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Research Article

Knowledge and Perception of Antimicrobial Resistance in Aquaculture in the Nairobi River Basin, Kenya

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ABSTRACT

Increased food demand in low and middle-income countries (LMICs) has led to the intensification of production, underpinning environmental and health hazards such as increased water needs or misuse of antimicrobials. Epidemics of diseases still emerge often, necessitating the routine administration of antimicrobials to curb their spread. Sub-therapeutic concentrations of these medications persist in water and sediments for extended periods, creating favourable circumstances for developing and selecting resistant microorganisms and stimulating horizontal gene transfer. This study aimed to understand the knowledge and perception of fish farmers towards antimicrobial resistance (AMR) to further responsible usage of antimicrobials and promote antimicrobial stewardship programs. A study involving 34 farmers was undertaken using structured questionnaire interviews and face-to-face workshops to determine the Source, Exposure pathway and Main receptors (S-P-R) of antimicrobials along the Nairobi River basin. Most respondents (59%; n=20) were familiar with "antimicrobial resistance." However, in the last five years, fish diseases and infections on the farm were recognized as a concern, although not a major one (50%; n=17). This is supported by the fact that the majority of respondents (65%; n=22) reported having no specific training in fish health management. Untreated or partially treated wastewater and solid waste disposal/scavenging are the major hotspots for human exposure to AMR. The results of this study provide a baseline understanding of potential risk factors for AMR in aquaculture and can be used in the formulation of appropriate risk-management measures to prevent AMR in cultures fish.

Keywords: *Antimicrobial resistance, aquaculture, farming, Nairobi River Basin.*

Kenya'daki Nairobi Nehri Havzası'nda Su Ürünleri Yetiştiriciliğinde Antimikrobiyal Direnç Hakkında Bilgi ve Algı

ÖZET

Düşük ve orta gelirli ülkelerde (LMICs) artan gıda talebi, üretimin yoğunlaşmasına yol açarak artan su ihtiyacı veya antimikrobiyallerin yanlış kullanımı gibi çevresel ve sağlık riskleri gibi sorunları beraberinde getirmiştir. Hastalık salgınları hala sıkça ortaya çıkmakta, bu durum da antimikrobiyallerin rutin olarak kullanılmasını ve yayılmalarının önlenmesine engel olmaktadır. Bu ilaçların su ve sedimentlerde uzun süreler boyunca sub-terapötik konsantrasyonlarda kalması, dirençli mikroorganizmaların gelişimini ve seçilimini teşvik eden ve gen transferini tetikleyen uygun koşullar oluşturmaktadır. Bu çalışma, balık çiftlikçilerinin antimikrobiyal direnç (AMR) konusundaki bilgi ve algılarını anlamayı ve antimikrobiyallerin bilinçli kullanımını teşvik etmeyi amaçlamaktadır. Nairobi Nehri havzası boyunca antimikrobiyallerin Kaynak, Maruziyet yolu ve Ana alıcılar (S-P-R)ını belirlemek için 34 çiftçi ile planlanmış anket görüşmeleri ve yüz yüze atölye çalışmaları kullanılarak çalışma yürütülmüştür. Katılımcıların çoğu (%59; n=20) "antimikrobiyal direnç" terimi ile tanıdık olmakla birlikte, son beş yılda çiftliklerdeki balık hastalıkları ve enfeksiyonları önemli bir sorun olarak görmemektedir (%50; n=17). Bu durum, katılımcıların çoğunun (%65; n=22) özgül balık sağlığı yönetimi eğitimi almamış olması gerçeği ile desteklenmektedir. Arıtılmamış veya kısmen arıtılmış atık sular ve katı atık bertarafı/taraması, insanların AMR'ye maruz kalmasının başlıca kaynaklarıdır. Bu çalışmanın sonuçları, akuakültürde AMR'yi önlemek için uygun risk yönetimi önlemlerinin formülasyonunda kullanılabilecek akuakültürdeki AMR için potansiyel risk faktörlerine dair temel bir anlayış sağlamaktadır.

Anahtar kelimeler: *Antimikrobiyal direnç, çiftçilik, Nairobi Nehri Havzası, su ürünleri yetiştiriciliği.*

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Introduction

Global fish production is experiencing rapid growth and increased from 21.8 to 156.4 million tonnes between 1960 and 2018 (Little et al., 2016; FAO, 2020). Due to declining capture fisheries, aquaculture accounts for the majority (52%) of aquatic food production, with expansion expected through 2030 (FAO, 2022). The increasing demand for animal protein has led to a transition from extensive to intensive farming, which in terrestrial food animal sectors has historically been accompanied by the increasing use of antimicrobials (Van Boeckel et al., 2015; 2017). The terrestrial and aquatic food production industries have emerged as the largest consumers by volume (73.7% and 5.7%, respectively) of antimicrobials globally (Laxminarayan et al., 2013; Schar et al., 2020).

