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Antibiotics usage practices in aquaculture in Bangladesh and their associated factors

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ABSTRACT

Background: Irrational and inappropriate use of antibiotics in aquaculture can contribute to the development of antibiotic resistance.
Objectives: In this study, we aimed to assess antibiotic usage in inland and coastal fish farms in Bangladesh and identify factors associated with this practice.
Methods: We conducted a cross-sectional study to collect antibiotic usage information from 672 fish farmers in Bangladesh. The frequency of use, the types of antibiotics, the purpose of usage, and antibiotic prescribing practices were estimated. Adjusted odds ratios (aOR) were calculated to measure the association between antibiotic usage and factors related to the characteristics of the farms and farmers using multivariable logistic regression models.
Results: Twenty-two farms reported using antibiotics in the last 24 h preceding the interview (3%, 95% CI: 2–5%); 36 farms (5%, 95% CI: 4–7%) in the last 72 h, 141 farms (21%, 95% CI: 18–24%) in the last 14 days, and 478 farms (71%, 68–75%) reported antibiotic usage at least once since the start of their production cycle. Antibiotics usage in the last 14 days preceding the interviews was higher in freshwater fish farms (98%) than in brackish water farms (2%). Oxytetracycline, ciprofloxacin, and amoxicillin were the most frequently used antibiotics. Most of the antibiotics were reported to be used for both therapeutic and prophylactic purposes (71%, 95% CI: 63–78%). Antibiotics used within the last 14 days were mainly advised by feed dealers or drug sellers (51%, 95% CI: 43–60%), followed by farmers themselves (31%, 95% CI: 23–38%) and local service providers (18%, 95% CI, 12–25%). Fish farms having history of antibiotic use within the last 14 days preceding interviews was significantly associated with illness in fish (aOR 1.98, 95% CI:1.21–3.29) compared to farms with healthy fish and fishes cultured in ponds (aOR 9.34, 95% CI: 3.69–23.62) compared to enclosure cultures.
Conclusions: Improvement of fish health through better farming practices and changes in feed dealers' and farmers' attitudes towards self-prescription of antibiotic without veterinarian diagnostics may help to reduce the levels of antibiotic usage and thus contribute to mitigating antimicrobial resistance.

1. Introduction

Aquaculture: the farming of aquatic organisms is growing rapidly worldwide [1,2]. It is one of the fastest-growing food-producing sectors contributing in a significant way to food security by filling the supply and demand gaps for nutritious protein [3–5]. With intensification of

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aquaculture comes a number of issues such as overstocking, physical stress and poor water quality. Freshwater carp, tilapia and shrimp aquaculture are the major contributors to the inland and coastal aquaculture [6]. Cultured fish are constantly exposed to their aquatic environment with microorganisms, some of which can lead to diseases caused by bacteria, viruses, fungi, parasites etc. Infectious diseases are considered to be one the leading obstacle causing significant morbidity, mortality, and production losses [7], limiting the growth of the sector. Half of the production losses in aquaculture are attributed to diseases with more pronounced impacts in developing countries [8]. Estimated economic losses due to diseases have been valued over 6 billion US dollars per annum [8]. The economic losses in finfish aquaculture alone is estimated between 1.05 and 9.58 billion US dollars per annum [9]. The most common infectious diseases affecting aquatic animals during aquaculture production generally are caused by bacteria (54.9%), then viruses (22.6%), parasites (19.4%) and fungi (3.1%) [10,11].

Many antibiotics such as oxytetracycline, amoxycillin, and sulphadiazine-trimethoprim are frequently used in aquaculture to treat or prevent fish diseases [7]. Despite advances in diagnostic methods to identify infectious agents for adequate treatments, a lack of diagnostic capacity, particularly in low- and middle-income countries, hampers small-scale farmers from detecting diseases quickly and correctly, which may lead to antibiotic use or misuse [12]. Irrational and unrestricted use of antibiotics in aquaculture may contribute to antimicrobial resistance (AMR) emergence, which may pose a severe threat to human and animal health worldwide [2,13]. Prophylactic antibiotic use to prevent diseases during aquaculture production is on an increasing trend [2]. Intensive aquaculture, poor farming practice, insufficient hygiene, and a contaminated environment increase the risk of infection in fishes and antibiotic use [2]. Antibiotics are administered to fish either through their food, in baths, or by injections [13,14]. Antibiotics residues accumulate in fishes and their aquatic environments. If farmers after using antibiotics do not observe proper withdrawal periods before harvesting fish destined for sales, there is a risk that antibiotic residues may affect the health of consumers [15,16]. There are evidences that antibiotic resistance bacteria can transmit between the environments of aquatic and terrestrial animals [17,18]. Human, agricultural, and industrial wastewater can cycle back to the aquatic and terrestrial environments in developing countries without adequate sewage treatment plants to remove contaminants and pathogens. This can adversely affect the organisms and the communities that depend on them [2,19,20].

