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Widespread Use of Antibiotics, Pesticides, and Other Aqua-Chemicals in Finfish Aquaculture in Rajshahi District of Bangladesh

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Abstract: Aquaculture is the fastest-growing, most dynamic, and vital food-producing sector compared to other food-producing industries. However, aquaculture production is hampered by a variety of bacterial, viral, fungal, and parasitic diseases. Fish farmers routinely apply various types of aqua-chemicals, particularly antibiotics and pesticides, to reduce the disease burden. Antibiotics and pesticides are widely used to increase fish production around the world, including Bangladesh. Between March 2020 and February 2021, a survey was conducted via face-to-face interviews with fish farmers in the Rajshahi district, Bangladesh, to determine the current status of the use of antibiotics, pesticides, and other aqua-chemicals in the rearing of freshwater finfishes. Nine active antibiotics ingredients belonging to 11 trade names of antibiotics, various pesticides, numerous disinfectants, and aqua-chemicals were found to be used in finfish rearing. The renamycin (active ingredient: oxytetracycline) was most commonly used antibiotics by freshwater finfish farmers in the study areas. In case of pesticides, sumithion and timsen were found to be used mostly by fish farmers. In addition, four distinct probiotics were found to be used in aquaculture in the study areas. The present study revealed several issues related to the use of aqua-drugs in the study areas. For instance, the majority of fish farmers (88%) lacked knowledge in the use of aqua-chemicals and antibiotics, and 81% of fish farmers were unaware about the effective dosages of chemicals in fish farming. Thirty seven percent of fish farmers in the study areas reported the indiscriminate use of chemicals. Furthermore, a considerable proportion of fish farmers (72%) reported ignorance about the residual effects of the aqua-chemicals on the aquatic environment and human health. As a result, this preliminary study suggests that the use of antibiotics, pesticides, and other aqua-chemicals in aquaculture should be strictly monitored and controlled by the responsible authorities of Bangladesh. Moreover, further research needs to be expanded on the detection of residues from aqua-drugs and antibiotics in the aquaculture system, and their consequences on the ecosystem and human health.

Keywords: aquaculture; antibiotics; pesticides; aqua-chemicals; probiotics; fish health management; diseases; impacts; awareness

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1. Introduction

Bangladesh is the fastest-growing country in aquaculture production compared to other food-producing sectors. Currently, Bangladesh is placed in fifth position in world aquaculture production [1] and produced 26.39 lakh tons in 2020–2021 [2]. Over the past two decades, the aquaculture sector of Bangladesh has grown, diversified, and adopted advanced technology and new aquaculture techniques [3–5]. With the expansion and

strengthening of the aquaculture sector, there has been a growing demand for the use of antibiotics, pesticides, and other aqua-chemicals [6].

Aqua-chemicals are mainly applied for the prevention and treatment of bacterial, fungal, and parasitic diseases, to improve water quality, to increase the productivity of fish culture ponds, or to act as growth promoters [7–10]. Although the use of these chemicals can contribute to the growth and development of the aquaculture sector, it has been criticized for its potential adverse effects on the environment, as well as on human health [9,11–18]. More specifically, residues from the aqua-chemicals that can be transmitted via the food chain to the human body may possess significant health implications, including neurological, respiratory, gastrointestinal, and reproductive complications [19–21]. Moreover, the excessive use and misuse of the antibacterial substances, and their presence as residues in food-borne organisms, would contribute to the selection of antimicrobial-resistant bacteria [22,23]. The potential ecological risk due to the residues of antibiotics has also been reported in several studies [24,25].

Aquaculture, mainly finfish culture, has recently become popular in different regions of Bangladesh, particularly in the Rajshahi district. Rajshahi is one of the districts in Bangladesh that produces a high quantity of fish, and it reached sixth place in pond-based aquaculture production in Bangladesh [2]. During the period 2020–2021, approximately 63.40 thousand tons of fish, the second-highest in the Rajshahi division after the Bogura district, were produced in the pond-based aquaculture system in Rajshahi [2]; this was equivalent to 3.03% of the total pond-based aquaculture production of Bangladesh. Farmers in this area generally use different kinds of aqua-chemicals for various purposes. In Bangladesh, approximately 400 different aquaculture chemical products are produced and commercialized by around 100 pharmaceuticals companies [26]. Occasionally, some pharmaceutical companies' representatives encourage the farmer to use their products. However, there is minimal knowledge of the number of active ingredients of antibiotics, pesticides, and other chemicals used in different aquaculture production systems and regions of Bangladesh [27]. Only a few studies reported the aqua-drugs, chemicals, and antibiotics used in the aquaculture systems in some regions of Bangladesh, including Bogura [28], Chandpur and Cumilla [29], Feni [30], Khulna [31], Moulvibazar [32], Mymensingh [33], Narsingdhi [34], Noakhali [35], Patuakhali [36], Rangpur [37], and Satkhira [38] districts. The number and types of aqua-chemicals used in aquaculture can vary in the regions depending on the culture system and culture species [39]. Despite the considerable contribution of the Rajshahi district to the pond-based aquaculture production of Bangladesh, few researchs have addressed the issue of the indiscriminate use of different aqua-drugs, chemicals, and antibiotics in the finfish polyculture of this region. Therefore, the present study was conducted to determine the current state of the use of antibiotics, pesticides, and other aqua-chemicals in finfish aquaculture in Rajshahi district, the northwest region of Bangladesh.

2. Materials and Methods

2.1. Study Area

Rajshahi, in the northwest region of Bangladesh, is one of the areas that produce a large quantity of fish and is identified as having high concentrations of aquaculture operation [2]. The present study was carried out in three survey stations, namely, Bagmara (24.5970° N, 88.8311° E), Durgapur (24.4451° N, 88.7710° E), and Puthia (24.3750° N, 88.8500° E) upazilas in the Rajshahi district (Figure 1), where farmers usually follow the polyculture (around 95% fish farmer) technique in fish farming.

Carps, mainly the Indian major carp (e.g., *Labeo rohita*, *Gibelion catla*, *Cirrhinus cirrhosus*) and Chinese carp (e.g., *Hypophthalmicthys molitrix*, *Ctenopharyngodon idella*) are the most common cultivated species (Table 1) in the studied areas.

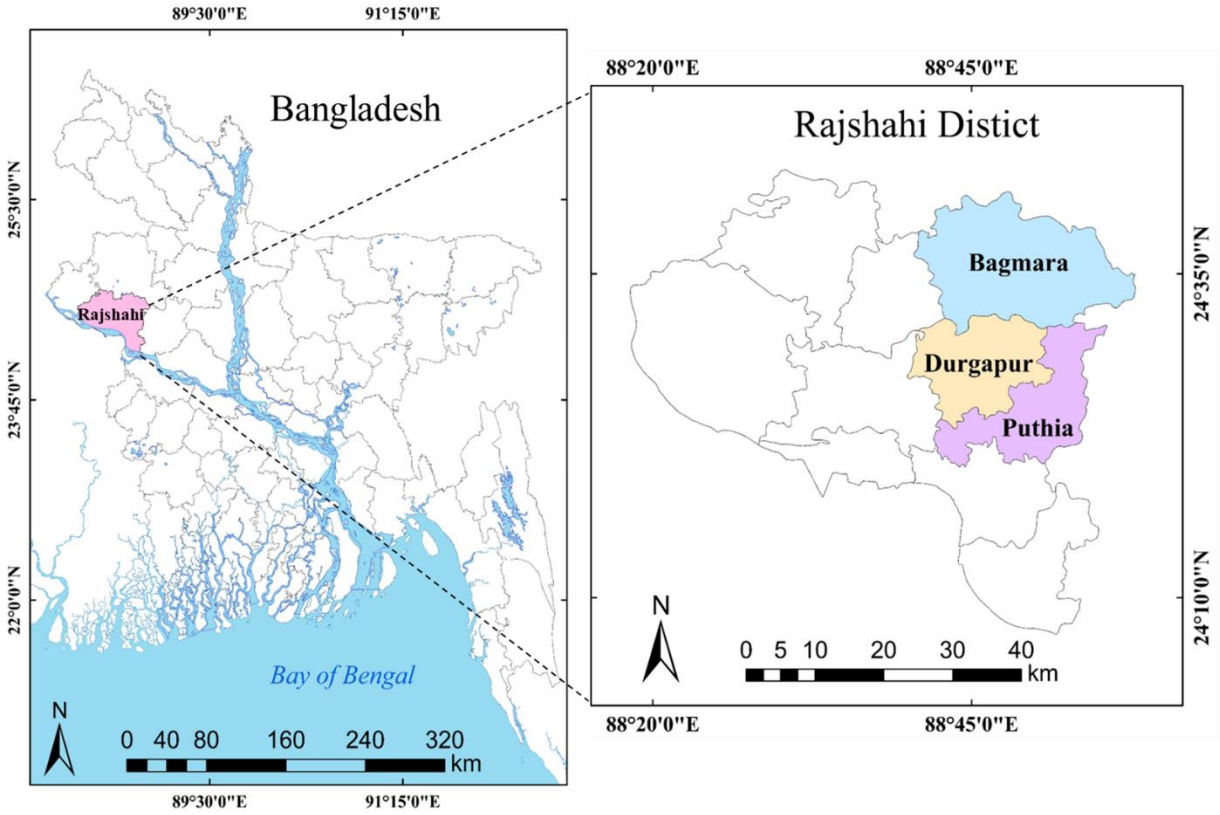

Figure 1. Sampling stations (color-filled) of the study areas in Rajshahi district, Bangladesh.

Table 1. List of fish species commonly cultured in the study areas.

