International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print), 2222-5234 (Online)
http://www.innspub.net
Vol. 20, No. 3, p. 1-15, 2022

RESEARCH PAPER OPEN ACCESS

Farmer's knowledge on aquaculture management practices and challenges in Tanzania

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Key words: Aquaculture, Management practices, Antimicrobial, Disinfectants, Food security.

http://dx.doi.org/10.12692/ijb/20.3.1-15 Article published on March 30, 2022

Abstract

This study aimed at investigating the current management practices and status of the use of antimicrobials, disinfectants, and parasiticides in farm-raised fish in northern and eastern zones of Tanzania. Structured and semi-structured interviews were conducted across 130 aquaculture enterprises in both regions. Farmers reported using a total of seven different antimicrobial agents, including those for treating bacterial diseases such as *bacillary necrosis* of *Pangasius* (BNP) and *motile aeromonad septicaemia* (MAS), as well as a variety of disinfectants and parasiticides. Some farm owners and managers neither had advanced degrees nor specialized aquaculture training to manage, diagnose, and treat diseases in aquaculture environments. Tilapia and catfish were the two main fish species raised in both regions, either under concrete or earthen ponds in semi-intensive monoculture systems. To save on overall production costs, the majority of the farmers prepared their fish feed using locally available ingredients. However, they lacked proper knowledge of formulating high-quality fish feed and/or safe pond water management during production; these have a huge impact on overall fish health and consumer safety. For sustainable development of fish farming and good aquaculture management practices (GAMP), there's a need for the fish farmers to have aquaculture technical training and access to available fish disease diagnosis services in order to ensure the fish farmers can make informed treatment choices, improve aquaculture knowledge and use innovative fish farming approaches.

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Introduction

Aquaculture has a great potential to improve food and nutrition security in developing countries where more than 815 million chronically undernourished individuals reside (Béné *et al.*, 2016). Aquaculture is considered one of the sectors that play an important role in the alleviation of global hunger and malnutrition. This sector provides fish and other aquatic products that are rich in essential nutrients (Thilsted *et al.*, 2015). Fish is packed with protein, vitamins, and minerals with high biological value. It is also an excellent source of omega-3-fatty acids, which is important for brain development and cognitive performance of young children and adolescents (Thilsted *et al.*, 2015).

In most developing countries, aquaculture is conducted on a small scale for the purpose of addressing family-level subsistence and livelihood needs. The majority of farmers are characterized by having little investment in terms of ongoing husbandry and infrastructure, resulting in very low growth and yields (Brummett *et al.*, 2000). Some farmers practice integrated fish farming by utilizing the synergetic effects of inter-related farm activities. In this method, animal waste (manure) is used as the source of food for aquatic animals and the wastewater from the fish pond is used to irrigate vegetables (Petersen *et al.*, 2002). This kind of fish farming practice has the benefit of reducing feeding costs despite glaring food safety concerns. Manure used as food sources could potentially have pathogenic microbes and chemical residues that could end up in the fish pond and compromise consumer health and safety. Thus, to understand the risks associated with integrated fish farming, there is an urgent need to study the dynamics of pathogenic microbes and hazardous chemicals circulating in integrated fish farming. Aquaculture production can bridge the supply and demand gap of aquatic food in developing countries. However, in the effort to achieve this potential, the sector is facing significant challenges. The trends indicate that the sector continues to intensify its system and practices (Naylor *et al.*, 2000). This kind of aquaculture practice is characterized by high stock density in a limited space, creating a stressful condition, and increasing fish susceptibility to diseases (Adorable-Asis *et al.*, 2016). Fish farmers heavily use antibiotics, pesticides, disinfectants, and parasiticides for disease prevention and treatment. The residue from these chemicals can end up in the human gut upon the consumption of contaminated fish. Additionally, inappropriate use of farm chemicals could lead to occupational health hazards such as respiratory, skin, and other health problems associated with direct exposure. There's also the risk of contracting infectious diseases such as zoonotic pathogens like *Vibrio spp*. and *Aeromonas spp*. (Phu *et al.*, 2016). Today, the scope and extent of aquaculture management practices and occupational health hazards among fish farmers and workers in the aquaculture sector in Tanzania are not fully understood. Therefore, this study aimed at investigating the types of management practices used by fish farmers in Tanzania and the effectiveness of fish health management practices with regard to water management, fish feed quality, disease prevention, and treatment.

Materials and methods

Sample design

A stratified sampling technique was used to capture data from emerging aquaculture-producing regions, namely, Arusha and Morogoro. Both regions are emerging as reliable aquaculture resources in the country, thus could illuminate current aquaculture practices in Tanzania. Five villages from each region were selected for this study (Fig. 1). Kihonda,Langali, Mikese,Mkindo, and Tangeni villages from Morogoro region; Kikwe, Nambala, Maweni, Manyata, and Samalia villages from Arusha region. A total of 130 fish ponds were randomly selected with 65 fish ponds for each region and were found to use either integrated, non-integrated, or semi-integrated fish farming methods. Integrated fish farming uses animal waste as the only source of fish feed. Non-integrated fish farming depends on commercial fish feed as the main source of feed. Semi-integrated fish farming use both animal waste and commercial and/or non-commercial fish feed.

