



Antimicrobial Resistance in Catfish Aquaculture in Indonesia: Antibiotic Use, Resistance Genes, and One Health Risks

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ABSTRACT

Catfish (*Clarias* spp.) aquaculture plays a crucial role in food security and rural livelihoods in Indonesia. Inappropriate antimicrobial use (AMU) can increase antimicrobial resistance (AMR), posing risks to aquaculture, environmental health, and food safety. The present study aimed to review AMR associated with catfish aquaculture in Indonesia within a One Health framework. A review was carried out according to structured literature review guidelines. Relevant peer-reviewed articles published between 2020 and 2026 were found in Scopus, Web of Science, PubMed, ScienceDirect, and Google Scholar. The searches employed specific combinations of keywords concerning catfish aquaculture, antimicrobial usage, antimicrobial resistance, and Indonesia. Data on AMU, resistant bacteria, antimicrobial-resistance genes (ARGs), and antibiotic residues were extracted from the included studies and categorized into these four subjects descriptively. Findings across studies were compared to identify commonly reported antimicrobials, patterns of bacterial resistance, detected ARGs, and the occurrence of antibiotic residues. Due to differences in study designs, sampling methods, bacterial species, and antimicrobial susceptibility testing methods, the findings were synthesized narratively rather than pooled statistically. The current findings indicated that oxytetracycline, tetracycline, and enrofloxacin were the most commonly used antibiotics. Resistant bacteria, particularly *Aeromonas hydrophila*, frequently exhibited resistance to tetracycline, oxytetracycline, ampicillin, and amoxicillin. Other pathogens, including *Edwardsiella tarda* and *Proteus* spp., also demonstrated multidrug resistance to tetracycline, oxytetracycline, ampicillin, and amoxicillin. The ARGs such as *tetA*, *tetE*, *qnrA*, *qnrB*, *qnrS*, *ampC*, *blaGES*, and *mexF* were detected in bacterial isolates and aquaculture environments. Antibiotic residues, including fluoroquinolones, sulphonamides, chloramphenicol, and tetracycline, were detected in aquatic environments and catfish products. Oxytetracycline residues ranging from 0.14 to 0.90 mg/kg were detected in catfish meat, with 25% of 59 samples exceeding the reported maximum residue limits. The current findings suggested that catfish aquaculture in Indonesia may contribute to the emergence and spread of AMR. The co-occurrence of antibiotic use, resistant bacteria, ARGs, and environmental contamination highlighted the need for strengthened antimicrobial stewardship, surveillance, and integrated disease management under a One Health approach.

Keywords: Antimicrobial resistance, Catfish aquaculture, Gene, One Health

INTRODUCTION

Aquaculture is an important source of animal protein and livelihoods, particularly in low- and middle-income countries (Koroma et al., 2025). In Indonesia, freshwater aquaculture plays a vital role in providing affordable nutrition, with catfish (*Clarias* spp.) as a key commodity because of its fast growth, adaptability to various environments, and strong market demand (Segaran et al., 2023). National production has remained consistently high in recent years, reflecting the economic and nutritional importance of catfish farming in both rural and urban communities (Susilowati et al., 2024).

High stocking densities, limited water exchange, and variable environmental conditions are common in intensive catfish aquaculture and collectively heighten the risk of infectious disease outbreaks. Bacterial pathogens such as *Aeromonas* spp., *Edwardsiella* spp., *Proteus* spp., and *Vibrio* spp. are commonly linked to diseases in catfish production (Ma et al., 2025; Dompheh et al., 2026). High stocking density and poor or unstable water quality can adversely affect fish health and production, leading farmers to use antibiotics to control disease (Wise et al., 2021). Appropriate antimicrobial treatments can be effective against bacterial infections; however, frequent or uncontrolled antimicrobial use (AMU) can contribute to antimicrobial resistance (AMR; Shahi et al., 2025).

Antimicrobial resistance is a growing global health issue, and AMU in livestock contributes to the emergence of resistant microorganisms. In aquaculture, antibiotics are used primarily to treat bacterial infections, although inappropriate use may occur when treatment is administered without proper diagnosis or veterinary decision (Ye et al., 2025). The mentioned practices may exert selective pressure that promotes the survival and proliferation of resistant organisms (Tiseo et al., 2020; Shahi et al., 2025). In Indonesia, growing concerns about antimicrobial use in aquaculture have prompted regulatory requirements for veterinary oversight of antibiotic administration, complemented by recent efforts to monitor AMU and mitigate AMR (Ministry of Marine Affairs and Fisheries, 2024). Aquaculture environments provide unique ecological conditions that facilitate AMR persistence and distribution (Okeke et al., 2022). Residual antibiotics, resistant bacteria, and antimicrobial resistance genes (ARGs) can accumulate in water, sediment, and cultured organisms, enabling interactions between environmental and pathogenic microbial communities (Yuan et al., 2023; Ariyani et al., 2024). Antibiotic residues, resistant bacteria, and antimicrobial resistance genes (ARGs) may subsequently transfer across ecological compartments via water discharge, aquaculture products, and human exposure, supporting the relevance of a One Health approach that integrates animal, environmental, and public health perspectives (Al-Khalaifah et al., 2025).