Aquaculture is one of the largest agro-based industries in Bangladesh that has expanded significantly over the last decades. According to the Food and Agriculture Organization (FAO), Bangladesh is the 3rd largest inland fish producing country and 5th in all aquaculture production globally [21]. In 2019–20, the total fish production was >4.5 million metric tons [22]. The fishery resources are mainly categorized into two sectors; inland fisheries and marine fisheries [23]. Inland fisheries take place in various types of waterbodies such as pond, ditch, baor, pen/cage and enclosure cultures (waterbodies surrounded by an embankment or a net structure), beel, river, estuary, lake, floodplain areas, and seasonal cultured waterbodies following different farming systems [16]. The area of inland fisheries in Bangladesh is estimated at around 0.837 million hectares [24].

It is not uncommon for farmers to use antibiotics during their aquaculture operations [25–29]. By law, the government of Bangladesh has banned antibiotics, growth hormones, and insecticides use in animal and fish feed [30]. There are limited reliable data on antibiotic usage at the national level for inland aquaculture but the Directorate General of Health Services, Bangladesh approved National Action Plan for Antimicrobial Resistance Containment (ARC) to guide national antibiotic stewardship efforts [31].

Monitoring of antibiotics use in aquaculture will help to understand the current antibiotic usage practices and its associated factors. This study aims to draw attention to the risks associated with irrational antibiotic use among fish farmers and policymakers. Moreover, it will help aquaculture authorities reduce antibiotic usage through targeted interventions.

2. Materials and methods

2.1. Study design

We conducted a large-scale cross-sectional study to collect antibiotic usage information from selected fish farms in Bangladesh. The study was completed from March to September 2021. Through consultations with fish feed dealers, 14 sub-districts with the highest number of fish farms were chosen (Fig. 1). Those were selected from six districts (Mymensingh, Cumilla, Bagerhat, Jashore, Khulna, and Satkhira). In each of these selected sub-districts, the field team enrolled 48 fish farms. In total 672 fish farmers were interviewed from those 14 sub-districts. Without a reliable initial list of fish farms, we used a snowball sampling approach to identify the targeted number of farms in each sub-district. Prior to the start of the survey, feed dealers operating in the selected sub-districts were asked to provide a list with the addresses of few prominent fish farms. After the first fish farm enrollment, the farmer was asked to share the address of the nearest fish farm, which was then recruited. This farm search procedure was repeated until reaching the targeted sample size. The sample size was calculated assuming an 18% expected prevalence of prophylactic antibiotic usage, with a 95% level of significance and 3% precision [26]. We included both freshwater and brackish water fish farms.

A total of 14 fish feed dealers were interviewed, one from each of the 14 above-mentioned selected sub-districts. In each sub-district, a large feed dealer was selected purposively who sold a larger amount of fish

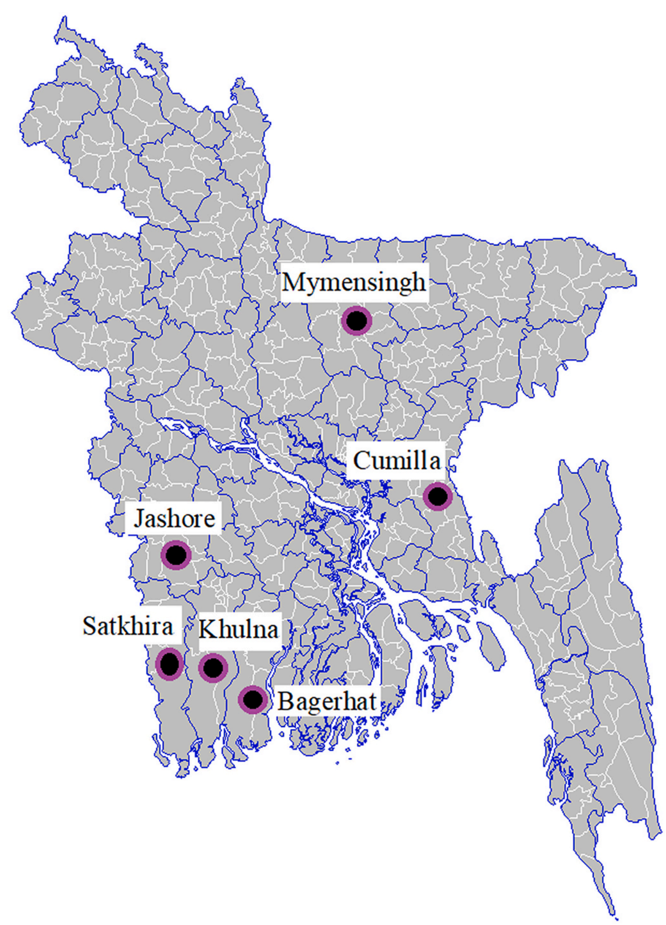

Fig. 1. Map of the study sites for fish farms sampling.

feed and medicine. Every selected feed dealer was visited once, preferably during the busiest hours, as farmers visited their shop. During those visits, enumerators recorded drug dispensing practices by observing interactions with five consecutive fish farmers. A total of 70 interactions with fish farmer clients (five farmers per feed dealer) were observed. Available antibiotic brands kept for sale in each feed dealer shop at the time of the visit were also recorded.