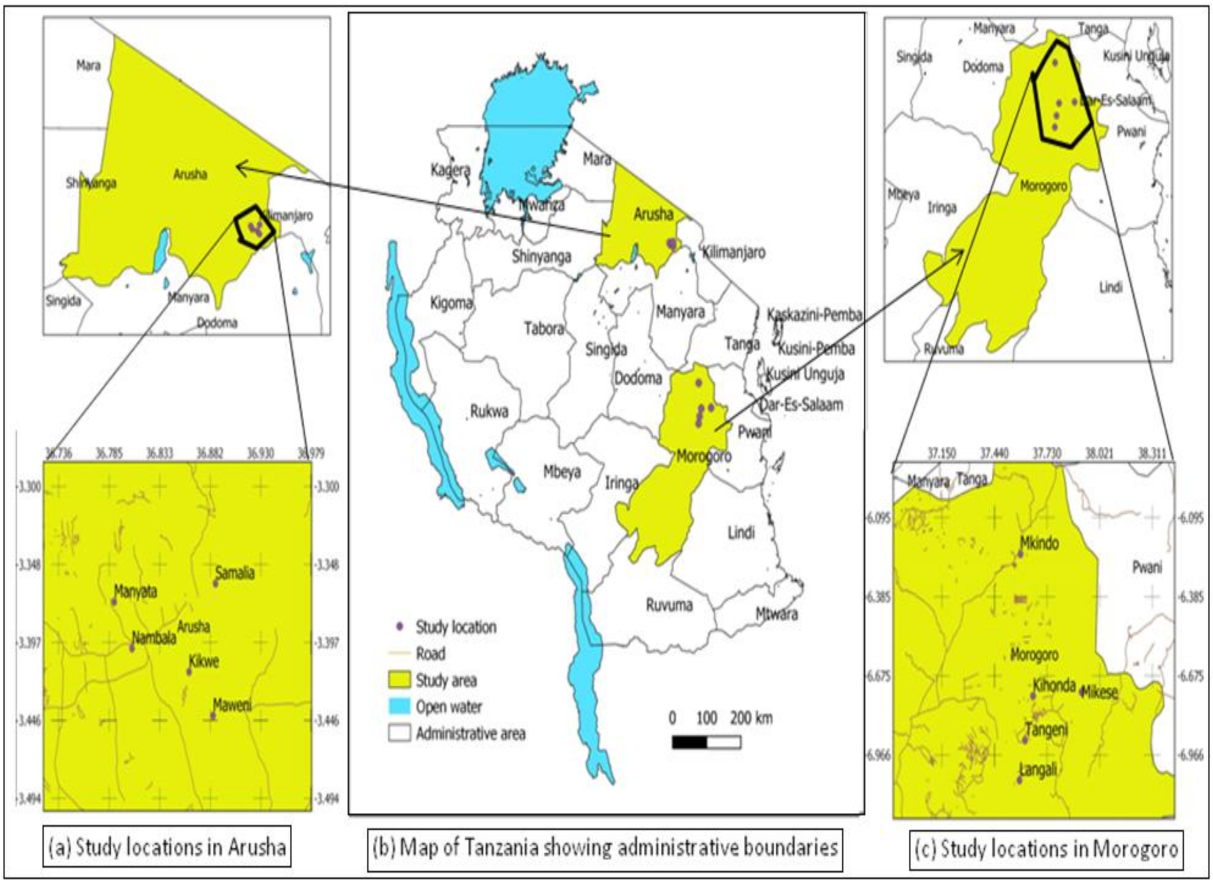

Fig. 1. Map of Tanzania showing the areas where the survey was conducted.

Survey design and data collection

On-site interviews and a set of pre-tested structured questionnaires were used to collect information from a sample of fish farm owners and managers in each region. The information collected captured the following: aquaculture knowledge background of the respondents, their farm infrastructure (e.g., pond area, volume and stocking density), details of the antimicrobials, parasiticides, and disinfectants usage during the last crop, and whether they were used for disease prevention or treatment. The interviews also probed for types and frequency of diseases and respondents' understanding of the clinical symptoms of these diseases. In some farms, direct observation and description of feed medication practices were recorded. Types and dosages of the applied antimicrobials and disinfectants were collected from the farmers' records. The farmers also provided registration of the chemicals used in the farms and the rationale for the choice of each chemical was explored. Additionally, the farmers were asked about perceived health hazards associated with their work, e.g., personal protection equipment (PPE) used when handling chemicals, knowledge on toxicological and exposure risks of chemical use, and accident occurrences due to chemical use. To triangulate the data on types and doses of chemical use reported by farmers, data were cross-checked by comparing with supplier product label information from the shops selling chemicals for aquaculture.

Data description and statistical analysis

Data were entered into Microsoft Excel for descriptive analysis (mean and SD). For comparative purposes, the type and frequency of reported diseases and chemical use are presented as ratios, i.e., given the unbalanced nature of the sample design. The chemical and biological products were grouped into antimicrobials, disinfectants, and parasiticides. For fish farmers who used chemicals, the concentration of active ingredient(s) was recorded based on information on product labels. When not clearly labeled, active ingredients were identified by cross-referencing product names with supplier inventories or published literature. Additional data collected included the type of fish feed, frequency of feeding, water management during and after production.

Multivariate analyses were used to evaluate correlations between (1) respondents, farm characteristics (independent variables), and reported diseases (dependent variable) in the farms and, (2) reported diseases (independent variables), and the chemical treatments used (dependent variable). Redundancy Analysis (RDA) was used to test for the significance of any correlation between the independent variables and the variance in the dependent variable dataset. The correlation of the tested independent variable was considered significant when $p \le 0.05$. Individual bi-plots were constructed only for those independent variables that showed significance at $p \le 0.05$.

Results

Farmers' background information and farm characteristics

The majority of the respondents surveyed in both regions were farm owners (75%), while the rest (25%) were farm managers. According to the data collected, 43% of the farmers surveyed in the Arusha region had some university degrees compared to only 23% of those from the Morogoro region. Likewise, the high number of farmers with degree holders in the Arusha region also correlated with a high number (76%) of those with aquaculture knowledge compared to those from the Morogoro region (9%).

Table 1. Farmers' background information and farm characteristics.

	Variable	Morogoro region N=65	Arusha region N=65	Mean	χ^2	F-test
Respondent characteristics	Role in the farm[a]	O(85); M(15)	O(66); M(34)	O(75); M(25)		
	General education level[b]	NO(22); PS(25); SS(31); U(23)	NO(8); PS(22); SS(28); U(4)	NO(15); PS(23); SS(29); U(33)		
	Aquaculture knowledge[c]	NO(8); UE(83) TA (9)	NO(4); UE(21); TA(76)	NO(6); UE(52); TA(42)	1.5472^{**}	
Farm characteristics	Aquaculture type[d]	C(74); EP(26)	C(37); EP(63)	C(56); EP(44)	2.8249^{*}	
	Production practices[e]	M(89); P(11)	M(90); P(10)	M(90); P(10)	-	
	Farmed species[f]	B(11); C(29); T(61)	B(9); C(5); T(87)	B(10); C(17); T(74)	1.4126^{ns}	
	Pond size(M^2)[g]	20-100(80); 101-150(12);151-200(8); >200(0)	20-100(45); 101-150(26);151-200(5); >200(25)	20-100(62); 101-150(19); 151-200(6); >200(12)		1.305^{ns}
Production	Initial number of fishes[h]	<100(1); 101-1000(80); 1001-2000(17); 2001-3000(2); >3001(0)	<100(0); 101-1000(55); 1001-2000(36); 2001-3000(5); >30001(5)	<100(0.5); 101-1000(67.5); 1001-2000(26.5); 2001-3000(3.5);>3000(2.5)		0.3137^{ns}
	Total Fish harvest[i]	<65(2); 66-1000(82); 1001-2000(14); 2001-3000(2); >3000(0)	<100(0); 101-1000(56); 1001-2000(36); 2001-3000(5); >3000(3)			0.2735^{ns}
	Feeding[k]	C (14); FS (9); HM (77)	C (12); FS (2); HM (86)	C (13); FS (5); HM (82)	2.2391^{ns}	

Note: Statistically significant at *P < 0.05, **P < 0.01, ***P < 0.001; ns = not significant.

All information showed in this table was collected during the chemical use interviews.

Numbers in parentheses is the percentages.

[a] O: Owner; M: Manager.

[b]NO: None; PS: Primary school; SS: Secondary School; U: University.

[c]NO: None; UE: Untrained with aquaculture experience; TA: Trained in aquaculture.

[d]C: Cage; EP: Earth pond.

[e]M: Monoculture; P: Polyculture.

[f]C: Catfish; T: Tilapia; B: Both catfish species.

[k]C: Commercial; FS: Food scraps; HM: Homemade.

Those farmers with aquaculture knowledge also reported having attended some training, short courses, and/or workshops organized by various stakeholders such as universities, Non-Government organizations (NGOs), and fish feed companies to supplement their knowledge. Of course, fish farming is a very center business. As a result, farm owners need to understand how to accomplish successful fish farming from a business perspective through fish education and training.