Despite growing global attention to AMR in aquaculture, evidence from Indonesian catfish production remains limited and dispersed across studies. Available studies have explored different facets of AMR, such as AMU, phenotypic resistance in bacterial isolates, ARGs, and antimicrobial residues, but these results were rarely considered together (Mohammed et al., 2025; Kawsar et al., 2026). Therefore, the present review aimed to synthesize available evidence on AMR associated with catfish aquaculture in Indonesia, focusing on AMU, resistant bacteria, ARGs, and antimicrobial residues, and to interpret the findings from a One Health perspective in order to identify links among aquaculture practices, aquatic environments, food products, and potential public health concerns, as well as to highlight priorities for surveillance and antimicrobial stewardship.

SEARCH STRATEGY

A structured literature search was conducted to identify studies addressing AMR and AMU in catfish aquaculture, with particular emphasis on evidence from Indonesia and relevant international studies for contextual comparison. Literature searches were performed using Scopus, Web of Science, PubMed, and ScienceDirect, with Google Scholar and Google searches serving as supplementary sources to expand the literature retrieval. The search strategy combined terms representing the target species, production system, antimicrobial exposure, resistance, and geographical context, including catfish (catfish or *Clarias*), aquaculture, antimicrobial exposure (antibiotic or antimicrobial), resistance (resistance or antimicrobial resistance or AMR), and Indonesia. A total of 81 records were retrieved from Scopus, 113 from Web of Science, 59 from PubMed, 120 from ScienceDirect, and 195 through supplementary Google Scholar/Google searching. All retrieved references were collected, organized, and managed using Mendeley version 1.19.8, resulting in a reference library containing 217 records. The Mendeley count was not considered additional yield because it represented records imported from different databases and supplementary search sources. The collected records were reviewed for relevance to catfish aquaculture and AMR-related outcomes. Studies were considered relevant when they provided extractable information on AMU, phenotypic antimicrobial resistance, antimicrobial-resistant bacteria, ARGs, antimicrobial residues, or other AMR-related outcomes in catfish, catfish products, or aquaculture-associated environments. Indonesian studies formed the main evidence base, while international studies on catfish or relevant freshwater aquaculture systems were kept separate for contextual comparison. After selecting the literature and completing full-text assessments, 34 studies were included in the final analysis, 13 from Indonesia and 21 from international or relevant contexts. Complete numerical records of duplicate removal and the initial title-and-abstract assessment were not retained during the original literature-selection process; therefore, only verifiable numbers were reported, and no unrecorded selection data were retrospectively estimated.

Data extraction

Relevant information was extracted from the selected literature, including author, year, country or Indonesian location, production or environmental system, AMU, antimicrobial residues, bacterial species, phenotypic resistance results, and ARGs. Outcomes not reported in an article were recorded as not reported rather than interpreted as negative findings. Indonesian evidence and international contextual evidence were synthesized separately to prevent the direct extrapolation of international findings to the Indonesian context. Because the included studies differed substantially in study design, bacterial species, sampling strategies, antimicrobial panels, laboratory methods, and reported outcomes, the evidence was synthesized using a narrative and descriptive approach rather than quantitative meta-analysis.

CURRENT EVIDENCE ON ANTIMICROBIAL RESISTANCE IN CATFISH AQUACULTURE

Bacterial pathogens

Bacterial species reported in Indonesian catfish evidence included *Aeromonas hydrophila* (*A. hydrophila*) and other *Aeromonas* spp., *Edwardsiella tarda*, *Proteus mirabilis*, *Proteus vulgaris*, *Escherichia coli*, *Salmonella* spp., and *Vibrio cholerae* (Table 1). *Aeromonas* spp. have been reported in several regions of Indonesia, including Jambi, East Java, and other local production environments (Mulia et al., 2021; Dewi et al., 2023; Mawardi et al., 2023; Wulandari et al., 2024). Because the included studies did not consistently report mortality estimates, no general quantitative statement on mortality was performed.

Antibiotic usage

Antimicrobial exposure reported in Indonesian catfish studies included oxytetracycline, tetracycline, enrofloxacin, sulfamethoxazole, ciprofloxacin, furazolidone, ampicillin, erythromycin, kanamycin, and chloramphenicol (Table 1). Oxytetracycline was reported in multiple catfish studies (Mulia et al., 2021; Kurniawan, 2023; Mawardi et al., 2023; Putri and Triyanto, 2023), whereas enrofloxacin has been frequently reported (Mulia et al., 2021; Dewi et al., 2023; Kurniawan, 2023; Mawardi et al., 2023; Putri and Triyanto, 2023). The extracted data indicated which antimicrobials were reported but did not establish farmers' motivations for selecting particular medicines.

