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Navigating antimicrobial use in Indian freshwater aquaculture: Regulatory frameworks and sustainable alternatives

Gulla Gnaneshwar, Neha W. Qureshi*, Abhilash Thapa, Ganesh Kumar, Naila M. Bhat

Fisheries Economics, Extension and Statistics Division, ICAR - Central Institute of Fisheries Education, Mumbai, India

Abstract

Freshwater aquaculture drives over 95% of India's production but intensified practices lead to disease and antimicrobial usage, causing antimicrobial resistance. Many developing nations lack regulations, resulting in unchecked antibiotic use and compromised health management. It is noteworthy that while antibiotic usage in brackish water aquaculture is stringently monitored due to international regulations for seafood exports, the same rigor is absent in freshwater aquaculture. A comprehensive study, conducted primarily in Andhra Pradesh, spotlighted the antibiotic landscape in India's aquaculture industry. Notably, Andhra Pradesh is at the forefront of aquaculture efforts. The study scrutinized antimicrobial regulations in other nations and explored alternative strategies, with the aim of proposing effective measures for regulating antimicrobial usage in Indian freshwater aquaculture. The study collected primary and secondary data through a survey conducted in West Godavari and Krishna districts of Andhra Pradesh and research articles, proceeding papers, government institution websites respectively. The study highlighted that a significant proportion of antibiotics are utilized in Indian freshwater aquaculture farms, with Enrofloxacin, Oxytetracycline, Cephalexin, Doxycycline, and Erythromycin being the most commonly used antibiotics. It proposed alternatives like antimicrobial peptides, herb extracts, pro-, pre-, synbiotics, and vaccination. The study underscored the urgency of further research in this realm and suggests tight antibiotic regulations, required aquaculture prescriptions, and limited drug choices to counter overuse. Other countries' successful strategies, like strict regulations, vet engagement, records, and alternatives, provide a model to cut antibiotic use. By adopting these steps, India can proactively curb misuse, safeguard aquatic ecosystems, and lower risks of antibiotic-resistant pathogens to the environment and health.

Keywords:
Antibiotics, Antimicrobial resistance, Freshwater Aquaculture, Regulations, India

***Corresponding author:**
nehaq@cife.edu.in

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Introduction

Freshwater aquaculture is crucial in providing food and improving nutritional security for many underdeveloped countries worldwide. In 2020, global aquaculture production was 87.5 million metric tonnes, with inland aquaculture contributing 62% (54.4 MMT) of total aquaculture production, valued at $265 billion (FAO, 2022). Freshwater aquaculture contributes to over 95% of the total aquaculture production in India, it makes up almost 55% of India's total fish production (Mishra et al., 2017). However, diseases remain a major challenge in finfish aquaculture, causing significant economic losses estimated between US$1.05 and US$9.58 billion annually (Monir et al., 2015; Dias and Martins, 2017). Disease emergence and transmission are influenced by various water quality parameters, such as dissolved oxygen, temperature, and nutrition, among others (Piasecki et al., 2004; Clausen et al., 2015; Henriksson et al., 2018). Antibiotics are frequently used in aquaculture to control disease outbreaks, but their overuse can lead to antibiotic-resistant bacteria and potential environmental pollution (Cabello et al., 2013). Additionally, there is a lack of knowledge about their proper application, potential side effects, and efficacy in controlling diseases (Rasul et al., 2017). To address these concerns and reduce the use of antibiotics and other chemicals in aquaculture, alternative and sustainable practices such as integrated multi-trophic aquaculture (IMTA), recirculating aquaculture systems (RAS), and biofloc technology are being promoted (Chatla et al., 2020). These practices can help control disease outbreaks, improve water quality, and reduce the need for antibiotics (Chatla et al., 2020).

