Research in
ISSN : P-2409-0603, E-2409-9325
AGRICULTURE, LIVESTOCK and FISHERIES
An Open Access Peer-Reviewed International Journal

Article Code: 497/2025/RALF
Article Type: Research Article

Res. Agric. Livest. Fish.
Vol. 12, No. 2, August 2025: 319-332.

Detection of Bioavailable Tetracycline Using Whole-Cell Biosensor Bacteria From Fish Ponds In Patuakhali Sadar, Bangladesh

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ARTICLE INFO

Received
24 July 2025

Revised
22 August 2025

Accepted
31 August 2025

Key words:
Antibiotics
Tetracycline
Relative light units
Induction coefficient
Standard curve

ABSTRACT

Aquaculture has widely and successfully used antibiotics due to its rapid expansion. The large-scale use of a wide range of antibiotics, including those that are not biodegradable, ensures their prolonged presence in the aquatic environment. One common class of antibiotics is tetracycline, which is widely used in aquaculture operations to treat diseases. The goal of this study was to detect the concentrations of bioavailable tetracycline from fish ponds in Patuakhali Sadar, Bangladesh. Water samples were collected from 50 fish ponds over 6 months, from February 2024 to July 2024. A whole-cell biosensor, utilizing the biosensor bacterium E. coli K12 pTetLux1, was employed to measure tetracycline concentrations. A luminometer was used to measure Relative Light Units (RLU) to quantify the initial reaction. For both standard solutions and water samples, IC (Induction Coefficient) values were determined, and an identical standard curve was created. Subsequently, the concentration of tetracycline in the water samples was determined by entering their individual IC values into the formula obtained from the standard curve. Antibiotics were indiscriminately used in all the ponds when fish became diseased. Among the 50 sampled ponds, 15 ponds were found below the detection level, and 35 ponds were found to contain tetracycline concentrations within the detection level. The highest concentration, 3036.57 µg/l, was found in a pond of Notun Bazar. The measured tetracycline concentrations ranged from 152.95 to 3036.57 µg/l, indicating the presence of bioavailable tetracycline in different ponds of Patuakhali Sadar, Bangladesh. To fully understand the effects of using antibiotics in aquaculture, more investigation is required.

To cite this article: Shamima S. and M. A. Razzak, 2025. Detection of bioavailable tetracycline using whole-cell biosensor bacteria from fish ponds in Patuakhali sadar, Bangladesh. Res. Agric. Livest. Fish. 12(2): 319-332.

DOI: https://doi.org/10.3329/ralf.v12i2.84210

Introduction

Bangladesh is a country of rivers with a wealth of different types of fisheries and water resources. The country has exceeded the target production of 47.82 lakh metric tons (MT) of fish by 2022-2023. Furthermore, the aquaculture sector helps to provide 60% of the nation's requirements for animal protein. Fish, shrimp, and other fishery products are exported by Bangladesh, which generates a sizeable amount of foreign exchange earnings—0.80% of the country's overall export revenue (DoF, 2023). Bangladesh was ranked third in the world for inland open water capture production and fifth overall for aquaculture production, according to the FAO report The State of World Fisheries and Aquaculture 2018. Bangladesh is currently ranked third in Asia and fourth globally in terms of tilapia production (Nahiduzzaman et al., 2018). The world's largest food production industry, aquaculture, may one day help ensure sustainable food production (Hameed et al., 2022). Bangladeshi aquaculture has advanced, extended, and improved over the past 20 years, and in certain areas of the country, there has been a growing trend toward intensifying cultural practices (Belton and Azad, 2012; Ali et al., 2013). Utilizing synthetic substances and organic goods has become more popular as the aquaculture industry grows and expands (Faruk et al., 2008). One of Bangladesh's most successful and dynamic industries, the fishing sector has a lot of room to grow in the future. Large, diverse fisheries that can be broadly divided into inland and marine fisheries exist in Bangladesh. Inland capture and inland culture are the two subsectors of the 47.07 lakh hectares devoted to inland fisheries. Compared to inland capture, which occupies an area of 38.61 lakh hectares and consists of *beels*, rivers, estuaries, Kaptai Lake, and flood plains, inland culture, which occupies an area of 8.46 lakh hectares, consists of *ponds, ditches, baors,* pen culture, cage culture, shrimp/prawn farms, and seasonal cultured water bodies (DoF, 2023). The most popular fish in Bangladesh include rui, catla, mrigal, and other huge Indian carp. Pangas are highly regarded by fish farmers for their quick growth, straightforward culture system, robust features, high survival rate, ability to withstand high stocking densities, strong disease resistance, and tolerance of a variety of environmental conditions, much like other cultured catfish (Begum et al., 2012).

