Aquatic food systems and antimicrobial use in Bangladesh: A One Health perspective

In partnership with

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Photo credit

Front cover, Shafiq Rheman/WorldFish.

Table of contents

List of abbreviations

AMR	antimicrobial resistance
AMU	antimicrobial use
APHA	Animal and Plant Health Agency
AWaRe	access, watch and reserve (list)
BLRI	Bangladesh Livestock Research Institute
Cefas	Centre for Environment, Fisheries and Aquaculture Science
DOF	Department of Fisheries
DLS	Department of Livestock
ESP	enhanced sustainable production
EUS	epizootic ulcerative syndrome
FAO	Food and Agriculture Organization
FAO ECTAD	FAO Emergency Centre for Transboundary Animal Diseases
FFCGB	Fleming Fund Country Grant Bangladesh
FY	fiscal year
GIFT	Genetically Improved Farmed Tilapia
ICDDRB	International Centre for Diarrhoeal Disease Research, Bangladesh
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
NGO	nongovernmental organization
NRCP	National Residue Control Plan
ODA	Official Development Assistance
QCL	quality control laboratory
SIS	small indigenous species
TiLVD	tilapia lake virus disease
VMD	Veterinary Medicines Directorate
WHO	World Health Organization
WOAH	World Organization for Animal Health
WP	work package
WSSD	white spot syndrome disease

List of figures

List of tables

Executive summary

Protecting Human Health through a One Health Approach is a One CGIAR Initiative that was launched in January 2022. The initiative aims to protect human, animal and environmental health by detecting, reducing and controlling the outbreak of zoonoses, foodborne diseases and antimicrobial resistance (AMR) in low- and middle-income countries. This cross-sectoral collaborative One Health Initiative has five work packages (WPs) and is implemented by four CGIAR research centers: the International Food Policy Research Institute (IFPRI), the International Livestock Research Institute (ILRI), the International Water Management Institute, and WorldFish. The initiative is being implemented in seven countries in Africa and Asia, including Bangladesh. In Vietnam, Bangladesh and Kenya, WP3: AMR will collect evidence on how reducing antimicrobial use (AMU) affects livestock and fish production and farm profits while implementing alternative herd and fish health approaches. In collaboration with the ILRI and IFPRI, WorldFish is implementing WP3 in Bangladesh to reduce the emergence and spread of antimicrobial-resistant zoonotic pathogens in aquaculture settings.

This scoping review is one of the deliverables of WP3, which reviews past literature and projects on AMU and AMR in the aquatic food systems of Bangladesh from a One Health perspective. The purpose of this review is to gain a better understanding of the challenges of AMU and AMR in the prevailing aquatic food production systems in Bangladesh using a One Health approach. The review also sheds light on past and ongoing initiatives led by government agencies, nongovernmental organizations (NGOs) and collaborative research partners to reduce the burden of AMU and AMR in aquaculture in Bangladesh.

Aquaculture is one of the fastest-growing food industries in Bangladesh. The industry contributes significantly to the food security and socioeconomic fabric of the country, averaging an impressive growth of 8.59% annually. Bangladesh has diversified fisheries resources, including many native fish species that have been successfully domesticated for aquaculture in recent years. In addition, several fast-growing exotic fish species, such as Thai pangas (*Pangasianodon hypopthalamus*), Vietnamese koi/Thai koi (*Anabas testudineus*), common carp (*Cyprinus carpio*), bighead carp (*Hypophthalmichthys nobilis*), silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*), tilapia (*Oreochromis mossambicus* and *O. niloticus*), have been introduced into Bangladesh.

Rohu (*Labeo rohita*), pangas (*Pangasius* spp.) and tilapia (*Oreochromis* spp.) are the top-three finfish species farmed commercially countrywide in Bangladesh, particularly in the districts of Cumilla, Mymensingh, Jashore, Chattogram and Rajshahi. These species are farmed in various types of aquaculture farming systems, predominantly in earthen ponds, following a polyculture system approach in which more than one fish species are farmed together. Shrimp (*Penaeus monodon*) and prawn (*Macrobrachium rosenbergii*) are primarily produced in the southern, southwestern and southeastern coastal regions of Bangladesh, mainly in the districts of Bagerhat, Khulna, Satkhira, Noakhali, Potuakhali and Cox's Bazar, predominantly in converted rice fields known as ghers. These tow crustaceans make up only 6% of total inland aquaculture production, but they are significant export commodities.

