29 (25.0)
Biocides	2 (0.8)	2 (1.7)
Oxygen enhancers	35 (13.9)	30 (25.9)
Harmful gas reducers	66 (26.3)	47 (40.5)
Growth promoters	5 (2.0)	4 (3.4)
Probiotics	5 (2.0)	5 (4.3)
Feed supplements	3 (1.2)	3 (2.6)
Lime	28 (11.2)	28 (24.1)
Salt	31 (12.4)	31 (26.7)
Potassium permanganate	2 (0.8)	2 (1.7)
Bleaching powder	1 (0.4)	1 (0.9)

Table 15. Treatment products used in the tilapia ponds.

Farmers reported using 12 commercial antibiotic brands and 1 brand containing antibiotic as feed additive, encompassing 8 distinct antibiotic classes during the most recently completed production cycle in the selected tilapia ponds (Table 16). All the reported antibiotics were classified as either critically important antibiotics (CIA) or highly important antibiotic (HIA) for human medicine, as categorized by the World Health Organization (WHO). The highest reported antibiotic being used was oxytetracycline hydrochloride (23.8%, 5/21), followed by enrofloxacin, and the erythromycin-thiocyanate-sulphadiazine-trimethoprim combined drug (each 19%, 4/21).

Brands	Antibiotic ingredients	Treatments N (%)	WHO categorization
Cotrim-Vet Suspension	TMP, SMX	2 (9.5)	HIA
Renamycin (vet), Otetra-vet 50	OTC hydrochloride	5 (23.8)	HIA
Ciptec 10%	CIP hydrochloride	1 (4.8)	CIA
Renamox 30% (Vet)	AMX trihydrate	3 (14.3)	CIA
Erocot, Erazine VET, Erisen-Vet, Micronid (vet)	ERY (thiocianate), SFD, TMP	4 (19.0)	CIA
Enrosef, Enroflox DS Vet	ENR	4 (19.0)	CIA
Pansol-Vet	CIP, ENR hydrochloride, COL-Sulphate	1 (4.8)	CIA
ASCO-Cvita (Antibiotic as feed additive)	OLA	1 (4.8)	CIA
SMX=Sulphamethoxazole, TMP=Trimethoprim, OTC-HCL=Oxytetracycline hydrochloride, CIP-HCL= Ciprofloxacin hydrochloride, AMX= Amoxicillin, ERY= Erythromycin, SFD= Sulphadiazine, ENR= Enrofloxacin, COL=Colistin, OLA=Oxolinic acid, HIA=Highly important antibiotic, CIA=Critically important antibiotic			

Table 16. Reported antibiotics used in the tilapia ponds.

Based on the responses of farmers who used antibiotics in the selected pond during the most recent completed production cycle, low mortality, and clinical signs of illness in the farmed fish were the two prevalent reasons for using antibiotics, accounting for 64.7% (11/17) and 58.8% (10/17) respectively. Administration of antibiotics in response to high mortality (29.4%, 3/17) was approximately one and a half percent lower compared to low mortality. Reported usage of antibiotics at early stages, such as in cases of suspected stress or to prevent sickness, was rare (Figure 15).

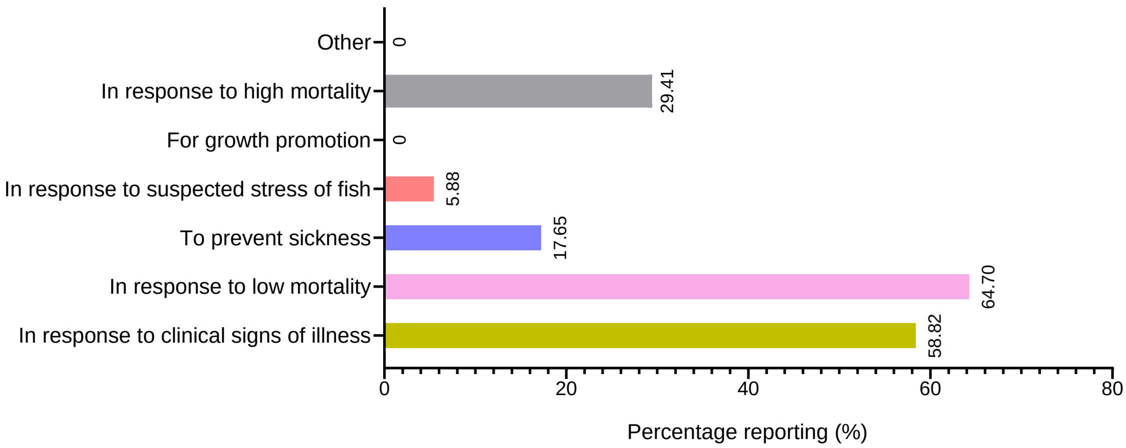

Figure 15. The rationale behind farmers' antibiotic usage in the tilapia ponds (n=17).