Occurrence of antimicrobial resistance bacteria

Phenotypic resistance differed according to bacterial species and study location (Table 1). In the Jambi region, Indonesia, *A. hydrophila* isolates exhibited resistance to tetracycline (100%), oxytetracycline (94.42%), ampicillin (77.70%), amoxicillin (77.72%), and ciprofloxacin (16.68%), while no resistance to enrofloxacin or streptomycin was reported (Wulandari et al., 2024). Mawardi et al. (2023) reported *A. hydrophila* resistance to oxytetracycline (54.54%), tetracycline (15.06%), and enrofloxacin (16%). Mulia et al. (2021) reported *Aeromonas* spp. resistance to ampicillin (80%), erythromycin (70%), oxytetracycline (40%), chloramphenicol (30%), and kanamycin (10%), with 0% resistance to enrofloxacin. *Edwardsiella tarda* isolates were resistant to erythromycin (88.89%), enrofloxacin (88.89%), and oxytetracycline (66.67%; Putri and Triyanto, 2023). *Proteus mirabilis* and *P. vulgaris* demonstrated significant resistance to multiple Beta-lactam antibiotics and erythromycin; however, the reported Indonesian isolates exhibited no resistance to ciprofloxacin (Wibawati et al., 2021).

Detection of antimicrobial resistance genes

The Indonesian evidence reported ARGs such as *tetA* and *tetE* (conferring tetracycline resistance), *qnrA*, *qnrB*, and *qnrS* (linked to quinolone resistance), *ampC* and *bla_{GES}* (Beta-lactam resistance), *sul1* (sulphonamide resistance), *mexF* (related to multidrug efflux resistance), and *strA-strB* (streptomycin resistance; Table 1). Wulandari et al. (2024) detected *ampC* in 57.14% of Beta-lactam-resistant *A. hydrophila* isolates, and among the quinolone-resistant isolates, *qnrA* and *qnrS* were detected in 75%, and *qnrB* in 25%. Ikhrami et al. (2024) identified *sul1* at 67%, *tetA* at 63%, *bla_{GES}* at 55%, and *mexF* at 25% in an irrigation canal and aquaculture pond. Kurniawan (2023) identified *tetE* in *Aeromonas* spp., while Mulia et al. (2021) reported the presence of *tetA* and *strA-strB* in *Aeromonas* species.

Antibiotic residues in aquatic environments and catfish products

Antibiotic residues were detected in different aquaculture environments and catfish products (Table 1). Ariyani et al. (2024) detected multiple antimicrobial compounds including norfloxacin (31.0 ng/L), enrofloxacin (23.0 ng/L), ofloxacin (22.0 ng/L), sulfamethoxazole (11.6 ng/L), ciprofloxacin (11.55 ng/L), chloramphenicol (4.55 ng/L), and tetracycline (3.4 ng/L), in Cirata Reservoir water. Ulkhaq et al. (2024) found chloramphenicol residues under 0.3 ppb in 16.67–36.37% of catfish samples collected from three traditional markets in Banyuwangi, Indonesia, with all concentrations below the maximum residue limit specified in their study. Hakimah et al. (2021) detected oxytetracycline residues above the maximum residue limit in 25% of 59 catfish meat samples obtained from traditional markets in Yogyakarta, Indonesia, with concentrations ranging from 0.14 to 0.90 mg/kg. The mentioned findings indicated antimicrobial exposure in the tested catfish products but should not be extended to other locations.

Integrated evidence of antimicrobial resistance

Indonesian studies identified four related types of evidence, including reported AMU or exposure, phenotypically resistant bacteria, ARGs, and antimicrobial residues (Table 1). The individual studies did not consistently measure all four components within the same farms or samples. Consequently, the synthesis demonstrated co-occurrence across the Indonesian evidence, rather than establishing a direct causal link within individual production units.

Table 1. Antimicrobial use, antimicrobial residues, antimicrobial-resistant bacteria, and antimicrobial-resistance genes reported in Indonesian catfish aquaculture and related aquatic environments from 2020 to 2026