2.2. Data collection

A cross-sectional structured questionnaire was used to collect data on fish farm demographics, antibiotic usage in the last 24 h, 72 h, and 14 days preceding the interview, and since the start of the production cycle. We also collected information on the purpose(s) of antibiotic usage, name of antibiotics used, pro-biotic usage, antibiotic prescribing practices by authorized practitioners. Farmers were also asked for any report of fish morbidity and mortality they experienced over the last 14 days, about their education level and duration of their fish farming experience and how familiar they were with the term “AMR”. The questionnaire for fish feed dealers included antibiotic dispensing practices, name of the antibiotics they kept for sale, antibiotic prescribing practices by authorized practitioners, and their familiarity with the term “AMR”. The field team obtained written informed consent from all selected fish farmers and animal feed dealers before they participated in the study.

2.3. Statistical analysis

We summarized the characteristics of fish farms, including aquaculture farming type, using descriptive analyses. The proportion of farmers using each antibiotic and its 95% confidence interval was estimated separately for 24 h, 72 h, and 14 days. To describe the association between categorical farm management or demographic or geographic variables and the use of antibiotics on fish farms, the odds ratio (OR) was calculated first using bivariable logistic regression analysis. Then, multivariable analyses were performed to estimate the adjusted odds ratio (aOR) using additional explanatory variables. Variables with a p value ≤ 0.2 at a likelihood ratio test were used to build a multivariable logistic regression model. We used a backward stepwise selection of variables with an inclusion threshold of 0.05. Hosmer-Lemeshow test was used to calculate model $\chi 2$ statistic and McFadden's pseudo-R^2 (the coefficient of determination) to explain variance and measure goodness-of-fit for the multivariate regression model. All statistical analyses were performed in Stata 13 software (StataCorp LP, College Station, TX).

2.4. Ethical approval

The study protocol was reviewed and approved by icddr,b Research Review Committee, Ethical Review Committee and Animal Experimentation Ethics Committee (PR-20116).

3. Results

3.1. Demographic characteristics of fish farms and farmers

Among the 672 surveyed fish farms, 74% cultured fish in ponds and 99% of them practiced polyculture farming. The most cultured fish was rohu (96%), followed by catla (91%), grass carp (74%), and mrigal (71%) (Table 1). Rohu (*Labeo rohita*), catla (*Catla catla*), grass carp (*Ctenopharyngodon Idella*), mrigal (*Cirrhinus cirrhosis*), tilapia (*Oreochromis niloticus*) and pangas (*Pangasius pangasius*) were mostly cultured in Mymensingh, Cumilla and Jashore. Most of the prawn and shrimp farms (99%) were located at Bagerhat, Khulna and Sathkhira. The average number of aquaculture units (e.g. pond) per farm was 3 (range: 1–28). The mean surface size of the aquaculture unit was 1.73 acres (range: 0.04–35 acres). Only three fish farms had air pump systems to supply oxygen. The majority of the fish farmers who participated in this study were male (98%, $n = 657$), and 46% ($n = 307$) of the farmers had secondary-level education. >60% of the farmers had >10 years of fish farming experience.

Table 1
Demographic characteristics of fish farms (n = 672) investigated during March to September 2021 in Bangladesh.

Characteristics	Number of fish farms (%)	*95% CI*
Areas, n (%)	192 (29)	25–32%
Mymensingh	96 (14)	12–17%
Cumilla	96 (14)	12–17%
Bagerhat	96 (14)	12–17%
Jashore	96 (14)	12–17%
Khulna	96 (14)	12–17%
Satkhira	96 (14)	12–17%
Types of water bodies		
Pond	495 (74)	70–77%
Enclosure cultures	160 (24)	21–27%
Both	17 (3)	1–4%
Types of aquaculture		
Monoculture (single species)	9 (1)	1–3%
Polyculture (> single species)	663 (99)	97–99%
Types of fish species		
Pangas	155 (23)	20–26%
Tilapia	465 (69)	66–73%
Prawn	243 (36)	33–40%
Shrimp	200 (30)	26–33%
Common carp	339 (50)	47–54%
Tyangra (tengra)	53 (8)	6–10%
Grass carp	494 (74)	70–77%
Silver carp	551 (82)	79–85%
Rohu	642 (96)	94–97%
Catla	610 (91)	88–93%
Climbing perch	8 (1)	1–2%
Walking Catfish	55 (8)	6–11%
Mrigal	477 (71)	67–74%
Pabda	82 (12)	10–15%
Stinging catfish (shingi)	176 (26)	23–30%