Local Name	Common Name	Scientific Name
Bata	Bata	*Labeo bata*
Bighead carp	Bighead carp	*Hypophthalmicthys nobilis*
Common carp	Common carp	*Cyprinus carpio*
Ghainna	Kuria labeo	*Labeo gonius*
Grass carp	Grass carp	*Ctenopharyngodon idella*
Kalibaus	Orangefin labeo	*Labeo calbasu*
Katol	Catla	*Gibelioncatla*
Mrigel	Mrigal	*Cirrhinus cirrhosus*
Pangas	Striped catfish	*Pangasianodon hypophthalmus*
Rui	Rohu	*Labeo rohita*
Silver carp	Silver carp	*Hypophthalmicthys molitrix*
Tengra	Catfish	*Mystus gulio*
Thai punti	Silver barb	*Barbonymus gonionotus*
Tilapia	Tilapia	*Oreochromis mossambicus*

2.2. Data Collection

A questionnaire is widely employed in research to collect qualitative and quantitative information about a topic of interest. Dworkin [40] recommended that a minimum of 25–30 respondents are required to reach saturation in studies that use face-to-face interviews. In this research, we targeted 100 farmers from 100 different fish farms of three selected upazilas, to interview. Therefore, 33 fish farmers from Durgapur upazila, 33 from Puthia upazila, and 34 from Bagmara upazila were randomly selected to reach our targeted sample size (n = 100). Before the face-to-face interview, each fish farmer was informed about the purpose of this current study and how their information would be used and protected. We first sought the farmers' permission to use their information for research purposes, and then proceeded to collect the information based on the questionnaire. Pre-testing is an

essential step in constructing questionnaires, and it is also critical in collecting good-quality data [41]. Therefore, to verify the appropriateness of the prepared questionnaire, pre-testing was conducted with 10 farmers (10% of the total sample size) to obtain appropriate answers to the questions included in the questionnaire. After collecting the data from the pre-testing of the questionnaire, we revised the questionnaire slightly. A simple random sampling method was chosen for the face-to-face interviews. In addition, focus group discussions were conducted with chemical sellers, technical service personnel, and representatives of different fish feed and pharmaceutical companies in the study areas to validate the information, particularly the information about the brand name, active ingredients, and manufacturing company of aqua-chemicals and antibiotics, and the unit price (in taka) of chemicals, which was gathered from the fish farmers during the interviews. Finally, some information obtained during the face-to-face interviews, direct field observations, and focus group discussions, were used to support several points in the discussion section.

2.3. Data Analysis and Presentation

All of the data were collected, accumulated, and analyzed in the Microsoft Excel version, 2019, and then tabular and descriptive statistical method were used to show the findings of the study. Mostly, the number of antibiotics, pesticides, and other aqua-chemicals used for various purposes (e.g., to control fish diseases, improve the water quality of fish farm, increase fish growth etc.) in aqua-farms, along with their trade or brand names, active ingredients, application doses, manufactures name, and unit prices, were presented in the summery tables. Aligning with the objectives of the study, simple bar diagrams were also prepared to display what proportion (%) of fish farmers in the investigated areas utilized a certain aqua-chemicals.

3. Results

3.1. Antibiotics Used to Treat Infectious Diseases

Nine different types of active antibiotic ingredients, namely amoxicillin, ciprofloxacin, doxycyline, erythromycin, levofloxacin, neomycin, oxytetracycline, sulfadiazine, and trimethoprim, belonging to 11 different trade names were found be used in the study areas to control the bacterial diseases; these are shown in Table 2. Mostly, farmers were found to be using different antibiotics in the carp fish (e.g., *Gibelion catla*, *Labeo calbasu*, *L. rohita* etc.) culture system to treat various bacterial diseases. However, micronid were found to be used with fish feed, particularly in Pangas (*P. hypophthalmus*) and Tilapia's (*O. mossambicus*) culture ponds, to treat ulcerative lesions in skin, fin erosion, and gill necrosis. Among the fish farmers interviewed, the present study found that renamycin (45%) was the most commonly used antibiotic followed by oxysenthin-20% (9%), ranamox (8%), and ciproflox (7%), in the study areas (Figure 2). Some other antibiotics with trade name micronid, neomin-50, renaflox, cipro-A vet, levoflox, oxy-D vet, and renatrim, were used to a lesser extent.

3.2. Use of Pesticides and Other Chemicals to Treat Diseases

The list of pesticides and other chemicals that were found by this study and their active ingredients, doses, sources, and approximate prices, are shown in Table 3. Of the 100 fish farmers interviewed, sumithion (44%), timsen (35%), and acimec-1% (26%), were mostly used by the fish farmers in the study areas (Figure 3). The study found that various pesticides with cypermethrin or deltamethrin as active ingredient were used in the study areas to control a variety of harmful aquatic insects, including backswimmer, damselfly, dragonfly nymph, water boatman, and water scavenger beetle. The fish farmers in the study areas mostly used the argulex and corolux in carp polyculture ponds to control the Argulosis. Moreover, it was found that deletix was used (but to a lesser extent) to control *Argulus* infestations (Table 3). In addition to pesticides, other chemicals such as salt (77%), lime (51%), and potash (30%), were the widely used chemicals found in the Durgapur, Bagmara, and Puthia regions of Rajshahi (Figure 3).

Table 2. Availability of different antibiotics and their uses in fish farming for the treatment of infectious disease of cultured fish at Rajshahi district of Bangladesh.

Serial No.	Brand Name	Active Ingredients	Dose	Host Fish Species	Name of the Disease Symptoms	Producers	Price *
1	Cipro-A vet	Ciprofloxacin	0.05 mL/1–2 kg feed	All carp species, *P. hypophthalmus*, *O. mossambicus*	Fins and tails erosions, discoloration and disintegration	ACME Laboratories Ltd., Dhaka, Bangladesh	540/100 mL (6)
2	Ciproflox	Ciprofloxacin hydrochloride	250 mg/1–2 kg of feed	All carp species, *P. hypophthalmus*	Fin erosion, gill necrosis	SK+F Ltd., Dhaka, Bangladesh	1050/kg (11.67)
3	Levoflox	Levofloxacin	6.61 mg/L of water for 3–5 days	All carp species	Skin necrosis, gill, fin erosion	Drug International Limited, Dhaka, Bangladesh	300/20 piece (3.33)
4	Micronid	Erythromycin, Sulfadiazine, Trimethoprim	5000 mg/kg feed for 3–5 days	*P. hypophthalmus* *O. mossambicus*	Ulcerative lesions in skin, fin erosion, gill necrosis	Renata Limited, Dhaka, Bangladesh	362/100 g (4.02)
5	Neomin-50	Neomycin sulphate	500 mg/1–1.5 L of water	All carp species	Skin necrosis	Local supplier	294/100 g (3.27)
6	Oxy-D vet	Oxytetracycline-20% Doxycyline-10%	5000–10,000 mg/kg body weight of fish for 5–7 days	All carp species	Gill, fin and skin necrosis	Eon Animal Health Products Ltd., Gazipur, Bangladesh	170/100 g (1.89)
7	Oxysenthin-20%	Oxytetracycline HCl BP	500–1000 mg/kg feed	All carp species	Fins and tails erosions, discoloration and disintegration	Novartis (Bangladesh) Ltd., Dhaka, Bangladesh	965/kg (10.72)
8	Ranamox	Amoxicillin trihydrate	300–400 mg/kg feed	*P. hypophthalmus*	fin erosion, gill necrosis	Renata Limited	140/100 g (1.56)
9	Renaflox	Ciprofloxacin hydrochloride	500 mg/1–1.5 L water	*P. hypophthalmus*, All carp species	Fin erosion, rotting gill filament	Renata Limited	250/100 g (2.78)
10	Renamycin	Oxytetracycline	300–420 mg/kg feed	All carp species	Gill, fin and skin necrosis, Ulcerative lesions in skin	Renata Limited	82/100 g (0.91)
11	Renatrim	Sulfadiazine, Trimethoprim	3–5 mL/kg feed for 3–5 days	*P. hypophthalmus*, All carp species	Ulcerative lesions in skin, fin bleeding at the base of the fins, gill necrosis	Renata Limited	1440/100 mL (16)

* Values outside the parentheses shows the price in taka, and the value inside the parentheses indicates the price in USD (1 USD = 90 BDT).

3.3. Aqua-Chemicals Used as Disinfectant

The present study found that 18 different types of disinfectant were used in the three study areas of Rajshahi (Table 4). Timsen (63%), followed by bleaching powder (48%), and benzalkonium chloride (BKC, 27%), were used mostly as disinfectants in the study areas (Figure 4). Other disinfectants (e.g., pathonil, micronil, protect life, polgard, virocid, etc.) were used with only a small percentage.

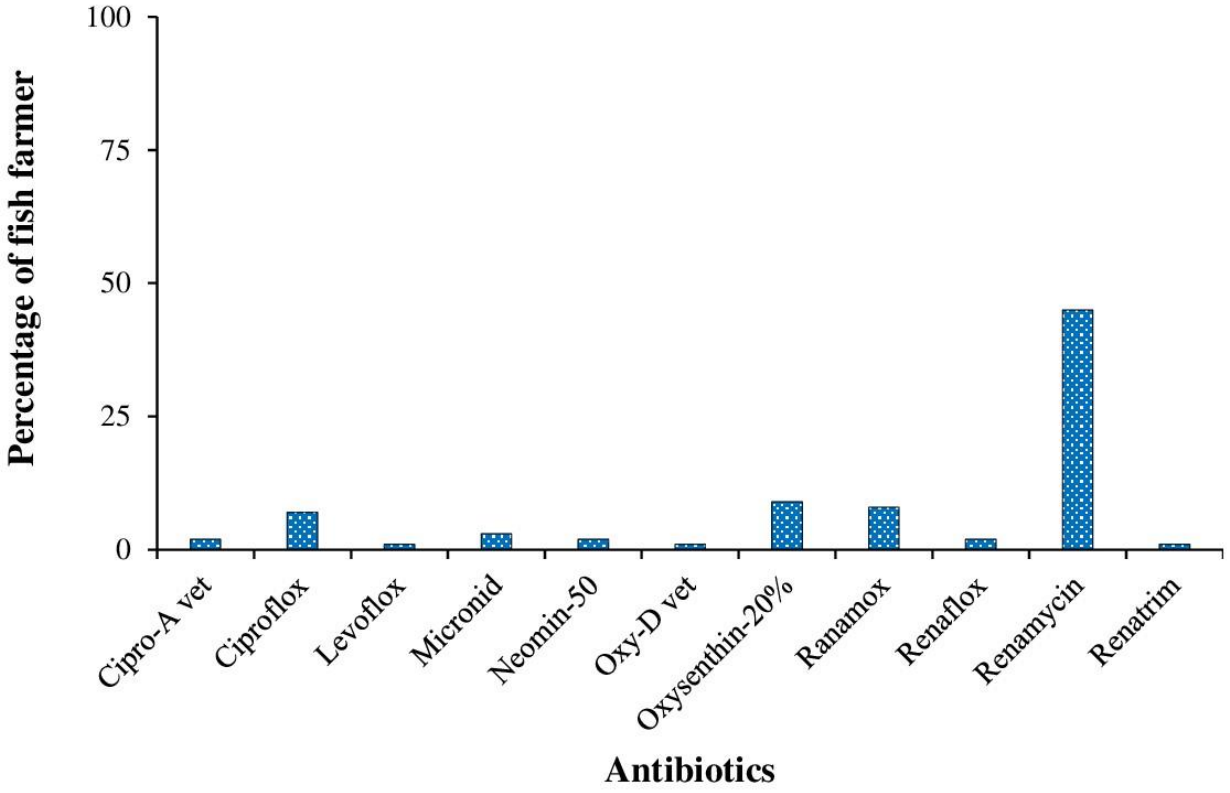

Figure 2. Percentage of the fish farmers (n = 100) used different antibiotics in fish farming at Rajshahi district of Bangladesh.