Antimicrobial resistance (AMR) has been described as one of the global serious public health threats especially for developing countries (Dadgostar, 2019). Antimicrobial resistance occurs when microorganisms such as bacteria, viruses, fungi, and parasites adapt and grow in the presence of an antimicrobial drug at a concentration that typically kills or inhibits their growth (Founou et al., 2017). This occurs due to natural processes and widespread anthropogenic activity or through mutation or, more likely, horizontal gene transfer (HGT) in the environment via natural transformation, transduction, or conjugation (Watts et al., 2017; Sun et al., 2020). The rise in intensification of aquaculture and farming in small areas has led to increased disease occurrence and a rise in the use of antimicrobials to treat diseases and also as growth promoters (Watts et al., 2017; Limbu et al., 2018). Though there is a national policy on prevention and containment of antimicrobial resistance using the one health approach in Kenya, specific regulations when it comes to the use of antimicrobials in aquaculture do not exist, and there is a reliance on the Animal Disease Act CAP 364 of 2012, which provides guidelines on the treatment of animals.

Most aquaculture and livestock production in the city occurs in small spaces along the riparian land of the Nairobi River (CoG, 2021), mainly in the informal settlements of Mukuru kwa Ruben, Mathare, Kawangware, Kayole, and Ruai (Madara et al., 2022). Farming in these places is unregulated and is characterized by the use of antimicrobials, which are purchased over the counter without any prescription and administered to the animals without the supervision of a veterinarian increasing the risk of antimicrobial resistance (Muloi et al., 2019).

Source, exposure pathway, and main receptors (S-P-R) mapping of antimicrobials in the Nairobi river basin is vital in indicating the possible hotspots of antimicrobial resistance and the various linkages with the food web and the environment, thus enabling the identification of targeted areas to address the challenges associated with antimicrobial resistance. It is therefore important to have an understanding of the knowledge and perception of the fish farmers towards antimicrobial resistance for successful antimicrobial stewardship programs. This study was carried out to assess the level of awareness, attitudes, usage of antimicrobials, and behaviours related to antimicrobial resistance among farmer communities in the Nairobi River basin.

Materials and Methods

Ethical Statement

The study was conducted following the standard operating procedures (SOPs) of the Kenya Marine and Fisheries Research Institute (KMFRI) guidelines for research registered with the National Commission for Science, Technology, and Innovation (NACOSTI) registration number NACOSTI/2016/05/001. The SOPs comply with the Prevention of Cruelty to Animals Act 1962, CAP 360 (Revised 2012) of the laws of Kenya, and the EU regulation (EC Directive 86/609/EEC). Informed consent for this study was obtained from all individual participants included in the study. The study did not involve animals as subjects; hence, ethical committee approval was not required.

Study Area

The study was carried out in Nairobi County at 1.2921° S, 36.8219° E. The target population was fish farmers along the Nairobi River basin in Nairobi County. The locations of the surveyed farms are shown in Figure 1.

Instrument and Procedure

A questionnaire was developed into four sections. The sections were: preliminary information describing the location of the farm; socio-demographics; farm profile, including the species of farmed fish; experience in farming; culture systems; management practices and antimicrobial use; feeds and feeding and the additives used in the feed, including the antimicrobials; risk for diseases and biosecurity measures in the farm; and awareness of antimicrobial resistance in aquaculture. Respondents were required to provide only simple responses (e.g., yes or no) or to select from a list of options. A pilot study was conducted on ten farmers who attended the workshop to improve the comprehension and consistency of the items in the questionnaire.

Questionnaire Administration

The contacts and locations of the farms were obtained from the County Director of Fisheries Office in Nairobi County. The farmers were visited for self-administration of the questionnaire using a mobile application tool (Kobo Collect), which was also used to take the GPS position of the farm. The questionnaire was administered to fish farmers along the Nairobi River basin in Nairobi County between July and August 2021. The study involved 34 fish farmers who were located in the Riverine sub-counties in the Nairobi river basin. Data were submitted to a central database and collated for analysis.

Workshop to Map Aquaculture Systems

A workshop was held with seasoned aquaculture and

AMR experts. The workshop had four aims: 1) to develop systems thinking and experience in mapping systems; 2) to build collaborations and understanding of different expertise; 3) to create maps of the aquaculture sector and the drivers of AMR; 4) to identify the most likely routes of exposure to AMR for humans. The workshop had a combination of presentations, focus group discussions, and plenary discussions.

Statistical Analysis

Data analysis was done using Stata (Version 14.0) statistical software. Data analysis entailed descriptive analysis presented in tables and graphs. We followed a pathway analysis to develop the source, exposure pathway, and main receptors (S-P-R) map.