To raise fish, commercial fish farms in Bangladesh rely on various inputs, such as feeds, fertilizers, aquamedicines, drugs and supplements. Feed is one of the main inputs, accounting for 60%–70% of the total cost of fish production in commercial finfish farms. Despite being prohibited by law to manufacture, distribute and use medicated feeds (the Fish Feed and Animal Feed Act, 2010, and the Fish Feed Rules, 2011), fish farmers often mix various chemicals, such as hormones, enzymes, growth promoters, antibiotics and other substances, in farm-made feeds. There are also concerns that commercial fish feeds could contain antimicrobials. Predominant farming systems, particularly carp polyculture, depend heavily on organic fertilizers such as livestock manure and poultry litter to enhance primary productivity. Using untreated organic manure from livestock and poultry can be a potential driver for spreading antimicrobial-resistant pathogens of livestock origin, and the risk of AMR could be higher in Bangladesh, where regulations on veterinary drug use in the livestock sectors need to be strengthened.

The commercialization and associated transformation of aquaculture farming in Bangladesh have also provided incentives to establish several support services for fish farmers, especially those related to fish health management and disease treatments. Currently, around 100 pharmaceutical companies in Bangladesh are marketing about 400 different types of aquamedicines, including antibiotics, which can be easily purchased over the counter. Many farmers also use livestock drugs and medicines that are not intended for aquaculture applications.

Bangladesh's commercial pond aquaculture system is going through a huge transformation, particularly in terms of intensification. Many popular farming systems are now undergoing semi-intensive to intensive operation practices. Using high stocking densities in intensified production systems can be a predisposing factor to disease outbreaks in aquaculture farms and can lead to the emergence of virulent pathogens and increased transmission rates within and between farms. A number of fish and shrimp/prawn diseases are prevalent in the industry, posing a significant threat to its sustainability. In Bangladesh, fish diseases are mainly reported based on their clinical signs, and exact causes or etiological agents of many of these diseases have not been confirmed by laboratory diagnostic methods. Incorrect disease diagnosis can lead to inappropriate use of antimicrobials, contributing to the emergence, transmission and dissemination of virulent pathogens.

Different drivers make the aquaculture sector a hotspot for the emergence and transmission of antimicrobial-resistant pathogens. These drivers include direct and indirect use of antimicrobials, disease prevalence in aquaculture farms, poor infection prevention and control practices, use of waste materials from terrestrial animal farming systems, and the transfer of contaminated water. In Bangladesh, systematic AMR surveillance and research in aquaculture settings are limited. However, several research findings from aquaculture settings and at the point of consumption have confirmed the presence of antimicrobial-resistant pathogens of human significance, raising serious concerns about the nutrition, health and food safety of millions of people in the country.

WorldFish, an organization with over 30 years of experience working with the Government of Bangladesh and development partners, has established a strong network of policymakers, leaders and experts in the fisheries and aquaculture fields in Bangladesh. In an effort to reduce the burden of AMU and AMR in Bangladesh's aquatic food systems, WorldFish has been leading and implementing One Health Aquaculture projects since 2018 with national and international partners, competent national authorities, research institutions and farmers. The aim is to understand the major drivers of AMU and to strengthen AMR surveillance on key pathogens from aquatic foods by providing technical assistance and diagnostic services.

1. Introduction

Aquaculture is one of the fastest-growing food industries in Bangladesh. In the 2019–2020 fiscal year (FY), the country produced 4.5 million metric tons of fish, with aquaculture accounting for 57.38% of that total, and over the past 12 years the sector has achieved an impressive average annual growth of 8.59% (DOF 2020). Bangladesh is now the fifth-largest inland aquaculture producer in the world (FAO 2022a), and experts believe that this growth will continue in the coming years.

Historically, fish has been an integral part of Bengali culture and culinary tradition. Over time, the sector has become a major contributor to the social, political and economic development of Bangladesh, providing food, nutrition, livelihoods and employment to millions of people. Fish accounts for about 60% of the country's total human intake of animal food (DOF 2020), and the industry as a whole, including both the fisheries and aquaculture sectors, provides jobs to 17.8 million people, 1.4 million of whom are women (Choudhury et al. 2017). Although the sector has brought many positive changes to the socioeconomic structure of the country, there are several One Health challenges that pose risks to its sustainability. These include farming intensification, disease prevalence, AMU and associated transfer of One Health-significant AMR pathogens through interlinked food chains and their associated risks to public health.

Using high stocking densities in intensified production systems can be a predisposing factor to disease outbreaks in aquaculture farms (Krkosek 2010) and lead to the emergence of virulent pathogens and increased transmission rates within and between farms. Diseases in aquatic animals are a major obstacle to sustainable fish production globally (Subasinghe et al. 2019). It has been reported that the use of chemicals is often the first response to disease management in aquaculture in Bangladesh (Uddin et al. 2016).