Drugs and chemicals have been employed for a variety of purposes in recent years, including treating illnesses, lowering metabolic rates, lessening fish excitability, and simplifying the handling of fish. Sick aquatic animals are treated with a wide range of medicinal drugs and aquatic chemicals (Rico et al., 2013). The most significant class of antibiotics is tetracycline-based. In the latter half of the 1940s, the naturally occurring antibacterial agents oxytetracycline and chlortetracycline were first identified. Antibiotics are widely used in agriculture and aquafarming, as well as to treat and prevent infectious diseases in humans and cattle, to improve the development rate and feed efficiency of animals (Cabello, 2006; FDA, 2009; McEwen and Fedorka-Cray, 2002; McManus et al., 2002). After using antibiotics, a significant amount is released into different ecological zones (Zhou et al., 2013). Domestic sewage releases up to 90% of all antimicrobials used in humans and cattle into the environment unmodified (Jjemba, 2006; Lienert et al., 2007). Aquaculture, agriculture, animal husbandry, and human medicine all make extensive use of antibiotics. The widespread use of antibiotics has resulted in their widespread presence in environmental media such as water, soil, and sediment that have been contaminated by sewage sludge, wastewater, animal dung, etc. One important worry is that these antibiotics can cause resistance in native bacteria when exposed to the environment, which can lead to the formation of the environmental resistome and reduce the efficiency of antibiotics in treating bacterial diseases. One of the best ways to slow down the spread of antibiotic-resistant genes and bacteria is to stop antibiotics from being introduced into the environment. Furthermore, a variety of antibiotics have been extensively employed in aquaculture to boost fish yield and stop bacterial infections. Tetracyclines are a class of antibiotics that are widely used in livestock and fish farming, and they are crucial to modern intensive agriculture production. Tetracycline and other antibiotics are often used in aquaculture techniques around the world to prevent and treat illnesses in fish farms (FAO, 2018). However, because of their growing use in aquaculture, worries have been expressed over the possible harm to the environment and public health that could arise from the discharge of these compounds into aquatic habitats (Cabello, 2006). Beyond its effects on the environment, tetracycline use in aquaculture has extensive consequences. According to recent statistics released by the Food and Agriculture Organization of the United Nations (FAO, 2018), the public's health may be affected by antibiotic residues in fish and fish products. Antibiotic resistance and the emergence of antibiotic-resistant bacteria are major issues when tetracycline residues are found in fish that are meant for human consumption.

One of the most popular antibacterial medications in aquaculture systems for sickness control, illness prevention, and in-feed growth stimulation is oxytetracycline (OTC) (Erdogdu, 2012). Modern over-the-counter antibiotics are widely used as preventative measures in freshwater aquaculture in Bangladeshi fish farms because of their many uses, affordability, and accessibility. However, during the treatment of disease in aquaculture techniques, antibiotics cannot be appropriately delivered (Ali et al., 2015). The broad use of antibiotics may result in the indiscriminate accumulation of excessive antibiotic residues in edible fish tissues, which may pose a risk to public health. Antibiotic residues in the human diet could alter the intestine's ecology and promote the growth of resistant microflora (Perrin-Guyomard et al., 2001). Antimicrobial residues in aquatic foods might also result in decreased marketing and export values of aquaculture products (Serrano, 2005). Antibiotic usage control, residual contamination reduction, and antimicrobial resistance (AMR) management must be given top priority in order to assure the safe production of aquatic foods, given the possible health hazards connected to the fishing sector (Hasan et al., 2022). In Bangladesh, the first-ever large-scale nationwide screening of bioavailable tetracyclines using whole-cell bioreporters from pangas and tilapia aquaculture systems was carried out across the Mymensingh, Cumilla, Bogura, Jashore, Feni, Chandpur, Madaripur, Shariatpur, and Sathkhira regions in 2023. But this type of research was not carried out in the Patuakhali region. For this reason, bioavailable tetracyclines were detected using whole-cell biosensor bacteria from fish ponds in Patuakhali Sadar, Bangladesh, where fish farming is an important means of supplying the country's increasing need for fish protein.