Location	Category/system	Antibiotics used	Antibiotic residues	Resistant bacteria and genes	Resistance profile	Reference
Cirata Reservoir, West Java, Indonesia	Reservoir environment associated with intensive aquaculture and other anthropogenic inputs	Not directly quantified; fluoroquinolone occurrence was considered potentially associated with aquaculture and other human activities.	24/65 residues detected in water and/or sediment, major classes included fluoroquinolones, tetracyclines, sulphonamides, diaminopyrimidines, lincosamides, sulphones, and amphenicols.	Potential antibiotic-resistant bacteria	Potential selection pressure for antibiotic-resistant bacteria, particularly from fluoroquinolones; not phenotypically measured	Ariyani et al. (2024)
	Reservoir-based aquaculture and river-reservoir catchment	Enrofloxacin was reported by 20% of surveyed aquaculture farmers for common carp and tilapia during the wet season.	14 antibiotics were modeled from human, livestock, and aquaculture sources; antibiotic residues were also evaluated against measured concentrations in river and reservoir water.	Not investigated	Not investigated	Ariyani et al. (2025)
Palembang, South Sumatra, Indonesia	Environment / Urban River environment (Kedukan, PU, and Buah Rivers)	Tobramycin Ampicillin Tetracycline Kanamycin Ciprofloxacin Cotrimoxazole Cefixime Gentamicin Chloramphenicol	Not investigated	<i>Escherichia coli</i> , <i>Coliform</i>	Tobramycin: 95% Ampicillin: 75% Tetracycline: 18% Kanamycin: 36% Ciprofloxacin: 18% Cotrimoxazole: 36% Cefixime: 36% Gentamicin: 75% Chloramphenicol: 55%	Sunarti et al. (2022)
Kulon Progo, Yogyakarta, Indonesia	Environment / irrigation canal and aquaculture ponds	None reported by the surveyed farmers.	Not investigated	Antibiotic Resistance Genes: <i>sul1</i> , <i>tetA</i> , and <i>blaGES</i> detected in aquaculture pond water; <i>mexF</i> detected in the irrigation system.	Not investigated	Ikhrami et al. (2024)
Jambi Province, Indonesia	Catfish aquaculture ponds	Not investigated	Not investigated	<i>Aeromonas hydrophila</i> ; <i>ampC</i> (57.14%), <i>qnrA</i> (75%), <i>qnrS</i> (75%), and <i>qnrB</i> (25%) among corresponding resistant isolates	Tetracycline (100%), Oxytetracycline (94.42%), Ampicillin (77.70%), Amoxicillin (77.72%) Ciprofloxacin (16.68%) Enrofloxacin (0%) Streptomycin (0%)	Wulandari et al. (2024)
East Nusa Tenggara, Indonesia	Freshwater aquaculture; tilapia and catfish farms	Oxytetracycline (80-90%) Enrofloxacin (10%) Sulfamethoxazole (10%) Ciprofloxacin (5%) Furazolidone (5%)	Not investigated	<i>Aeromonas veronii</i> <i>Aeromonas hydrophila</i> <i>Aeromonas caviae</i> ; <i>tetE</i> detected in 13/14 Oxytetracycline-resistant strains.	39% (16/40) of <i>Aeromonas</i> strains resistant to ≥ 1 tested antibiotic; Oxytetracycline (20-50%) Sulfamethoxazole (0-50%) Amoxicillin (100-50) Florfenicol (0-50%) Enrofloxacin (0%)	Kurniawan (2023)

West and Central Java, Indonesia (Sukabumi, Bogor, Banyumas, Magelang)	Freshwater aquaculture farms, including <i>Clarias gariepinus</i> .	Tetracycline Oxytetracycline Enrofloxacin	Not investigated	<i>Aeromonas hydrophila</i>	Oxytetracycline (54.54%) Tetracycline (15.06%) Enrofloxacin (16%)	Mawardi et al. (2023)
Pasuruan, East Java, Indonesia	Farmed African catfish (<i>Clarias gariepinus</i>); 25 diseased fish from five sub-districts.	Enrofloxacin; reported as commonly used in local catfish farming, but farm-level use was not quantitatively assessed	Not investigated	<i>Aeromonas hydrophila</i> (23/25), <i>Aeromonas salmonicida</i> (2/25)	No Enrofloxacin resistance reported for <i>A. hydrophila</i> ; inhibition zones 24-44 mm.	Dewi et al. (2023)
Yogyakarta, Indonesia	Aquaculture / catfish system.	Erythromycin Oxytetracycline Enrofloxacin	Not investigated	<i>Edwardsiella tarda</i>	Erythromycin (88.89%) Enrofloxacin (88.89%) Oxytetracycline (66.67%)	Putri and Triyanto (2023)
Banyuwangi, East Java, Indonesia	Aquaculture / catfish system.	Not directly assessed	Not investigated	<i>Proteus mirabilis</i> (3/74)	Penicillin (100%) Ampicillin (100%) Oxacillin (100%) Cefadroxil (100%) Erythromycin (66.7%) Cefixime (33.3%) Tetracycline (0%) Ciprofloxacin (0%) Streptomycin (0%) Chloramphenicol (0%)	Wibawati et al. (2021)
				<i>Proteus vulgaris</i> (8/74)	Oxacillin (100%) Penicillin (75%) Ampicillin (62.5%) Cefadroxil (62.5%) Erythromycin (62.5%) Streptomycin (50%) Cefixime (25%) Tetracycline (0%) Ciprofloxacin (0%) Chloramphenicol (0%)	
Java, Indonesia (Yogyakarta, Central Java, and West Java)	Aquaculture / Diseased farmed walking catfish.	Ampicillin Erythromycin Oxytetracycline Kanamycin Enrofloxacin Chloramphenicol	Not investigated	<i>Aeromonas</i> spp. (<i>A. dhakensis</i> , <i>A. veronii</i> bv. <i>veronii</i> , <i>A. caviae</i> , and <i>A. hydrophila</i>), Antibiotic Resistance Genes: <i>tetA</i> (30%), <i>strA</i> (30%), <i>qnrA</i> not detected.	Ampicillin (80%) Erythromycin (70%) Oxytetracycline (40%) Chloramphenicol (30%) Kanamycin (10%) Enrofloxacin (0%)	Mulia et al. (2021)
Banyuwangi, East Java, Indonesia	Product / Farmed African catfish (<i>Clarias gariepinus</i>) from traditional markets (n = 90).	Not directly assessed	Chloramphenicol detected in 36.37% of samples from Kertosari, 23.33% from Banyuwangi Kota, and 16.67% from Blambangan; all detected residues < 0.3 ppb	Not investigated	Not investigated	Ulkhqaq et al. (2024)
Yogyakarta City, Indonesia	Product / Marketed catfish (<i>Clarias</i> sp.); 59 samples from 59 sellers in 16 traditional markets	Not directly assessed	Oxytetracycline residues detected above the maximum residue limit in 25% of 59 samples; 0.14-0.90 mg/kg	Not investigated	Not investigated	Hakimah et al. (2021)