3.2. Frequency and characteristics of antibiotic usage

Out of 672 fish farmers interviewed, 3% ($n = 22$, 95% CI: 2–5%) reported using antibiotics within the last 24 h preceding our visit. The majority of the farmers (77%) administered antibiotics for therapeutic and prophylactic purposes. Fish farmers used diverse classes of antibiotics, including tetracyclines, fluoroquinolones, macrolides, and aminoglycosides. The most commonly reported antibiotics were oxytetracycline, ciprofloxacin, and amoxicillin (Table 2). According to fish farmers' responses, antibiotics were mainly prescribed by feed dealers or drug sellers (54%), followed by local service providers (23%) and by the farmers themselves (23%) (Table 2). In the last 72 h preceding the interview, 36 farmers (5%, 95% CI: 4–7%) reported having used antibiotics. Antifungals (27%) and vitamins (22%) were identified as the most commonly used medicines (Tables 3).

The antibiotic usage in the last 14 days preceding the interview was 21% ($n = 141$, 95% CI: 18–24%). Use of antibiotics for prophylactic and therapeutic purposes was reported by 71% of the fish farmers ($n = 478$, 95% CI: 68–75%). Similarly to antibiotics used in the last 24 h, antibiotics used in the last 14 days were mostly prescribed by feed dealers or drug sellers (51%), followed by farmers themselves (31%) and local service providers (18%) (Table 4). Most of the antibiotic usages were reported in pangas fish farms (43%), followed by shingi (42%), pabda (40%), walking catfish (29%), tilapia (25%), mrigal (25%), grass carp (24%), silver carp (24%), common carp (22%), catla (22%), and rohu (21%) fish farms.

Table 2
Farm-level antibiotic use within the 24 h preceding visits to selected fish farms (N = 672) in Bangladesh during March to September 2021.

Variables	Number of farms n (%)	95% CI
Uses of at least one antibiotic	22 (3)	2–5%
Number of antibiotics	**N = 22**	
Single antibiotic	13 (59)	36–79%
Two antibiotics	9 (41)	21–64%
Purposes of antibiotic use	**N = 22**	
Prophylaxis	–	–
Treatment	5 (23)	7–45%
Both	17 (77)	55–92%
Antibiotic suggested by	**N = 22**	
local service providers	5 (23)	8–45%
Feed dealers or drug sellers	12 (54)	32–76%
Self-decision	5 (23)	8–45%
Name of the antibiotic	**N = 22**	
Oxytetracycline	14 (63)	41–83%
Amoxicillin	6 (27)	11–50%
Ciprofloxacin	4 (18)	5–40%
Levofloxacin	1 (5)	1–22%
Erythromycin	1 (5)	1–22%
Sulfadiazine	1 (5)	1–22%
Trimethoprim	1 (5)	1–22%

Table 3
Drugs, and associated products used within the 72 h preceding visits to selected fish farms (N = 672) in Bangladesh during March to September 2021.

Product	Yes n (%)	No n (%)
Vitamins	150 (22)	522 (78)
Minerals	37 (6)	635 (94)
Antibiotics	36 (5)	636 (95)
Antifungal	181 (27)	491 (73)
Antiprotozoal	16 (2)	656 (98)
Growth promoters	13 (2)	659 (98)
Probiotics	20 (3)	652 (97)

Table 4
Farm-level antibiotics used within the 14 days preceding visits to fish farms (N = 672) in Bangladesh, during March to September 2021.

Variables	Number of farms n (%)	95% CI
Usage of at least one antibiotic	141 (21)	18–24%
Purposes of antibiotic use	**N = 141**	
Prophylaxis	8 (6)	2–11%
Treatment	33 (23)	17–31%
Both	100 (71)	63–78%
Antibiotic suggested by	**N = 141**	
local service providers	26 (18)	12–25%
Feed dealers or drug sellers	72 (51)	43–60%
Self-decision	43 (31)	23–38%
Water types	**N = 141**	
Brackish water	3 (2)	1–6%
Fresh water	138 (98)	94–99%
Both	–	–

3.3. General practices with regards to antibiotics, disinfectants, medicines and chemicals usage

>70% of the farmers reported using antibiotics in their fish production cycle. A few farmers (9%, $n = 58$) used antibiotics on the first day of the fish production cycle prophylactically. Most farmers (99%, $n = 668$) said not to use antibiotics on a regular basis, and 69% of them when their fish become sick. One-third (33%) of the farmers knew about the importance of antibiotics withdrawal periods before selling their animals for human consumption. Most farmers ($n = 670$) do not mix antibiotics in fish feed but administered them to fish through water. According to farmers' estimations, the mean cost of antibiotics per production cycle was USD 43 (standard deviation, SD ± 56) per acre. Most farmers (99%, $n = 666$) reported using disinfectants on a regular basis to reduce microbial contamination in water. The most commonly used disinfectants were lime, potassium permanganate, and bleaching powder (calcium oxychloride). Other commonly reported chemicals included zeolites, organophosphate insecticide, sodium percarbonate, and salt (sodium chloride). Zeolites are the aluminosilicate members of the family of microporous solids that are widely used in aquaculture to remove ammonia. Sodium percarbonate is used in water to quickly release available oxygen in the water, providing a suitable environment for fish.