Fish production practices in both regions were also taken into consideration. About 74% of Morogoro fish farmers raise their fish in concrete ponds, whereas 63% of Arusha farmers use earth ponds. Farmers in both regions, however, seemingly use the monoculture production method. According to our findings, tilapia and catfish are the only fish species farmed in both regions (Table 1). Among the farmers surveyed in the Arusha region, the production of tilapia and catfish is 86.78 and 4.62%, respectively, whereas their numbers in the Morogoro region are found to be 60.61 and 28.79%, respectively, suggesting the farmers mostly preferred tilapia farming in both regions. Pond sizes also varied in both regions. The majority (80%) of Morogoro region farmers own pond sizes ranging from 20 to about 100M² with an average capacity of 100-1000 fingerlings. None of the farmers surveyed had ponds larger than 200M² in size (Table 1). However, some Arusha region farmers own ponds ranging from 100 to over 200M² with average initial fingerlings ranging from 100-30000, indicating water volume impact stocking capacity.

Table 2. Summary data on the use of antibiotics, disinfectants, and parasiticides in the surveyed farms: total number of recorded compounds (n) and percentage of farms that use them (% use).

		Arusha region	Morogoro region
Antibiotics	Total number of recorded compounds (n)	5	5
	Percentage of farms that use them (%)	30.76	15.38
Disinfectants	Total number of recorded compounds (n)	5	4
	Percentage of farms that use them (%)	18.46	12.30
Parasiticides	Total number of recorded compounds (n)	4	3
	Percentage of farms that use them (%)	9.23	10.76

In this research, we found that the majority (82%) of fish farmers in both regions produced their fish feed. To reduce cost, they used a single or a mixture of locally available feed ingredients such as maize bran, sardines, wheat bran, cassava meal, and sunflower seedcake. Unfortunately, most of the fish farmers surveyed had no formal training on fish feed formulation, processing, handling, and storage techniques. Many had little knowledge or understanding of restrictive feeding techniques and break feeding schedules. The lack of know-how of fish feed requirements could be the reason why most farmers realized undersize fish despite the regular feeding of their stock. Semi-intensive feeding was the most common type of feeding practice. All the fish farmers incorporated manure to increase the production of natural food organisms such as phytoplankton, zooplankton, and insects to supplement the fish diet.

Farm water management

Fig. 2 a-d show the result of water resources and management efforts in the Arusha and Morogoro regions. According to our findings, most fish farmers depend on three main sources of water. We found that the majority (approximately 45%) of the farms used boreholes as their major source of water, followed by tap water (40%) (Fig. 2a). Groundwater provides potable water for rural water demands in many parts of Tanzania. Therefore it makes sense that the fish farmers would adopt borehole drilling to provide clean water for their ponds throughout the year. All aspects of water treatment play a significant role in intensive fish production. Unfortunately, most of the fish farmers didn't have technical knowledge and equipment and lacked basic knowledge for testing the quality of their water supply.

Consequently, about 87% of all farmers surveyed did not treat their water before stocking (Fig.1b) and only about 2% of them changed their pond water regularly (Fig. 2c). In this research, we found that the fish farmers from both regions had poor wastewater management. Sadly, about 95% of the fish farmers released untreated wastewater freely into the environment (Fig. 2d). Because many of the farmers lacked formal training in fish farming, they had a limited understanding of how waste components of intensive fish farming can cause serious environmental problems.

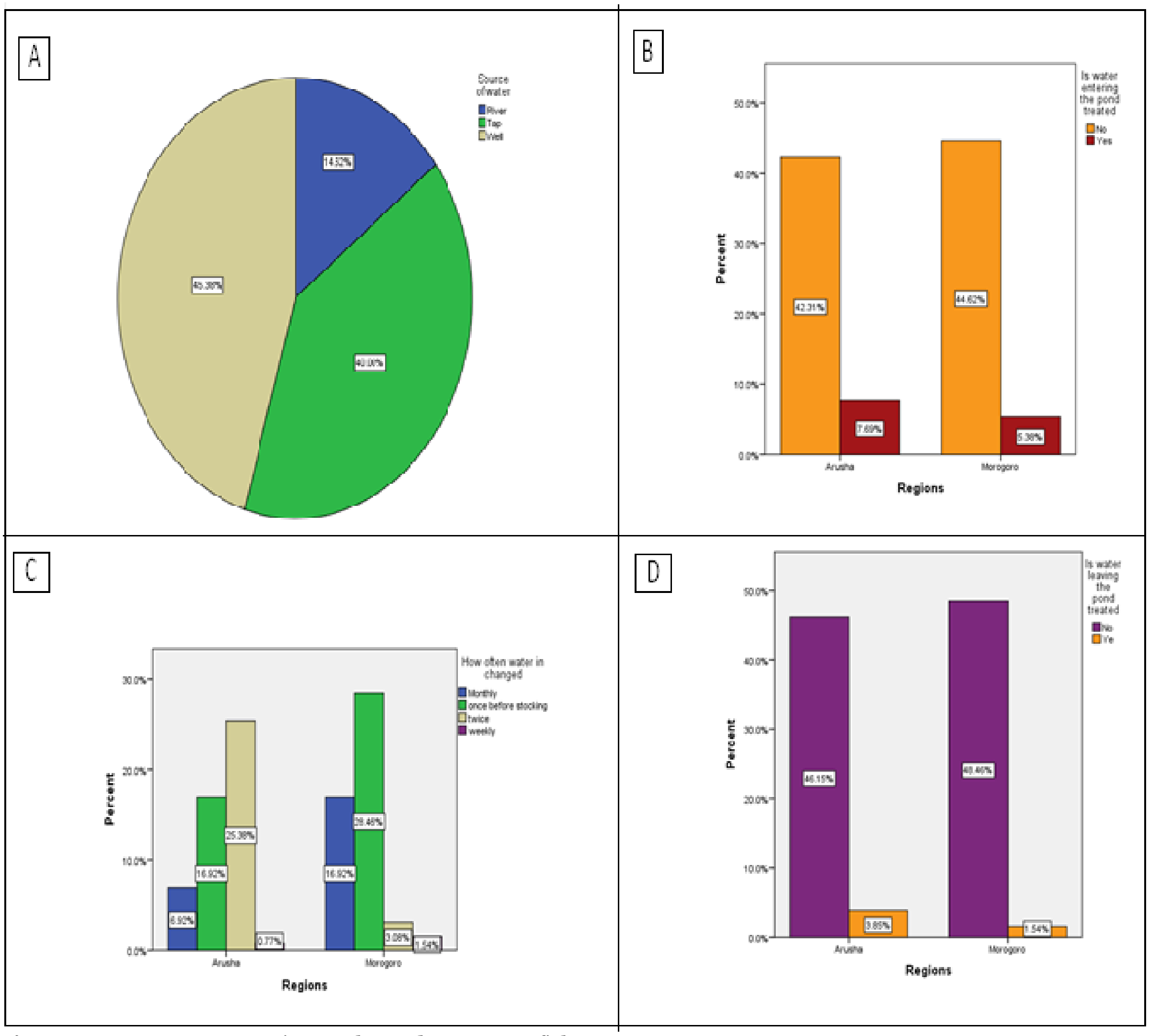

Fig. 2. Water management in Arusha and Morogoro fish Farms.

Disease occurrence and diagnostic capacity

Disease occurrence was reported by fish farmers from both regions (Fig. 3), which could lead to significant production losses. Unfortunately, the majority of the fish farmers had neither disease diagnostic equipment nor a health management plan for preventing and treating diseases in case of outbreaks.

To overcome losses because of infectious pathogens in aquaculture, it is important to act upon every health issue experienced and it should begin with proper record keeping and stock management. However, we observed that less than 21% of the surveyed farmers kept written records on the initial number of fingerlings stocking, final fish harvested, water management, diseases diagnosed, chemicals applied, and purpose of such application. Besides keeping proper records, knowledge regarding surveillance for diseases and having sensitive and specific disease diagnostic tests are invaluable to assure healthy fish.