Table 2. Antimicrobial use, antimicrobial residues, antimicrobial-resistant bacteria, and antimicrobial-resistance genes reported in catfish aquaculture and related freshwater aquaculture systems across different countries and regions, from 2020 to 2026

Location	Category / System	Antibiotics used	Antibiotic residues	Resistant bacteria	Antibiotic resistance genes and profile	Reference
Multiple countries/regions (Global evidence)	Aquaculture systems, including freshwater aquaculture and catfish-related evidence	Ampicillin Ceftriaxone Chloramphenicol Ciprofloxacin Co-trimoxazole Erythromycin Oxytetracycline Quinolone	Antibiotic residues reported across aquatic environments; heterogeneous across reviewed studies	<i>Proteobacteria</i> <i>Cyanobacteria</i> <i>Actinobacteriota</i> <i>Bacteroidota</i> <i>Verrucomicrobiota</i>	<i>tetA, tetB, tetC, tetG, tetM, sul1, qnrB, ermF, cat1 and int1</i>	Mohammed et al. (2025)
				<i>Plesiomonas shigelloides</i>	<i>emrD, macB, catB, ksgA, tolC, MdfA, sul1, bacA and DegP</i>	
				<i>Salmonella</i> spp.	<i>stn, bcfC, avrA, sodC1, ssaQ</i>	
				<i>Escherichia coli</i>	β -lactam: 92%	
				<i>Aeromonas</i> spp.	Ampicillin, Amoxicillin, Cephalexin, Cephalothin, Ceftiofur, Chloramphenicol, Florfenicol, Nalidixic Acid, Gentamicin, Kanamycin, Erythromycin, Tetracycline, Oxytetracycline, Trimethoprim, Sulfamethoxazole, Trimethoprim-Sulfamethoxazole, Ticarcillin, Cefotaxime, Nitrofurantoin, Ciprofloxacin, Norfloxacin, Doxycycline, and Streptomycin	
Global and Bangladesh	Aquaculture; comprehensive review	Azithromycin Chlortetracycline Amoxicillin Ciprofloxacin Oxytetracycline Sulfadiazine Erythromycin Trimethoprim	Residues of Fluoroquinolones, Sulfonamides, Nitrofurans, Chloramphenicol, and other antimicrobials reported in aquaculture products and environments	<i>Vibrio</i> spp.	Ampicillin, Amoxicillin, Carbenicillin, Cephalexin, Cephalothin, Cefotaxime, Cefpodoxime, Ceftiofur, Chloramphenicol, Florfenicol, Colistin, Nalidixic Acid, Oxalinic Acid, Gentamicin, Kanamycin, Erythromycin, Tetracycline, Oxytetracycline, Trimethoprim, Sulfamethoxazole, Trimethoprim-Sulfamethoxazole, Streptomycin, Rifampicin, Spectinomycin, and Vancomycin	Afroze et al. (2025)
				<i>Escherichia coli</i>	Ciprofloxacin, Nalidixic Acid, Tetracycline, Sulfamethoxazole, Ampicillin, Trimethoprim, Chloramphenicol, Penicillin, Kanamycin, Gentamicin, Streptomycin, Trimethoprim-Sulfamethoxazole, and Ticarcillin	
				<i>Salmonella</i> spp.	Ampicillin, Erythromycin, Gentamicin, Nalidixic Acid, Nitrofurantoin, Penicillin, Streptomycin, Tetracycline, and Trimethoprim	
				<i>Staphylococcus aureus</i>	Streptomycin, Ampicillin, Penicillin, Erythromycin, Cephalothin, Rifampicin, Nitrofurantoin, Piperacillin, Ceftriaxone, Ceftazidime, Ciprofloxacin, Nalidixic Acid, Tetracycline, Sulfamethoxazole, Trimethoprim, Chloramphenicol, Kanamycin, and Gentamicin	
				<i>Pseudomonas</i> spp.	Ampicillin, Amoxicillin, Amoxicillin-Clavulanic Acid, Cephalothin, Ceftazidime, Cefotaxime, Ceftiofur, Chloramphenicol, Florfenicol, Nalidixic Acid, Oxalinic Acid, Ciprofloxacin, Norfloxacin, Tetracycline, Oxytetracycline, Doxycycline, Gentamicin, Kanamycin, Streptomycin, Erythromycin, Sulfamethoxazole, Trimethoprim, Trimethoprim-Sulfamethoxazole, Nitrofurantoin, and Ticarcillin	
Global	Catfish aquaculture; review	Penicillin Tetracyclines Macrolides Sulphonamides, Enrofloxacin, and other antimicrobials reported across catfish production systems	Not specifically quantified	<i>Aeromonas hydrophila</i> <i>Aeromonas</i> spp. <i>Vibrio</i> spp. Enterobacteriaceae <i>Escherichia coli</i> <i>Edwardsiella tarda</i> ; Antibiotic Resistance Genes include β -lactam, Tetracycline, Aminoglycoside, and Folate-pathway antagonist resistance genes	Resistance to multiple antimicrobial classes reported across catfish systems, including Beta-lactams (Penicillin, Cephalosporins): High resistance (Extended-spectrum beta-lactamases-mediated) Tetracyclines: High resistance Sulphonamides: Moderate to high resistance Macrolides: Variable resistance Fluoroquinolones: Variable resistance (generally lower than beta-lactams) Carbapenems: Low resistance	Shahi et al. (2025)