Antimicrobial practice

Antimicrobials and their metabolic residue enter the environment through various means, such as human waste, animal and aquaculture run-off, and the spread of manure over agricultural fields (Sarmah et al., 2006; Marshall & Levy, 2011; Andrieu et al., 2015; Robinson et al., 2016; Henriksson et al., 2017). According to Lulijwa *et al*. (2019), oxytetracycline, florfenicol, and sulfadiazine were used by 73% of the major aquaculture-producing countries, while 55% used erythromycin, amoxicillin, sulfadimethoxine, and enrofloxacin. These medications are used for therapeutic, preventative, rehabilitative, and growth-promoting purposes in animals (Cabello, 2004; Quesada et al., 2013). Fish are administered antibiotics through their food, as well as through baths and injections (Rasul and Majumdar, 2017).

However, the effective use of antimicrobials while minimizing resistance remains a major challenge (Aly & Albutti, 2014). Several issues hinder the effective use of chemotherapeutants, including the lack of pharmacokinetic data for many drugs used, the absence of standardized protocols for their use, safety concerns related to handling, storage, and application, the lack of licensed products, the cost and time involved in registration and licensing requirements, and varying legislation that can range from highly restrictive to non-existent (Subasinghe, 2009).

Effects of antibiotic use

The widespread prophylactic use of antibiotics in fish farms is primarily responsible for the emergence of antibiotic resistance, as noted by (Hemamalini *et al*., 2021). Although particular contamination levels are difficult to verify, antibiotic doses in aquaculture can be routinely greater than those in terrestrial animal farming (Romero et al., 2012; Hossain et al., 2022). (Burridge et al., 2010; Romero et al., 2012) reported that 75% of antibiotics given to fish are excreted into the water, leading to the evolution of resistant bacteria in sediments where unutilized medicinal feed may accumulate (Reantaso et al., 2023). This can result in the predominance of resistant strains over non-resistant ones in the population when antibiotics are present (Vignesh et al., 2011). Furthermore, antibiotics such as oxytetracycline and amoxicillin, which are commonly used in aquaculture, are also essential for human medicine, and there is a significant correlation between terrestrial and aquatic resistors (Watts et al., 2017; Preena et al., 2020). Antibiotic-resistant gut-associated aeromonads have been reported in *Ctenopharyngodon idella, Labeo rohita,* and *Catla catla*, which are resistant to ampicillin, oxytetracycline, amoxicillin, and novobiocin (Hatha et al., 2005; Preena et al., 2020). Antibiotic resistance can emerge in the aquatic environment through various processes, including horizontal gene transfer, mutation, and efflux pumps. Antibiotics can also alter the natural environment by inhibiting or killing beneficial microbial flora in the gut, affecting fish nutrition, physiology, and immunity (Rekecki et al., 2009; Rawls et al., 2007; Maynard et al., 2012; Banerjee & Ray, 2017). If these resistant bacteria infiltrate the food chain through contaminated fish or other seafood, they can cause diseases in humans that are challenging to treat, as noted by Romero *et al*., (2012). Beyene, (2016) reported that chloramphenicol residues increase the risk of cancer and may cause aplastic anaemia at lower concentrations. Moreover, penicillin hypersensitivity, gentamicin mutagenicity and nephropathy, and immunopathology and carcinogenic effects from sulfamethazine, oxytetracycline, and furazolidone are other lethal effects, as highlighted by Ibrahim *et al*.(2020). Therefore, understanding the procedures used to rear aquatic species such as fin fish and shrimp and bring them to the dinner table is crucial (Pham *et al*., 2015).

Global antimicrobial consumption

Antimicrobial resistance (AMR) is a serious global issue, with low- and middle-income countries bearing the greatest burden of the yearly mortality rate, which is expected to reach 1.27 million fatalities in 2019 (Murray et al., 2019; Caputo et al., 2023). The World Health Organization (WHO) has identified six common classes of antibiotics that are commonly used in aquaculture farming worldwide, including Penicillins, Aminoglycosides, Tetracyclines, Macrolides, Quinolones, and Sulfonamides (Ibrahim et al., 2020). The most frequently used antimicrobial categories globally are Quinolones (27%), Tetracyclines (20%), Amphenicols (18%), and Sulfonamides (14%) (Schar *et al*., 2020). The Asia–Pacific region, especially China (57.9%), India (11.3%), Indonesia (8.6%), and Vietnam (5%), represents the largest share of global antimicrobial consumption in aquaculture, estimated at 10,259 tons in 2017 (Schar et al., 2020). Antibiotic residues in aquaculture products and water have been documented in studies from Bangladesh, India, Indonesia, and Thailand. The concentrations were as follows: Chloramphenicol - up to 5ng/L in Bangladesh, Chloramphenicol - up to 32ng/L in India, Chloramphenicol up to 45ng/L in Indonesia, Erythromycin and tetracyclines - up to 180 ng/L in Thailand, Fluoroquinolones - up to 46100 ng/L in