Results

A total of 34 participants were surveyed (Table 1). The majority were male (79%, n=27) between the ages of 40 and 49. More than 35% of the farmers' level of education was below secondary school level. The commonly used culture system was liner ponds, while other culture systems reported to be common were tanks and aquaponics.

The farms sampled were conducting integrated farming (57.58%), whereby both animal and crop production were connected, as indicated in Figure 2. Animal manure from livestock was being used in crop production and pond fertilization. The pond water was also used to water crops on the farms.

In these integrated systems, chicken dominated other poultry being kept by farmers along the Nairobi River basin (Figure 3).

The majority of the farmers, 66%, did not use any additives in the feeds, and more than 80% of respondents agreed to procure fish feeds from commercial companies rather than on-farm formulated feeds (Table 2). The minority who mixed additives into the feeds, such as vitamins, antibiotics, and probiotics, may reflect farm-lev-

Table 1. Socio-demographic characteristics of fish farmers in NairXobi County

Variable	Indicator	Frequency
Age (Years)	18-29	3(9)
	30-39	7(21)
	40-49	13(38)
	50-59	6(18)
	60 – 69	3(9)
	70 +	2(5)
Gender	Female	7(21)
	Male	27(79)
Education Level	Postgraduate	3(9)
	Diploma	5(15)
	Certificate	8(24)
	Secondary	9(26)
	Primary	3(9)
Responsibility Role	Farm manager	9(26)
	Farm manager & Farm owner	9(26)
	Farm owner	9(26)
	Farm worker	7(22)
Culture system	Earthen ponds	5(15)
	Earthen ponds & Liner ponds	1(3)
	Earthen ponds & Tanks	1(3)
	Liner ponds	14(41)
	Liner ponds & Tanks	2(6)
	Other	1(3)
	Tanks	9(26)
	Tanks & Other	1(3)