Global	Aquaculture; systematic review and modelling of antimicrobial consumption, including catfish as a distinct species group	Catfish: estimated mean antimicrobial-use intensity 157 mg/kg biomass (95% UI: 9-2,751); catfish accounted for an estimated 8.3% of global aquaculture antimicrobial consumption in 2017. Across aquaculture, Quinolones, Tetracyclines, Amphenicols, and Sulfonamides were the most frequently reported classes	Not investigated	Not investigated	Not investigated	Schar et al. (2020)
Africa	African aquaculture; scoping review of 41 studies, predominantly pond-based systems; tilapia and catfish were the main species studied	Tetracyclines, Penicillin, Sulphonamides, Fluoroquinolones were the most frequently reported classes; use was predominantly therapeutic	Residues of Tetracyclines, Sulfonamides, and Cephalosporins were reported in fish, sediment, and feed; concentrations of 70-450 µg/kg were reported across studies, with some exceeding MRLs	<i>Escherichia coli</i> <i>Salmonella</i> spp. <i>Aeromonas hydrophila</i> <i>Vibrio</i> spp.	43% multidrug resistance; ARGs: <i>tet</i> , <i>sul</i> , <i>bla</i> 40% multidrug resistance; ARGs: <i>tet</i> , <i>sul</i> , <i>bla</i> 63% multidrug resistance, 29% Extensively Drug-Resistant; antimicrobial-resistance genes: <i>tet</i> , <i>sul</i> , multiple antibiotic resistance index: 0.3-0.7 Antimicrobial-resistance genes: <i>tet</i> , <i>bla</i>	Matee (2026)
USA (Alabama)	Pond-based channel catfish	Not investigated	Not investigated.	<i>Enterococcus</i> spp.	Ampicillin (~44.8%) rifampicin (~42.4%) Tetracycline (~38.4%); Multidrug resistance observed in 36% of isolates antimicrobial-resistance genes included <i>aac(6')-Iid</i> (65.7%), <i>aac(6')-Ii</i> (22.9%), <i>efmA</i> (20.0%), <i>msr(C)</i> (20.0%), <i>lsa(A)</i> , <i>emeA</i> , <i>efrA</i> , <i>efrB</i> , and <i>dfrE</i> ; plasmid replicons also detected.	Soku et al. (2025)
Africa (Nigeria)	Farmed catfish	Antibiotic use reported as widespread/intensive; specific agents and frequencies were not quantified	Not investigated	<i>Aeromonas</i> spp. (<i>A. caviae</i> , <i>A. dhakensis</i> , <i>A. enteropelogenes</i> , <i>A. hydrophila</i> , and <i>A. veronii</i>)	Beta-lactams: High resistance Additional resistance to Oxytetracycline, Neomycin, Sulfamethoxazole, and Colistin; Multidrug resistance prevalence 36.09% and extensive drug resistance 60.43%; Multiple Antibiotic Resistance Index 0.20-0.80; Susceptibility retained to Ciprofloxacin, Gentamicin, and Florfenicol	Adah et al. (2024)
Egypt (Dakahlia Governorate)	Freshwater fish farmers: Catfish and Tilapia	Not directly assessed	Not investigated	<i>Edwardsiella tarda</i>	Multidrug resistance to ≥6 antibiotic classes: Penicillin, Aminoglycosides, Fluoroquinolones, Tetracyclines, Sulphonamides, and Lincosamides. Antibiotic Resistance Genes: <i>blaTEM</i> , <i>blaCTX-M</i> , <i>sul1</i> , <i>tetA</i> , <i>aadA1</i> , <i>qnrA</i> , <i>qnrS</i>	Algammal et al. (2022)
Asia	Cultured and wild-caught aquatic food animals; systematic review and meta-analysis of 749 point-prevalence surveys	Antimicrobial use generally unspecified; reported on-farm use was associated with higher multidrug resistance	Not investigated	<i>Aeromonas</i> spp. <i>Vibrio</i> spp. <i>Escherichia coli</i>	Carbapenems: ~40.3% Cephalosporins: ~69.6%) Aztreonam: ~56.6% Colistin: ~51.5% Colistin: ~42.7% Colistin: ~5.2%	Schar et al. (2021)
Cambodia	Pond aquaculture of striped catfish and giant snakehead; fish, water, and sediment from 17 ponds/8 farms	Ampicillin Oxytetracycline Cefpodoxime Ciprofloxacin Trimethoprim-Sulfamethoxazole Gentamicin Florfenicol Oxalinic Acid Erythromycin	Not investigated	<i>Aeromonas</i> spp. <i>Escherichia coli</i> <i>Enterobacteriaceae</i> <i>Pseudomonas</i> spp.	High resistance to Trimethoprim-Sulfamethoxazole, Oxalinic Acid, Oxytetracycline Multidrug-resistant isolates resistant to Ampicillin, Cefpodoxime, Trimethoprim-Sulfamethoxazole, and Florfenicol Resistant to Ampicillin (100%); Partial resistance to Trimethoprim-Sulfamethoxazole, Oxytetracycline, Cefpodoxime, Gentamicin, and Florfenicol Resistant to Ampicillin (100%), Cefpodoxime, Trimethoprim-Sulfamethoxazole, and Florfenicol; Susceptible to Ciprofloxacin, Oxytetracycline, and Gentamicin.	Peng et al. (2024)