We found a statistical correlation between aquaculture knowledge and disease occurrence, suggesting proper aquaculture education, training, and application of good aquaculture management practices can result in the ultimate health protection of fish in aquaculture (Fig. 4).

There was no significant correlation between pond size, pond structure, stocking density, feeding types, and general education level. Those farmers with aquaculture knowledge were also more likely to adhere to veterinarians and/or fish technicians on chemical usage.

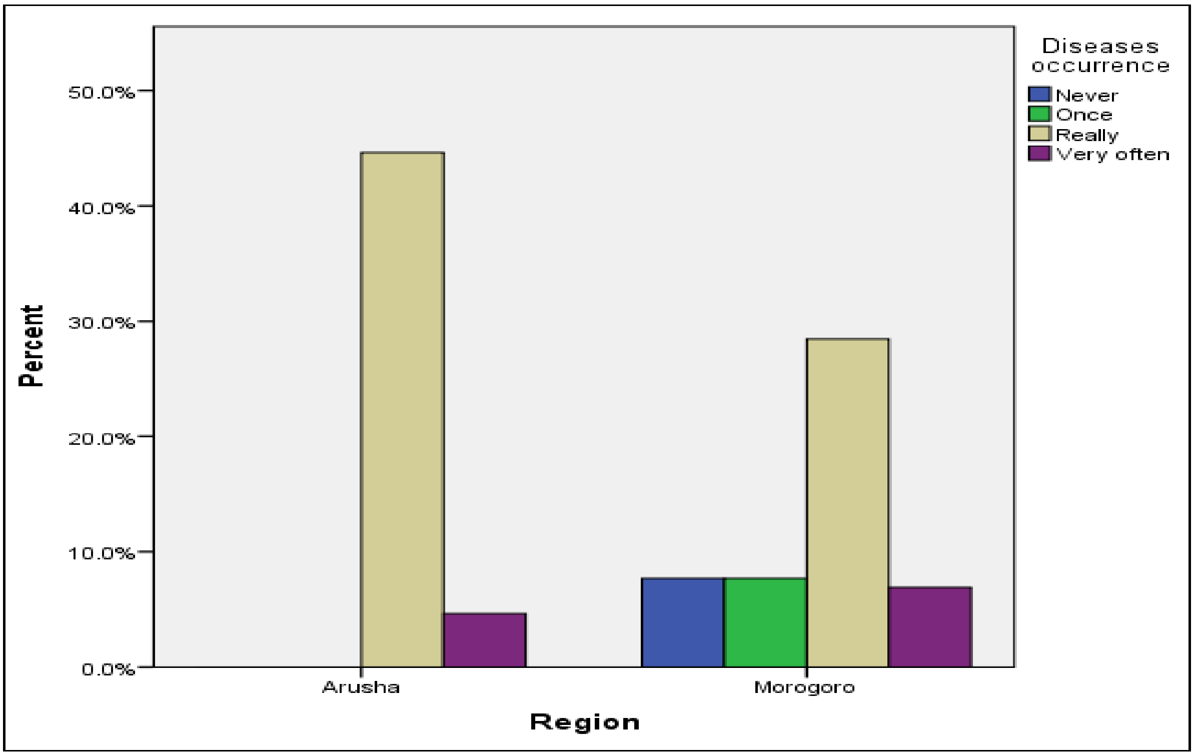

Fig. 3. Frequency of disease occurrence in Arusha and Morogoro surveyed fish farms.

Disease treatment practices

In this study, the number of chemical agents used by the farmers for disease control in Arusha and Morogoro fish ponds was found to vary considerably (Table 2). However, farmers' intentions were similar: disease prevention. Overall, antibiotics for disease control were used heavily by fish farmers in both regions (Table 2) despite their known side effects in the development of drug resistance by microorganisms.

Antibiotics are used for bacteria treatment during the nursing of fingerlings and when farmers visually see bacterial infection symptoms. The choice of antibiotics slightly varied with the region. We found that fish farmers in the Morogoro region most preferred oxytetracycline, sulfadiazine, and trimethoprim (Fig. 5) while those in the Arusha region preferred oxytetracycline, gentamycin, and florfenicol (Fig. 6). In general, oxytetracycline was the most preferred antibiotic in both regions for reducing pathogens and avoiding transferring pathogens from one stock to another. However, some fish farmers in the Morogoro region had reported using a mixture of more than one antibiotic. There are several disinfectants fish farmers can use in treating their ponds. In this study, we found that chlorine, formaldehyde, hydrogen peroxide, and iodine solutions were the most common disinfectants used by fish farmers in the Morogoro region (Fig. 5), while those in the Arusha region mostly preferred iodine solutions (Fig. 6) for water treatment before stocking and throughout production. Sanitation of equipment is also essential in preventing the introduction of pathogens to aquaculture facilities. Pesticides such as calcium hypochlorite were used to disinfect farmers' protective gear, including boots and other farm equipment.

The fish farmers surveyed in both regions reported that in order to control internal parasites, they predominantly used a parasiticide called mebendazole (Fig. 5 & 6). The other commonly used parasiticides in both regions were copper sulfate and trichlorfon but to a lesser degree compared to mebendazole, while azadirachtin was only used by the fish farmers in Arusha (Fig. 6).

In this study, no fish farmer in any region reported using internationally banned antimicrobials such as chloramphenicol, fluoroquinolones, nitrofurans, and quinolones classes of antibiotics. We also found that the choice of antibiotics used by most of the fish farmers was based on experience. Unfortunately, most of the fish farmers reported not following the dosage recommendation provided by the suppliers of the chemical agents.

Discussion

Aquaculture is essential because fish demand is increasing. Fish is a vital source of animal protein in the human diet. Commercial fish farming supplements capture fisheries. In Tanzania, fish farming plays a great role in food security and livelihood to many households. In Arusha and Morogoro regions, the most common holding structures for aquaculture production were found to be earthen ponds and concrete tanks. These culture methods have become more intensive for producing higher yields (Akinwole *et al.*, 2014) to meet the demand level for fish. The choice of culture facility could have been influenced by the cost of fish pond establishment and availability of space or awareness of available innovations.