3.4. Health status of fish

On the day of the fish farm visits, 192 of the farmers (29%) reported having at least one sick and/or dead fish on their fish farm(s). According to the farmers' observations, 10 fish (range: 0–400) were apparently sick on average per farm in the last 14 days, whereas five fish (range: 0–200) were dead during the same period.

3.5. Interaction between fish farmers and feed dealers

One-third of farmers (33%, $n = 219$) had interactions with feed dealers. Fish farmers received support from feed dealers mainly on feed supply (33% of farmers) and medicine supply (28% of farmers). According to farmers' reports, their fish production was less dependent on feed dealers' credits (1% of farmers) and fish seed supply (2% of farmers) (Table 5).

3.6. Antibiotics, vitamins, probiotics and growth promoters dispensed at feed dealers

Total 14 feed dealers and 70 farmers who visited feed dealer were

Table 5
Nature of interaction between farmers, feed dealers and other associated partners (N = 672).

Characteristics	Number of fish farms (%)
Presence of interaction between fish farmers and feed dealers	219 (33)
Types of support provided by feed dealers	
Feed supply to the fish farms	219 (33)
Fish seedsupply to the fish farms	16 (2)
Medicine supply to the fish farms	185 (28)
Aquaculture depends on	
Credits from feed dealers	5 (1)
Credits from large fish farms	12 (2)
Credits from hatcheries	5 (1)
Agreements between farmers and feed dealers	184 (27)
Agreements between farmers and large fish farms	7 (1)
Agreements between farmer and hatcheries	5 (1)
No dependency (no financial agreements)	477 (71)

interviewed. During visits to the shops of feed dealers, only vitamins (53%, $n = 37$) were most commonly dispensed to farmers, followed by antibiotics (14%, $n = 10$), probiotics (24%, $n = 17$), and growth promoters (17%, $n = 12$). Among the farmers purchasing antibiotics (n = 10), most were advised by feed dealers (80%, $n = 8$) and oxytetracycline was the main antibiotic dispensed (80%, n = 8). The field team recorded three to eight generic classes of antibiotics at feed dealer shops. Oxytetracycline, ciprofloxacin, amoxicillin, and sulfadiazine were the four most commonly found antibiotics. According to the self-reported data, 80% of feed dealers usually suggest 10–60% of farmers to buy antibiotics. Most feed dealers (86%, n = 12) said they knew about AMR. Of the 70 farmers, 49% farmers ($n = 34$) knew about AMR and 73% farmers ($n = 51$) had no knowledge on antibiotic withdrawal periods. Many feed dealers (50%, $n = 7$) suspected that antibiotics are mixed in commercial fish feed by feed producers despite understanding that antibiotic use in commercial animal feed is banned by the Bangladesh government.

3.7. Factors associated with antibiotic usage in fish farms in the last 14 days preceding the farm visits

The bivariable regression analysis showed that farms located in Cumilla (OR 25.15, 95% CI: 13.95–45.34) and Mymensingh (OR 17.39, 95% CI: 9.84–30.73) were more likely to use antibiotics than those in Bagerhat (Table 6). Farmers that cultured fish in ponds (OR 20.22, 95% CI:5.68–72.01), had occurrence of illness in their fishes (OR 4.35, 95% CI: 2.19–8.63), with no prior exposure to aquaculture training(s) (OR 6.19, 95% CI: 1.21–31.45), with poor knowledge on antibiotics usage (OR 3.18, 95% CI:1.09–9.23) and shorter farming experiences (OR 2.84, 95% CI:1.25–6.48) were more likely to use antibiotics compared to farmers who had not these characteristics (Table 6).

The multivariable regression analysis suggested that farms that had fish experiencing signs of illness (aOR 1.98, 95% CI: 1.21–3.29) in the last 14 days prior of our visits and farms culturing fish in ponds (aOR 9.34, 95% CI: 3.69–23.62) were associated with higher odds of antibiotic usage. The odds were also higher for fish farms located in Cumilla (aOR 20.04, 95% CI: 8.69–46.18), Mymensingh (aOR 12.52, 95% CI: 5.11–30.66), and Jashore (aOR 11.21, 95% CI: 4.88–25.73) compared to farms in Bagerhat district. The final model (χ^2 1.95, $p = 0.7447$, and $R^2 = 0.1083$) seemed to fit the data well (Tables 6).

4. Discussion

This study surveyed a large number of inland freshwater and coastal brackish water fish farms from a wide range of geographical locations in Bangladesh. This study showed that antibiotic usage was not uncommon

Table 6
Factors associated with antibiotic use within the 14 days preceding visits to selected fish farms (N = 672), during March to September 2021, Bangladesh.