Thailand, Fluoroquinolones - up to 1130 ng/L in Vietnam (Hays, 2020). Most antibiotics used in the animal health industry are used to promote growth rather than for treatment (Walia et al., 2019). The consumption of antimicrobials in aquaculture is projected to rise by 33% from 2017 to 2030 if current trends persist (Schar et al., 2020). This underscores the ongoing necessity for endeavours aimed at diminishing and efficiently managing antimicrobial usage (Schar et al., 2020). To address this global issue, strict measures, legislation, and regulations for the use of antimicrobials in aquaculture should be developed and implemented, as recommended by (Rasul and Majumdar, 2017) and efforts must be made to reduce antibiotic usage in aquaculture and to urge stakeholders to embrace other disease-prevention approaches (Santos and Ramos, 2018). This study aims to identify alternatives to antibiotics and discuss legislation and policies from other countries that can be implemented in India to limit antimicrobial use.

Over the recent five years, ICAR-CIFT has actively engaged in Antimicrobial Resistance (AMR) investigation across four states in India: Kerala, Andhra Pradesh, Maharashtra, and Gujarat. Their primary emphasis has been on examining different bacteria such as *Staphylococcus aureus, Escherichia coli, Vibrio cholerae, Vibrio parahaemolyticus, Listeria monocytogenes*, and other similar microorganisms (Murugadas and Prasad, 2019). ICAR-CIFE is running a National Surveillance Programme for Aquatic Animal Diseases (NSPAAD-Phase 2), 2022-25 under Pradhan Mantri Matsya Sampada Yojana (PMMSY). A survey was conducted on approximately 240 freshwater fish farms in the states of Odisha and Andhra Pradesh. The purpose was to examine the presence of Antimicrobial Resistance (AMR) in fish. Significant advancements have been achieved in recording the progress of new treatments and options for maintaining health and managing diseases in fish. These advancements include AMPs, Probiotics, herbal items, immunopotentiators (TLRs), medicinal plants, and herbal formulations to address parasitic diseases in fish (ICAR-CIFA Annual Report, 2021).

Issues in managing antimicrobial use in freshwater aquaculture in India

In India, freshwater fish farming is mainly intended for local consumption, and unfortunately, there is no monitoring of antibiotics in these fishes. Moreover, when contrasted with shrimp production, the economic viability of freshwater fish is comparatively reduced. As a consequence, there is a lack of significant focus on overseeing antibiotic usage . As a result, there are no security checks or screenings for domestically consumed fish. Moreover, the main monitoring agency in India, the Department of Fisheries (DoF), is understaffed, and due to the highly diversified and scattered nature of fish farms, it is challenging to understand the type and pattern of antibiotics used. Additionally, fish farmers often lack awareness on disease identification and are easily taken advantage of by Aqua-chemical consultants who aim to profit by selling pre-pro biotics and antibiotics. With this background, this study was envisaged to fulfil following objectives:

- To document current status of antimicrobial use in freshwater aquaculture in India
- To comparatively assess antimicrobial regulation and alternatives followed by other countries
- To suggest suitable measures to regulate antimicrobial use in freshwater aquaculture in India