Table 3. List of pesticides and other chemicals used by fish farmers at Rajshahi district including their active ingredients, application doses, unit prices and purpose of uses in fish farming.

Serial No.	Brand Name	Active Ingredients	Dose	Producers	Price *	Purpose of Use
1	Acimec-1%	Ivermectin	0.4 mg/kg of body weight	ACI Animal Health, Dhaka, Bangladesh	923/kg (10.26)	To control the ectoparasitic (e.g., copepods) infestations
2	Angreb	Cypermethrin	0.42 mL/decimal	Eon Animal Health Products Ltd.	130/100 mL (1.44)	To control the various aquatic insects like Backswimmer, Damselfly, Dragonfly nymph, Water boatman, water scavenger beetle
3	Antistress	L ascorbic polyphosphate, citric acid	2000–3000 mg/kg feed	Fishtech (BD) Limited, Dhaka, Bangladesh	100/kg (1.11)	This chemical relieve stress and increase disease resistance.
4	Bicothrin	Cypermethrin	1 mL/L water	Bismillah Corporation Ltd., Dhaka, Bangladesh	70/50 mL (0.78)	To control the various aquatic insects like Backswimmer, Damselfly, Dragonfly nymph, Water boatman, Water scavenger beetle
5	Corolux	Quinalphos	6.07 mL/decimal	Corbel International Ltd., Dhaka, Bangladesh	365/400 mL (4.06)	Specially used to control *Argulus* infestation

Table 3. *Cont.*

Serial No.	Brand Name	Active Ingredients	Dose	Producers	Price *	Purpose of Use
6	Cyperin	Cypermethrin	50–400 mg/L	Square Pharmaceuticals Ltd., Dhaka, Bangladesh	115/100 mL (1.28)	To control the various aquatic insects like Backswimmer, Damselfly, Dragonfly nymph, Water boatman, water scavenger beetle
7	Deletix	Deltamethrin	0.25–0.30 mL/decimal	Fishtech (BD) Limited	255/100 mL (2.83)	To control Argulosis and to kill other aquatic insects
8	Energy plus	Dextrose anhydrous USP 98% and ascorbic acid BP 2%	1000–2000 mg/L water	ACI Animal Health	140/500 g (1.56)	This chemical is used as stress controller
9	Fatah	Potassium peroxymonosulfate triplesalt, Sodium dodecyle benzene sulfonate, NaCl	606–758 mg/decimal	Intefa, Dhaka, Bangladesh	265/50 g (2.94)	Used as disinfectant
10	Fifenon	Deltamethrin, Ethion	606–758 mg/decimal	Local supplier	1175/kg (13.06)	To control the various aquatic insects like Backswimmer, Damselfly, Dragonfly nymph, Water boatman, water scavenger beetle
11	Fishmethrin	Deltamethrin	250–300 mg/decimal	Local supplier	225/100 g (2.5)	To control the various aquatic insects like Dragonfly nymph, Water boatman, Water scavenger beetle (at low dose)
12	Argulex	Trichlorfon 40%	250 mg/decimal	Eon Animal Health Products Ltd.	1500/kg (16.67)	Mainly used in carp polyculture ponds to control Argulosis
13	Lime	$CaCO_3$, $Ca(OH)_2$, CaO	1–2 kg/decimal	Local Supplier	20/kg (0.22)	To maintain the pH of water and also used as disinfectant
14	Malathion	Active malathion	5 mL/decimal	Shetu Corporation Ltd., Rajshahi, Bangladesh	63/100 mL (0.7)	To kill harmful insects (to a lesser extent)
15	OSSI-C	Oxolinic Acid, Beta glucan, Vitamin C	4000–5000 mg/kg feed	Fishtech (BD) Limited	380/100 g (4.22)	Used as vitamins to improve the immunity of the fish
16	Potash	$KMnO_4$	10,000 mg/decimal	Local supplier	190/kg (2.11)	To control bacterial and fungal infections and to treat common fish pathogens
17	Ripcord	Cypermethrin	1 mL/L water	BASF Bangladesh Limited, Dhaka, Bangladesh	150/100 mL (1.67)	To eradicate insects from fish culture ponds
18	Salt	NaCl	0.5–1 kg/decimal	Local supplier	15/kg (0.17)	Used as disinfectant
19	Sumithion	Fenitrothion	6–7 mL/decimal	Shetu Corporation Ltd.	142/100 mL (1.57)	To kill harmful aquatic insects
20	Timsen	n-alkyl dimethyl benzyl ammonium chloride 40%, stabilized urea 60%	2424.25 mg/decimal (for treatment)	Eon Animal Health Products Ltd.	261/50 g (2.90)	To prevent and eliminate pathogens in cultured fish

* Values outside the parentheses shows the price in taka, and the value inside the parentheses indicates the price in USD (1 USD = 90 BDT).

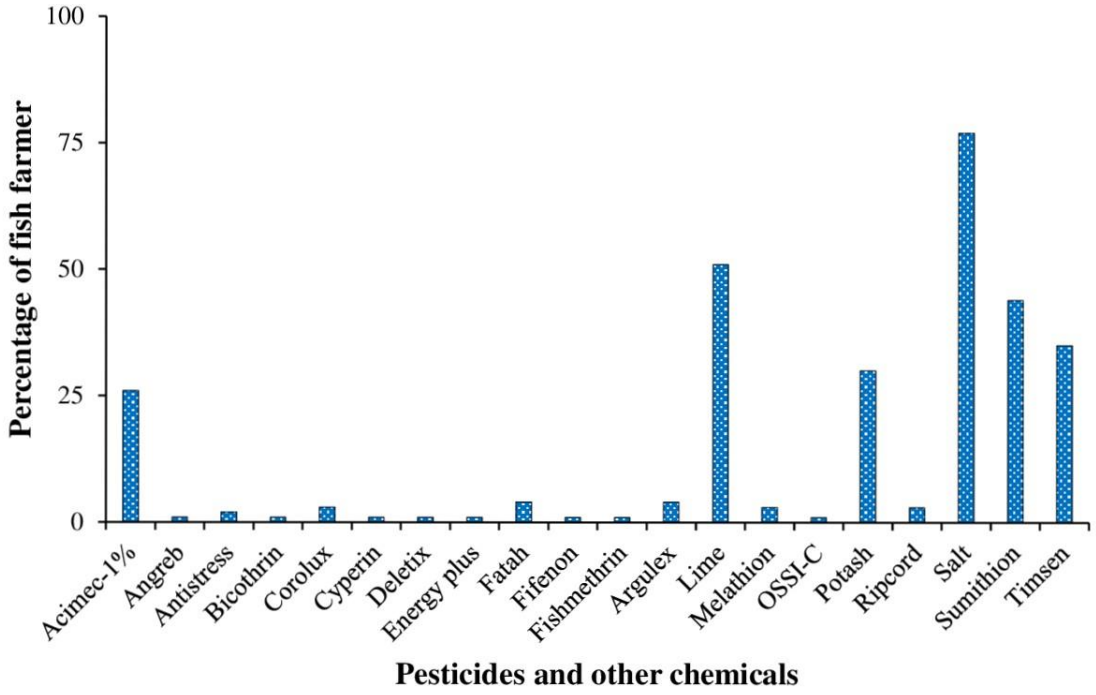

Figure 3. Proportion of fish farmers (n = 100) used various pesticides and other chemicals in fish farming at Rajshahi district of Bangladesh.

Table 4. List of chemicals used as disinfectants at Rajshahi district of Bangladesh.

Serial No.	Brand Name	Active Ingredients	Dose	Producers/Suppliers	Price *
1	Aquakleen	Tetradesail Tri-methyl Amonium bromid, BKC	5–10 mL/decimal	Square Pharmaceuticals Ltd.	330/L (3.67)
2	BKC	Benzalkonium chloride	0.5 mg/L	Mita Chemical Suppliers, Dhaka, Bangladesh	1550/kg (17.22)
3	Bleaching powder	Chlorine	0.1–1 mg/L	AZM Chemical Industry Ltd., Dhaka, Bangladesh	55/kg (0.61)
4	Eon CTC	Efinol	5000–8000 mg/L	Eon Animal Health Products Ltd.	1600/kg (17.78)
5	Fam-30	Iodine, non-ionic surfectant, phosphoric acid, sulfuric acid	3.03 mL/decimal	Renata Limited	103/100 mL (1.14)
6	Germnil	BKC 50% with Glutaraldehyde	4–5 mL/decimal	NAAFCO Pharma Ltd., Mymensingh, Bangladesh	260/100 mL (2.89)
7	GPC-8	Iodine, non-ionic surfectant, phosphoric acid, gluteraldehyde	3.03 mL/decimal	Renata Limited	110/100 mL (1.22)
8	Micronil	BKC	6.06 mL/decimal	SK+F Ltd.	270/100 mL (3.00)
9	Miras	BKC 80%	6.06 mL/decimal	Intefa	265/100 mL (2.94)
10	Pathonil	BKC 80%	6.06 mL/decimal	ACI Animal Health	253/100 mL (2.81)
11	Polgard	3 methyl,4 alkyl two chain brominated halogen compound, potentizers, buffers, stabilizers, emulsifiers	0.5 mL/L/decimal	Fishtech (BD) Limited	500/200 mL (5.56)

Table 4. *Cont.*

Serial No.	Brand Name	Active Ingredients	Dose	Producers/Suppliers	Price *
12	Potash	$KMnO_4$	5–15 mg/decimal	Brenntag Bangladesh Ltd., Dhaka, Bangladesh	190/kg (2.11)
13	Protect Life	Glutaraldehyde-15%, Alkyl benzyl dimethyl ammonium chloride-20%, (Quaternary ammonium compound)	3.50–4.50 mL/decimal	Local supplier	120/100 mL (1.33)
14	Salt	NaCl	0.5–1 kg/decimal	Local supplier	15/kg (0.17)
15	TH4	Didecyldimethylammonium chloride, Dioctyldimethylammonium chloride, Octyldecyldimethylammonium chloride, Alkyl dimethyl benzyl ammonium chloride, Glutaraldehyde, Terpin & Pine oil QS	10 mL/L	Century Agro Ltd., Dhaka, Bangladesh	1098/L (12.20)
16	Timsen	n-alkyl dimethyl benzyl ammonium chloride 40%, stabilized urea 60%	606 mg/decimal (for prevention), 2424 mg/decimal (for treatment)	Eon Animal Health Products Ltd.	261/50 g (2.90)
17	Virex	Potassium peroxymono sulphate 50%	3030–6060 mg/decimal	ACI Animal Health	110/100 g (1.22)
18	Virocid	Querternary ammonia, glutaraldehyde, isopropanol, buffering agents	2.5–5 mL/L water	CID Lines, Ypres, Belgium	198/100 mL (2.20)

* Values outside the parentheses shows the price in taka, and the value inside the parentheses indicates the price in USD (1 USD = 90 BDT).