Materials and Methods

Study Area

The study was carried out in Patuakhali Sadar, Bangladesh, for a period of 6 months from February 2024 to July 2024.

Sample Collection

Using sterile plastic bottles, water samples were collected from 50 fish ponds. Then the water samples were kept in a freezer at the Fish Pathology and Nutrition Laboratory of the Faculty of Fisheries in Patuakhali Science and Technology University.

Determination of Bioavailable Tetracycline Using Biosensor Bacteria (*E. coli* K12 pTetLux1)

Bioluminescent biosensor bacteria (*E. coli* K12 pTetLux1) were used to detect bioavailable tetracycline.

The Protocol for Assessing Bioavailability of Tetracycline Using *E. coli* K12 pTetLux1 Related to a Series of Steps

Luria Broth (LB) Media Preparation

An electric balance was initially used to quantify yeast, NaCl, and peptone precisely. 10 g each of NaCl, peptone, and yeast were weighed. When the volume reached 1000 ml, the measured amounts were then dissolved in distilled water in a conical flask. To ensure proper dissolution, the solution was heated on a hot plate for a few minutes while being thoroughly agitated. Thereafter, the mixture was autoclaved for 15 minutes at 121°C. With the autoclaved LB media removed, the experiment continued with the next steps after the predetermined autoclaving time.

Ampicillin Solution Preparation

In a flask, 0.001 g of ampicillin powder was dissolved in distilled water to create the ampicillin solution. After that, distilled water was added until 20 ml was the total.

E. coli Culture Media Preparation for Tetracycline

The culture medium for *E. coli* was prepared using a Falcon tube. 25 ml of LB media and 25 µl of the ampicillin solution were added to the Falcon tube and thoroughly mixed. Using an inoculation loop, the *E. coli* K12 bacterial strains were streaked and then combined with the Falcon tube. After giving the mixture's tube a good shake, it was placed in an incubator set to 37°C for the whole night. Following the incubation period, the tube was taken out of the incubator and centrifuged for 10 minutes at 5000 rpm and 20°C. The solid residue, referred to as the precipitate, was resuspended in 20 ml of LB media, and the supernatant—the liquid above the sediment—was discarded. 20 ml of LB medium was mixed with 20 µl of the reconstituted solution. After being moved to an appropriate freezing container, this combination was kept in a freezer under regular freezing conditions.

Preparation of Tetracycline Standard Solution and Water Sample Solution for *E. coli* K12 pTetLux1 Biosensor Assay

Four Falcon tubes were filled with distilled water, with the first tube containing 10 ml and the remaining three tubes containing 9 ml each. In the first tube, 0.01 g of tetracycline was added and mixed well to create a solution with a concentration of 1000 µg/ml. A volume of 1 ml from the first tube was transferred to the second tube and thoroughly mixed, resulting in a concentration of 100 µg/ml. Similarly, 1 ml from the second tube was transferred to the third tube and mixed well, achieving a concentration of 10 µg/ml. Finally, 1 ml from the third tube was added to the fourth tube and mixed thoroughly, giving a concentration of 1 µg/ml. From this prepared solution, a series of standard tetracycline solutions was prepared in Eppendorf tubes.