Methodology

The data for this study was gathered from both primary and secondary sources. For primary data, a survey was conducted over two months, in November and December, 2022 in the West Godavari and Krishna districts of Andhra Pradesh. The study focused on these districts as they are known for being leading fish producers in Andhra Pradesh. A total of 93 samples from freshwater fish farmers were collected from Mogalthur and Undi in the West Godavari district, and Kaikaluru and Gudivada in the Krishna district, as well as fisheries research stations in Telangana by adopting multistage random sampling. The data collection involved interviews using an interview schedule with key informants and conducting focused group discussions (FGDs). The selected fish species for the study were Catla, Rohu, Pangasius, and Roopchand. In addition to primary data, secondary data was collected from various sources, such as research articles, review articles, proceeding papers, book/chapters, news clippings, and websites of government institutions like the Coastal Aquaculture Authority (CAA) and Marine Products Export Development Authority (MPEDA). The selected nations for the case analysis were divided into two groups according to the literature assessment: developed nations (Norway, Chile, USA and Brazil) with stringent regulations and developing nations (China, Thailand, Vietnam and Japan) with less stringent regulations which ought to have more similarities with India. To conduct the case study, a methodology of collective case study was adopted which involves studying multiple cases simultaneously to gain a broader understanding of a specific issue (Baskarada, 2014). After data collection, the information was compiled and analysed using tabular and descriptive statistical tools of MS Excel.

Results and discussion

The survey classified farms into three categories based on farm size. The majority of the farmers observed in the current study were marginal farmers, 54% (with 5-10 acres), followed by large farmers, 40% (> 15 acres), and small farmers, 6% (< 5 acres). The seed source for aquaculture came from private hatcheries, and all farms use advanced fingerlings (45%) and yearlings (55%) used as their stocking size. Stocking density varied depending on the species being cultured. Commonly observed diseases include Red disease, Columnaris, Fin rot, Argulosis, Gyrodactylosis Dactylogyrosis and Dropsy. Farmers could recognize these diseases based on clinical symptoms such as mortality, abnormal behaviour, and reduced feed intake. The spread of diseases is attributed to high stocking density and the contamination from the neighbouring farms through the water canals which serves as an inlet source. According to the survey, approximately 40% of fish farmers are resorting to the use of antibiotics like enrofloxacin, oxytetracycline, furazolidone, amitraz, ciprofloxacin, doxycycline, Malachite green, and Cypermethrin to combat bacterial diseases. Enrofloxacin is the most commonly used antibiotic, accounting for 36% of the cases, followed by oxytetracycline at 20% and furazolidone at 16% (Table 1). These antibiotics are primarily administered through medicated feed. Among the selected farms, pangasius farms have the highest usage of antibiotics at 45%, followed by IMC (Indian Major Carps) farms at 40%, and Roopchand farms at 15%. Regarding the prescription of antibiotics, the majority of fish farmers (60%) reported that they prescribe antibiotics themselves, while the remaining 40% rely on drug sellers for obtaining antibiotics.

Table 1. Most commonly used antibiotics in freshwater aquaculture in Andhra Pradesh (Sampled farms)

Antibiotics	Frequency (n=68)
Enrofloxacin	26
Oxytetracycline	14
Furazolidone	11
Amitraz	5
Ciprofloxacin	4
Malachite green	3
Doxycycline	3
Cypermethrin	2

Table 2. Different aqua chemicals used in Indian freshwater aquaculture

State	Antimicrobials (%)	Antibiotics (%)	Probiotics (%)	Feed supplements (%)	Water quality remediator (%)	Anti-parasitic drugs (%)
Jharkhand	23%	9%	23%	32%	9%	4%
Chhattisgarh	8%	-	25%	50%	17%	-
Odisha	12%	5%	17%	31%	22%	13%
Andhra Pradesh	12%	2%	31%	28%	17%	10%

(*Source:* Mishra et al., *2017)*

Table 3. Antibiotics and other pharmacologically active substances and their maximum permissible residual level in ppm by CAA