Various types of agrochemicals, aquamedicines and drugs, including antibiotics and supplements, are frequently used in many predominant aquaculture systems in Bangladesh, and many of these drugs are not registered with drug control authorities. The use of antimicrobials in the country's fish production systems has been categorized as "problematic" (Grace et al. 2015). The irrational and inappropriate use of antimicrobials in aquaculture can lead to the emergence and persistence of antimicrobial-resistant pathogens, and the risk of transfer of these pathogens from aquaculture settings through interlinked human-animal-environment pathways can be high. Experts have identified several predisposing factors contributing to the development of AMU and AMR in the aquaculture sector in Bangladesh. Some of them are the result of a lack of monitoring, regulatory and surveillance services, awareness and knowledge gaps, high disease prevalence in aquaculture farm settings, and the intervention of unqualified health service providers (UOE 2019).

1.1. Objectives

The purpose of this scoping review is to gain a wider understanding of the major aquatic food production systems and associated AMU and AMR concerns in Bangladesh's aquaculture sector from a broader One Health perspective. The review also highlights various initiatives that have been led by government agencies, NGOs and collaborative partners to reduce the burden of AMU and AMR in the sector.

The scoping review has four main objectives:

1. Understand the major aquaculture production systems in Bangladesh.
2. Assess AMU and AMR concerns relating to commonly used inputs and the prevalence of disease in Bangladesh's aquaculture production systems.
3. Identify a network of international and national partners to engage in future One Health Initiatives.
4. Identify action research interventions to reduce the burden of AMR in aquaculture settings in Bangladesh.

2. Major aquaculture species and production systems in Bangladesh

Bangladesh is currently the fifth-largest inland aquaculture producer in the world, and the sector itself is a core component of the country's economy. Officially, there are 240 fish and 24 prawn species recorded from inland freshwater, out of which more than 20 fish, including shrimp and prawn, are commercially farmed in inland aquaculture production systems. In 2019–2020, the country produced 2.58 million metric tons of fish from its diversified aquaculture production systems (DOF 2020).

This section reviews Bangladesh's major aquaculture production systems and farmed species.

2.1. Fish farming systems based on farming techniques

2.1.1. Fish farming in earthen ponds

Fish farming in earthen ponds of different sizes, depths and shapes is the predominant type of finfish farming system in Bangladesh. This practice can be broadly categorized into two groups: (1) homestead pond culture and (2) entrepreneurial or commercial pond culture.

Homestead ponds are small household-owned rural backyard ponds ranging in size from 0.08 to 1 ha, and they are used for multiple purposes, such as bathing, washing clothes, cleaning pots, watering livestock, cooking and drinking water (Belton et al. 2011). Many of these ponds are not built for fish cultivation. Instead, they are originally developed for other purposes, such as excavating the ground to build mud houses or to elevate the floor of the house as a measure to prevent flooding during rainy months or the flood season.

Homestead ponds are generally inherited from generation to generation, so multiple ownerships are common. In the past, these ponds were stocked with wild fish, captured during floods, and sometimes minimally stocked with juvenile fish with little or no additional management (Belton et al. 2011). Fish produced in homestead ponds are mainly used for household consumption, and any surplus is sold in the local market.

The proportion of households owning homestead ponds varies considerably across the country. According to some geographically circumscribed studies, they can differ as much as 20% (Jahan et al. 2010) to 80% (Choudhury et al. 2017). There are now over 4 million homestead ponds—covering an area of 266,259 ha—in Bangladesh, and they have become important aquaculture production systems in the country (Belton and Azad 2012). An earlier study implies that households consume about 12.5% to 50% of the fish produced from such ponds (Jahan et al. 2010).

The advancement of aquaculture knowledge and technologies, the availability of hatchery-produced seeds, and economic incentives for fish culture, along with extension efforts from government agencies and NGOs, have all provided incentives for renovating and/or constructing new ponds for fish culture. Numerous initiatives from government agencies and NGOs have also advocated adopting improved management and cultural practices to enhance fish production from homestead ponds. In many instances, the yield from homestead ponds has increased dramatically. In fact, fish farming in such ponds has become popular and has now turned into a viable business model (DOF 2016).

In homestead ponds, farmers mainly stock large and fast-growing fish species following a polyculture system approach. Species diversity in such ponds is usually high, with between 5 and 10 fish species stocked. Mainly, indigenous (Indian major carps) and exotic major carps, such as rohu, catla (*Catla catla*), mrigal (*Cirrhinus cirrhosis*), common carp, bighead carp and silver carp, are farmed together (Castine et al. 2017). Recognizing the potential of homestead ponds to ensure food security and better economic returns for poor households, numerous projects have aimed to diversify the culture of traditionally preferred fish varieties with fast-growing species, such as tilapia and highly nutritious small indigenous species (SIS) (Hossain et al. 2013; Islam et al. 2017). Some farmers also stock pangas, koi and shingi (*Heteropneustes fossilis*) with carps (Jahan et al. 2015).