Procedure for Measuring Bioluminescence

To ensure adequate setup, the GloMax 20/20 luminometer was turned on and calibrated according to the manufacturer's instructions. The software or interface of the luminometer was configured to capture the measurements. The luminometer was either positioned in a darkened space or an enclosure that was light-tight to reduce interference from background light. The standard solution and the water sample solution were removed from the prepared Eppendorf tubes. After making sure the first Eppendorf tube was correctly aligned and the measurement acquisition was started in the luminometer software, the proper integration time and recording parameters were configured. The luminometer sensed and measured the light that the sample released, or bioluminescence. The measurement was left to run during the allotted integration time. For the first sample, the Relative Light Units (RLU) that were acquired using the luminometer software were noted. The initial Eppendorf tube was then taken out of the luminometer chamber and disposed of appropriately. One by one, these procedures were carried out for every additional Eppendorf tube until all samples had been measured. The RLU values for each sample were recorded and kept once all measurements were finished. The recorded data were examined to compare the bioluminescence levels of various samples or in accordance with the experimental specifications. In order to guarantee that the integrity of the instrument was maintained, the luminometer chamber and any accessories were cleaned in compliance with the manufacturer's recommendations.

Statistical Analysis

Microsoft Excel Software 2016 was used to carry out the statistical analysis. The gathered information was coded and then put into a database and examined.

RESULTS

General Characteristics of Ponds

For this experiment, a total of 50 ponds were selected. Most of the fish farmers used commercial pellet feed, and some farmers added mustard oil cake to the pond. Generally, Urea and TSP were used by fish farmers in their ponds. The average age of the ponds was 12.08 years. The average depth of the experimental ponds was 1.68 meters. The water source of most ponds was rainwater. Besides, some farmers depended on deep tube wells to fill their ponds.

RLU Value of Standard Solution and Water Sample Solution

The Relative Light Units (RLU) values obtained from the 12 standard solutions and 50 water samples using the luminometer exhibited variations. The RLU values for the standard solutions ranged from 45 to 98, while the RLU values for the water samples ranged from 48 to 164.

Table 1. RLU value of standard solution

Standard Solution (µg/ml)	RLU (Relative Light Units)
0.5	87
0.4	62
0.3	59
0.2	78
0.15	65
0.1	98
0.075	72
0.05	65
0.025	58
0.0125	76
0.00625	69
0	45

Table 2. RLU value of water sample

Water Sample	RLU (Relative Light Unit)
P-1	69
P-2	67
P-3	104
P-4	67
P-5	69
P-6	86
P-7	67
P-8	74
P-9	134
P-10	164
P-11	71
P-12	99
P-13	84
P-14	143
P-15	77
P-16	59
P-17	72
P-18	88
P-19	53
P-20	90
P-21	68
P-22	67
P-23	99
P-24	71
P-25	86
P-26	91
P-27	48
P-28	65
P-29	79
P-30	75
P-31	77
P-32	71
P-33	71
P-34	64
P-35	58
P-36	83

Table 2. RLU value of water sample (Contd.)

P-37	79
P-38	65
P-39	89
P-40	93
P-41	75
P-42	56
P-43	71
P-44	79
PS-45	74
PS-46	63
PS-47	68
PS-48	70
PS-49	61
PS-50	64

Table 3. Value of IC for standard solution

SL. No.	Standard Solution (µg/ml)	IC
1	0.5	1.93
2	0.4	1.38
3	0.3	1.31
4	0.2	1.73
5	0.15	1.44
6	0.1	2.18
7	0.075	1.60
8	0.05	1.44
9	0.025	1.29
10	0.0125	1.69
11	0.00625	1.53
12	0	1

Values of Induction Coefficient (IC) for Standard Solution

The study determined the values of the Induction Coefficient (IC) for the standard solution. The IC values of the 12 standard solutions were 1.93, 1.38, 1.31, 1.73, 1.44, 2.18, 1.60, 1.44, 1.29, 1.69, 1.53, and 1. These are the matching IC values that were measured for these concentrations. A quantifiable indicator of the induction response produced by the biosensor; these IC values were determined by experimental investigation. Using their IC values, they provide benchmarks for creating a standard curve and formulating a formula to ascertain the tetracycline concentration in unidentified samples.