Global antimicrobial resistance in catfish aquaculture

Global and regional studies provided contextual evidence that AMR was widely reported in catfish and freshwater aquaculture (Table 2). Reported resistant organisms included *Aeromonas* spp., *Escherichia coli*, *Vibrio* spp., *Salmonella* spp., *Pseudomonas* spp., *Enterococcus* spp., and *Edwardsiella tarda*, with multidrug resistance observed in several settings (Schar et al., 2020, 2021; Algammal et al., 2022; Adah et al., 2024; Peng et al., 2024; Afroze et al., 2025; Mohammed et al., 2025; Shahi et al., 2025; Soku et al., 2025; Matee, 2026). Resistance to tetracyclines, Beta-lactams, sulphonamides, and other antibiotic classes was frequently reported, although resistance patterns differed substantially among bacterial taxa, countries, and antimicrobial panels (Schar et al., 2021; Algammal et al., 2022; Adah et al., 2024; Peng et al., 2024; Afroze et al., 2025; Shahi et al., 2025; Soku et al., 2025; Matee, 2026). Global studies identified ARGs including *tet*, *sul*, *bla*, and *qnr* groups and detected antimicrobial residues in aquaculture-related matrices (Algammal et al., 2022; Mohammed et al., 2025; Matee, 2026). Contextual evidence highlighted the importance of aquatic environments in AMR persistence and distribution, although global data did not specifically represent conditions on Indonesian catfish farms (Schar et al., 2020, 2021; Mohammed et al., 2025; Shahi et al., 2025; Matee, 2026).

CHALLENGES AND PRIORITIES FOR ANTIMICROBIAL RESISTANCE CONTROL IN INDONESIAN CATFISH AQUACULTURE

Indonesian studies indicated that AMR in catfish aquaculture included bacterial, genetic, environmental, and food-product domains. The most consistent finding across studies was resistance to *Aeromonas* spp., along with reports of ARGs and antimicrobial residues in aquaculture and catfish meat (Kurniawan, 2023; Ariyani et al., 2024; Wulandari et al., 2024). However, the findings were contradictory and geographically limited, and the reviewed studies did not establish a nationally representative AMR prevalence (Schar et al., 2020).

Oxytetracycline, tetracycline, and enrofloxacin were consistently reported in the Indonesian catfish studies (Mulia et al., 2021; Dewi et al., 2023; Kurniawan, 2023; Mawardi et al., 2023; Putri and Triyanto, 2023). The recurrence of these agents was consistent with broader aquaculture studies indicating extensive use of tetracyclines and other broad-spectrum antimicrobials (Schar et al., 2020; Shahi et al., 2025). The present review did not specifically investigate why Indonesian farmers chose these medicines. Accessibility, cost, diagnostic limitations, and empirical treatment may relate to farmers' choices.

Susceptibility to antibiotics differed markedly within *Aeromonas* spp., with enrofloxacin resistance ranging from 0% (Mulia et al., 2021; Dewi et al., 2023; Wulandari et al., 2024) to 16% (Mawardi et al., 2023). The differences in susceptibility profiles across studies may reflect variation in bacterial populations, sampling approaches, antimicrobial exposure, laboratory methods, and production settings (Mulia et al., 2021; Dewi et al., 2023; Mawardi et al., 2023; Wulandari et al., 2024).