* Values in brackets indicate percentages

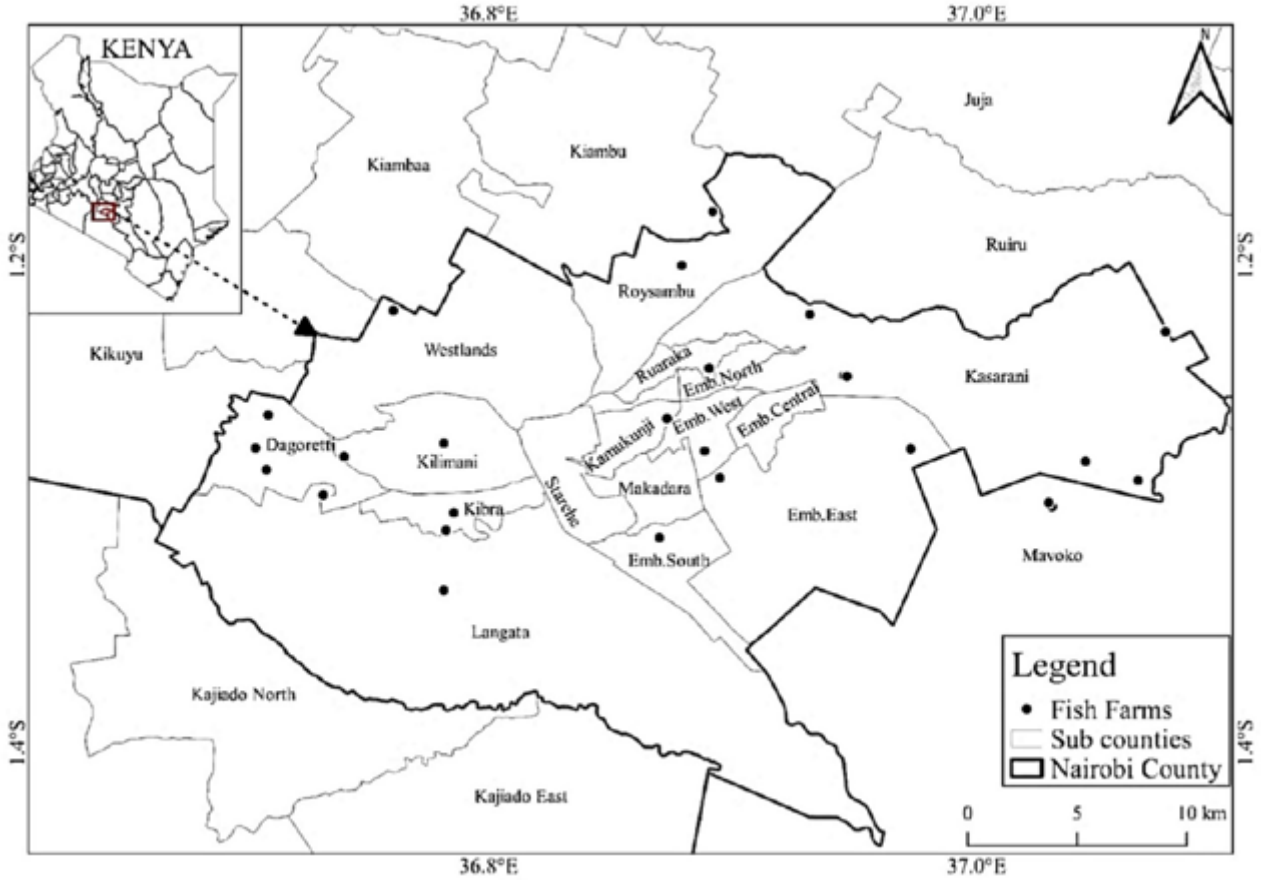

Figure 1. Map of Nairobi County showing the surveyed aquaculture farms

el formulated feeds since the commercial feeds did not indicate the additives in the labels as indicated during the workshop.

Most of the fish farmers did not report mortality of the fish in the last 12 months (56%). The mortality observed was linked to the lack of knowledge of husbandry practices (Table 3).

The respondents' awareness and lack of awareness of antimicrobial resistance were split at 59% and 41%, respectively (Table 4). This is also related to the level of education, whereby about 35% of the respondents had secondary education and below, while the rest had post-secondary education, of which only 35% had received training in fish health management.

More than half of the respondents (59%; n=20) were aware of the term "antimicrobial resistance." In contrast, fewer than half (41%; n=14) were aware of the use of probiotics. These findings are validated by the fact that most respondents reported that they had no specific training in fish health management (65%; n=22) (Table 4). Fish disease and infections on the farm in the last five years were reported as a problem but not major (50%; n=17).

Source, Exposure pathway and Main receptors (S-P-R) of Antimicrobials

The SPR model, informed by the workshop and the survey, shown in Figure 4, is supported by a summary of current evidence on the SPR of AMR in aquaculture. Mapping the SRP of antimicrobials identifies practices and operations that warrant prioritization by future surveillance efforts for antimicrobial resistance. The potential routes of exposure were occupational (different handling points of antimicrobials), food consumption, water contaminated with antimicrobial residues and bacteria, and the environment where the antimicrobials are disposed of. Due to the interconnection of the production systems, the cultured animals (fish and livestock) and the cultivated crops become the receptors of the antimicrobials in the environment.

The potential interventions to reduce antimicrobial resistance identified during the workshop are presented in Table 5 with the responsible stakeholders and actors in the respective areas. The intervention ranges from the farm level to the market level and the consumers of the farmed products. Implementation of best management practices at the farm level and leadership from the government and the industry are required.

Discussion

Antimicrobial resistance is one of the global challenges, and awareness about it is important among Kenyans. The use of antimicrobials must be accepted as a responsibility rather than a right for improved fish health to minimize the potential risk of poor antimicrobial usage in animal production. The results of this study show a low level of women participating in aquaculture activities. This is in