Standard Curve

A standard curve was created to show how the respective IC values (induction coefficient on the y-axis) and the concentration of tetracycline (standard solution concentration on the x-axis) relate to one another. $y = 78.279x^3 – 59.721x^2 + 12.181x + 1.0002$ was found to be the equation of the standard curve. By entering the unknown samples' IC values into the formula and solving for x, it is possible to estimate the tetracycline concentration in those samples. When calculating tetracycline levels using the IC values from the biosensor analysis, the standard curve is a useful tool.

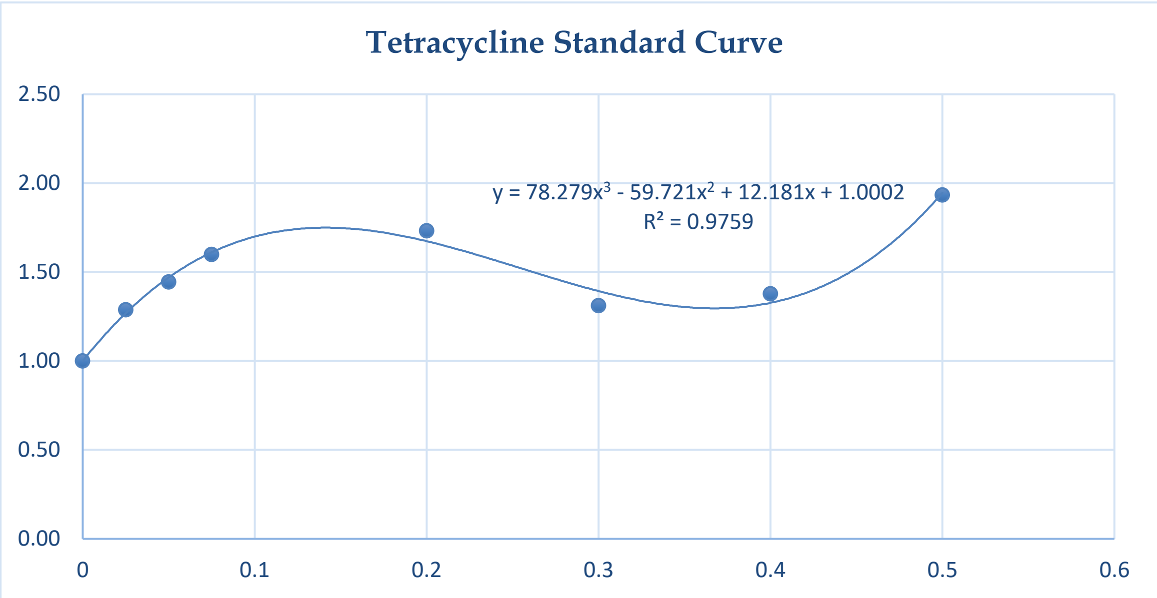

Figure 1. Standard curves for the biosensor assay with *E. coli* K12 (pTetLux1) for tetracycline

Here,

$y = 78.279x^3 – 59.721x^2 + 12.181x + 1.0002$

a= 78.279 b= -59.721

c= 12.181 d= 1.0002

Bioavailable Tetracycline Concentration of Different Ponds

An *E. coli* K12 pTetlux1 whole cell bacterial biosensor was used in a lab setting to measure the bioavailable tetracycline concentrations in 50 ponds. In tables 6 and 7, as well as in figures 4 and 5, the entire situation and comparison analysis of bioavailable tetracycline are displayed. 15 samples were below the tetracycline detection level, while the remaining 35 were within the range. We assumed that the value below the detection limit was 0 (zero) in order to make our calculations easier. The highest concentration, 3036.57 µg/L, was found in a pond of Puran Bazar, and the lowest concentration, 152.95 µg/L, was found in a pond of Kholisakhali and Mithapur. Table 4 provides a summary of the samples' locations, induction coefficients, concentrations, and detection levels.