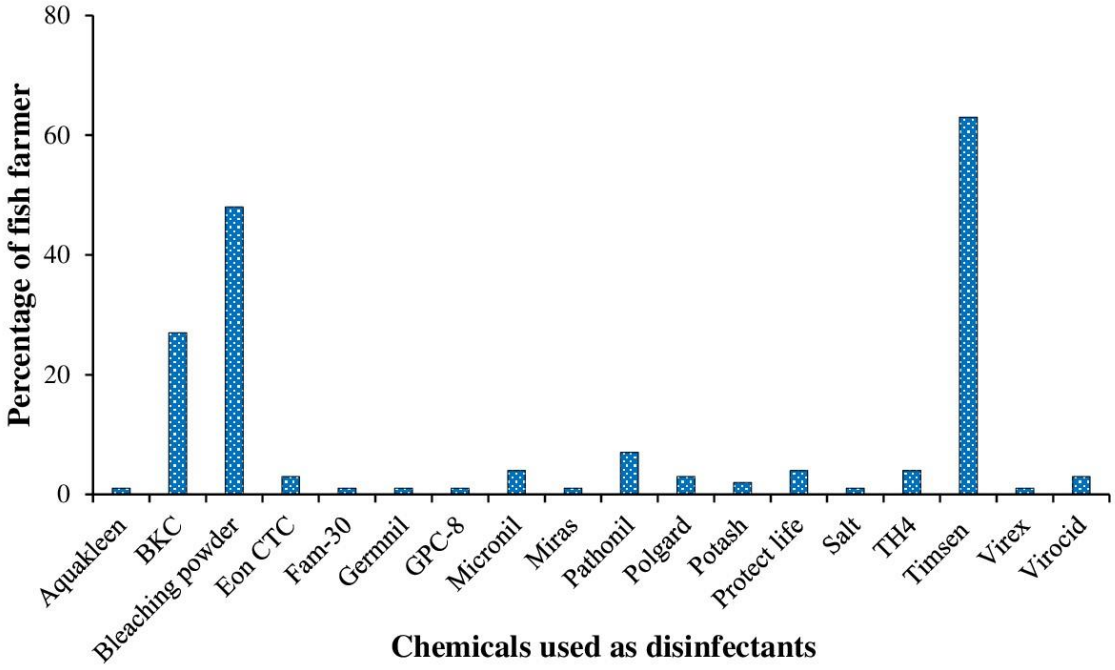

Figure 4. Percentage of fish farmers (n = 100) used different chemicals as disinfectants at Rajshahi district of Bangladesh.

3.4. Chemicals Used for Pond Preparation and Water Quality Management

A number of chemicals were found to be used in studied areas for the preparation of the ponds for fish culture and to improve the water quality of the cultured system. The list of these chemicals from the study areas with their active ingredients, prescribed dose, producers, and approximate price, are shown in Table 5. The study found that lime, zeolite, zeotox, and bioaqua were the most commonly used chemicals in these three upazillas of Rajshahi. Specifically, 95% of fish farmers used lime as a clearing agent and to maintain the suitable pH level (Figure 5). In addition, zeolite was used by 60% of the fish farmers interviewed. Regarding the fertilizers, 38% of fish farmers used triple super phosphate (TSP) and 20% used urea to increase the primary productivity of the pond (Figure 5).

Table 5. Availability of chemicals used for pond preparation and water quality management at Rajshahi district of Bangladesh.

Serial No.	Brand Name	Active Ingredients	Approximate Dose	Producers	Price *
1	Aqualite	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.06–0.08 kg/decimal	Tulip Meditex, Kolkata, India	75/kg (0.83)
2	Bioaqua	Extract of *Yucca schidigera*	0.02 mL/decimal	Eon Animal Health Products Ltd.	265/100 mL (2.94)
3	Blue vitriol	$CuSO_4.5H_2O$	8–10 mL/decimal	Innova Corporate, New Delhi, India	260/100 mL (2.89)
4	Cal zeolite	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.2 kg/decimal	Century Agro Limited	105/kg (1.17)
5	Zeolite gold	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.15–0.2 kg/decimal	Fishtech (BD) Limited	450/10 kg (5.00)
6	Hunter	Rotenon, $C_{23}H_{22}O_6$	0.05–0.06 kg/decimal	Eon Animal Health Products Ltd.	265/100 g (2.94)
7	Lime	CaO, $Ca(OH)_2$, CaCO3	1 kg/decimal	Local supplier	20/kg (0.22)
8	Matrix	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.1 kg/decimal	Square Pharmaceuticals Ltd.	575/5 kg (6.39)
9	Mega zeo plus	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O and Mn	0.2 kg/decimal	ACI Animal Health Ltd.	350/10 kg (3.89)
10	MH aqua powder	CaO, Al_2O_3, Trace elements	0.06 kg/decimal	Genetica Industries Ltd., Dhaka, Bangladesh	115/kg (1.28)
11	Rotenone	$C_{23}H_{22}O_6$	0.05–0.07 kg/decimal	Square Pharmaceuticals Ltd.	400/kg (4.44)
12	Seaweed Powder	Alginate	0.05 kg/decimal	Qingdao Haidelong Biotechnology Co., Ltd., Qingdao, China	400/kg (4.44)
13	TSP	$Ca(H_2PO_4)$	0.05–0.075 kg/decimal	Karnaphuli Fertilizer Company Limited, Chattogram, Bangladesh	25/kg (0.28)
14	Urea	CH_4N_2O	0.1–0.15 kg/decimal	Jamuna Fertilizer Company Ltd., Jamalpur, Bangladesh	15/kg (0.17)
15	Yucca	Yucca plant extract, Saponin Components Glyco components	2–3 mL/decimal	Opsonin Pharma Ltd., Dhaka, Bangladesh	315/500 mL (3.50)
16	Zeolite	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.2–0.3 kg/decimal	National AgriCare Import & Export Ltd., Dhaka, Bangladesh	550/10 kg (6.11)
17	Zeotox	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	0.2–0.25 kg/decimal	Novartis (Bangladesh) Ltd.	450/10 kg (5.00)

* Values outside the parentheses shows the price in taka, and the value inside the parentheses indicates the price in USD (1 USD = 90 BDT).

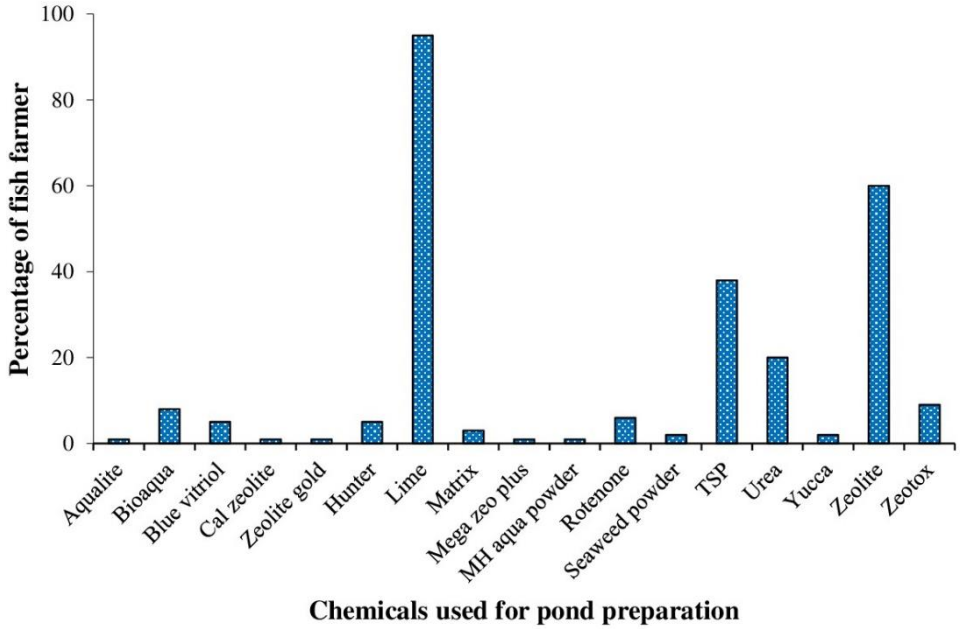

Figure 5. Percentage of fish farmers (n = 100) used different chemicals for pond preparation and water quality management at Rajshahi district of Bangladesh.

3.5. Chemicals Used for Oxygen Supply

It was found that fish farmers in the study areas used several types of chemical whenever they faced any situation of oxygen depletion in the water body. The study found 14 different branded oxygen-supplying chemicals used by the fish farmers and available in chemical shops in the market (for details, see Table S1). The study showed that the most commonly used chemicals for oxygen supply were oxymore (13%), oxylife (8%), oxymax (8%), best oxygen (7%), oxy-A (7%), azla (6%), ACI-ox (5%), and oxypro (5%) (Figure 6). Sodium percarbonate works as an oxidizing agent and is the main active ingredient of the most of these chemicals (Table S1).

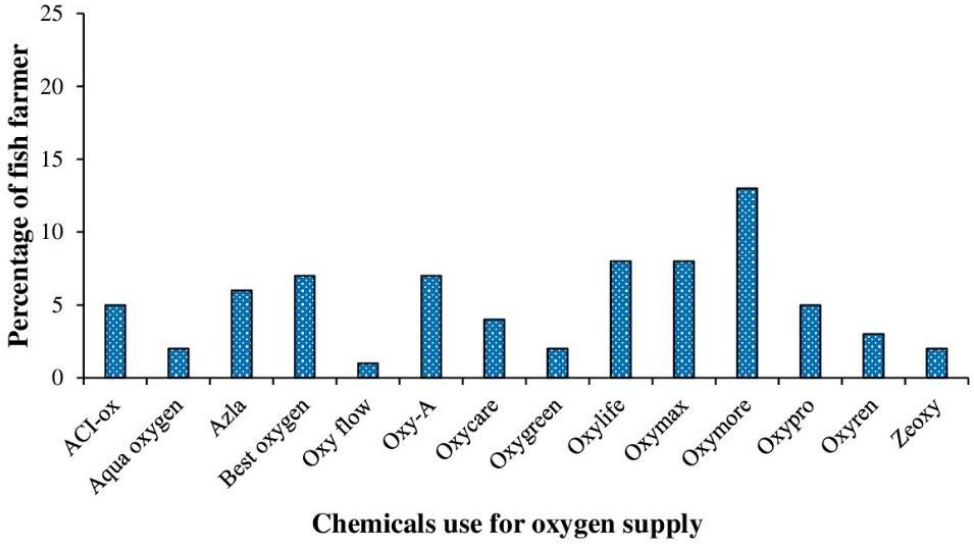

Figure 6. Proportion of fish farmers (n = 100) used chemicals for oxygen supply in culture ponds at Rajshahi district of Bangladesh.