ONE HEALTH IMPLICATIONS OF ANTIMICROBIAL RESISTANCE IN CATFISH AQUACULTURE

Aeromonas spp., particularly *A. hydrophila*, warrant attention as they were recurrently identified in Indonesian catfish samples and possess phenotypic resistance and ARGs (Mulia et al., 2021; Mawardi et al., 2023; Wulandari et al., 2024). Wulandari et al. (2024) detected *ampC* and *qnr* genes, while Mulia et al. (2021) detected *tetA* and *strA-strB*. Similar reports from other aquaculture settings indicated that *Aeromonas* spp. can harbor a variety of resistance genes (Hayatgheib et al., 2021; Jeamsripong et al., 2025). The presence of mobile or transferable resistance genes in aquatic bacteria is important for horizontal gene transfer and the spread of AMR in aquatic environments (Hayatgheib et al., 2021; Jeamsripong et al., 2025). However, the Indonesian studies in this review did not directly quantify gene-transfer conditions (Mulia et al., 2021; Wulandari et al., 2024).

Environmental evidence further broadened the One Health perspective. Ikhrami et al. (2024) detected *sul1*, *tetA*, *bla_{GES}*, and *mexF* in an irrigation canal and aquaculture pond, while Ariyani et al. (2024) detected multiple antimicrobial residues in reservoir water. The findings indicated that AMR-related factors and antimicrobial compounds were found outside fish tissues and clinical isolates. Aquatic cultures may therefore serve as interfaces where resistant organisms, resistance genes, antimicrobial residues, animals, and humans interact (Okeke et al., 2022; Prata, 2022; Yuan et al., 2023).

Evidence on food safety was limited but significant. Residues of chloramphenicol were identified at low concentrations in catfish sold in Banyuwangi (Ulkhag et al., 2024), whereas Hakimah et al. (2021) documented oxytetracycline levels exceeding the maximum residue limit in 25% of 59 samples collected from markets in Yogyakarta. Although the geographically limited evidence was insufficient to estimate national consumer exposure, the findings emphasize the importance of residue monitoring, adherence to withdrawal periods, and a more integrated approach to antimicrobial use and food safety surveillance (Hakimah et al., 2021; Ulkhag et al., 2024). Sub-inhibitory antimicrobial concentrations can create selection pressure in environmental microbial communities, providing a plausible biological basis for integrated monitoring approaches (Chow et al., 2021).

CONCLUSION

Findings from Indonesian studies indicated that catfish aquaculture and associated aquatic environments were affected by antimicrobial exposure and harbored resistant bacteria, ARGs, and antimicrobial residues. *Aeromonas* spp. were the most consistently detected resistant bacteria, while studies conducted in Indonesia also reported resistance to *E. tarda* and *Proteus* species. Antimicrobial resistance genes from the tetracycline, quinolone, beta-lactam, sulphonamide, streptomycin, and multidrug resistance classes were documented. Antimicrobial compounds were detected in aquatic environments and marketed catfish, including oxytetracycline above the reported maximum residue limits.

The current evidence supports the enhancement of One Health surveillance and antimicrobial stewardship initiatives. Future studies should prioritize integrated farm-level investigations that simultaneously assess antimicrobial use, phenotypic resistance, resistance genes, and antimicrobial residues to better clarify the sources and transmission pathways of AMR in Indonesian catfish aquaculture. The conclusions should, however, be interpreted with caution because the available Indonesian evidence remains geographically limited and heterogeneous, the review protocol was not prospectively registered, complete records of the early screening process were unavailable, and a formal risk-of-bias assessment was not performed.

DECLARATIONS

Authors' contributions

Kadek Karang Agustina conceptualized and designed the study, as well as contributed to the literature review, data collection, data analysis, and manuscript preparation. I Made Sukada, Ida Bagus Krisna Pradnyadana, Putu Arya Duta Adnyana, Ni Putu Dewi Setia Sari, Ni Ketut Harmini Saraswati, and Ida Bagus Kade Suardana participated in the literature review, data collection, data analysis, and manuscript preparation. All authors rigorously reviewed the manuscript, approved the final edition, and accepted responsibility for all aspects of the study.

Availability of data and material

All data synthesized in this review are derived from the cited publications and sources listed in the references of the manuscript.

Competing interests

The authors have declared no conflict of interest.

Ethical considerations

ChatGPT, created by OpenAI, was used exclusively for editing and proofreading in English to enhance grammar, clarity, readability, and academic tone. The authors carefully reviewed and edited all AI-assisted revisions and assume full responsibility for the AI-edited content. ChatGPT was not used to generate, analyze, or interpret the study data, and the authors take full responsibility for the accuracy, originality, and integrity of the final manuscript before submission, after primary acceptance, and at final stage of publication.

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