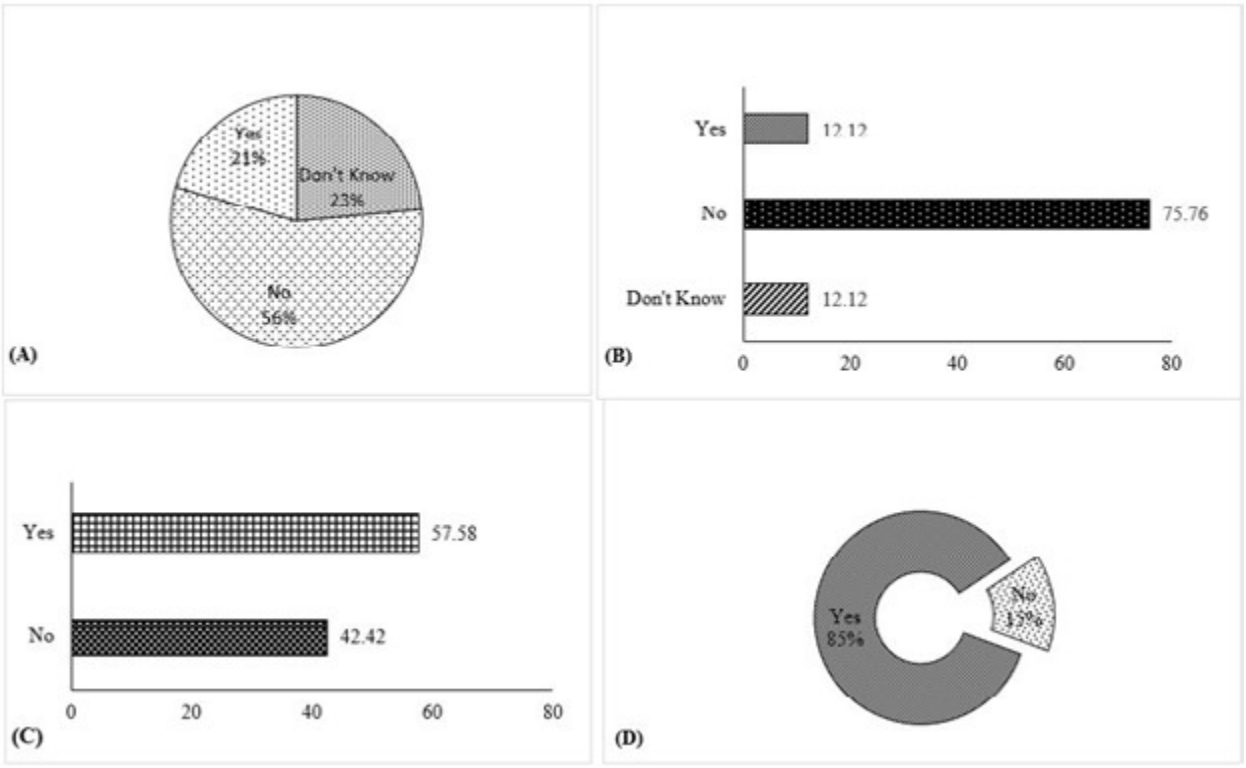

Figure 2. (A) Connection of farm water source with Nairobi River, (B) Sharing of water with nearest farms, (C) Integration with crops, and (D) Presence of livestock in farm site

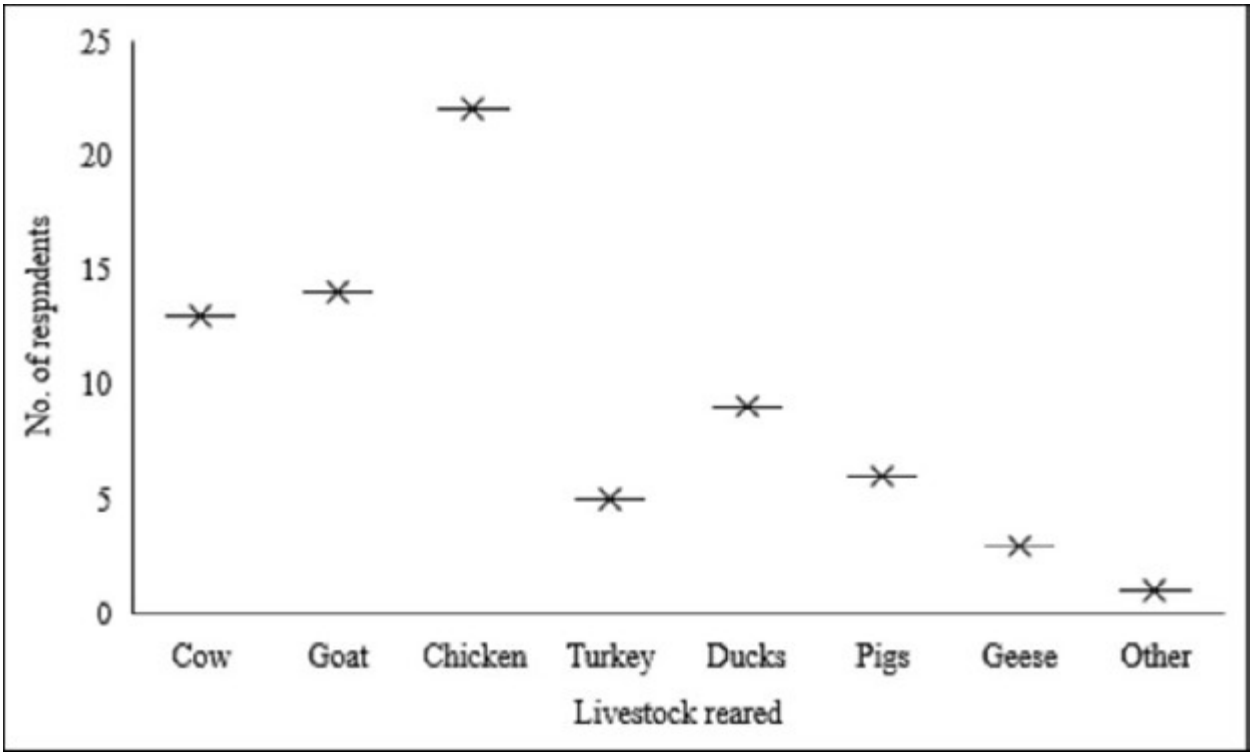

Figure 3. Livestock reared in surveyed farms in Nairobi County, Kenya

line with previous studies, which reported less engagement among women in aquaculture activities (Abwao & Fonda, 2019). Aquaculture is labour-intensive in pond construction; thus, more men are involved, while women sometimes participate in feeding and post-harvest fish processing (Kipkemboi et al., 2007; Awuor, 2021). The most commonly used culture systems were liner ponds, followed by aquaponics. The dominance of liner ponds could be attributed to the soil type. At the same time, other culture units, such as tanks, are suitable in areas with limited land, such as urban and peri-urban areas, which was the case in the Nairobi river basin. The