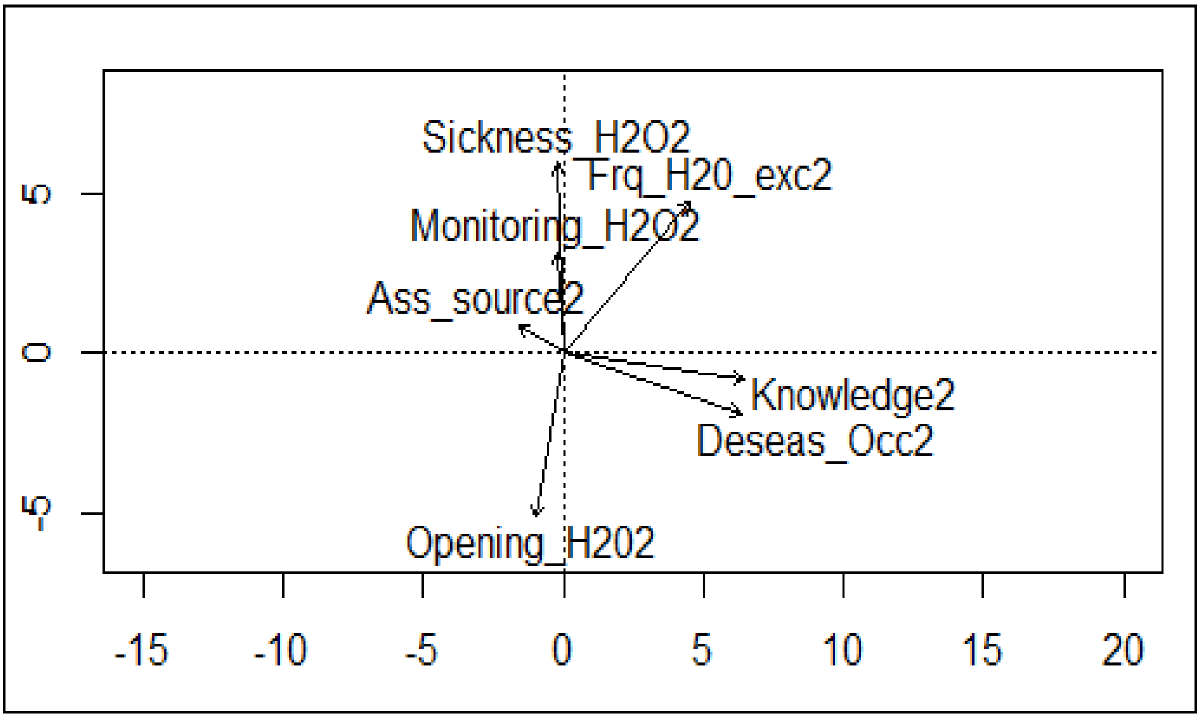

Fig. 4. Ordination diagram (redundancy analysis; RDA) showing the relationship between frequency of disease occurrence and independent variables that emanated insignificant effects ($p<0.05$) on the variance of the frequency of disease occurrence dataset. Disease_Occ2, frequency of disease occurrence; Opening_H_2O_2, Water treatment during pond opening; Knowledge2, Aquaculture knowledge; Frq_H_2O_2_exc2, Frequency of water exchange; Ass_Source2, Source of technical assistance, Sickness_H_2O_2, Fish sickness in relation to water management; Monitoring_H_2O_2, percentage of water change.

Fish farming in Tanzania is practiced by smallholder producers using various production systems. An intensive monoculture system—where only one fish species is raised—was the most predominant aquaculture method used by farmers in both regions. As previously noted by Adeogun *et al.* (2007) and Akinwole *et al.* (2014), this culture system enables the farmer to make the feed that will meet the requirement of a specific fish species. As other authors previously reported (Brummet *et al.*, 200), tilapia was the most cultured fish species in both zones, followed by catfish. Tilapia is a traditional and favorite dish in Africa. In Tanzania, for example, it is consumed as an affordable source of protein in poor rural communities as well as in affluent urban centres. Therefore, the markets for tilapia are diverse

(Norman-Lopez *et al.*, 2008) and tilapia product prices are increasingly becoming favorable for traders.

However, commercial fish farmers face many production challenges. One of the biggest constraints in aquaculture production in Tanzania is the high cost of nutritious commercial feed. Fish farmers require high-quality feeds to produce high-quality fish that would attract commensurate prices high enough to ameliorate whatever constraints they may face. In fact, fish feed and feeding are reportedly responsible for over 70% of operating costs in fish production (Edet *et al.*, 2018). This ultimately cuts into the farmers' profits. Our findings revealed that most of the fish farmers in the Arusha and Morogoro regions preferred to formulate their fish feed using locally available raw ingredients such as vegetable proteins and cereal grains to reduce feeding costs. Another related study previously reported that fish producers have to cope with high production costs associated with fish feeds (Gabriel *et al.*, 2007). Good fish feed should provide proper nutrition so that the fish can feed efficiently and grow to their full potential.

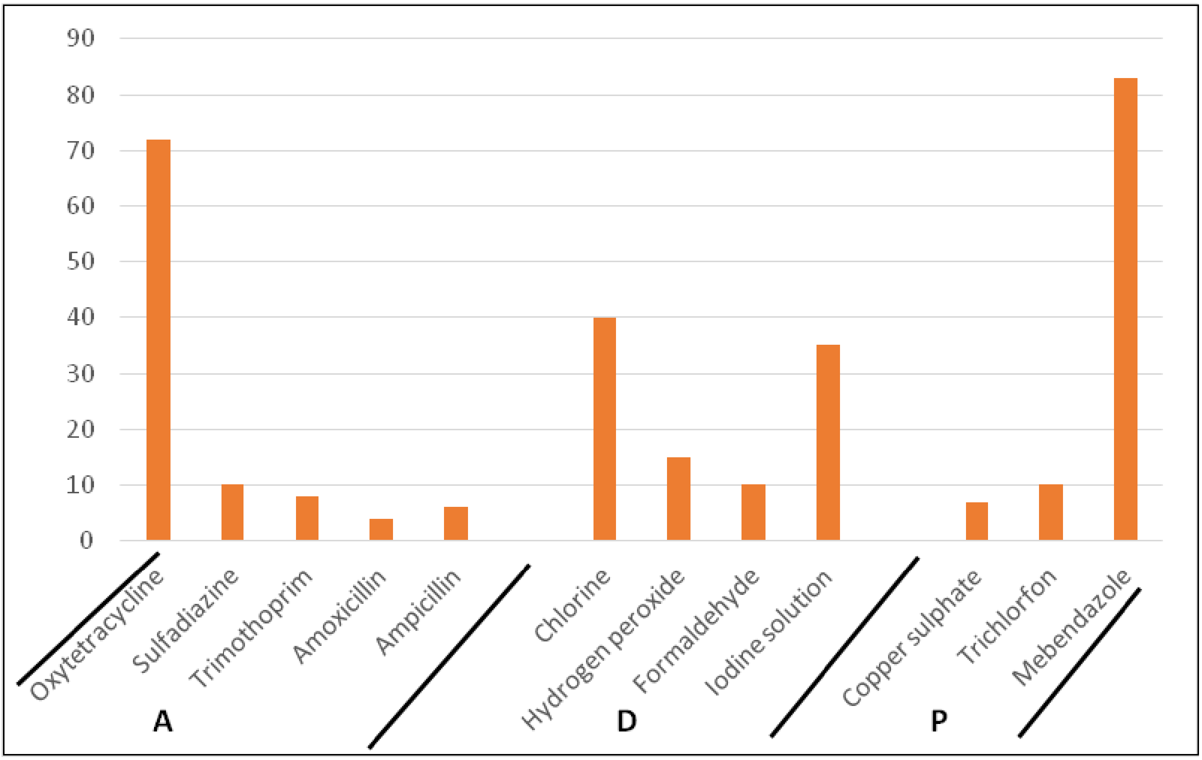

Fig. 5. Percentage of farmers using antibiotics (A), disinfectants (D) and parasiticides (P) in Morogoro region studied farm groups.