3.6. Chemicals Used as Growth Promoter

The present study found that 18 various branded growth promoters from different companies were used by fish farmers in the study areas (for details, see Table S2). The most popular brands of growth promoter used by farmers in the Rajshahi district were renafish (10%), followed by fish vita plus (9%), G growth (7%), aqua boost (6%), faster growth (6%), cevit vet (5%), megavit aqua (5%), and vitamix F aqua (5%). Other growth promoters (safegut, aqua mix, rena WS power, aqua growth, liqua vit, etc.) were used with only a small percentage of farmers (Figure 7).

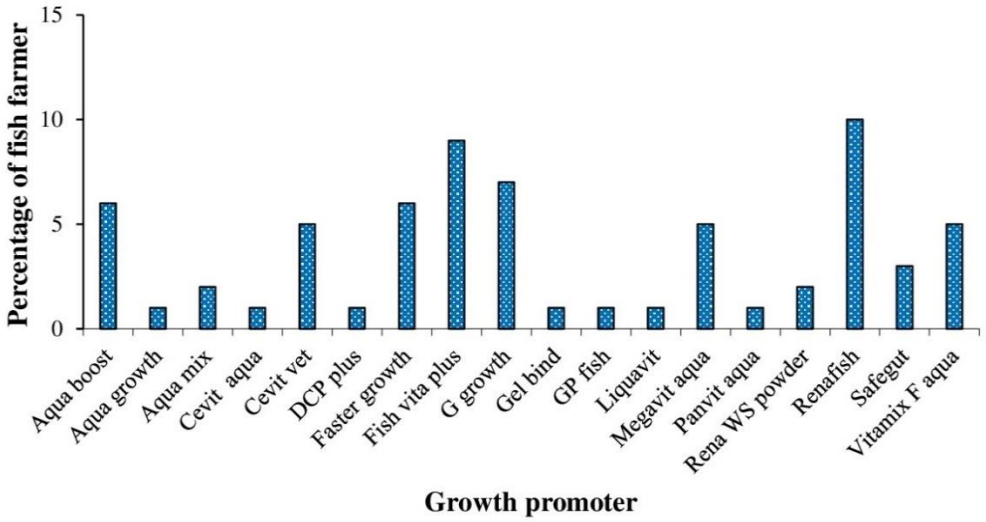

Figure 7. Percentage of fish farmers (n = 100) used chemicals as growth promoter in fish farming at Rajshahi district of Bangladesh.

3.7. Use of Probiotics in Fish Farming

The present study showed that four different branded probiotics (gasonil, enzyme plus, hariz, and pondcare) were found to be used in the investigated areas (Table 6). Pondcare had the highest percentage (18%) compared to other probiotics used in fish culture ponds (Figure S1).

Table 6. List of probiotics used in fish farming at Rajshahi district of Bangladesh.

Serial No.	Brand Name	Active Ingredients	Dose	Producers	Price *
1	Gasonil	*Bacillus subtilis*, *B. licheniformes*, *B. megaterium*, *B. coagulans*, *B. polymyxa*, Yucca	1500–2000 mg/decimal	SK+F Ltd.	460/100 g (5.11)
2	Enzyme plus	*B. subtilis*	250–500 mg/kg feed	Diamond Agro Care, Natore, Bangladesh	300/100 g (3.33)
3	Hariz	*B. amyloliquefaciens*, *B. pumilus*, *B. licheniformis*, $CaCO_3$, Starch	909.1 mg/decimal	Intefa	620/250 g (6.89)
4	Pondcare	*Streptococcus faecalis* and other bacteria inhibit pathogenic bacteria	500 mg/decimal	SK+F Ltd.	375/100 g (4.16)

* Values outside the parentheses shows the price in taka, and the value inside the parentheses indicates the price in USD (1 USD = 90 BDT).

3.8. Chemicals Used for Toxic Gas Removal

In the study areas, it was found that nine percent of fish farmers used eight chemicals (e.g., tara, ammonil, gastrap, pondkleen) to remove the toxic gas from the fish culture pond (for details, see Table S3). Of these chemicals, tara was used by 2% of the total farmers interviewed (Figure 8).

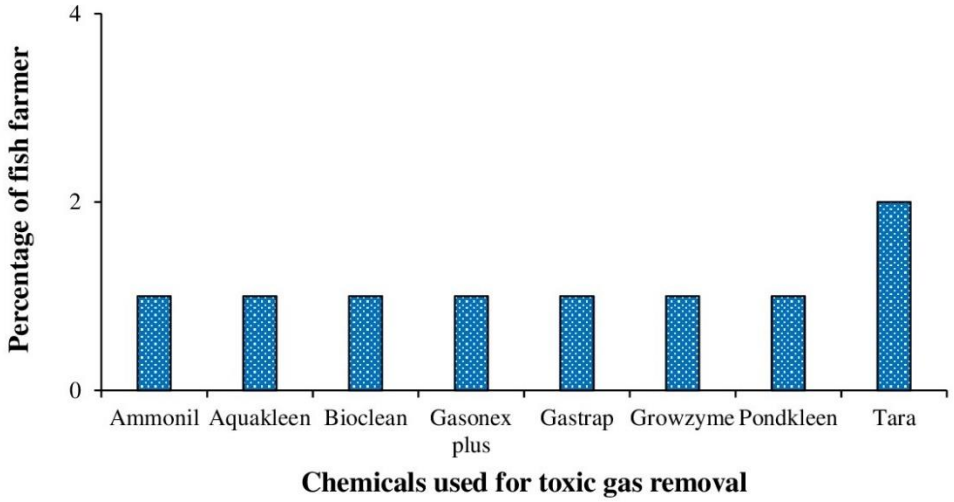

Figure 8. Proportion of fish farmers (n = 100) used various chemicals as toxic gas remover from culture ponds at Rajshahi district of Bangladesh.

3.9. Aqua-Chemicals Introduced Recently in the Study Areas

The aqua-chemicals that have been recently introduced in the study areas are shown in Table 7. It was found that antibiotics, particularly micronid (trade name), the combination of three antibiotics (erythromycin, sulfadiazine, and trimethoprim) were used in the study areas. Moreover, neomycin-50 and levoflox were also found to be used in fish farming. In addition to antibiotics, several aqua-chemicals, such as aqualite, azla, antistress, energy plus, gel bind, etc., have been recently introduced in the study areas (Table 7).

Table 7. List of recently introduced aqua-chemicals in aquaculture of the studied areas.

Serial No.	Chemicals	Active Ingredients	Purpose of Use	Producer
1.	Aqualite	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	Pond preparation and water quality management	Tulip Meditex
2.	MH aqua powder	CaO, Al_2O_3, Trace elements	Pond preparation and water quality management	Genetica Industries Ltd.
3.	Seaweed powder	Alginate	Pond preparation and water quality management	Qingdao Haidel Biotechnology Co. Ltd.
5.	Protect life	Glutaraldehyde-15%, Alkyl benzyl dimethyl ammonium chloride-20%, (Quaternary ammonium compound)	Disinfectant	-
6.	Azla	$2Na_2CO_3$. $3H_2O_2$	Oxygen supply	Intefa
7.	Aqua oxygen	$CuSO_4$, $Al_2(SO_4)_3$, KH_2O, Caustic thiosulfate, sodium salt, NH_4, Blue vitriole	Oxygen supply	RnF Agro and Food Industries Ltd., Chattogram, Bangladesh
8.	Fatah	Potassium peroxymonosulfate triple salt, Sodium dodecyle benzene sulfonate, NaCl	Diseases treatment and disinfectant	Intefa

Table 7. *Cont.*

Serial No.	Chemicals	Active Ingredients	Purpose of Use	Producer
9.	Antistress	L ascorbic polyphosphate, citric acid	Diseases treatment	Fishtech (BD) Ltd.
10.	Energy plus	Dextrose anhydrous USP 98% and ascorbic acid BP 2%	Diseases treatment	ACI Animal Health
11.	Micronid	Erythromycin, Sulfadiazine, Trimethoprim	Antibiotic	Renata Limited
12.	Neomin-50	Neomycin sulphate	Antibiotic	Local supplier
13.	Levoflox	Levofloxacin	Antibiotic	Drug International Bangladesh
14.	Gel bind	Protein, Fat, CHO, P, Ca, Vit A, D3, E, K3	Growth promoter	Rims BD, Dhaka, Bangladesh
15.	Hariz	*B. amyloliquefaciens*, *B. pumilus*, *B. licheniformis*, CaCO3, Starch	Probiotic	Intefa

3.10. Issues Related to the Use of Aqua-Chemicals and Antibiotics

The present study revealed several issues related to the use of aqua-drugs in the study areas (Table 8). The majority of fish farmers (88%) claimed that they lacked expertise regarding the uses of aqua-chemicals and antibiotics, and most of them (81%) do not know the effective doses of chemicals used in their culture ponds. Moreover, a substantial number of fish farmers reported that they lacked knowledge of residual effects of the aqua-chemicals (72%), and safety issues in the use of hazardous chemicals in fish ponds (67%). The influence of the pharmaceutical personnel and pesticide suppliers to the fish farmers (44%), as well as the high price of the chemicals or drugs (40%), the insufficient supply or unavailability of the chemicals (39%), the indiscriminate use of aqua-drugs (37%), the lack of disease diagnostic tools (34%), and the lack of information on the labelling of chemical substances (26%), were some of the issues that were discovered during the investigation.

Table 8. Some issues related to the use of aqua-chemicals and antibiotics at Rajshahi district of Bangladesh.

Issues Related to the Use of Aqua-Chemicals and Antibiotics	Responses of Fish Farmers (number)			Overall Responses (%; *n* = 100)
	Durgapur (*n* = 33)	Puthia (*n* = 33)	Bagmara (*n* = 34)	
Lack of knowledge about the use of chemicals or drugs	28	30	30	88
Lack of knowledge about the effective doses of the chemicals or drugs	25	28	28	81
Lack of knowledge of residual effects	24	21	27	72
Lack of knowledge of safety issues in the use of hazardous chemicals	20	22	25	67
The influence of the pharmaceutical personnel and pesticide suppliers on the fish farmers	12	17	15	44
High prices of the chemicals or drugs	16	14	10	40
Insufficient supply or unavailability of the chemicals or drugs	12	12	15	39
Indiscriminate use of chemicals	12	14	11	37
Lack of disease diagnostic tools	11	15	8	34
Lack of information on the labelling of chemical substances	10	8	8	26

4. Discussion

Aquaculture makes a significant contribution toward food security and livelihood for millions of people across the world. Global food fish intake grew at an average yearly rate of three percent over the period 1961–2019 [1]. In response to the increasing need for animal protein as a consequence of the growing global population, aquaculture activities have intensified and expanded globally. However, the lion share (over 90% production) of global aquaculture production comes from Asian countries [1]. Aligning with the global trend of aquaculture operation, Bangladesh's aquaculture industry is expanding and diversifying due to the rising demand for fish protein [42]. It is becoming increasingly essential for the improvement of aquaculture production in Bangladesh to make use of a wide variety of aqua-chemicals [34]. Therefore, the purpose of this study was to determine the current status of culture composition and the use of various kinds of antibiotics, pesticides, and other aqua-chemicals in aquaculture operation in the Rajshahi district of Bangladesh.