Pond practices: aquamedicin administrations

Table 17 highlights the practices regarding the adoption of basic safety measures when applying inputs, including chemicals and drugs, to fishponds. Most respondents (43.10%) reported not using any personal protective equipment (PPE) while administering treatment products. Among those who did use PPE, only about 34.48% reported using face masks, and 25.00% reported using hand gloves. Most farmers indicated that they had a dedicated storeroom for storing treatment chemicals; only farmers reported using human medicines for fish.

Treatment administration	**Farms (N)**	**Responses (%)**
Did you wear any of the following PPEs while administering treatments at the farm?		
Gloves	29	25.00
Mask	40	34.48
Face shield	0	0
Goggles	0	0
Apron/Protective clothing	0	0
None	50	43.10
Where do you normally keep treatment chemicals?		
In a storage box	25	21.55
In a shelf	27	23.28
In the storeroom	53	45.69
In home with no dedicated place	12	10.34
Do you sometimes use human medicines for fish?		
No	115	99.14
Yes	1	0.86
What's the reason for doing it?		
I already have them on hand	0	0
Less expensive than fish medicine	0	0
More effective	1	100
Fish medicines are not easily available	0	0

Table 17. Safety practices followed for administration of treatment products.

Summary and conclusion

This study seeks to comprehensively evaluate commercial tilapia farming practices through a One Health lens, focusing on the interconnected aspects of human, animal, and environmental health. It aims to identify the factors influencing AMU and assess farmers' knowledge, attitudes, and practices (KAP) regarding AMU and the principles of the One Health approach within commercial tilapia production systems in Bangladesh.

The study underscores the importance of assessing these factors, behaviors and practices to design effective interventions and policy recommendations. Understanding the behavioral and practical aspects of AMU provides the foundation for experimental research to test the impact of reducing antimicrobial use on fish farming productivity, profitability, and long-term sustainability.

Retrospective cross-sectional data was collected in November 2022 from commercial tilapia farms across five upazilas in Mymensingh district, one of the major tilapia production hubs in Bangladesh. A total of 120 farms were randomly selected from a list of currently active commercial tilapia farms in the region. The survey was conducted using the SurveyCTO® mobile data collection platform on Android tablet devices, utilizing a pretested and validated survey questionnaire to assess the farming system. The survey aimed to capture the following:

- Socioeconomic/demographic information
- Farm layout and worker information
- General farming techniques
- Water source and management
- Effluent discharge
- Pond sludge removal
- General farm biosecurity practices
- AMR awareness and attitudes
- Pond-level information from previous completed production cycle: stocking, feeding, fertilization and harvesting, disease, mortality, response to mortality, Usage of antimicrobials and other treatment products, production economics.

Our findings revealed that nearly half of the surveyed commercial tilapia farms (45.7%) administered various antimicrobial treatments at least once during the last production cycle, with 14.7% of farms using antibiotics. We cataloged twelve different antibiotic products and one feed product containing an antibiotic (oxolinic acid), spanning eight antibiotic classes. Some most reported antibiotics were oxytetracycline hydrochloride (23.8%), enrofloxacin (19.0%) and erythromycin-sulphadiazine-trimethoprim (19.0%) drug combination. Antibiotics in the studied farms were primarily used for therapeutic purposes. The likelihood of AMU was significantly greater where fish exhibited clinical signs of illness or experienced mortality events compared to those without reported illness or mortality. Most farmers (75.0%) did not report disease outbreaks on their farms and primarily relied on chemical or drug suppliers (68.0%) for professional assistance during disease outbreaks.

Fish diseases were mostly diagnosed based on clinical signs, with only two respondents (1.7%) sending samples to a laboratory for confirmatory diagnosis. An overwhelming majority of farmers (98.3%) reported not implementing any of the four critical aspects of internal biosecurity measures: vehicle disinfection, footwear disinfection, hand sanitization, and equipment disinfection. Water management practices were suboptimal, with many farms using multiple water sources and discharged untreated effluents into the environment (77.59%). Approximately half of the respondents (56.0%) were unaware of any negative impacts of antibiotic use. Additionally, majority of the respondents (88.8%) had never heard of antibiotic resistance and could not explain what it is or how it develops.