Despite the fact that the locally formulated fish feed can significantly reduce fish farming costs (Gabriel *et al.*, 2007), fish farmers must understand the nutritional requirements of their fish stock at every stage while developing the fish feed. Fish feed formulations and feed preparation require knowledge of the nutritional requirements for various fish species and skill in feed manufacturing. Nutrients essential to fish are similar to those required by most other animals. Fish nutrition, however, is an inexact science (Aizam *et al.*, 2018). Fish feed blends or formulas must deliver balanced nutrients and should consider fish age and specific nutritional requirements. Though the farmers we surveyed can prepare their fish feeds from locally available ingredients, the majority lacked the basic knowledge and technology for proper feed formulation for their tilapia and catfish stocks. Arguably, these farmers reported a high percentage of fish loss and low fish weight gain than expected. A fish feed with low nutritional values and poor texture can decrease fish appetite; poor feeding will, in turn, increase their susceptibility to diseases, morbidity, and mortality (Elfitasari and Albert, 2017). In this study, we observed that the farmers never analyzed the locally grown raw ingredients they used in making their fish feeds before use or the finished blends for nutrient content. It is concerning how little importance was placed on fish nutritional needs and diet. Pond feeding can also be done using manure (livestock waste), which is an ecologically appropriate method for raising fish. Manure in the ponds provides energy for the fish as well as nutrients and organic matter for autotrophic and heterotrophic production. Even though the use of manure in aquaculture reportedly reduces feed costs and enrich the ponds with additional food sources such as planktons (Kang'ombe *et al.*, 2006), this system requires fish farmers to adhere to good aquaculture practices to ensure the safety of the consumers, especially against pathogenic microorganisms (Kamaruddin *et al.*, 2015).

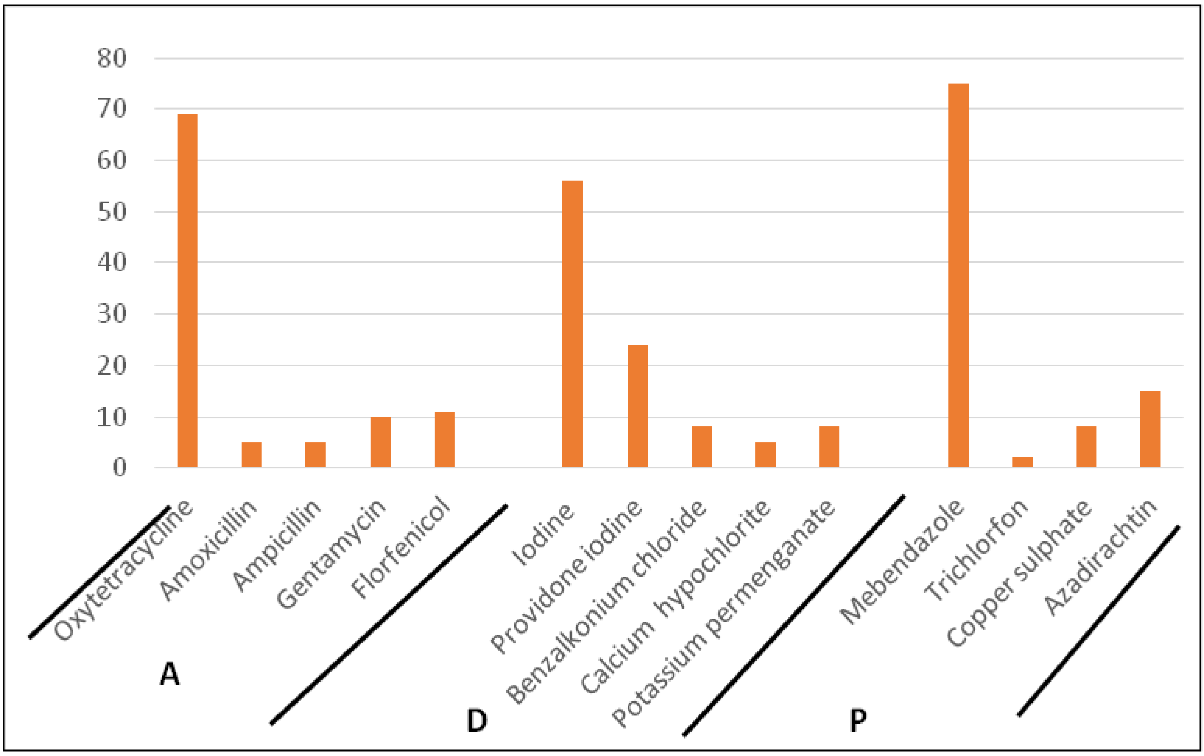

Fig. 6. Percentage of farmers using antibiotics (A), disinfectants (D) and parasiticides (P) in the Arusha region studied farm groups.

Related to that, fish farmers using manure should never use feed containing banned compounds considered harmful to humans. Similarly, farmers utilizing wastewater to rear fish must consider the potential risk of contaminants and other industrial chemical residues that might compromise the safety of the consumers (Uddin *et al.*, 2018; Ali *et al.*, 2016). Undoubtedly, fish grown under environmentally friendly practices and good aquaculture practices is a responsible way for farmers to avoid banned substances in their facilities. In this study, all the fish farmers surveyed reported not using any of the internationally banned compounds in their facilities.

Water quality plays an important role in the production of fish, especially in intensive aquaculture systems (Boyd 2017). In fact, suitable water quality parameters are a prerequisite for the healthy production of sufficient fish and fish food. The productivity of a water body depends on physical, chemical, and other intrinsic factors. In Arusha and Morogoro regions, boreholes and tap water are the two major sources of water used by fish farmers. Pond sizes the farmers use in both regions are depicted in Table 1. Pond water capacity depends on pond depth and size. Fluctuation in water depth would result from evaporation, rain and water seepage. Inadequate water depth is one of the most important factors for fish mortality (Baleta *et al.*, 2019). Lower water depth would not provide the fish with sufficient space for movement and feeding. In this study, the fish farmers in both regions reported water scarcity during the dry season and flooding during the rainy season. For those using boreholes, water scarcity resulted from low water levels often experienced during prolonged drought. Some farmers (15%) reported using rivers as their main source of water for their ponds. Actually, fish farmers in Arusha and Morogoro regions have effectively used water from rivers for fish cultures to improve their livelihood and income generation.

There are multiple challenges fish farmers in both regions face regardless of the water source. Two common issues were high water temperature and flooding. The farmers complained about high water temperature during dry, hot seasons or drought. Various strains of tilapia and catfish differ with respect to their tolerance to water temperature in terms of feeding, growth, and spawning. However, overall, the ideal water temperature for good health and growth should be between 20-30°C. It's been reported that when pond water warms up, the metabolic rates of tilapia and catfish also rise, leading to, in some cases, death (Qiang *et al.*, 2019).

Flooding during the rainy seasons was the other huge concern for the fish farmers. Flooding results in losses when pond structures are compromised and fish wash away. Flooding also increases fish susceptibility to diseases, infections, and contamination, potentially from the compounds from industrial and agricultural runoff (Reid *et al.*, 2019; Rutkayova *et al.*, 2018). Even though some fish farmers acknowledged that the integrity of their pond structures was a challenge during rainy seasons, we didn't find any statistical correlation between pond structure and disease occurrence. This could have been due to the fact that the data were collected during the dry season. In general, monitoring water quality parameters require technical knowledge and appropriate equipment. The majority of the farmers we surveyed did not apply proper management of water quality due to a lack of basic aquaculture management knowledge and technique. We observed that most of the fish farmers rely on visual checks to monitor the quality of their pond water. Over 70% of the farmers did not treat the water in their ponds before adding the fingerlings. The water of poor quality can cause diseases and infections, as other authors previously reported (Mishra *et al.*, 2018). We also found that the farmers discharged the wastewater from their ponds into the environment untreated. It's well understood that a load of pollutants in wastewater such as suspended solids, nitrates, phosphates, trace elements, and microorganisms can lead to pollution of natural water bodies (Amirkolaie, 2008; Cao *et al.*, 2007).