In homestead pond fish farming, mainly extensive to improved-extensive management practices prevail, which have a low input and small carbon footprint farming system. Using fertilizers, both organic and inorganic, can boost the natural productivity of these ponds. Commercial feed is rare in this type of system, as farmers mainly use homemade feed, such as rice bran, mustard oil cake and boiled rice, to provide nutrition to the fish. Fish are usually farmed for 1 year (April/May to March/May) (Jahan et al. 2015), but intermittent harvesting is common, especially for self-generating SIS and fast-growing species, including tilapia. Production from homestead ponds depends on many factors, such as species combination and management strategy, and is low compared to commercial fish farming systems. Extensively managed homestead ponds can produce as little as 0.5 to 1.7 t/ha (Jahan et al. 2015). With improved management strategies, however, production can reach as high as 3 t/ha (Belton et al. 2011).

Entrepreneurial or commercial pond culture differs from homestead pond culture in the sense that it uses purpose-built or renovated ponds for commercial fish production. This culture system adopts improved fish management techniques, and significant investment is made for fish production. Ponds are usually constructed in low-lying lands, such as rice fields, beels and other natural waterbodies or depressions.

Commercial pond culture is a relatively new addition to Bangladesh's aquaculture systems and has scaled up since the late 1990s (Belton et al. 2011). In the past three decades, fish production from ponds has increased tremendously, and experts believe that this is mainly a result of the expansion of commercial pond culture throughout the country. One study revealed that in Trishal Upazila, one of the main fish producing areas under Mymensingh District, the commercial pond area increased almost eight-fold from 2000 to 2016, whereas the area of homestead ponds decreased during the same time period (Palash et al. 2018). Tilapia, indigenous and exotic carps, koi (climbing perch) and pangas are some of the popular finfish species commercially farmed in this system. Management systems generally followed are improved extensive and semi-intensive to intensive, and depend heavily on input supplies, such as seed, commercial feed, fertilizer, water, agro-chemicals and disease treatment medicines.

Catfish farming in earthen ponds is expanding rapidly in many parts of Bangladesh, including in Mymensingh District, which is an important fish production region of the country. Advancements in artificial propagation techniques, the availability of hatchery-produced fry, high market demand, and lucrative prices, along with a better feed conversion ratio—as claimed by the farmers—are some of the driving factors behind the rapid expansion of different types of catfish monoculture or polyculture production systems in Bangladesh. In fact, in many parts of the country, farmers are switching from tilapia to catfish farming. Besides pangas, several other catfish species are farmed commercially, such as pabda (*Ompok pabda*), shing , magur (*Clarias batrachus*), tengra *(Mystus tengara*) and gulsha (*Mystus cavasius*).

2.1.2. Integrated fish farming

In integrated fish farming systems in Bangladesh, fish culture is integrated with agricultural crops or livestock, poultry and duck production. Agriculture-based integrated systems mostly include rice-fish integration and horticulture-fish systems. In an integrated fish-livestock or fish-poultry farming system, farmers use manure from ducks, chickens, pigs and cattle in their fishponds—either applying it themselves or building their system in such a way that the animal droppings fall directly into the pond. This increases the production of natural food organisms, such as plankton, for the fish to eat and reduces the need to buy chemical fertilizers and supplementary feeds.

The integration of fish culture with the production of ducks and chickens first started at the Bangladesh Fisheries Research Institute (BFRI) in Mymensingh, with some promising results. About 500 Khaki Campbell ducks were raised on a 1 ha carp pond that produced 4.5 t of fish per hectare without any additional feed or fertilizer (FAO 2022b). The most promising integrated farming in Bangladesh is the rice-fish culture system, which is found in many parts of the country. Traditionally, one or more sump ponds are constructed at the lowest corner of a paddy field. There, stocked fish accumulate naturally following the inclination of the land when the water level in the field drops and are harvested without any additional stocking or management.

2.1.3. Gher farming

Ghers are mainly large low-lying rice fields converted into shrimp, prawn or fish farms. They usually withdraw water from a common source or are filled with rainwater during the monsoon period. The two most prominent types of gher systems in Bangladesh are freshwater-based prawn-paddy culture and brackish or saline water-based shrimp culture.

Prawn-paddy farming in ghers is an agricultural system developed by farmers in low-lying agricultural land, mainly in the southwest regions of Bangladesh, such as the districts of Khulna, Bagerhat, Goplalganj Satkhira and Jashore. In such farming systems, prawns are farmed along with carps and rice in ghers (Kamp and Brand 1994; Shah et al. 2008). The whole gher area is filled with rainwater during the monsoon season, from June to December, and closely resembles a typical earthen pond. It dries naturally from January to April, except when inundated with water from the canals. Freshwater-based prawn-paddy culture can follow two approaches: (1) simultaneous culture in which prawn post-larvae are stocked after 20–25 days of paddy planting or (2) sequential culture techniques in which the paddy is cultivated first and then prawn post-larvae are released later in the same gher (Shah et al. 2008).