Table 4. Bioavailable tetracycline concentration of different ponds in Patuakhali Sadar, Bangladesh

Pond	Location	IC	Concentrations (µg/L)	Detection Level
P-1	Chawrasta	1.53	161.26	
P-2	Chawrasta	1.49	0.00	Below detection level
P-3	Chawrasta	2.31	675.48	
P-4	Notun Bazar	1.49	0.00	Below detection level
P-5	Notun Bazar	1.53	161.26	
P-6	Bonanir Mor	1.91	352.06	
P-7	Bonanir Mor	1.49	0.00	Below detection level
P-8	Puran Bazar	1.64	207.36	
P-9	Puran Bazar	2.98	1572.24	
P-10	Puran Bazar	3.64	3036.57	
P-11	Sarkit House	1.58	178.77	
P-12	Sarkit House	2.20	571.44	
P-13	Laker Par	1.87	324.35	
P-14	Kolikapur	3.18	1945.62	
P-15	Boloikathi	1.71	238.84	
P-16	Awliapur	1.31	0.00	Below detection level
P-17	Awliapur	1.60	187.99	
P-18	Bollobpur	1.96	381.31	
P-19	Bollobpur	1.18	0.00	Below detection level
P-20	Bollobpur	2.00	412.13	
P-21	Kholisakhali	1.51	152.95	
P-22	Kholisakhali	1.49	0.00	Below detection level
P-23	Gabua	2.20	571.44	
P-24	Gabua	1.58	178.77	
P-25	Bodorpur	1.91	352.06	
P-26	Bodorpur	2.02	428.15	
P-27	Bodorpur	1.07	0.00	Below detection level
P-28	Bodorpur	1.44	0.00	Below detection level
P-29	Tushkhali	1.76	261.51	
P-30	Tushkhali	1.67	217.52	
P-31	Vojna	1.71	238.84	
P-32	Vojna	1.58	178.77	
P-33	Fultola	1.58	178.77	
P-34	Fultola	1.42	0.00	Below detection level
P-35	Fultola	1.29	0.00	Below detection level
P-36	Tengra Khali	1.84	311.05	
P-37	Tengra Khali	1.76	261.51	

Table 4. Bioavailable tetracycline concentration of different ponds in Patuakhali (Contd.)

P-38	Muslim Para	1.44	0.00	Below detection level
P-39	Muslim Para	1.98	396.52	
P-40	Zila Road	2.07	461.41	
P-41	Zila Road	1.67	217.52	
P-42	Badura	1.24	0.00	Below detection level
P-43	Badura	1.58	178.77	
P-44	Badura	1.76	261.51	
P-45	Majhkhali	1.64	207.36	
P-46	Majhkhali	1.40	0.00	Below detection level
P-47	Mithapur	1.51	152.95	
P-48	Mithapur	1.56	169.87	
P-49	Siyali	1.36	0.00	Below detection level
P-50	Siyali	1.42	0.00	Below detection level

Comparative Study of Bioavailable Tetracycline

A comparative study of bioavailable tetracycline in different ponds in Patuakhali Sadar was done. Samples were categorized into 4 sections. These were below detection, >0 - ≤ 200 µg/L, >200 - ≤ 400 µg/L and > 400 µg/L. Among these, 15 ponds were below the detection limit. The section with concentrations greater than 400 µg/L showed the lowest number of ponds, specifically 9. The section >200 - ≤ 400 µg/L showed the highest number of ponds, and the number was 15. A Comparative study of bioavailable tetracycline in different locations of Patuakhali Sadar is given in Table 5 and Figure 2.