Factors	Antibiotic use within last 14 days		OR, 95% CI	*p*	Adjusted OR, 95% CI	*P*
	Yes	No				
Areas, n (%)						
Bagerhat	3 (1)	93 (14)	Ref.		Ref.	
Mymensingh	69 (10)	123 (18)	17.39 (9.84–30.73)	<0.001	12.52 (5.11–30.66)	<0.001
Cumilla	43 (6)	53 (8)	25.15 (13.95–45.34)	<0.001	20.04 8.69–46.18)	<0.001
Jashore	26 (4)	70 (10)	11.51 (5.82–22.79)	<0.001	11.21 (4.88–25.73)	<0.001
Khulna	–	96 (14)	undefined		undefined	
Satkhira	–	96 (14)	undefined		undefined	
Types of water bodies						
Enclosure cultures	3 (1)	157 (23)	Ref.		Ref.	
Pond	138 (21)	357 (53)	20.22 (5.68–72.01)	<0.001	9.34 (3.69–23.62)	<0.001
Both	–	17 (3)	undefined			
Types of aquaculture						
Monoculture	3 (1)	6 (1)	Ref.			
Polyculture	138 (21)	525 (78)	0.52 (0.29–0.97)	0.04		
Presence of illnesses in the fish flock within the last 14 days						
No	64 (10)	416 (62)	Ref.		Ref.	
Yes	77 (11)	115 (17)	4.35 (2.19–8.63)	<0.001	1.98 (1.27–3.1)	0.003
Received training on aquaculture						
Yes	3 (1)	63 (9)	Ref.			
No	138 (21)	468 (70)	6.19 (1.21–31.45)	<0.001		
Knowledge on the purpose of antibiotic use						
Used to treat all diseases	57 (8)	411 (61)	Ref.			
Used to treat bacterial diseases	65 (10)	77 (11)	6.08 (2.62–14.14)	<0.001		
Used to treat viral diseases	19 (3)	43 (6)	3.18 (1.09–9.23)	0.033		
Farmers education						
Graduate	19 (3)	46 (7)	Ref.			
Higher Secondary	18 (3)	50 (7)	0.87 (0.45–1.68)	0.682		
Secondary	76 (11)	231 (34)	0.79 (0.36–1.73)	0.568		
Primary	20 (3)	156 (23)	0.31 (0.11–0.83)	0.02		
Illiterate	8 (1)	48 (7)	0.4 (0.12–1.28)	0.126		
Farming experiences						
> 10 years	56 (8)	350 (52)	Ref.			
5–10 years	54 (8)	113 (17)	2.98 (1.68–5.3)	<0.001		
1–5 years	31 (5)	68 (10)	2.84 (1.25–6.48)	0.013		

Model fit: model $\chi2$ 1.95, p 0.7447 and R^2 0.1083.

in inland aquaculture. The data on antibiotic usage data was collected over different timeframes, i.e. 24 h, 72 h, 14 days preceding our farm visits and over the entire production cycle. To the best of our knowledge, no previous published studies have reported antibiotic usage in aquaculture using similar time frames for Bangladesh. This approach was useful for estimating the frequency or prevalence of antibiotic usage at particular points in time during aquaculture production. This study identified 21% of fish farmers using antibiotics in the last 14 days preceding our farm visit, which was similar to another study (12–34%) conducted in 2008 in Bangladesh [32]. According to other study report, antibiotics usage was higher in koi (climbing perch) farm (15%), followed by pangas (12%), prawn (3%), and carp (3%) [25]. Antibiotic use in aquaculture reported by several studies from other countries was also found extensive. A review from Ronald et al. (2019) showed that 11 of the top 15 fish-producing countries used 67 antibiotic compounds, and 73% of them were oxytetracycline, sulphadiazine, and florfenicol. Among the 15 countries, antibiotics were mostly used in Vietnam (39 antibiotics), followed by China (33 antibiotics) and Bangladesh (21 antibiotics). Majority of these countries (73%) reported to use oxytetracycline, sulphadiazine and florfenicol in aquaculture [33]. A survey on antibiotic usage in freshwater aquaculture conducted in Vietnam revealed that 56% of the farmers are using antibiotic(s) at least once during their production cycle [34]. According to the previous studies reports from Bangladesh, shrimp hatcheries used comparatively more antibiotics than other types of fish farms, varying from 8 to 40% [29,35]. A study from Thailand reported that 74% shrimp hatcheries used antibiotics on a daily basis [36]. Data of antibiotic use in Bangladesh aquaculture collected from this work and from other studies in other countries raises some significant concerns that excessive and improper antibiotic use will accelerate the development of antibiotic resistant pathogens in the aquatic environment, farmed aquatic animals and the people that rely on them. This will lead to higher treatment costs, increased mortality, and reduced productivity.