Shrimp farming is mainly practiced in the southern and southeastern coastal regions of Bangladesh in the districts of Bagerhat, Khulna, Satkhira and Cox's Bazar. Gher farming is the prevalent culture system for shrimp, though some entrepreneurs farm shrimp semi-intensively in purpose-built ponds. Ghers with saline water shrimp usually have their own gates to control the inflow and outflow of water and are commonly connected to estuaries and canals for water exchange during spring and neap tides.

2.1.4. Pen culture

Fish farming in pens is a relatively new farming technique in Bangladesh that is practiced in inland open waterbodies such as floodplains, canals, small rivers, lakes and waterlogged areas. In this culture technique, fish are raised in water enclosed with various types of barriers, such as bamboo fences, earthen dikes and polythene nets, on all sides except the top and bottom. The bed of the waterbody serves as the bottom of the pen, while the top of the pen remains open. The structure is usually kept in place with bamboo poles or twigs.

Although fish polyculture in pens has shown great potential for increasing fish production in Bangladesh (Haque et al. 2006), it is only practiced in suitable geographical areas, where tilapia and native and exotic carps are being farmed. In 2019–2020, a total of 7263 ha of water area—which is only 0.3% of the country's total inland fish production area—were used for pen culture, producing an estimated 13,425 t of fish for an average productivity of 1.85 t/ha (DOF 2020).

2.1.5. Cage fish farming

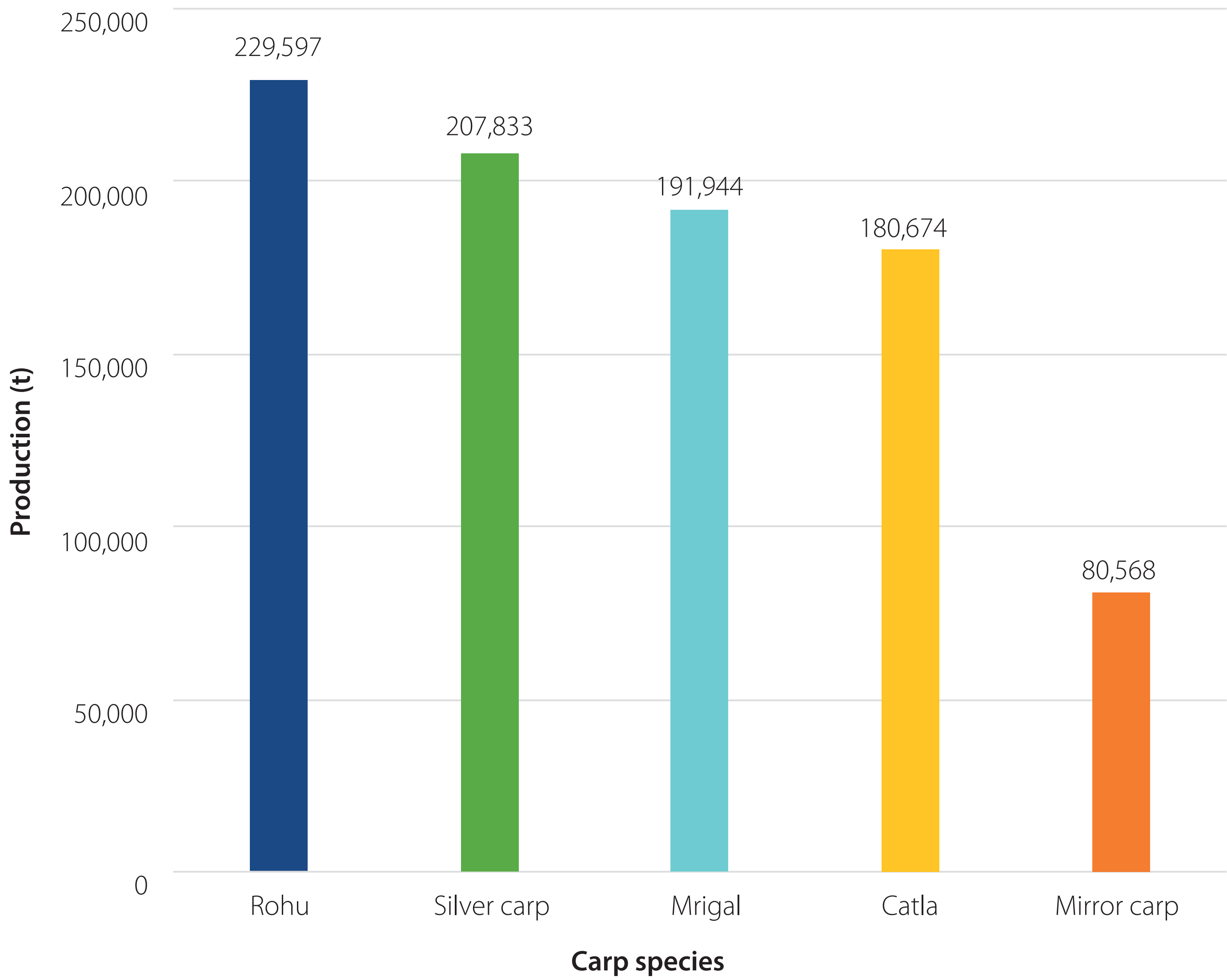
Cage fish farming, in which fish are reared in cages with sufficient water movement, is another aquaculture method practiced limitedly in Bangladesh. The cages are made of nets and are framed on all sides with bamboo or steel. They either float or are submerged in water and are anchored to the bottom of the waterbody. In Bangladesh, cages are usually placed in wetlands such as in rivers, baors, beels and floodplains and also sometimes in ponds with sufficient depth. According to the DOF (2020), cage fish farming in the country in 2019–2020 covered a total area of 179,223 m^3, from which 4590 t of tilapia were harvested.