This study underscores the need for comprehensive strategies that integrate farmer training, improved access to veterinary services, increased awareness, and strengthened regulatory oversight, which are essential for advancing responsible AMU practices and fostering a sustainable commercial tilapia aquaculture industry.

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Annex

Annex 1: Treatment products used in the selected tilapia ponds during the last completed production cycle.

Brand names	Frequency	Category	Active ingredients
Cotrim-Vet Suspension	2	Antibiotic	Sulphamethoxazole and Trimethoprim
Renamycin (vet)	4	Antibiotic	Oxytetracycline hydrochloride
Ciptec 10%	1	Antibiotic	Ciprofloxacin
Renamox 30% (Vet)	3	Antibiotic	Amoxicillin
Erocot	1	Antibiotic	Erythromycin thiocyanate, Sulphadiazine and Trimethoprim
Erazine VET	1	Antibiotic	Erythromycin thiocyanate, Sulphadiazine and Trimethoprim
Erisen-Vet	1	Antibiotic	Erythromycin thiocyanate, Sulphadiazine and Trimethoprim
Micronid (vet)	1	Antibiotic	Erythromycin thiocyanate, Sulphadiazine and Trimethoprim
Enrosef	3	Antibiotic	Enrofloxacin
Otetra-vet 50	1	Antibiotic	Oxytetracycline hydrochloride
Pansol-Vet	1	Antibiotic	Ciprfloxacion 705%, Enrofloxacine HCL 2.5%, Colistin Sulphate 0.25%
Enroflox DS Vet	1	Antibiotic	Enrofloxacin
ASCO-Cvita	1	Antibiotics as feed additive	99% Ascorbic acid, Beta-glucans, oxolinic acid
TIMSEN	23	Disinfectant	N-alkyl dimethyl benzyl ammonium chloride 40%
POLGARD+	3	Disinfectant	3-Methyl, 4 Alkyl two chain brominated halogen compound
Micronil	1	Disinfectant	Benzalkonium chloride 800 mg
Bactonil	1	Disinfectant	Benzalkonium chloride 80%
VIROCID	4	Disinfectant	Alkyldimethylbenzylammonium chloride and Didecyl dimethyl ammonium chloride
Aquakleen	1	Disinfectant	Brominated organic salt, Buffered amino nitrogen and Benzalkonium chloride
PROTECTOR-PLUS	1	Biocides	Benzalkonium chloride and Tetradecyl trimethyl ammonium bromide
TOPPER-AQUA	1	Biocides	Alkyldimethylbenzylammonium chloride and Expient
PARATICS	12	Antiparasitic	Deltamethrin 2.75% EC
TERMINATE	4	Antiparasitic	Deltamethrin 1.75% EC
FIRST KILLER	1	Antiparasitic	Deltamethrin 2.8% EC
Verkil Vet	2	Antiparasitic	Ivermectin BP 1%
Panvit-Aqua	2	Growth promoter	Vitamin A, D3, B1, B2, B6, nicotinamide, calcium D pantothenate and ascorbic
Heparen	1	Growth promoter	Vitamin BT, sorbitol, choline chloride and artichoke extract
BUTAMIN	1	Growth promoter	25 mg cyanocobalamin; 500 mg methyl hydroxyenzoat, 50 g phosphonic acid; expient
Hepaprotect-Aqua	1	Growth promoter	Flavonoids
Lime	28	Non-brand products	-
Salt	31	Non-brand products	-
Potash	2	Non-brand products	-
Bleaching powder	1	Non-brand products	-