In the investigated areas, the proportion of the carp polyculture was the greatest. In the Rajshahi and Natore districts of Bangladesh, carp polyculture is the most common form of aquaculture practice [43]. Some earlier research also presented a similar kind of culture composition in various regions of Bangladesh [36,44,45]. From the starting point of aquaculture operation (the preparation of the ponds) to raising fish in the culture system, farmers use various types of antibiotics, pesticides, and other chemicals to treat diseases, to improve water quality, and promote fish growth, thereby enhancing fish production. In the studied areas, broadly, eight distinct categories of aqua-medicine (e.g., antibiotics, pesticides, disinfectants, growth promoters, toxic gas removers, etc.) were found to be in use for various purposes. A number of authors have also documented comparable findings in Bangladeshi aquaculture practices [28,33,34,36].

Fish disease has evolved as one of the most significant barriers that have emerged in the process of intensifying aquaculture in recent time [34]. The most common health problems of fish species in these three areas of Rajshahi, reported by the farmers, were tail and fin rot, dropsy, gill rot, saprolegniasis, and Epizootic Ulcerative Syndrome (EUS). To combat the disease burden and the prevention of pathogenic infestations, fish farmers of the Rajshahi district routinely use various antibiotics (nine active ingredients), pesticides, and disinfectants with different trade names (Tables 2–4). Antibiotics such as aquamycin (Oxytetracycline HCl 25%), oxy-dox-F 100 (oxytetracycline HCl 20% + doxycycline), captor (chlortetracycline HCl 45%), oxysenthin-20% (oxytetracycline HCl 200 mg), doxy-A vet WSP (doxycycline hyclate USP), tetra-vet WSP (oxytetracycline HCl 500 mg/g), moxilin vet WSP (amoxycillin-trihydrate 300 mg/g), renamycin (oxytetracycline 200 mg), and oxy-D vet (oxytetracycline 20% + doxycycline 10%), have been used for the treatment of bacterial diseases in aquaculture in Bangladesh [6,46,47]. In line with our findings, Hasan et al. [36] reported that renamycin (active ingredient: oxytetracycline) is the most commonly used antibiotic in aqua-farming in the Patuakhali district of Bangladesh. To cure diseased fish, 44% of farmers in the Cumilla region of Bangladesh used oxytetracycline [44]. Oxytetracycline is the main antibiotic applied in aquaculture in the northeastern region of Bangladesh [48]. In India, tetracyclines were the most common antibiotics among the six reported antibiotics (cephalexin, doxycycline, enrofloxacin, erythromycin, sulphamethoxazole-trimethoprim, and tetracyclines) applied in different fish farming systems [49]. In Thailand, enrofloxacin was the most common antibiotic, followed by oxytetracycline, amoxicillin, and sulfadiazine, combinedly used with trimethoprim, to control infectious diseases in Tilapia [50]. According to the information provided by representative of Novartis (Bangladesh) Ltd., oxysenthin-20% works against the most common bacterial diseases. Some antibiotics were found to be effective against diseases such as dropsy, tail and fin rot, and gill rot of fish (Table 2). It was found that most of the antibiotics were used to treat bacterial diseases, especially for the carp polyculture in the studied areas, and the farmers use the antibiotics for 3–5 days, with feed, when the diseases were identified.

Likewise, several pesticides and chemicals were being used in the study area to control aquatic insects, parasitic infestation, and to treat fungal infection, along with the eradi-

cation of unwanted organisms from the culture systems. Fish farmers of the study areas reported that they used some particular pesticides during pond preparation to eradicate the unwanted fishes, and they mostly use pesticides when parasitic or insect infestation, and several fungal diseases have been identified. The majority of the respondents were engaged in the polyculture of carp and tilapia and had a problem with insect attack and fungal disease outbreak in their culture system. According to the farmers, the fish species are sometimes attacked by different kinds of external and internal parasites, making them uncomfortable and unhealthy, and limiting their natural growth. Hossain et al. [29] reported eight pesticide compounds used in freshwater aquaculture in the southeastern region of Bangladesh. Moreover, Ali et al. [4] reported that seven pesticides, Yucca plant extract, rotenone, malathion, trichlorfon, methylene blue, fenitrothion, and malachite green, have been applied to combat fungal and parasitic infestation in aquaculture in Bangladesh. Argulosis is the most common problem in fish culture in Bangladesh, and *Argulus* infestation is comparatively higher in carp polyculture than in the monoculture of carps [51]. Patil et al. [49] reported that deltamethrin is an antiparasitic compound used frequently in India for fish farming. Similar to our findings, cypermethrin, invermectin, and quinalphos, have been commonly used in India to control fish parasites [49]. Sumithion had the greatest percentage of application out of all of the pesticides that fish farmers in the Rajshahi district used to control aquatic insects. Some findings of earlier research revealed that sumithion is widely used in Bangladesh to control insect attacks to culture fishes, to control the various kinds of ectoparasites, and to eradicate predatory and weed fishes [27,52,53].

In addition to antibiotics and pesticides, disinfectants such as timsen, bleaching powder, and benzalkonium chloride (BKC), were found to be in use in the study area with a greater number of fish farmers. A number of disinfectants were used in Bangladesh to sterilize the equipment needed for aquaculture operation, to maintain hygiene and biosecurity, and, in some cases, for the prevention and treatment of various diseases of farmed fish caused by pathogenic microorganisms [34,36]. Similar to our findings, Kawsar et al. [34] reported that timsen, salt, and BKC, were mostly used by fish farmers as disinfectants in their culture systems in the Narsingdi district of Bangladesh. In addition, Ali et al. [4] reported that potassium permanganate, sodium percarbonate, hydrogen peroxide, chlorine, and chlorine derived compounds, such as quaternary ammonium compounds, were commonly used in Bangladesh as disinfectants in aquaculture. According to technical service personnel, bleaching powder works well against saprolegniasis. Fish farmers of the study area stated that BKC has been effective in limiting the spread of harmful substances in the aquatic body by improving hygiene. It has also been used for clearing the water, as a general disinfection of the premises, for the prevention of infectious diseases, and the removal of parasites. Timsen was used to keep the water body free from pathogens and for the removal of pollution. It has been reported that potassium permanganate was used as disinfectant by 22% of the farmers in their culture ponds in the Cumilla region [44]. Our study revealed similar findings. A previous study reported that 38% of fish farmers in north Chittagong used commercial disinfectants, such as aquakleen, timsen, and pathonil [45]; these chemicals were also common in our surveyed area. However, Mishra et al. [54] showed that virgo, viranil, mizuphor, ecodyne, germicida, bionex-80, methylene blue, sokrena-WS, formalin, potassium permanganate, hydrogen peroxide, malachite green, and copper sulfate, were commonly used as disinfectant in India.

Water quality is one of the key issues in fish farming [35]. To improve the water quality of fish culture ponds, our study revealed that lime and zeolite were commonly used by fish farmers in the three upazillas of the Rajshahi district. Lime has been considered as the most cost-effective chemical, and used for the effective and efficient management of pond water [55]. In the Noakhali district of Bangladesh, lime, zeolite, fish toxin, insecticides, and different fertilizers were used for pond preparation and water quality management [56]. Moreover, Faruk et al. [6] reported that geotox, JV zeolite, mega zeo, and bio aqua were found to be most effective in improving the water quality of fish ponds.

In this study, a number of the aqua-chemicals were used in aquaculture as an oxygen precursor, growth stimulator, gas remover, and as probiotics to improve digestion and maintain a healthy aquatic environment. Ten aqua-chemicals used as an oxygen precursor were reported by Akter et al. [28] from the Bogura districts of Bangladesh, many of these chemicals (e.g., oxymore, oxymas, oxy-A, oxyren, oxylife) were found to be commonly used in fish ponds in our study areas. In line with our findings, Ali et al. [4] showed that sodium percarbonate and hydrogen peroxide were mainly applied as an oxidizing agent to enhance the water quality and the health status of the farmed fishes.

Recently, the usage of growth promoters has been rapidly increasing in aquaculture globally to improve the growth performance of cultured fish [57]. We have reported 18 various growth promoters used in aquaculture of the selected three upazilas of the Rajshahi district. Several studies reported that growth promoters have significant positive effects on fish health, and they can improve the feed efficiency of fish, reduce the oxidative stress of fish during the culture period, and improve the resistance against pathogenic invasion [58,59]. Because of its positive impacts on fish growth, several types of growth promoter with different names are available in local markets across Bangladesh (e.g., [34,44]). In the case of probiotics, it was found that very few farmers use probiotics in the study areas, as this is new for most of them. Kawsar et al. [34] documented 11 brands of probiotics used in fish culture ponds in the Narsingdi district of Bangladesh, and similar to our findings they reported that pondcare is the most common probiotics used by fish farmers. However, Rahman et al. [44] reported that 39% of fish farmers used proofs as a probiotic in the Cumilla region. The use of probiotics has been increased recently since it results in good development in the culture system. Probiotics, which are naturally occurring bacteria that have a positive effect on the fishes, and the modification of the microbial community in communication with the fishes provides the improved use of the feed, or enhanced its nutritional value and increased the host's response to the disease [60–62]. Beneficial bacteria such as *Bacillus sp.*, *Rodococcus sp.*, *Rodobacter sp.*, and *Streptococcus faecalis* are the main constituents of probiotics [44].

In Bangladesh, bio aqua, gasonex, gastrap, and ammonil are used for toxic gas removal [44]. Kawsar et al. [34] reported that 16 chemicals were used to remove gas from fish ponds in the Narsingdi district, Bangladesh; however, our study found eight chemicals used as a gas remover from the fish culture ponds. A substantial number of fish farmers (42%) in the Narsingdi district mostly used the extract of Yucca plant to remove toxic gas; Yucca extract powders were also used as organic chemicals to eradicate predators from fish culture ponds [34]. The different types of chemicals were readily available at the chemical shops and found to be used in fish farms as a gas remover across Bangladesh, including oxygreen, oxy-A, bio-ox, best oxygen, zeoxy, oxygen plus, oxy pro, oxyflow, aqua oxygen, oxylife, azla, oxymax, oxymore, and oxyplus, etc. [28–30,33,34,37].