Antibiotics and other Pharmacologically Active Substances	Maximum Permissible Residual Level (ppm)	Antibiotics and other Pharmacologically Active Substances	Maximum Permissible Residual Level (ppm)
Chloramphenicol	Nil	Colchicine	Nil
Nitrofurans including: Furaltadone, Furazolidone,Furylfuramide, Nifuratel, Nifuroxime, Nifurprazine, Nitrofurantoin, Nitrofurazone	Nil	Dapsone	Nil
Neomycin	Nil	Dimetridazole	Nil
Tetracycline	0.1	Metronidazole	Nil
Oxytetracycline	0.1	Ronidazole	Nil
Trimethoprim	0.05	Ipronidazole	Nil
Oxolinic acid	0.3	Other nitroimidazoles	Nil
Nalidixic acid	Nil	Clenbuterol	Nil
Sulphamethoxazole	Nil	Diethylstilbestrol (DES)	Nil
Aristolochia spp and preparations thereof	Nil	Sulfonamide drugs (except approved Sulfadimethoxine, Sulfabromomethazine and Sulfaethoxypyridazine)	Nil
Chloroform	Nil	Fluroquinolones	Nil
Chlorpromazine	Nil	Glycopeptides	Nil

(Source: CAA, 2001)

Table 4. Use of chemotherapeutants in freshwater aquaculture and hatchery systems in India (from Rao et al., 1990; Pathak et al., 2000)

Item	Purpose	Doses	Mode of application	Remarks
A. Parasitic diseases				
Oxytetracycline	*Myxobolus* spp.	5 gm/ 100 kg fish	Supplemented in the feed 2-3 instalments	Prevents secondary bacterial infection
Sodium chloride	Epistylls spp., Zoothamnium spp.	20-50 kg/ha		Pond water application
Malathion/ Dichlorvos	*Dactylogyrus* spp.	0.2 ppm	Supplemented in the feed 2-3 installments2-4 instalments	
	Gyrodactylus spp.	0.15-0.25 ppm (Malathion)		
	Argulus spp.,			
	Lernaea spp.,	0.05-0.1 ppm		
	Ergasilus spp.			
Gammexane	As above			Immersion treatment
B. Bacterial/fungal diseases				
Sulphadiazine + Trimethoprim	Ulcerative and systemic type (*Aeromonas hydrophila*)	5 gm/ 100kg	Applied for 7 days	Water dispersible powder
Chloro-tetracycline		7 gm/100 kg		Supplemented in feed
Oxy-tetracyclIne	Columnaris disease	7-10gm/100 kg		Supplemented in feed
Nitrofurans	Microbial gill disease	10 gm/100 kg	Applied for 10 d	Immersion treatment
Trimethoprim		5-7 gm/100 kg		
Copper sulfate	*Saprolegnia* spp., *Branchiomyces*	0.2-0.5 ppm	2-3 installments at 3-4 d interval	Immersion treatment

According to Bhushan *et al*. (2016), The Central Drugs Standard Control Organisation (CDSCO) has issued recommendations on the use of antibiotics in aquaculture, including a list of approved medicines and restrictions on their use. Furthermore, the CAA (Table 3), MPEDA, and FSSAI have banned certain antimicrobials to regulate antibiotic use in Indian aquaculture, but antibiotic resistance remains a concern. Patil *et al*. (2022) reported that there are approximately 250 registered pharmaceutical companies producing around 3,000 aquaculture healthcare products and chemicals in India. Mishra *et al*. (2017) reported the percentage of different aqua chemicals used in freshwater aquaculture in States like Jharkhand, Chhattisgarh, Odisha, and Andhra Pradesh (Table 2). Rao *et al*., (1990); Pathak *et al*., (2000) had reported use of chemotherapeutants in freshwater aquaculture and hatchery systems in India (Table 4). Now, Oxymycin, Enrox, Lixen Powder, Hydrodox, Oxytetracycline, and Cefintas Aq are extensively used in Indian aquaculture (Mishra *et al*., 2017). According to Patil *et al*. (2022), tetracyclines were the most commonly used antibiotics in freshwater aquaculture, followed by Cephalexin, Doxycycline, Enrofloxacin, Erythromycin, and Sulpha methoxazole-trimethoprim. The authors also found that pangasius farmers used antibiotics more frequently (33.33%) than other farmers. Among antiparasitic agents, Deltamethrin (11.14%) was the most widely used, followed by quinalphos (5.14%), ivermectin (4.84%), amitraz (4.80%), cyclomethrin (4.48%), and albendazole (3.64%). In addition, Patil *et al*. (2022) found that disinfectants were used most frequently by farmers raising IMC+. Shrimp farmers were found to use probiotics most often, followed by pangasius, IMC, and IMC+. Table 3 shows that antibiotics and other Pharmacologically active Substances and their Maximum Permissible Residual level in ppm by CAA. These findings indicate the diversity of aquaculture practices and highlight the potential for variation in antibiotic use across different farming systems and regions in India.