2.2. Species-wise fish farming

2.2.1. Carp farming

Polyculture of native and exotic carps in earthen ponds is one of the most commonly practiced fish farming systems in Bangladesh, making up about 58% of total fish production from ponds (DOF 2020). Figure 1 shows the top-five carp species farmed in pond production systems. In this culture system, indigenous major carps, such as rohu, catla and mrigal, are stocked together with exotic carps, such as silver carp, grass carp and common carp and sometimes other fish groups, like tilapia and pangas, in the same waterbody. Rohu, catla, mrigal and silver carp combined comprise 43.01% of total fish production and represent about 77% of total carp production from aquaculture ponds. Of these, rohu is the single-most produced fish from aquaculture ponds (DOF 2020).

In the carp polyculture system, different species are stocked together to allow different trophic



Source: DOF 2020.

Figure 1. Production-wise, top-five carp species farmed in ponds.

levels and spatial niches of the pond system to be used efficiently for increased fish production. In this culture system, carp and other species are chosen carefully based on their feeding habits and preferred niches so that competition for food and space is minimal. Catla and silver carp are phytoplanktiphagus species that occupy the upper level of the pond, rohu stays in the middle level of the pond ecosystem and common carp/ mrigal are bottom dwellers. As such production techniques depend considerably on natural productivity, commercial carp farmers use both organic and inorganic fertilizers routinely to boost the natural productivity of their ponds. It has been reported that 73% of carp farms use organic fertilizers and 93% use inorganic fertilizers in their ponds, in addition to supplementary feeding with agriculture byproducts such as rice bran, wheat bran and mustard oil cake (Jahan et al. 2015).

Most farmers start to stock their farms with juvenile carps at the beginning of the summer months (March/April) and harvest them at the end of the year. In some places, farmers purchase overwintered carp fingerlings and stock them at the beginning of the summer months. Overwintered carps are able to grow more than 1 kg in size in a year because of longer exposure to warm temperatures, and subsequently fetch a higher market price which can not be achieved than typical carp polyculture systems in Bangladesh (Alam et al. 2002). Farmers mainly follow extensive to semi-intensive techniques for carp polyculture production systems. In extensive systems, however, production from carp polyculture is low, at just 1 t/ha, though production can reach 4–5 t/ha in improved intensive systems. Although carp polyculture technology has been developed to use the pond ecosystem efficiently to maximize production, there is still a chance to increase the yield from such farms by 31% (Hossain et al. 2022).

A number of diseases are known to cause economic loss in carp farms. Among these, epizootic ulcerative syndrome (EUS) is the most common that affects cultured carp species (Phillips 2000), though relatively few farms (8%) report experiencing a disease outbreak (Ali et al. 2016). Like many other commercial fish farming practices in Bangladesh, carp farmers also use various chemicals to tackle diseases. However, the number of chemicals used in carp farms is low compared to tilapia and pangas farming. Only 3%–5% of carp farms are reported to use antibiotics to control diseases (Phillips 2000; Ali et al. 2016).

Carp polyculture systems are known for their low impact on the environment (ADB 2004). Indeed, combining different carp species helps maintain water quality, recycle nutrients and improve the pond environment (FAO 1992).