The present study found that farmers were unaware of the mode of action of most of the chemicals, antibiotics, and pesticides, which were applied in fish culture ponds. Sometimes, farmers applied certain chemicals based on their own experiences or following the suggestion of chemical sellers and company representatives. Similar to our findings, Akter et al. [28] and Das et al. [37] also reported that in the northern part of Bangladesh, the lack of knowledge about the use and application procedures of the aqua-chemicals and antibiotics, the lack of safety awareness in the use of hazardous chemicals, the lack of knowledge of the residual effect of chemicals on aquatic environment and human health, the low availability of chemicals, the high price of aqua-chemicals, influences of the representative of aqua-drugs companies to use chemicals, and the lack of disease diagnosis tools, are the major issues related to antibiotic and other chemical use in fish farming. Moreover, antibiotics were used indiscriminately without detecting and knowing the exact reasons for disease, in Bangladesh [9,23,44,46]. The indiscriminate and irrational use of antimicrobial agents creates favorable conditions for the microbial organisms to emerge, spread, and persist in aquaculture environment. Consequently, residues of potentially toxic substances (antibiotics, pesticides etc.) and antibiotic-resistant genes can accumulate in the

treated animals, resulting in a potential hazard for consumers [15,16]. The extensive use of antibiotics in aquaculture can contribute to the development of antimicrobial-resistant pathogenic bacteria, both inside and outside the aquaculture farms [63–65]. For these reasons, resistance to certain antibiotics is constantly becoming more common, and there is a greater need for alternative treatments [66].

5. Conclusions

The present study found that the use of antibiotics, pesticides, and other aqua-chemicals is increasing in a substantial number in aquaculture sectors, and this could be related to the easy availability of the chemicals in the local market. This rapid increase in the use of chemicals will pose a great threat to the aquatic species and human health since more than 80% of people in Bangladesh consume fish as animal protein. The proper use of chemicals has great value to treat diseased fish; however, the misuse of antibiotics, pesticides, and chemicals, leads to potential impacts on aquaculture production. The diagnostic capacity of fish farmers should be improved by giving proper training, and their access to diagnostic and veterinary services should be controlled with appropriate rules and guidelines. Newly introduced probiotics, the vaccination of immune stimulants, bioremediation, and alternative therapeutic interventions, can be great alternatives to solve these problems. However, all the issues regarding aquaculture and the use of chemicals by fish farmers should be addressed properly, and government policy makers, fisheries professionals, researchers, and scientists, should come forward to reduce negative consequences and find new alternatives to minimize the use of antibiotics, pesticides, and other aqua-chemicals in aquaculture in Bangladesh.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su142417038/s1, Figure S1: Percentage of fish farmers used probiotics in fish farming at Rajshahi district of Bangladesh, Table S1: Chemicals used for oxygen supply in fish ponds at Rajshahi district of Bangladesh, Table S2: Chemicals used as growth promoter for cultured fish at Rajshahi district of Bangladesh, Table S3: Chemicals used to remove toxic gases from aquaculture ponds at Rajshahi district of Bangladesh.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

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References

1. FAO. *The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation*; FAO: Rome, Italy, 2022. [CrossRef]
2. DoF. *Yearbook of Fisheries Statistics of Bangladesh 2020–21*; Fisheries Resources Survey System (FRSS), Ministry of Fisheries and Livestock: Dhaka, Bangladesh, 2022.
3. Ali, H. Assessment of Stakeholders Perception Pangasius Aquaculture Dialogue (PAD) Standards in Two Villages, Mymensingh, Bangladesh. Master's Thesis, Department of Aquaculture, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2009.
4. Ali, H.; Rico, A.; Murshed-e-Jahan, K.; Belton, B. An assessment of chemical and biological product use in aquaculture in Bangladesh. *Aquaculture* **2016**, *454*, 199–209. [CrossRef]
5. Belton, B.; Azad, A. The characteristics and status of pond aquaculture in Bangladesh. *Aquaculture* **2012**, *358*, 196–204. [CrossRef]
6. Faruk, M.A.R.; Ali, M.M.; Patwary, Z.P. Evaluation of the status of use of chemicals and antibiotics in freshwater aquaculture activities with special emphasis to fish health management. *J. Bangladesh Agric. Univ.* **2008**, *6*, 381–390. [CrossRef]
7. Subasinghe, R.P.; Barg, U.; Tacon, A. *Chemicals in Asian Aquaculture: Need, Usage, Issues and Challenges*; Southeast Asian Fisheries Development: Quezon City, Philippines, 1996.
8. Bondad-Reantaso, M.G.; Subasinghe, R.P.; Arthur, J.R.; Ogawa, K.; Chinabut, S.; Adlard, R.; Tan, J.; Shariff, M. Disease and health management in Asian aquaculture. *Vet. Parasitol.* **2005**, *132*, 249–272. [CrossRef] [PubMed]
9. Rico, A.; Phu, T.M.; Satapornvanit, K.; Min, J.; Shahabuddin, A.; Henriksson, P.; Murray, F.; Little, D.C.; Dalsgaard, A.; Van den Brink, P.J. Use of veterinary medicines, feed additives and probiotics in four major internationally traded aquaculture species farmed in Asia. *Aquaculture* **2013**, *412*, 231–243. [CrossRef]
10. Hasan, M.A.R.; Haque, M.I.M.; Hossain, A.; Hasan, M.; Rahman, M.S. Bacterial loads in shrimp and fish hatchery environments of Bangladesh. *J. Asiat. Soc. Bangladesh. Sci.* **2017**, *43*, 37–47. [CrossRef]
11. Subasinghe, R.P.; Barg, U.; Tacon, A. Use of Chemicals in aquaculture in Asia. In Proceedings of the Meeting on the Use of Chemicals in Aquaculture in Asia, Tigbauan, Philippines, 20–22 May 1996.
12. Graslund, S.; Bengtsson, B. Chemicals and biological products used in Southeast Asian shrimp farming, and their potential impact on the environment—A review. *Sci. Total Environ.* **2001**, *280*, 93–131. [CrossRef]
13. Holmström, K.; Gräslund, S.; Wahlström, A.; Poungshompoo, S.; Bengtsson, B.E.; Kautsky, N. Antibiotic use in shrimp farming and implications for environmental impacts and human health. *Int. J. Food Sci. Technol.* **2003**, *38*, 255–266. [CrossRef]
14. Uddin, S.A.; Kader, M.A. The use of antibiotics in shrimp hatcheries in Bangladesh. *J. Fish. Aquat. Sci.* **2006**, *1*, 64–67.
15. Sapkota, A.; Sapkota, A.R.; Kucharski, M.; Burke, J.; McKenzie, S.; Walker, P.; Lawrence, R. Aquaculture practices and potential human health risks: Current knowledge and future priorities. *Environ. Int.* **2008**, *34*, 1215–1226. [CrossRef]
16. Heuer, O.E.; Kruse, H.; Grave, K.; Collignon, P.; Karunasagar, I.; Angulo, F.J. Human health consequences of use of antimicrobial agents in aquaculture. *Clin. Infect. Dis.* **2009**, *49*, 1248–1253. [CrossRef] [PubMed]
17. Hossain, A.; Nakamichi, S.; Habibullah-Al-Mamun, M.; Tani, K.; Masunaga, S.; Matsuda, H. Occurrence and ecological risk of pharmaceuticals in river surface water of Bangladesh. *Environ. Res.* **2018**, *165*, 258–266. [CrossRef] [PubMed]
18. Hossain, A.; Raknuzzaman, M.; Tokumura, M. Coronavirus (COVID-19) pandemic: Concern about misuse of antibiotics. *J. Biomed. Anal.* **2020**, *3*, 19–23. [CrossRef]
19. Arisekar, U.; Jeya Shakila, R.; Shalini, R.; Jeyasekaran, G. Pesticides contamination in the Thamirabarani, a perennial river in peninsular India: The first report on ecotoxicological and human health risk assessment. *Chemosphere* **2021**, *267*, 129251. [CrossRef]
20. Kim, K.H.; Kabir, E.; Jahan, S.A. Exposure to pesticides and the associated human health effects. *Sci. Total Environ.* **2017**, *575*, 525–535. [CrossRef]
21. Rani, L.; Thapa, K.; Kanojia, N.; Sharma, N.; Singh, S.; Grewal, A.S.; Srivastav, A.L.; Kaushal, J. An extensive review on the consequences of chemical pesticides on human health and environment. *J. Clean. Prod.* **2021**, *283*, 124657. [CrossRef]
22. Sun, M.; Chang, Z.; Van den Brink, P.J.; Li, J.; Zhao, F.; Rico, A. Environmental and human health risks of antimicrobials used in Fenneropenaeus chinensis aquaculture production in China. *Environ. Sci. Pollut. Res.* **2016**, *23*, 15689–15702. [CrossRef]
23. Heal, R.D.; Hasan, N.A.; Haque, M.M. Increasing disease burden and use of drugs and chemicals in Bangladesh shrimp aquaculture: A potential menace to human health. *Mar. Pollut. Bull.* **2021**, *172*, 112796. [CrossRef]
24. Yannarell, A.C.; Mackie, R.I. Environmental impacts of antibiotic use in the animal production industry. *Ecol. Anim. Health* **2012**, *2*, 228.
25. Hidayati, N.V.; Syakti, A.D.; Asia, L.; Lebarillier, S.; Khabouchi, I.; Widowati, I.; Sabdono, A.; Piram, A.; Doumenq, P. Emerging contaminants detected in aquaculture sites in Java, Indonesia. *Sci. Total Environ.* **2021**, *773*, 145057. [CrossRef]
26. Alam, M.A.; Rashid, M.M. Use of aqua-medicines and chemicals in aquaculture in Satkhira district, Bangladesh. *IOSR J. Pharm. Biol. Sci.* **2014**, *9*, 5–9. [CrossRef]
27. Rasul, M.G.; Majumdar, B.C.; Akter, T. Aqua-chemicals and antibiotics used in freshwater aquaculture of Sylhet, Bangladesh. *J. Agric. Sci. Eng.* **2017**, *3*, 20–26.
28. Akter, M.N.; Sarker, G.; Ali, M.M.; Zafar, M.A. Present status of using aqua medicines and chemicals on fish health management in Bogura district, Bangladesh. *Res. Agric. Livest. Fish.* **2020**, *7*, 129–138. [CrossRef]
29. Hossain, A.; Islam, S.; Al Asif, A.; Rahman, H. Aqua medicines, drugs and chemicals (AMDC) used in freshwater aquaculture of South-Eastern Bangladesh. *Asian Australas. J. Biosci. Biotechnol.* **2021**, *6*, 103–127. [CrossRef]