Regulations

The WHO has endorsed the 'One Health approach' to addressing the global issue of ABR through the 'Tripartite Alliance' formed by the WHO, FAO, and OIE (Walia *et al.*, 2019). A Tripartite work plan for 2019-2020 was developed, with five focus areas to be addressed through multi-sectoral collaboration: (1) implementation of the AMR NAP; (2) awareness and behavioural change; (3) surveillance and monitoring of AMR and antimicrobial use (AMU); (4) antimicrobial stewardship and optimal use; and (5) monitoring and evaluation (Caputo *et al.*, 2023). Antibiotic approval, usage practices, and residue restrictions in aquaculture products are governed by national regulations in each country (Reantaso *et al.*, 2023). Only a few nations examine the amount of antimicrobials used in aquaculture, therefore statistics on antimicrobial doses are few (Sapkota *et al.*, 2008; Ibrahim *et al.*, 2020). Important policy makers are the European Commission, the Food and Drug Administration, the European Medicines Agency, the Norwegian Veterinary Institute, the Norwegian Food Safety Authority, Codex, and government ministries (Lulijwa *et al.*, 2019). Regulatory agencies may define antibiotic usage rules, such as acceptable routes of administration, dose forms, withdrawal times, tolerances, and use by species, including dose rates and limitations (Romero *et al.*, 2012). In terms of exporting fisheries products, India ranks third behind China and Indonesia exporting 1.36 million tonnes of seafood worth US$ 7.76 billion (Handbook of fisheries statistics, 2022). Due to a rise in veterinary medication-related rejections of Indian seafood, the EU increased border checks from 10% to 50% in 2016 and led to decrease in the share of Indian frozen shrimp exports to EU from 22.2% in 2016 to 11.8% in 2021 (Patil *et al.*, 2022). The monetary value of rejected Indian seafood consignments in the United States, Europe, and Japan was estimated to be between USD 35 to 40 million (Patil *et al.*, 2022). Five percent of the import products that were rejected consisted of shrimp entry lines. These rejections occurred because these shrimp entry lines were found to contain banned antibiotics, including chloramphenicol and nitrofuran. From 2012-2015, about 17 cases of exported shrimp products were reported for the presence of antibiotics and its degraded products such as nitrofuran metabolite (furazolidone), nitrofurazone and chloramphenicol or for exceeding the amount of oxytetracycline by European countries as per the Rapid Alert System for Food and Feed of the European Commission (Rao and Prasad, 2015). There are standards, guidelines and an institution to manage the use of antibiotics and pharmacologically active substances in export-oriented brackish water aquaculture but it is lacking in freshwater (Bardhan and Abraham, 2021). Hence, strict regulations are required on antimicrobial usage in freshwater aquaculture too. Below given are the case study results conducted to assess and compare the regulations on antimicrobial use in aquaculture in these countries. It is essential to note here that in the countries selected for the case study, the regulations for antimicrobial use are common for the marine and inland aquaculture sectors unlike we have in India wherein CAA regulates the use of antibiotics in coastal and brackish water aquaculture.