Table 2. Fish feeds source, feeding and feed additives in surveyed farms in Nairobi County, Kenya

Variable	Indicator	%
Additives to feed in the last production cycle	Antibiotics	16
	Nothing	66
	Other	6
	Probiotics	3
	Vitamins	9
Ever fed your fish on chicken feed/ dairy meal	No	61
	Yes	39
Farm's main source of fish feeds	Commercial animal feeds	3
	Commercial fish feeds	80
	Own formulation	17

Table 3. Fish mortality, related signs and treatment of surveyed farms in Nairobi County, Kenya

Variable	Indicator	Frequency
Fish mortalities in the last 12 months	No	19(56)
	Yes	15(44)
No. of dead fish per pond (300m^2)	0-100	12(80)
	201-300	2(13)
	1001-1500	1(7)
Presence Clinical signs before fish mortality	Don't Know	3(20)
	No	5(33)
	Yes	7(47)
Actual signs identified	Bloated belly, Feacal dragging	1(14)
	Eroded fins	1(14)
	Gaping gills	1(14)
	White spots & cloudy eyes	1(14)
	Yellow fluid from vent	1(14)
	Red spots, Bloated belly	2(30)
Attempt to treat fish	Don't Know	2(6)
	No	27(79)
	Yes	5(15)
Treatment/chemical Used	Antibiotic	2(40)
	Potassium permanganate	1(20)
	Salt	1(20)
	Smash over-ripe avocado and fish feed	1(20)
Mode of administration/Treatment	In Feed	2(40)
	In water	2(40)
	Other	1(20)

* Values in brackets indicate percentages

Table 4. Disease infections in farms, training in fish health management, awareness of AMR and probiotics in surveyed farms in Nairobi, Kenya

Variable	Indicator	Frequency
Fish disease/infections in the farm in the last 5 years	A major problem	6(18)
	A problem but not major	17(50)
	Don't Know	4(12)
	Not a problem	7(20)
Specific training in fish diseases/fish health management	No	22(65)
	Yes	12(35)
Awareness of AMR	No	14(41)
	Yes	20(59)
Awareness of Probiotics	No	20(59)
	Yes	14(41)