30. Yesmin, R.; Rakeb-Ul-Islam, M.; Banik, P.; Nur, A.A.U.; Paul, S.K.; Saha, D.; Majumdar, P.R. A Comprehensive scenario on application of aqua drugs and chemicals for the fish health management in fish hatcheries and farms of south-eastern part, Bangladesh. *Asian J. Biol.* **2022**, *14*, 1–13. [CrossRef]
31. Hossain, M.J.; Ahmed, G.U.; Rashid, M.M.; Akhtar, S.; Rahman, M.M. Effect of aqua-drugs and chemicals on shrimp health and production in Khulna, Bangladesh. *Bangladesh J. Fish.* **2021**, *39*, 89–97. [CrossRef]
32. Singha, S.; Sultana, T.; Rima, N.N.; Hasan, M.R.; Habib, A. Status of aqua drugs applied in freshwater aquaculture of Moulvibazar district, Bangladesh. *Asian J. Biol.* **2020**, *10*, 22–31. [CrossRef]
33. Faruk, M.A.R.; Shorna, H.K.; Anka, I.Z. Use and impact of veterinary drugs, antimicrobials, and supplements in fish health management. *J. Adv. Vet. Anim. Res.* **2021**, *8*, 36–43. [CrossRef]
34. Kawsar, M.A.; Alam, M.T.; Pandit, D.; Rahman, M.M.; Mia, M.; Talukdar, A.; Sumon, T.A. Status of disease prevalence, drugs and antibiotics usage in pond-based aquaculture at Narsingdi district, Bangladesh: A major public health concern and strategic appraisal for mitigation. *Heliyon* **2022**, *8*, e09060. [CrossRef]
35. Ullah, M.A.; Naeem, M.A.; Hossain, A.; Al-Asif, A.; Hasan, M.R. Categorization and distribution of aqua-chemicals used in coastal farming of south-eastern part of Bangladesh. *J. Aquac. Res. Dev.* **2020**, *11*, 618.
36. Hasan, J.; Rahman, M.H.; Ullah, M.R.; Mredul, M.M.H. Availability of aqua drugs and their uses in semi intensive culture farms at Patuakhali district in Bangladesh. *Arch. Agric. Environ. Sci.* **2020**, *5*, 368–376. [CrossRef]
37. Das, S.; Akter, M.N.; Khatun, M.M. Status of chemicals and aqua-drugs used for freshwater fish health management at Rangpur district of Bangladesh. *Asian J. Med. Biol. Res.* **2020**, *6*, 283–293. [CrossRef]
38. Hossain, S.S.; Sultana, S.; Kabiraj, M.; Dey, S.R. Recent scenario of application of aqua drugs and chemicals in fish and shell fish health management in southwestern region of Bangladesh. *Int. J. Fish. Aquat. Stud.* **2018**, *6*, 203–210.
39. Al Asif, A.; Hossain, A.; Hamli, H.; Islam, S.; Kabir, S.L. Research trends of aqua medicines, drugs and chemicals (AMDC) in Bangladesh: The last decade's (2011–2020) story to tell. *Asian J. Med. Biol. Res.* **2021**, *7*, 90–106. [CrossRef]
40. Dworkin, S.L. Sample size policy for qualitative studies using in-depth interviews. *Arch. Sex. Behav.* **2012**, *41*, 1319–1320. [CrossRef] [PubMed]
41. Michalos, A.C. *Encyclopedia of Quality of Life and Well-Being Research*; Springer: Dordrecht, The Netherlands, 2014.
42. Shamsuzzaman, M.M.; Islam, M.M.; Tania, N.J.; Al-Mamun, M.A.; Barman, P.P.; Xu, X. Fisheries resources of Bangladesh: Present status and future direction. *Aquacul. Fish.* **2017**, *2*, 145–156. [CrossRef]
43. Mohsin, A.B.M.; Islam, M.N.; Hossain, M.A.; Galib, S.M. Constraints and prospects of carp production in Rajshahi and Natore districts, Bangladesh. *Univ. J. Zool. Rajshahi Univ.* **2012**, *31*, 69–72. [CrossRef]
44. Rahman, M.Z.; Khatun, A.; Kholil, M.I.; Hossain, M.M. Aqua drugs and chemicals used in fish farms of Comilla regions. *J. Entomol. Zool. Stud.* **2017**, *5*, 2462–2473. [CrossRef]
45. Kawsar, M.A.; Alam, M.T.; Ahamed, S.; Mou, M.H. Aqua drugs and antibiotics used in freshwater aquaculture of North Chittagong, Bangladesh. *Int. J. Fish. Aquat. Stud.* **2019**, *7*, 28–34.
46. Hossain, A.; Nakamichi, S.; Habibullah-Al-Mamun, M.; Tani, K.; Masunaga, S.; Matsuda, H. Occurrence, distribution, ecological and resistance risks of antibiotics in surface water of finfish and shellfish aquaculture in Bangladesh. *Chemosphere* **2017**, *188*, 329–336. [CrossRef]
47. Hossain, A.; Habibullah-Al-Mamun, M.; Nagano, E.; Kitazawa, D.; Masunaga, S.; Matsuda, H. Antibiotics, antibiotics resistant bacteria and resistance genes in aquaculture: Risks, current concern and future thinking. *Environ. Sci. Pollut. Res.* **2022**, *29*, 11054–11075. [CrossRef] [PubMed]
48. Rahman, M.M.; Alam, M.M.M.; Khalil, S.M.I.; Bari, S.M.; Rashid, M.M. Status of chemicals and aqua drugs used in freshwater aquaculture in north-eastern Bangladesh. *J. Sylhet Agric. Univ.* **2015**, *2*, 243–252.
49. Patil, P.K.; Mishra, S.S.; Pradhan, P.K.; Manna, S.K.; Abraham, J.T.; Solanki, H.G.; Shahi, N.; Swain, P.; Sahoo, S.N.; Avunje, S.; et al. Usage pattern of chemicals, biologicals and veterinary medicinal products in Indian aquaculture. *Rev. Aquac.* **2022**, *14*, 2038–2063. [CrossRef]
50. Rico, A.; Oliveira, R.; McDonough, S.; Matser, A.; Khatikarn, J.; Satapornvanit, K.; Nogueira, A.J.; Soares, A.M.; Domingues, I.; Van den Brink, P.J. Use, fate and ecological risks of antibiotics applied in tilapia cage farming in Thailand. *Environ. Pollut.* **2014**, *191*, 8–16. [CrossRef] [PubMed]
51. Bakshi, A.K.; Chandra, K.J.; Hoque, N. Argulosis in fish culture ponds of selected areas of Mymensingh. *J. Bangladesh Agric. Univ.* **2006**, *4*, 305–312.
52. Hossain, M.A.; Hoq, M.E.; Mazid, M.A. Use of chemicals and biological products in aquaculture in Bangladesh. *Agriculturists* **2008**, *6*, 29–42. [CrossRef]
53. Rahman, M.K. *Impact of Aquaculture Drugs and Chemicals on Aquatic Ecology and Productivity*; Bangladesh Fisheries Research Institute: Mymenshing, Bangladesh, 2013.
54. Mishra, S.S.; Choudhary, P.; Debbarma, J.; Sahoo, S.N.; Giri, B.S.; Swain, P.; Das, R.; Rathod, R.; Sahu, A.; Patil, P.K. Status of aqua-medicines, drugs and chemicals use in India. *J. Aqua. Fish.* **2017**, 1. [CrossRef]
55. Sultana, N. Use of Chemicals in Mymensingh. Master's Thesis, Department of Aquaculture, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2004.
56. Jelani, A.K.; Debasish, S.; Belal, M.H. Chemicals used in freshwater aquaculture with special emphasis to fish health management of Noakhali, Bangladesh. *Afr. J. Basic Appl. Sci.* **2012**, *4*, 110–114. [CrossRef]

57. Hamid, N.K.A.; Somdare, P.O.; Harashid, K.A.M.; Othman, N.A.; Kari, Z.A.; Wei, L.S.; Dawood, M.A. Effect of papaya (Carica papaya) leaf extract as dietary growth promoter supplement in red hybrid tilapia (Oreochromis mossambicus × Oreochromis niloticus) diet. *Saudi J. Biol. Sci.* **2022**, *29*, 3911–3917. [CrossRef]
58. Ahmadifar, E.; Pourmohammadi Fallah, H.; Yousefi, M.; Dawood, M.A.; Hoseinifar, S.H.; Adineh, H.; Yilmaz, S.; Paolucci, M.; Doan, H.V. The gene regulatory roles of herbal extracts on the growth, immune system, and reproduction of fish. *Animals* **2021**, *11*, 2167. [CrossRef]
59. Hasan, N.A.; Haque, M.M.; Bashar, A.; Hasan, M.T.; Faruk, M.A.R.; Ahmed, G.U. Effects of dietary Papaveraceae extract on growth, feeding response, nutritional quality and serum biochemical indices of striped catfish (Pangasianodon hypophthalmus). *Aquac. Rep.* **2021**, *21*, 100793. [CrossRef]
60. Akbari Nargesi, E.; Falahatkar, B.; Sajjadi, M.M. Dietary supplementation of probiotics and influence on feed efficiency, growth parameters and reproductive performance in female rainbow trout (Oncorhynchus mykiss) broodstock. *Aquac. Nutr.* **2020**, *26*, 98–108. [CrossRef]
61. Haque, M.M.; Hasan, N.A.; Eltholth, M.M.; Saha, P.; Mely, S.S.; Rahman, T.; Murray, F.J. Assessing the impacts of in-feed probiotic on the growth performance and health condition of pangasius (Pangasianodon hypophthalmus) in a farm trial. *Aquac. Rep.* **2021**, *20*, 100699. [CrossRef] [PubMed]
62. El-Saadony, M.T.; Alagawany, M.; Patra, A.K.; Kar, I.; Tiwari, R.; Dawood, M.A.; Dhama, K.; Abdel-Latif, H.M. The functionality of probiotics in aquaculture: An overview. *Fish Shellfish Immunol.* **2021**, *117*, 36–52. [CrossRef]
63. Sørum, H. Antibiotic resistance in aquaculture. *Acta Vet. Scand. Suppl.* **1999**, *92*, 29–36. [PubMed]
64. Inglis, V. Antibacterial chemotherapy in aquaculture: Review of practice, associated risks and need for action. Use of chemicals in Aquaculture in Asia. In Proceedings of the Meeting on Use of Chemicals in Aquaculture in Asia, Tigbauan, Philippines, 20–22 May 1996.
65. Le, T.X.; Munekage, Y.; Kato, S.I. Antibiotic resistance in bacteria from shrimp farming in mangrove areas. *Sci. Total Environ.* **2005**, *349*, 95–105. [CrossRef] [PubMed]
66. Bush, K.; Courvalin, P.; Dantas, G. Tackling antibiotic resistance. *Nat. Rev. Microbiol.* **2011**, *9*, 894–896. [CrossRef]