Good practice in the management of pond water is, therefore, necessary to avoid or reduce the negative impacts of aquaculture effluents on the environment. Proper wastewater management and practices by the fish farmers can help protect the future of our natural water resources. Overall, control of aquaculture health is critical for fish farmers to realize maximum productivity. In this regard, farmers must invest in disease diagnostic strategies to prevent outbreaks that often lead to significant stock losses. Unfortunately, we found that fish farmers had poor disease diagnostic capacity for preventing and controlling potential infectious diseases of their fish in an aquaculture environment. From our observations, a limited number of fish farmers had proper aquaculture training. The majority had poor record-keeping practices and lacked health management plans. Aquaculture disease diagnoses require special knowledge and technique, without which proper diagnosis can be complicated and challenging for the uneducated. In this respect, good farm management, proper disease diagnosis, and prevention based on globally accepted principles are some applicable strategies for ensuring sustainable aquaculture, which we can recommend for fish farmers locally. It is therefore important for the farmers to train and qualify for global Good Aquaculture Practices (GAP) certification as per the global GAP aquaculture standard of 2013. None of the fish farmers we surveyed had this important certification. No wonder many fish farms in developing countries with poor farm management methods and untrained personnel experience a high occurrence of disease outbreaks (Opiyo *et al.*, 2018).

In aquaculture, disease infections come in many forms and can occur at any stage of growth, but the highest mortalities are in fingerlings. The most important bacterial infection is bacillary necrosis of *Pangasius* (BNP), followed by motile aeromonad septicaemia (MAS) (Phu *et al.*, 2016). Both diseases are common during the beginning of wet rainy seasons. In this study, very few farmers reported cases of disease outbreaks in general.

Antibacterial drugs added to feeds are the most common treatment for BNP and MAS. However, there were some farmers who preferred dissolving the antimicrobial powder into a solution before adding it into the pond water. Oxytetracycline was the most commonly used antibacterial drug by fish farmers surveyed in both regions. Farmers need to have proper knowledge of antimicrobial drug use because abuse and misuse can cause widespread resistance to several commonly used drugs (Chuah *et al.*, 2016; Ye *et al.*, 2013; Romero *et al.*, 2012). Studies have shown antibiotic resistance by some pathogenic bacteria to streptomycin, chloramphenicol, and enrofloxacin (Liu *et al.*, 2017).

External parasitic infections predispose fish to bacterial infections (Huston and Cain, 2018), leading to reduced growth and thus poor weight gain. Protozoan parasites are especially problematic and can be severe during the wet rainy seasons. The most common parasiticides used by fish farmers to treat their ponds were mebendazole, copper sulfate and trichlorfon added to the water. Based on our survey, we observed that many fish farmers lacked the technical training required to diagnose aquatic diseases and make informed treatment choices in case of an outbreak. Most of them relied on past experiences. It's therefore easy to see how drugs and chemicals can be misused. A pond that has high-quality clean water is important in producing healthy fish. Disinfectants can be used throughout the production cycle to improve the quality of the water and disinfect the farm, as well as personal protective equipment (PPE). In this study, we found that fish farmers used various chemical agents for disinfection, primarily on PPEs and treating pond water. Chlorine and iodine solutions were the most commonly used disinfectants in Morogoro and Arusha, respectively. Chlorine, when used, must be neutralized to avoid the killing of fish. Additionally, organic matter in water can react with chlorine and calcium hypochlorite leading to unintended toxicity (Macedo *et al.*, 2019). Iodine and iodine-containing compounds reported by the farmers in both regions can be toxic and must be adequately rinsed off when used to disinfect PPEs (Postigo and Bozo, 2019). Sadly, none of the farmers surveyed was aware of the food safety hazards and environmental threats associated with the use of these chemical agents.

Conclusion

This study revealed that in both regions, tilapia and catfish are the main fish species raised in an intensive monoculture system either in concrete or earthen ponds utilizing borehole or tap water resources. However, a significant setback for farmers to achieve sustainable development of fish farming is the lack of relevant aquaculture training and/or awareness of available innovations on fish farming. Therefore, based on this study, fish farming management is still underdeveloped considering their poor water quality management approaches, untreated wastewater discharge into the environment, lack of accurate disease diagnostic methods, limited knowledge on feed formulation, preparation, and quality, and very importantly, limited understanding of the drugs and chemical agents used for prevention and control of diseases. As aquaculture matures in Tanzania, efforts should be placed on adherence to sustainable production practices. Based on this study, we believe it must begin with the proper maintenance of overall fish health. The first step will be to conduct a comprehensive evaluation of the nutritional content of the locally formulated fish feed in conjunction with the more responsible use of antibacterial drugs and a commitment to protecting the environment and natural water resources. We also encourage the government and other industry stakeholders to provide farmers with training on and access to aquatic disease diagnostic services. Finally, to ensure improvements of aquaculture management measures, we strongly suggest farmers consider training on good aquaculture practices for the overall health protection of fish and the consumers. More research is required to assess certain safety parameters such as pathogens, heavy metals, and drug residues on the farmed fish.

Acknowledgements

The authors are grateful to World Bank through Africa Centre for Research, Agricultural Advancement, Teaching Excellence and Sustainability (CREATES) for financial support.

Compliance with ethical standards

Conflict of interest: All authors declare that they have no conflict of interest.

Ethical approval

This article does not contain any studies with animals performed by any of the authors.

References

Adeogun OA, Ogunbadejo HK, Ayinla OA, Oresegun A, Oguntade OR, Tanko A, Williams SB. 2007. Urban aquaculture: Producer perceptions and practices in Lagos State, Nigeria. Middle-East Journal of Scientific Research **2,** 21-7.

Adorable-Asis AG, Cauyan GA, Pagulayan RC, Magbanua FS, Papa RD. 2016. The macro-gastropod communities of aquaculture-intensive lakes in the Philippines. Molluscan Research **36,** 223-30.
https://doi.org/10.1080/13235818.2016.1201016

Aizam NA, Ibrahim RA, Lung RL, Ling PY, Mubarak A. 2018.Mathematical modelling for fish feed formulation of mystus nemurus sp. catfish: Optimizing growth and nutrients requirements. Jurnal Teknologi **80**.

Ali H, Rico A, Murshed-e-Jahan K, Belton B. 2016. An assessment of chemical and biological product use in aquaculture in Bangladesh. Aquaculture **454,** 199-209.
https://doi.org/10.1016/j.aquaculture.2015.12.025

Amirkolaie AK. 2008. Environmental impact of nutrient discharged by aquaculture waste water on the Haraz River. Journal of Fisheries and Aquatic Sciences **3,** 275-9.

Baleta FN, Bolaños JM, Medrano WC. 2019. Assessment of Tilapia Cage Farming Practices in Relation to the Occurrence of Fish Mortalities along the Fish Cage Belt at Magat Reservoir, Philippines. Journal of Fisheries and Environment **43,** 1-3.

Béné C, Arthur R, Norbury H, Allison EH, Beveridge M, Bush S, Campling L, Leschen W, Little D, Squires D, Thilsted SH. 2016. Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Development **79,** 177-96.
https://doi.org/10.1016/j.worlddev.2015.11.007

Bhuyain MA, Hossain MI, Haque MA, Jewel MA, Hasan J, Akter S. 2019. Determination of the proximate composition of available fish feed ingredients in Bangladesh. Asian Journal of Agriculture Research **13,** 13-9.