In the absence of effective regulations, there is a risk for large number of antibiotics including medically important antibiotics becoming available for purchase by fish farmers over the counter without a prescription. Our study identified a diverse class of antibiotics used in aquaculture, including tetracyclines, fluoroquinolones, macrolides, and aminoglycosides, which was in accordance with previous reports in Bangladesh [25,27,29,35,37].

In Bangladesh, a total of 1338 drugs were licensed for veterinary use, out of which 818 (61%) were antimicrobials [37]. The total number of unique generic antimicrobials (antibiotics, antivirals, antifungals, etc.) was 73 and 85% of them were antibiotics [37]. The most common antibiotic classes were fluoroquinolone, tetracycline, penicillin and sulfonamide [37]. Oxytetracycline, ciprofloxacin, amoxicillin, metronidazole, gentamycin, ceftriaxone, a combination drug containing sulphamethoxazole and trimethoprim, doxycycline, neomycin, a combination of benzyl penicillin and procaine penicillin were the top licensed antibiotics [37]. Directorate General of Drug Administration of Bangladesh banned colistin, fosfomycin and azithromycin for veterinary use [38]. Oxytetracycline, amoxicillin, ciprofloxacin, levofloxacin, erythromycin, sulfadiazine, and trimethoprim were the most commonly reported antibiotics in our study. In Thailand, norfloxacin, oxytetracycline, enrofloxacin, and different sulphonamides were commonly used in aquaculture [36]. In the United States of America (USA), only five drugs are legally approved for aquaculture by the Food and Drug Administration (FDA). Among these five drugs, three are antibiotics (oxytetracycline HCL, sulfamerazine, and one combination of sulfadimethoxine and ormetoprim) [39]. The United Kingdom approved oxytetracycline, oxolinic acid, amoxicillin, sarafloxacin, and co-trimazine (trimethoprim-sulphadiazine) for use in aquaculture [7].

Besides antibiotics, a wide range of natural and synthetic products, including lime, salt, potassium permanganate, pesticides, fertilizers, and probiotics are used to treat, prevent diseases and improve water quality [32,40–43]. Our study found that lime, potassium permanganate, and bleaching powder (calcium oxychloride) were commonly used by fish farmers.

The occurrence of disease outbreaks on fish farms is common in Bangladesh. In this study, a substantial number of farmers (29%, n = 192) reported having a history of fish morbidity and mortality on their farms. An earlier study from Bangladesh reported higher fish mortality in small farms (8.7%) compared to large farms (5.6%) with diseases mostly occurring during the winter months, as reported earlier [44]. The common diseases and clinical symptoms reported in Bangladesh aquaculture are white spot disease in shrimp caused by White Spot Syndrome Virus (WSSV), Epizootic Ulcerative Syndrome (EUS) in fishes caused by *Aphanomyces invadans*, red spot disease or rectal/anal protrusion problem, tail and fin rot, Pop-eyes, fungal growth, nutritional diseases, *Argulosis, Lernaeasis, saprolegniasis, streptococcosis*, and gill rot [27,40,44].

Prophylactic and subtherapeutic level use of antibiotics in aquaculture may promote AMR emergence [2,7,45]. Antibiotics are typically used in water and non-metabolized residues and unused antibiotics might flow out to the surrounding environment [27]. In Thailand, the prophylactic use of antibiotics is a common practice by 86% of farmers with 14% of farmers using them on a daily basis [36]. In Vietnam, a study reported that 20% of the small-scale freshwater aquaculture farmers in the upper Mekong Delta, commonly used antibiotics as a prophylactic measure to prevent disease [34]. Our study found evidences of antibiotic use by fish farmers for both therapeutic and prophylactic purposes. Our results are in support with findings from a previous study that reported 12–31% of Bangladeshi fish hatcheries using antibiotics as a preventive measure against disease [35].

Based on our findings from farmers' reports, antibiotics usage was higher in freshwater fish farms compared to brackishwater fish farms. In their study in Bangladesh, Neela et al. (2012) reported that bacterial isolates (*Bacillus* spp., *Pseudomonas* spp., *Staphylococcus* spp., *Acinetobacter* spp., *Brevibacillus* spp., and *Enterobacter* spp.) from freshwater samples collected on shrimp farms showed more resistance against antibiotics than isolates recovered from shrimp brackish water samples [28].