2.2.2. Tilapia farming

Tilapia (*Oreochromis* sp.), originally an exotic fish species, was first introduced into Bangladesh from Thailand in 1954. Initially, the species was not very popular among local farmers because of its early maturation and prolific breeding, which led to overcrowding and stagnant growth. However, the foothold of the species became stronger over time, especially after the introduction of two new strains: Genetically Improved Farmed Tilapia (GIFT) and Chitralada. The advancement of hatchery technology in the production of monosex tilapia also helped overcome many of these limitations. Tilapia has now become one of the most cultured fish in Bangladesh and is often referred to as the "aquatic chicken" because of its potential for mass production in a relatively short period of time, along with its acceptability to consumers. Production-wise, tilapia is now the third-highest species farmed in Bangladesh, after pangas and rohu. In 2019–2020, the country produced about 370,000 t of tilapia, representing 9.69% of annual fish production from inland waterbodies and 14.52% of total fish produced from ponds (DOF 2020).

Although tilapia production systems are distributed across the country, there is no exact data on the total area of tilapia farming in Bangladesh. A previous study said it was 199,693 ha in 2011–2012, with predictions that it could reach up to 330,000 ha by 2015–2016 (Innovision 2013) and that about 201,000 farmers were engaged in tilapia farming (Rahman et al. 2021). Tilapia farming is widely practiced in both freshwater and brackish water in Bangladesh, but local production of tilapia and its relative contribution to total regional pond fish production varies widely across the country. Figure 2 shows the top-five tilapia producing districts in Bangladesh. Cumilla is the leading district, followed by Mymensingh, Jashore, Chattogram and Thakurgaon. Given the large number of species available for farming, market price usually defines which species farmers choose to stock to maximize their profits. In recent times, a considerable number of tilapia farmers have shifted to farming more valuable species of catfish, such as pabda, shing, magur, tengra and gulsha.

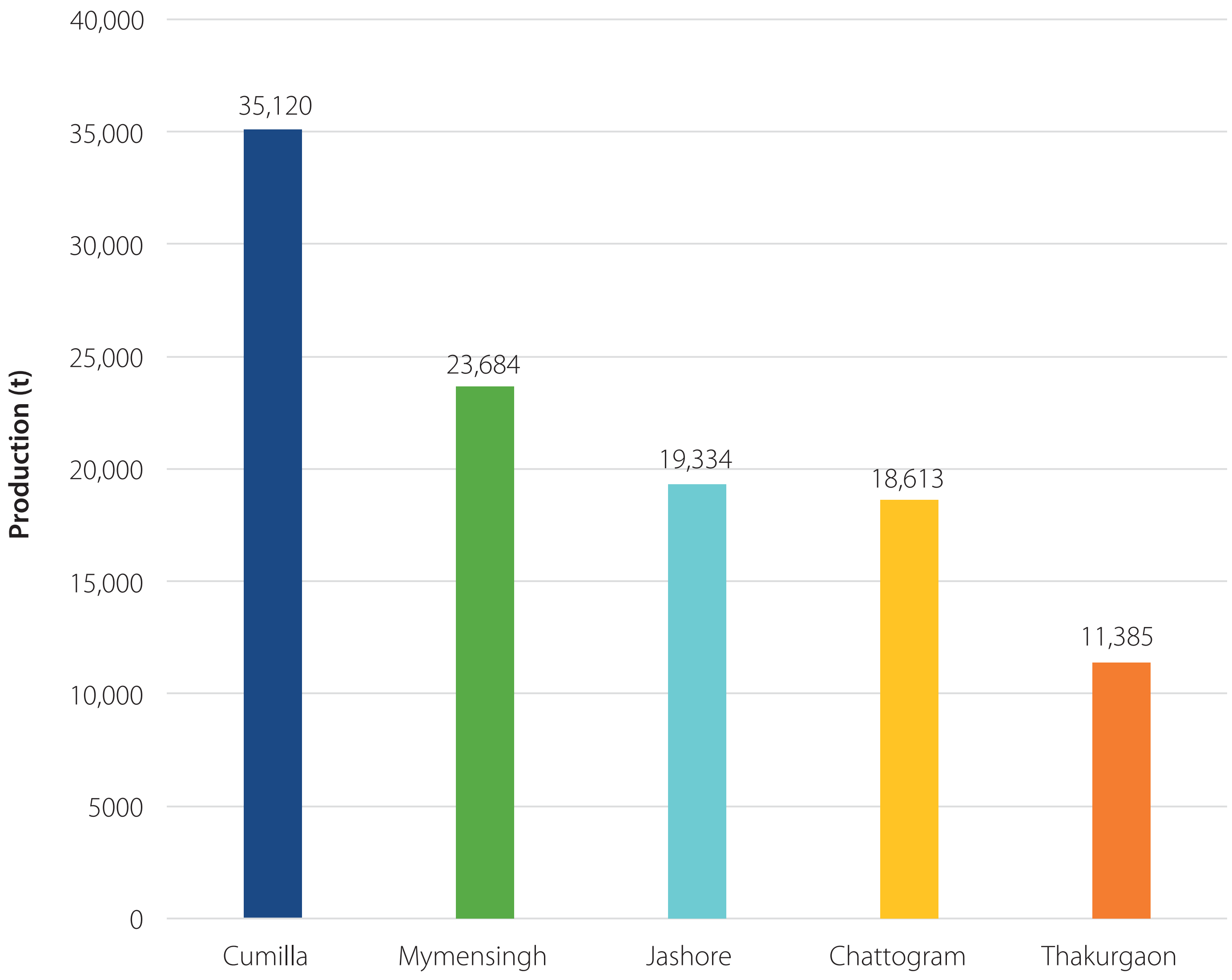
Finfish aquaculture in Bangladesh predominantly takes place in earthen ponds, and tilapia farming is no exception. The species is farmed in various types of waterbodies, including freshwater and brackish water ponds, seasonal waterbodies, beels, and shrimp or prawn ghers, following different methods and techniques, such as monoculture, polyculture, pen culture and cage culture. Yet despite various waterbodies and techniques used for tilapia farming, most of the production comes from commercial earthen fishponds, which contribute around 78% of total tilapia production in Bangladesh (DOF 2020).