Boyd CE. 2017. General relationship between water quality and aquaculture performance in ponds. Fish diseases **147**, 166.

Brummett RE, Williams MJ. 2000. The evolution of aquaculture in African rural and economic development. Ecological Economics **33**, 193-203.
https://doi.org/10.1016/S0921-8009(99)00142-1

Brummett RE, Lazard J, Moehl J. 2008. African aquaculture: Realizing the potential. Food policy **33,** 371-85.
https://doi.org/10.1016/j.foodpol.2008.01.005

Cao L, Wang W, Yang Y, Yang C, Yuan Z, Xiong S, Diana J. 2007. Environmental impact of aquaculture and countermeasures to aquaculture pollution in China. Environmental Science and Pollution Research-International **14,** 452-62. https://doi.org/10.1065/espr2007.05.426

Chuah LO, Effarizah ME, Goni AM, Rusul G. 2016. Antibiotic application and emergence of multiple antibiotic resistance (MAR) in global catfish aquaculture. Current environmental health reports **3,** 118-27. https://doi.org/10.1007/s40572-016-0091-2

Edet EO, Udoe PO, Uwah ED. 2018. Costs and return analysis of fish farming in Calabar metropolis, Cross River State Nigeria. Global Journal of Agricultural Sciences **17,** 23-31. https://doi.org/10.4314/gjass.v17i1.3

Elfitasari T, Albert A. 2017. Challenges encountered by small scale fish farmers in assuring fish product sustainability. Omni-Akuatika **13.** http://dx.doi.org/10.20884/1.oa.2017.13.2.256

Gabriel UU, Akinrotimi OA, Bekibele DO, Onunkwo DN, Anyanwu PE. 2007. Locally produced fish feed: potentials for aquaculture development in subsaharan Africa. African Journal of Agricultural Research **2,** 287-95. https://doi.org/10.5897/AJAR.9000470

Hutson SK, Cain KD. 2018. Pathogens and Parasites. Aquaculture: Farming Aquatic Animals and Plants **217**.

Kamaruddin R, Baharuddin AH. 2015. The importance of good aquaculture practices in improving fish farmer's income: A case of Malaysia. International Journal of Social Economics. https://doi.org/ 10.1108/IJSE-02-2014-0028

Mosha SS, Kang'ombe J, Jere W, Madalla N. 2016. Effect of organic and inorganic fertilizers on natural food composition and performance of African catfish (Clarias gariepinus) fry produced under artificial propagation. Journal of Aquaculture Research Development **7,** 1-7. https://doi.org/10.1111/j.1365-2109.2006.01569.x

Liu X, Steele JC, Meng XZ. 2017. Usage, residue, and human health risk of antibiotics in Chinese aquaculture: a review. Environmental Pollution **223,** 161-9. https://doi.org/10.1016/j.envpol.2017.01.003

Macêdo LP, Dornelas AS, Vieira MM, de Jesus Ferreira JS, Sarmento RA, Cavallini GS. 2019. Comparative ecotoxicological evaluation of peracetic acid and the active chlorine of calcium hypochlorite: use of Dugesia tigrina as a bioindicator of environmental pollution. Chemosphere **233,** 273-81. https://doi.org/10.1016/j.chemosphere.2019.05.286

Mishra SS, Swain P, Das R. 2018. Diseases in Freshwater Aquaculture and their Management. Mass Breeding and Culture Technique of Catfishes **141**.

Naylor RL, Goldburg RJ, Primavera JH, Kautsky N, Beveridge MC, Clay J, Folke C, Lubchenco J, Mooney H, Troell M. 2000. Effect of aquaculture on world fish supplies. Nature **405,** 1017-24. https://doi.org/10.1038/35016500

Norman-Lopez A, Asche F. 2008. Competition between imported tilapia and US catfish in the US market. Marine Resource Economics **23**, 199-214. https://doi.org/10.1086/mre.23.2.42629611

Opiyo MA, Marijani E, Muendo P, Odede R, Leschen W, Charo-Karisa H. 2018. A review of aquaculture production and health management practices of farmed fish in Kenya. International journal of veterinary science and medicine **6,** 141-8. https://doi.org/10.1016/j.ijvsm.2018.07.001

Petersen A, Andersen JS, Kaewmak T, Somsiri T, Dalsgaard A. 2002. Impact of integrated fish farming on antimicrobial resistance in a pond environment. Applied and Environmental Microbiology **68,** 6036-42. https://doi.org/10.1128/AEM.68.12.6036-6042.2002

Phu TM, Phuong NT, Dung TT, Hai DM, Son VN, Rico A, Clausen JH, Madsen H, Murray F, Dalsgaard A. 2016.An evaluation of fish health-management practices and occupational health hazards associated with P angasius catfish (P angasianodon hypophthalmus) aquaculture in the M ekong D elta, V ietnam. Aquaculture Research **47,** 2778-94. https://doi.org/10.1111/are.12728

Postigo C, Zonja B. 2019.Iodinated disinfection byproducts: Formation and concerns. Current Opinion in Environmental Science & Health **7,** 19-25. https://doi.org/10.1016/j.coesh.2018.08.006

Qiang J, Zhong CY, Bao JW, Liang M, Liang C, Li HX, He J, Xu P. 2019.The effects of temperature and dissolved oxygen on the growth, survival and oxidative capacity of newly hatched hybrid yellow catfish larvae (Tachysurus fulvidraco♀× Pseudobagrus vachellii♂). Journal of thermal biology **86,** 102436. https://doi.org/10.1016/j.jtherbio.2019.102436

Reid GK, Gurney-Smith HJ, Marcogliese DJ, Knowler D, Benfey T, Garber AF, Forster I, Chopin T, Brewer-Dalton K, Moccia RD, Flaherty M. 2019. Climate change and aquaculture: considering biological response and resources.Aquaculture Environment Interactions **11,** 569-602. https://doi.org/10.3354/aei00332

Romero J, Feijoó CG, Navarrete P. 2012. Antibiotics in aquaculture–use, abuse and alternatives. Health and environment in aquaculture **159**.

Rutkayová J, Vácha F, Maršálek M, Beneš K, Civišová H, Horká P, Petrášková E, Rost M, Šulista M. 2018. Fish stock losses due to extreme floods–findings from pond-based aquaculture in the Czech Republic. Journal of Flood Risk Management **11,** 351-9. https://doi.org/10.1111/jfr3.12332

Thilsted SH, Thorne-Lyman A, Webb P, Bogard JR, Subasinghe R, Phillips MJ, Allison EH. 2016. Sustaining healthy diets: The role of capture fisheries and aquaculture for improving nutrition in the post-2015 era. Food Policy **61**,126-31. https://doi.org/10.1016/j.foodpol.2016.02.005

Uddin S, Sarker SC, Mondal DK. 2018. Health risk from contaminated aquaculture fish. International Journal of Natural and Social Sciences **5,** 01-16.

Ye L, Zhang L, Li X, Shi L, Huang Y, Wang HH. 2013. Antibiotic-resistant bacteria associated with retail aquaculture products from Guangzhou, China. Journal of food protection **76,** 295-301. https://doi.org/10.4315/0362-028X.JFP-12-288