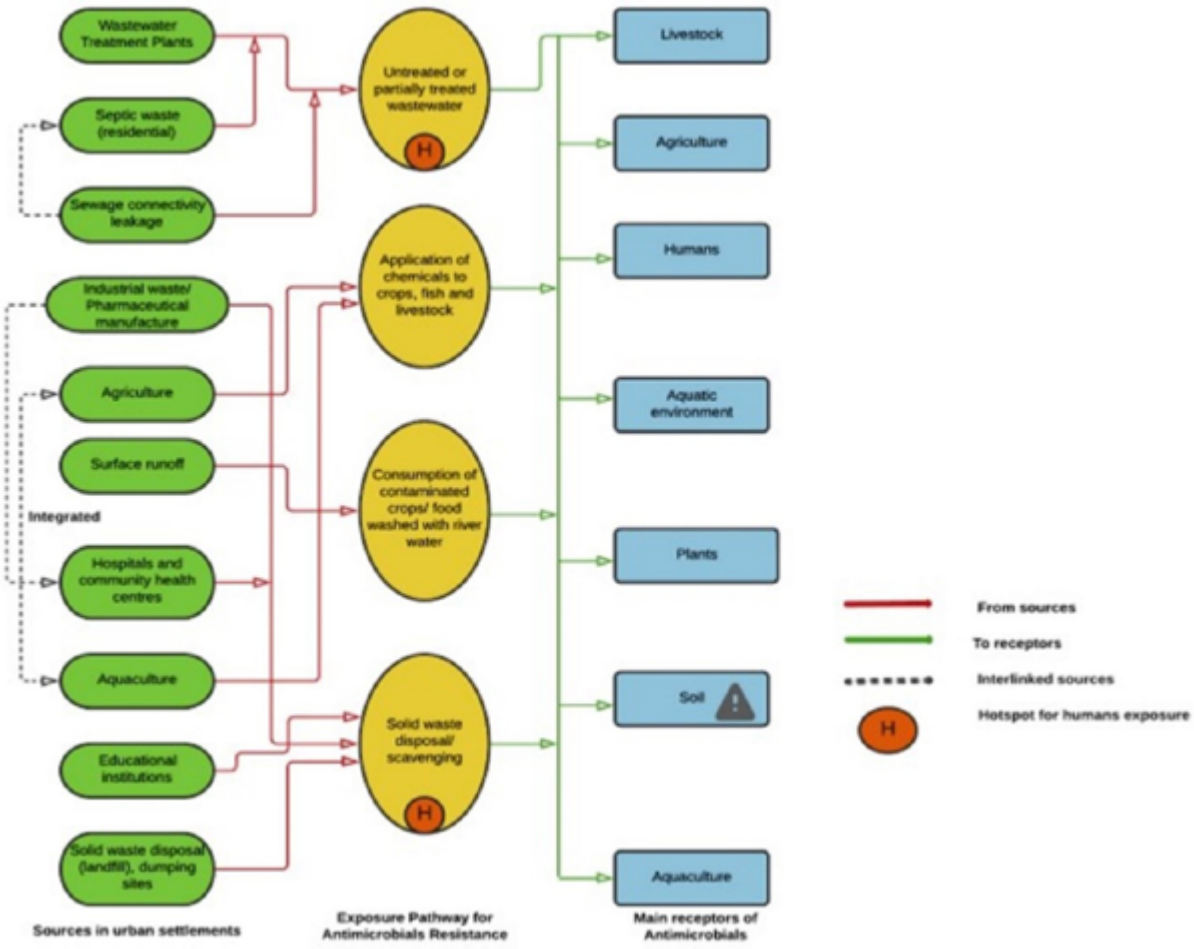

Figure 4. A schematic diagram showing the source, exposure pathway and main receptors (S-P-R) of antimicrobials

use of aquaponics, which are integrated systems used in vertical gardening while farming in small spaces, was also common in the study area. Aquaponics are known to maximize space, water utilization and efficiency, especially in water-deficit areas (Ani et al., 2022).

Integrated aquaculture provides a proven method to increase production efficiency. It also involved the use of crops, grass, and manure as feed and fertilizer, all in a complex, mutually beneficial system (Kaleem & Sabi, 2021; Awuor et al., 2023). The design allows waste from one system to be used as input in another system, conserving resources and boosting returns (Shoko et al., 2019). For instance, chicken droppings or cow manure

Table 5. Potential interventions to reduce antimicrobial resistance

Intervention	Proposed Stakeholder/Actor
Implementation of effective hygiene and biosecurity measures in the farm	Fish farmer
Promotion of better management practices (Good aquaculture practices)	Fish farmer / Industry
Strengthen Farmer Association and Cooperatives for knowledge sharing	Fish farmer / Industry
Avail alternatives to antibiotics (Vaccines, Prebiotics, Probiotics, Immunostimulants)	Industry / Research
Provision of Incentives to produce antibiotic free products	Government/Industry
Improve enforcement (in veterinary sector) on the sale of antibiotics	Government/Industry
Creation and implementation of AMR awareness campaigns	Government / Industry
Development and application of certification systems for antibiotic-free products	Government / Industry
Development of rapid diagnostic tools and increased diagnostic capacity in the field	Government / Research / Industry
Consumer awareness to encourage smart choices	Government / Industry
Adherence to standards to reduce AM residues	Certification bodies/ Government

are used to fertilize fish ponds, while the pond water is used to water crops or vegetables. In integrated farming involving livestock and crops, chicken was the poultry most kept among the farmers in the Nairobi river basin. This could be attributed to the fact that chicken is the most popular poultry reared in Kenya's households and in many countries in sub-Saharan Africa (Shoko et al., 2019). Its manure is also used for crops and pond fertilization.

Feeds and feed management practices are critical to the growth of the aquaculture sector. Fish farmers require nutritionally adequate and cost-effective feeds, as well as good feeding practices and feed management practices, to achieve high levels of aquaculture production (Munguti et al., 2021). Fish farmers need nutritionally adequate and cost-effective feeds, which are coupled with good feed management practices. Access to high quality and cost-effective feeds is one of the prerequisites to successful fish farming. This paper reviews the current status of the Kenyan fish feed industry and feed management practices. The review includes constraints and opportunities in fish feeds from a farmer's perspective. The review shows that the fish feed industry has been boosted by the development of fish feed standards, which has ensured access to high-quality fish feeds by all farmers. Feed management practices considerably impact on the economic performance in fish production. Thus, adopting appropriate feed management technologies and feeding strategies is instrumental in maximizing aquaculture productivity. Some of the major challenges faced by fish farmers in the feed sector including limited access to finance, lack of appropriate technical innovations, limited knowledge in feed formulation and processing and poor feed handling and storage are discussed. These challenges pose limitation in investment opportunities for a viable and sustainable fish feed processing and manufacturing to meet the rising demand occasioned by increased demand for fish food in Kenya There is a huge potential to develop public-private partnerships with farmer groups to improve access to training and information dissemination on feeds availability and quality. Training fish farmers on feed formulation using locally available feed ingredients provide an opportunity to reduce feed costs, increase feeding efficiency and improve profitability. This paper reviews the current status of the Kenyan fish feed industry and feed management practices including constraints and opportunities from a farmer's perspective. Farmers in the study area largely sourced their feeds from commercial manufacturers; farm-made feeds also existed where individual farmers made their feed at the farm level (Opiyo et al., 2014; Ragasa et al., 2022). Twice after 1 day, and twice after 2 days for a period of 7 months. Three hundred and seventy five fish were stocked into each of the nine, 150 m2 ponds with three replicates for each treatment. The fish were fed with a commercial diet (26% crude protein. In this study, the farmers were incentivized to buy and use packaged feeds, thus ensuring the source and quality of feeds.