Norway

Antibiotic usage in aquaculture is regulated by the Norwegian Food Safety Authority (NFSA) (Lulijwa *et al.*, 2019). Florfenicol, Flumequine, Oxolinic acid, Oxytetracycline, and an oxolinic acid-flumequine combination of sulphas are approved medications in aquaculture (Preena *et al.*, 2020). Antibiotics are exclusively used to treat sick fish; they are not utilized to prevent illness (Romero *et al.*, 2012). In addition, fish farmers must keep record of all antibiotic use and submit regular reports to the NFSA (Table 5) (Varona *et al.*, 2020). Furthermore, the Norwegian government has set a goal of reducing antibiotic use in aquaculture by 50% by 2020 and 75% by 2025. The NFSA has implemented steps such as improved surveillance of fish farms, stricter regulation of antibiotic sales, and the research of alternative treatments such as vaccinations and probiotics to achieve this goal (Caputo *et al.*, 2023).

USA

The U.S. Food and Drug Administration (FDA) and the U.S. National Oceanic and Atmospheric Administration (NOAA) are primarily responsible for regulating antibiotic usage in aquaculture in the United States (Table 5) (Fry *et al.*, 2014). Tolerable drug concentrations and lists of approved drugs for use in aquaculture have been established by the Food and Drug Administration (FDA) (Lulijwa *et al.*, 2019). Aquaculture activities in federal seas are managed by the NOAA's Fisheries Service, which is also responsible for regulating the use of antibiotics (Johns, 2012). The United States government has issued a ban on the use of antibiotics in aquaculture (Ibrahim *et al.*, 2020). It is illegal to use an antibiotic for purposes other than treating an infection (Rodgers and Furones, 2009). The antibiotic oxytetracycline was the most often used in the United States (Singh *et al.*, 2009; Preena *et al.*, 2020).

Brazil

In Brazil, the use of antibiotics in aquaculture is regulated by the Ministry of Agriculture, Livestock, and Food Supply (Lulijwa *et al.*, 2019). The Ministry of Agriculture, Livestock, and Supply (MAPA) and the Ministry of Health in Brazil have established the following regulatory programmes: the National Control of Biological Residues in Animal Origin Products (PNCRB) and the Programme of Veterinary Drugs Residue Analysis in Animal Origin Foods (PAMVet) (Quesada *et al.*, 2013). There are only 3 veterinary drugs approved for use in aquaculture: florfenicol, oxytetracycline, and a parasiticide based on trichlorfon (Quesada *et al*., 2013). The use of antibiotics as a preventive measure was prohibited (Lima *et al*., 2016). Brazil has established maximum residue limits (MRLs) for antibiotics in fish and seafood products (Brasil,2015; Lulijwa *et al*., 2019). Fish farmers are required to follow good aquacultural practices and keep records (Table 5) of antibiotic use to ensure compliance with MRLs (Lulijwa *et al*., 2019). In addition, Brazil has implemented a national plan which aims to promote the responsible use of antibiotics and reduce the risk of antibiotic resistance (Lulijwa *et al*., 2019).

Chile

In Chile, Article 86 of the Fisheries and Aquaculture Law restricts the preventive use of antimicrobials in aquaculture, as well as any usage injurious to human health (Lozano *et al*., 2018). The Ministry of Economy, Development, and Tourism in Chile regulates the use of antibiotics in aquaculture (SERNAPESCA, 2016; Lulijwa *et al*., 2019). A veterinarian should provide therapeutic treatments for populations of hydrobiological species (Lozano *et al*.,2018). Before using antimicrobials, fish samples should be collected for laboratory confirmation of the diagnosis (Lozano *et al*.,2018). Doxycycline, enrofloxacin, florfenicol, flumequine, neomycin, norfloxacin, oxolinic-acid, sulphadiazine, sulphamethazine, sulphamethoxazole, sulphamonomethoxine, thiamphenicol trimethoprim - oxytetracycline, erythromycin, amoxicillin, furazolidone, gentamicin and chloramphenicol are the approved antibiotics in Chilean aquaculture (Cabello *et al.,* 2013; Liu *et al*., 2017; Preena *et al*., 2020).