Many factors can influence antibiotic usage in fish farming. Our study showed that fish morbidity and mortality, farming of fish in ponds and in freshwater systems, lack of farmers exposure to aquaculture training, poor farmers knowledge on the purposes of antibiotics, and shorter farming experiences were all associated with more antibiotic being used. Hassan et al. (2021) showed that the number of chemical and biological products used by farmers was found to be positively correlated with high stocking density of fishes [46]. In an assessment study looking at chemical and biological product uses in aquaculture in Bangladesh, Ali et al. (2016) found that lack of knowledge and awareness of farmers on the proper use of chemicals, was a key driver that led to indiscriminate use of chemicals with dosing and method of application, not being followed [25]. In a study conducted by Holmstrom et al. (2003) on shrimp farming in Thailand, 86% of farmers experienced disease outbreaks, many of whom knew very little or nothing about safe antibiotic practices, and 27% of farmers used antibiotics to treat or prevent viral diseases, such as white spot. [36]. Farmers in Vietnam with a higher education level were more likely to give a correct explanation of antibiotic use (OR 16.3, 95% CI: 1.5–180) [34]. >70% of those farmers heard about the risk of AMR, and 20% believed their farm had AMR pathogens [34].

In Bangladesh, veterinary drugs are widely available in animal feed dealers shops and veterinary pharmacies. Farmers can easily purchase antibiotics over-the-counter (OTC) without a prescription from a veterinarian but the Bangladesh national drug policy from 2016, clearly states that no drugs except the ones approved for sell OTC can be dispensed without a prescription from a registered physician and/or veterinarian [47,48]. However, our study revealed that majority of the uses of antibiotics reported by the farmers, were suggested either by the feed dealers or the drug sellers. Although most feed dealers had a basic understanding of the risk of antimicrobial resistance, they still recommend farmers to purchase antibiotics from their shops for business interest. This unauthorized practice may contribute to irrational, over and sub-optimal use of antibiotics in aquaculture. Currently, Bangladesh has no approved standard treatment guideline for fish to guide the rational use of antibiotics [48]. Mixing antibiotics in animal feed is prohibited by law in Bangladesh but in certain situations (e.g. disease outbreaks), the Drug administration of the Government of Bangladesh may approve some antibiotics for use to prepare medicated fish feed pellets with the provision of a veterinarian prescription indicating the nature of the bacterial infection, type of antibiotic to be used, instruction on the safe handling of the antibiotic with accurate dosage information for preparation and clear treatment duration, Indication of the withdrawal periods to be observed by farmers before selling their fish to consumers is also very important.

This study has some limitations. We used purposive sampling instead of random sampling to select fish farms. Limited time and funding did not allow us to conduct a census of all fish farms in each selected upazila to support their random sampling. However, this may not have influenced the study findings as to the farm characteristics and reported antibiotics usage was consistent [32]. The information provided by fish farmers may have been affected by social desirability bias and recall bias for past occurrences (e.g., antibiotic usage in the previous week or month); this may have resulted in underestimating the usage of antibiotics.

In conclusion, the study's findings provide evidence of antibiotic usage in aquaculture production. Unrestricted use of antibiotics for prophylactic purposes increases the risk of developing AMR in the aquatic environment. Good farming practices through improved farm-level biosecurity, routine passive disease surveillance with better disease diagnostics by health professionals will be key to prevent and minimize introduction of pathogens and allow early pathogen identification to rule out bacterial infection as soon as the first unusual mortalities are observed. Enforcement by the national and local authorities to control and monitor antibiotic usage and sale along with education and training of drug sellers, feed dealers and farmers will increase awareness on the risks of AMU and AMR, and will contribute to reduce unnecessary use of antibiotics in aquaculture. Using antibiotics in aquaculture through water needs to be reevaluated carefully, considering that mixing antibiotics in water and spraying them throughout ponds is not a good practice as the antibiotic(s) are less effective because of dilution, leading to accumulation of antibiotic residues and contributing to AMR pool. The national AMR containment plan should have a clear direction or plan for reducing antibiotic use in aquaculture to protect the health of the aquatic environments/animals, aquaculture workers, and consumers.

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Data availability statement

The data of this study are available from the corresponding author upon reasonable request.

Author statement

The authors have read and approved the revised version submitted.

CRediT authorship contribution statement

Sukanta Chowdhury: Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Validation, Visualization, Writing – original draft, Writing – review & editing. **Shafiq Rheman:** Formal analysis, Writing – review & editing. **Nitish Debnath:** Formal analysis, Writing – review & editing. **Jerome Delamare-Deboutteville:** Formal analysis, Writing – review & editing. **Zubair Akhtar:** Formal analysis, Writing – review & editing. **Sumon Ghosh:** Formal analysis, Writing – review & editing. **Shahana Parveen:** Formal analysis, Writing – review & editing. **Khaleda Islam:** Formal analysis, Writing – review & editing. **Md. Ariful Islam:** Formal analysis, Writing – review & editing. **Md. Mahbubur Rashid:** Formal analysis, Writing – review & editing. **Zobaidul Haque Khan:** Formal analysis, Writing – review & editing. **Mahmudur Rahman:** Formal analysis, Writing – review & editing. **Vishnumurthy Mohan Chadag:** Formal analysis, Writing – review & editing. **Fahmida Chowdhury:** Formal analysis, Writing – review & editing.

Declaration of Competing 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.

Data availability

Data will be made available on request.

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