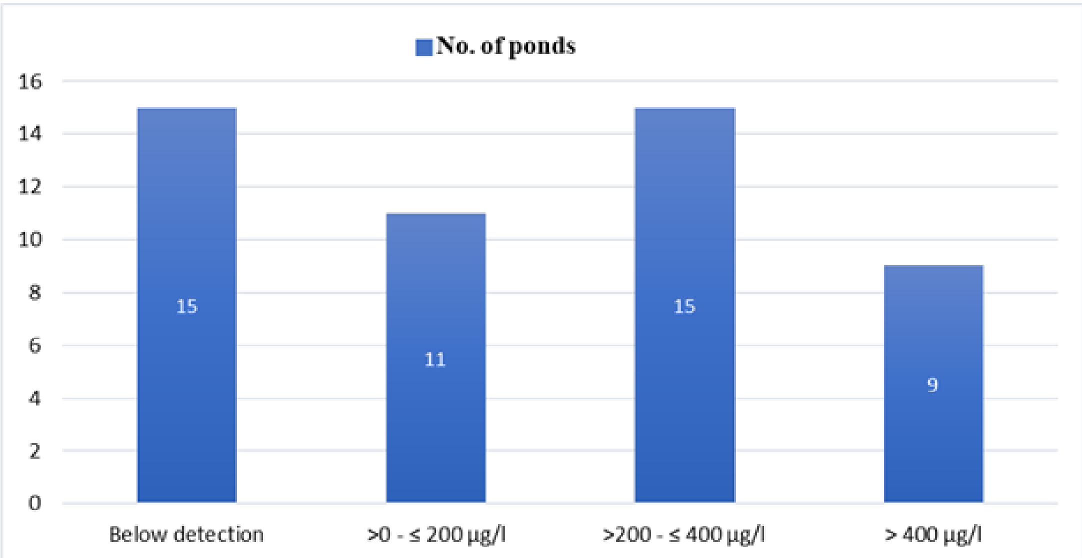

Figure 2. Number of ponds in different detection levels

Table 5. Comparative study of bioavailable tetracycline of different ponds in Patuakhali Sadar, Bangladesh

Detection limit	Below detection	>0 - ≤ 200 µg/L	>200 - ≤ 400 µg/L	> 400 µg/L
No. of ponds	15	11	15	9

Discussion

Antibiotics are the most widely used medications in veterinary medicine; the use of antibiotic therapy in aquaculture has been widespread for more than 60 years (Teh et al., 2020). Many factors, such as the amount and duration of antibiotic treatment, as well as the organism's metabolic processes, might lead to the accumulation of residues of potentially harmful antibiotic compounds in treated aquaculture animals (Carnevali et al., 2018). These residues can remain in edible tissues and may present health hazards to consumers. Furthermore, the identification of antibiotic residues in aquaculture products may raise concerns about food safety, trade barriers, and limitations, which in turn may impact the marketing and export of aquaculture output (Sapkota et al., 2008).

The important factor in evaluating the possible effects of antibiotic use on aquatic environments is the measurement of tetracycline in aquaculture ponds. The levels of tetracycline in the fish pond sampled for this investigation ranged from 152.95 to 3036.57 µg/L. This section will discuss the significance of these findings and their implications for aquatic environments, as well as provide a comprehensive analysis by relating them to relevant studies. The presence of this antibiotic in the aquatic environment is indicated by the measured amounts of tetracycline in the pond. Tetracycline, which is widely used in aquaculture to prevent and cure bacterial infections in farmed fish for its a broad-spectrum antibacterial activity. The detected concentrations fall within the range reported in previous studies, confirming the persistent presence of tetracycline in aquaculture environments (Cheng et al., 2017; Fang et al., 2019; Zhao et al., 2020).