OXYMAX	12	Oxygen enhancer	Sodium percarbonate
OXYMORE	3	Oxygen enhancer	Sodium carbonate peroxyhydrate
Oxy-Ren	3	Oxygen enhancer	Sodium carbonate peroxyhydrate
OXY-GOLD	1	Oxygen enhancer	Sodium carbonate peroxyhydrate
OXY POND	1	Oxygen enhancer	Sodium per carbonate (99%)
OXY KING	1	Oxygen enhancer	Sodium percarbonate
Oxy-A	6	Oxygen enhancer	Sustained release oxygen 13.5%
R-Oxy	1	Oxygen enhancer	Sodium percarbonate
Oxyflox	1	Oxygen enhancer	Sodium percarbonate
ACI-OX	1	Oxygen enhancer	Sodium percarbonate 90%
OXYPOL TAB	1	Oxygen enhancer	Sustained release oxygen 13.5%
NEX-OXY GOLD	1	Oxygen enhancer	Active oxygen 15%
CLINIQ-OX	1	Oxygen enhancer	Sodium per carbonate 13.5%
Bio-ox	1	Oxygen enhancer	-
All-Oxy	1	Oxygen enhancer	-
POLYMER VULCANIZED BACTERIA CLEAN	1	Probiotic	Active sulphate bacteria, active resistant to ultra-low oxygen compound bacteria and auxiliary, effective live bacteria > 500 million CFU/g
AQUA LIFE - S	1	Probiotic	*Bacillus* species, *Lactobacillus*, *Nitroibacter*
Safegut	1	Probiotic	Acid *Bacillus*, *B. subtilis*, *B. licheniformis*, *Aspergillus oryzae*, *A. niger*, *Saccharomyces boulardii*, vitamins and enzymes
PondCare 35	2	Probiotic	*Rhodococcus* sp., *Rhodopseudomonas* sp., *Bacillus subtilis*, *B. coagulans*, *B. pumilus*, *B. licheniformis*, *B. megaterium*, *B. amyloliquefaciens*, *B. polymyxa*, *B. mesentericus*, *Saccharomyces cerevisiae* and enzymes complex
Yuka	14	Harmful gas reducer	*Yucca schidigera* extract
NITRITES CLEAN	1	Harmful gas reducer	Nitrite degradation agent, mud purification agent, digestive enzymes, carriers, etc., effective bacteria >500 million CFU/g
Matrix	19	Harmful gas reducer	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, NeO
Bio Aqua-50	6	Harmful gas reducer	*Yucca schidigera* extract
Zeo-Fresh	1	Harmful gas reducer	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2 and LOI
AMMONIL	2	Harmful gas reducer	Hydrated sodium calcium, aluminosilicates, dried yeast active, encapsulated enzymes, *Bacillus subtilis*, yucca extract 9%
JV ZEOLITE	7	Harmful gas reducer	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, Mn and P
Ecopond	2	Harmful gas reducer	*Bacillus subtilis, B. megaterium, Lactobacillus plantarum, L. acidophilum, Saccharomyces cerevisiae, Asperzillus oryzae*, Xylanase, Protease, Cellulase, Beta-glucanase, amylase, *Yucca schidigera*, SiO_2, Al_2O_3, CaO, Na_2O, MnO_2, Fe_2O_3, KO and Maltodextrin
Gasonil	6	Harmful gas reducer	*Bacillus subtilis, B. licheniformis* and *B. polymyxa, B. coagulans,* Yucca 30%

AQUA PURE	4	Harmful gas reducer	Hydrated sodium alumino silicate with natural adsorbing and deodorizing agent, having the fastest mode of action through highest CEC.
Gastrap	2	Harmful gas reducer	Fortified Enzymes & Probiotics
Pondkleen	2	Harmful gas reducer	*Yucca schidigera*
REALBIND	1	Feed supplement	Essential proteins, vitamins, attractants and fats
Nutrigel	1	Feed supplement	Feed binder with vitamins, minerals and probiotics
Vitamix-F-Aqua	1	Feed supplement	Vitamin A 2000,000I.U, Copper 2gm, Vitamin D3 50,000I.U, Inositol 2gm, Vitamin E 5gm, Iodine 300mg, Vitamin K3 1gm, Iron 2gm, Vitamin B1 1gm, Magnesium 2gm, Vitamin B2 1gm, Manganese 2gm, Vitamin B6 1gm, Selenium 10mg, Vitamin B12 2mg, Zinc 3 gm, Vitamin B3 4gm, Calcium 200gm, Vitamin B5 2gm, Phosphorus 50gm, Folic acid 200mg, Sodium10gm, Biotin 20mg, DLMethionine 25gm, Vitamin C 10 gm, L-Lysin 15gm, Cobalt 160mg, Antioxidant & Anticaking agent.

About WorldFish
WorldFish is a nonprofit research and innovation institution that creates, advances and translates scientific research on aquatic food systems into scalable solutions with transformational impact on human well-being and the environment. Our research data, evidence and insights shape better practices,policies and investment decisions for sustainable development in low- and middle-income countries.

We have a global presence across 20 countries in Asia, Africa and the Pacific with 460 staff of 30 nationalities deployed where the greatest sustainable development challenges can be addressed throughholistic aquatic food systems solutions.

Our research and innovation work spans climate change, food security and nutrition, sustainable fisheries and aquaculture, the blue economy and ocean governance, One Health, genetics and AgriTech,and it integrates evidence and perspectives on gender, youth and social inclusion. Our approach empowers people for change over the long term: research excellence and engagement with national andinternational partners are at the heart of our efforts to set new agendas, build capacities and support better decision-maing on the criticapart of One CGIAR, the world's largest agricultural innovation network.