Fish mortality observed in this study could be attributed to diminishing dissolved oxygen in the culture water, less digestible feed, and parasitic and bacterial infections (Opiyo et al., 2018; Alfred et al., 2020) Bacterial infections can be treated with proper diagnosis, however, misdiagnosis and treatment with the wrong drugs or dosage are more lethal since the bacteria can develop resistance to drugs (Leonard et al., 2022). The lack of diagnosis of the diseases can result in the misuse of antimicrobials since the farmers reported that they could not identify sick fish. This can be linked to inadequate training of fish farmers to recognize fish diseases and could explain the reason some farmers were unable to identify clinical symptoms of fish diseases. A study by Nzeve et al. (2024) indicated that 10.9% of pond-based fish farmers

can observe and document clinical signs in diseased fish. This lack of knowledge can lead to poor documentation of diseases among fish farmers.

The Nairobi River, as an important water source for aquaculture, may pose a challenge in terms of antimicrobial resistance if antibiotics find their way into the river through point or non-point sources (Moldovan, 2006). Antibiotics have been found in a variety of ecosystems, causing widespread concerns globally (Kümmerer et al., 2004; Ben et al., 2019). They are continuously discarded in natural ecosystems through human and animal excretion, individual drug abuse, and hospital effluents. These drugs' residues can persist in aquatic environments, causing severe changes in the composition and structure of the bacterial community, leading to the development of drug-resistant genes (Leonard et al., 2022). The lack of awareness of antimicrobial resistance can be linked to limited training in fish diseases and health management and education levels. Since the farmers had limited knowledge of fish health management, their knowledge of probiotics used as prophylactics was also low. A similar scenario was reported by Nzeve et al. (2024) among pond fish farmers in Kenya.

Mapping and surveillance of antimicrobial resistance using the SPR model is critical to guiding AMR interventions. AMR hotspots are reported in untreated or partially treated wastewater and solid waste disposal as sources. Enhanced documentation of the SPR for AMR has the potential to inform targeted surveillance programmes and interventions in aquaculture (Brunton et al., 2019). A rise in AMR rates is expected to affect low and middle-income countries disproportionately, jeopardizing the development gains in vulnerable communities, widening economic inequality, and contributing to a rise in extreme poverty by 2030 (World Bank, 2017). Furthermore, resistant pathogens significant to aquaculture may reduce the efficacy of treatment options in commercial aquaculture, with potential implications for food security and nutrition (Watts et al., 2017; Henriksson et al., 2018). The SPR mapping undertaken during this study indicates that aquaculture is connected with other agricultural food production systems, and addressing antimicrobial resistance needs to be done in a one-health approach rather than focusing on human health while ignoring the environment and animals for human consumption and animals being handled by the various users. A similar scenario was reported in a study carried out in Vietnam targeting small-scale farmers (Brunton et al., 2019). The interventions require leadership from the government and the industry with clearly defined roles, and this will depend on the production systems at the farmer level. The implementation of biosecurity measures, best management practices, record-keeping for traceability, and farmer training are required in the management of antimicrobial resistance.

Conclusion

The study also indicated that the interconnectivity of the various farm practices led to the transfer of antimicrobial residues from one unit to another, which led to antimicrobial resistance in animals that were not exposed to antimicrobials. The results of this study indicate that more awareness of antimicrobial resistance and training on best management practices need to be given to fish farmers in Nairobi Country for the sustainable development of the aquaculture sector. Monitoring and surveillance will be required in the identified hotspots, and the various stakeholders need to work together to address the challenges of antimicrobial resistance in aquaculture.

Limitations of this study

Previous studies carried out in Kenya in aquaculture production indicated a large number of active fish farming activities. This study was limited to the Nairobi River basin which had a limited number of fish farmers hence the small sample size.

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Conflict of interest

The authors declare that they have no conflict of interest in this study.

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