Tetracycline concentrations found in the aquaculture pond prompt worries about possible ecological effects on the aquatic ecology. Tetracycline has been linked to a number of detrimental impacts on aquatic creatures, such as changed behavior, stunted growth, and disturbed reproductive processes (Yuan et al., 2018; Zhang et al., 2019). Moreover, tetracycline used in aquatic systems can stimulate the growth of antibiotic resistance in bacteria, which is extremely concerning for the general public's health (Zhao et al., 2020). The findings of this study emphasize the need for effective strategies to mitigate the release of tetracycline into aquatic environments and reduce its ecological consequences. Comparing the results of this study with other similar investigations conducted elsewhere can help us gain a better understanding of the findings in this study. The value of tetracycline concentration in this study ranged from 152.95 to 3036.57 µg/L, which is higher than Murat and Emine (2016), who found that the highest tetracycline concentration was 50.0±2.5 µg/L in the first week and the lowest was 8.2±0.41 µg/L in the seventh week. In their investigation, the average value of tetracycline concentration was 1.82±3.99 µg/L. Cheng et al. (2017) investigated the presence of tetracycline in aquaculture ponds in a different part of the world and discovered similar amounts between 12.4 to 28.9 µg/L. Tetracycline used in aquaculture settings appears to be a global problem rather than a localized one, based on this consistency. Furthermore, Fang *et al*. (2019) conducted a survey on various aquaculture systems and reported tetracycline concentrations ranging from 9.8 to 34.5 µg/L, providing more evidence that tetracycline contamination is a serious hazard in aquaculture environments. The tetracycline concentrations found in this study are clearly higher than the findings by Zhao et al. (2020). They detected tetracycline concentrations ranging from 18.6 to 32.5 µg/L in aquaculture ponds.

Tetracycline contamination in aquaculture environments is widespread, as these results highlight and are in accord with other studies. The implications of these findings extend to ecological concerns, such as potential adverse effects on aquatic organisms and the development of antibiotic resistance. It is crucial to adopt effective strategies to reduce tetracycline emission into aquatic ecosystems and lessen its negative effects on the environment, public health, and aquaculture farms.

Conclusion

Large doses of antibiotics, especially tetracyclines, are used extensively in the aquaculture sector of Bangladesh to treat and prevent disease. This investigation was conducted in Patuakhali Sadar, Patuakhali. The analysis of water samples from 50 fish ponds in the research area provided crucial information about the quantities of bioavailable tetracycline. Among the 50 ponds that were sampled, 15 (30%) were below the detection limit, and the other 35 (70%) had values that were within the limit. The amounts of tetracycline that were detected varied between 152.95 to 3036.57 µg/L. These results show that the fish ponds of the Patuakhali Sadar, Bangladesh, contain bioavailable tetracycline.

Through surface runoff, this may have an impact on terrestrial ecosystems in addition to the aquatic environment. Moreover, antibiotic residues—like those of tetracycline—may be harmful to human health. Consumers of aquaculture products may be exposed to these antibiotic residues in the food chain, which can have unfavorable consequences. It is obvious that immediate action is required to address the negative effects of the extensive and unchecked use of antibiotics in aquaculture. It is the joint duty of governments, farmers, and aquaculturists to guarantee the prudent use of antibiotics. This entails putting appropriate dosing procedures into place, keeping an eye on antibiotic residues, and advocating for substitute methods of illness prevention and control in aquaculture.

To properly grasp the long-term effects of antibiotic use in aquaculture, more investigation is required. Extensive research is needed to address the environmental impacts, dynamics of antibiotic resistance, and threats to human health posed by aquaculture operations. In aquaculture, safer and more efficient antibiotic substitutes must also be developed and implemented. Probiotics, vaccinations, better hygiene habits, and methods of preventing illness that lessen the need for antibiotics could all be part of this. The long-term health and well-being of aquatic ecosystems, human consumers, and the general integrity of the environment are all dependent on sustainable and responsible aquaculture operations, as these data highlight. We can work to create a stronger and more sustainable aquaculture sector in Bangladesh and elsewhere by overcoming the issues raised by the use of antibiotics in aquaculture.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgements

The authors are profoundly grateful to the Research and Training Centre (RTC) of Patuakhali Science and Technology University for the financial support to conduct the research work. The authors also wish to thank the competent authority, as well as all the officials and laboratory staff of the Department of Aquaculture, Faculty of Fisheries, Patuakhali Science and Technology University.

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