Vietnam

The Ministry of Fisheries (MOFI) in Vietnam regulate the antibiotic usage (MOFI, 2005; MARD, 2009b, 2014; Lulijwa *et al*., 2019). In Vietnam fish farmers has to obtain a prescription from a veterinarian before using antibiotics (Defoirdt *et al*., 2011). There are 39 antibiotics that have been approved for use in aquaculture (Lulijwa *et al*., 2019). In recent years, there have been some initiatives to address the issue of antibiotic use in aquaculture (Defoirdt *et al*., 2011). For example, the government has developed a national action plan to promote responsible use of antibiotics in agriculture, including aquaculture (Lulijwa *et al*., 2019) (Table 5).

China

The Ministry of Agriculture of the People's Republic of China regulates the antibiotic usage (MAPRC, 2002a,b, 2003, 2007; Lulijwa *et al*., 2019). At present, there are 6 kinds of antibiotics most widely used in the aquaculture: macrolides, β-lactam, sulfonamides, tetracyclines, furans and quinolones (He *et al*., 2016). In 2020, China released a new policy, and the policy restricts (Table 5) the use of antibiotics in aquaculture to treat and prevent diseases only and prohibits the use of antibiotics as growth promoters. The policy also establishes stricter standards for antibiotic residues in aquaculture products and strengthens the regulation of antibiotic production and sales (Li *et al*., 2021). Antibiotics are still permitted in food-producing animals to promote growth and prevent disease, posing significant enforcement and monitoring challenges in China (Chen *et al*., 2020).

Thailand

In Thailand the Department of Fisheries (DoF) continuously controls the use of veterinary medications and chemicals throughout the production process (Lulijwa *et al*., 2019). The Fisheries Act B.E. 2490 (1947) and other related laws and regulations are used by the DOF as a regulatory framework to control aquaculture production (Table 5) (Baoprasertkul *et al.,* 2012). All drugs must be registered through the pharmacies and wholesalers/ distributors and pharmacies must obtain a license from FDA, Thailand (Baoprasertkul *et al*., 2012). Only antimicrobial agents that have been approved by the FDA may be used for therapeutic treatment in

Table 5: Cross Country checklist of progress for antimicrobial use in aquaculture

Countries	Regulations	Monitoring	Research	Surveillance
Norway	✓	✓	✓	✓
USA	✓	✓	✓	✓
Brazil	✓	✓	✓	✓
Chile	✓	✓	✓	✓
Vietnam	✓	✓	✓	✓
China	✓	✓	✓	✓
Thailand	✓	✓	✓	✓
Japan	✓	✓	✓	✓
India*	✗	✗	✓	✗

**For India it's referring to Freshwater Aquaculture*

aquaculture (Baoprasertkul *et al*., 2012). In Thai aquaculture, registered pharmaceuticals such as oxytetracycline, tetracycline, sulfadimethoxine, trimethoprim, and ormetoprim are primarily used (Baoprasertkul *et al*., 2012).

Japan

In Japan, fishery products are regulated by the Food Sanitation Act and the Food Safety Basic Act (Lulijwa *et al*., 2019). Antibiotic regulations are strict, and only a few antibiotics are only licenced for use in aquaculture (Defoirdt *et al*., 2011).

Conclusion

The use of antibiotics in aquaculture has become a global concern due to its potential adverse effects on human health and the environment. In India, one of the major challenges is the absence of a standardized regulatory framework for antibiotic use, resulting in variations in regulations across the country. This lack of uniformity calls for the development of effective regulatory measures. Additionally, there is a significant gap in the establishment of standard protocols and procedures for monitoring and surveillance of antibiotic use in aquaculture, which is a major deficiency. The inadequate technical knowledge on the proper application of antibiotics for disease control further exacerbates the issue, leading to mishandling and improper use. This research also emphasizes the urgent need for intensive studies on the negative impacts of antibiotic use in aquaculture and the implementation of monitoring and surveillance mechanisms to ensure the judicious use of antibiotics. Through such measures, India can work towards safeguarding public health, preserving the environment, and fostering a sustainable aquaculture industry.

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Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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