There are two main culture techniques for tilapia farming in earthen ponds: monoculture and polyculture. The latter is the most prevailing practice in Bangladesh. Some commercial farmers also follow monoculture techniques for the production of tilapia species because it offers higher revenue than the polyculture system (Ferdoushi et al. 2019). In polyculture systems, tilapia is usually farmed with native and exotic major carps, such as rohu, catla, silver carp and grass carp. Other combinations, such as tilapia with catfish (pangas, pabda, singh and tengra), are also practiced but on a relatively small scale. In the southern part of the country, tilapia is popularly farmed in gher systems with giant freshwater prawn or tiger shrimp. In a polyculture system, tilapia can be the dominant or secondary species.

Tilapia is a fast-growing species that usually reaches acceptable market size within 4–5 months after stocking fingerlings in the pond, though some farmers rear the fish for longer periods to get larger fish (500–1000 g) in order to fetch a better market price. In some regions, a polyculture system with partial harvesting and stocking of tilapia is common, whereas in a monoculture system farmers are usually capable of harvesting two full crops in a year.

March/April to November/December is the most suitable time for tilapia production in Bangladesh, when the climate is comparatively warmer. Farmers usually avoid farming tilapia in the winter months because of the slow growth rate and a lack of hatchery-produced tilapia fry available. However, some in the Mymensingh region have been reported to stock tilapia fry at the end of the summer season to rear them during the winter months (November–February) and harvest the crop at the beginning of the summer months (March–April). They do so in order to fetch higher market prices because of the lower availability of farmed fish species in the markets during that time. Commercial tilapia farmers mainly stock hatchery-produced monosex fry. However, some farmers in the Mymensingh region also stock self-propagating (non-monosex) tilapia fry with other species, which allows them to harvest smaller tilapia intermittently without intentional restocking.

Input supply in tilapia farms depends on the culture system followed. In a polyculture system, tilapia is mainly farmed with low to medium levels of inputs under extensive or semi-intensive operations, with reported productivity of about 8 t/ha (Rahman et al. 2021a; Tran et al. 2021). Monoculture of this species has mainly adopted intensive to semi-intensive operations, where fish are stocked at higher densities of 20,000–50,000 fry/ha (Sharmin et al. 2019) and have a higher yield



Source: DOF 2020.

Figure 2. Top-five tilapia producing districts in Bangladesh.

per area of about 10 t/h (Rahman et al. 2021a; Tran et al. 2021) compared to polyculture systems.

In general, tilapia farming in Bangladesh is widely considered to have no major negative impacts on the environment (Innovision 2013). Lately, however, several concerns linked to tilapia farming have also arisen: (i) contamination by farm effluent water containing unused feed, agro-chemicals, antibiotics and hormones, (ii) the discharge of nutrient-rich water into the environment, leading to eutrophication, (iii) the establishment of exotic species (tilapia) in natural waterbodies, (iv) and their impact on native populations of fish and other biota (Canonico et al. 2005; Innovision 2013; Islam and Yasmin 2017). Recently, several diseases have been reported from tilapia farms in Bangladesh. Tilapia lake virus disease (TiLVD) is an emerging transboundary disease causing global tilapia mortality of up to 90%. It is a serious threat to the livelihoods and food security of millions of farmers (Chadag and Delamare-Deboutteville 2019; Aich et al. 2022) and has been circulating widely in tilapia farms and hatcheries across Bangladesh (Debnath et al. 2020; Chaput et al. 2020).

The recent hike in commercial fish feed prices is a major threat to the sustainability of tilapia farming in Bangladesh, as commercial tilapia farms in the country mainly use formulated feed. One study found that over 70% of tilapia farms in the country use commercial feed (Faruk et al. 2017).

2.2.3. Pangas farming

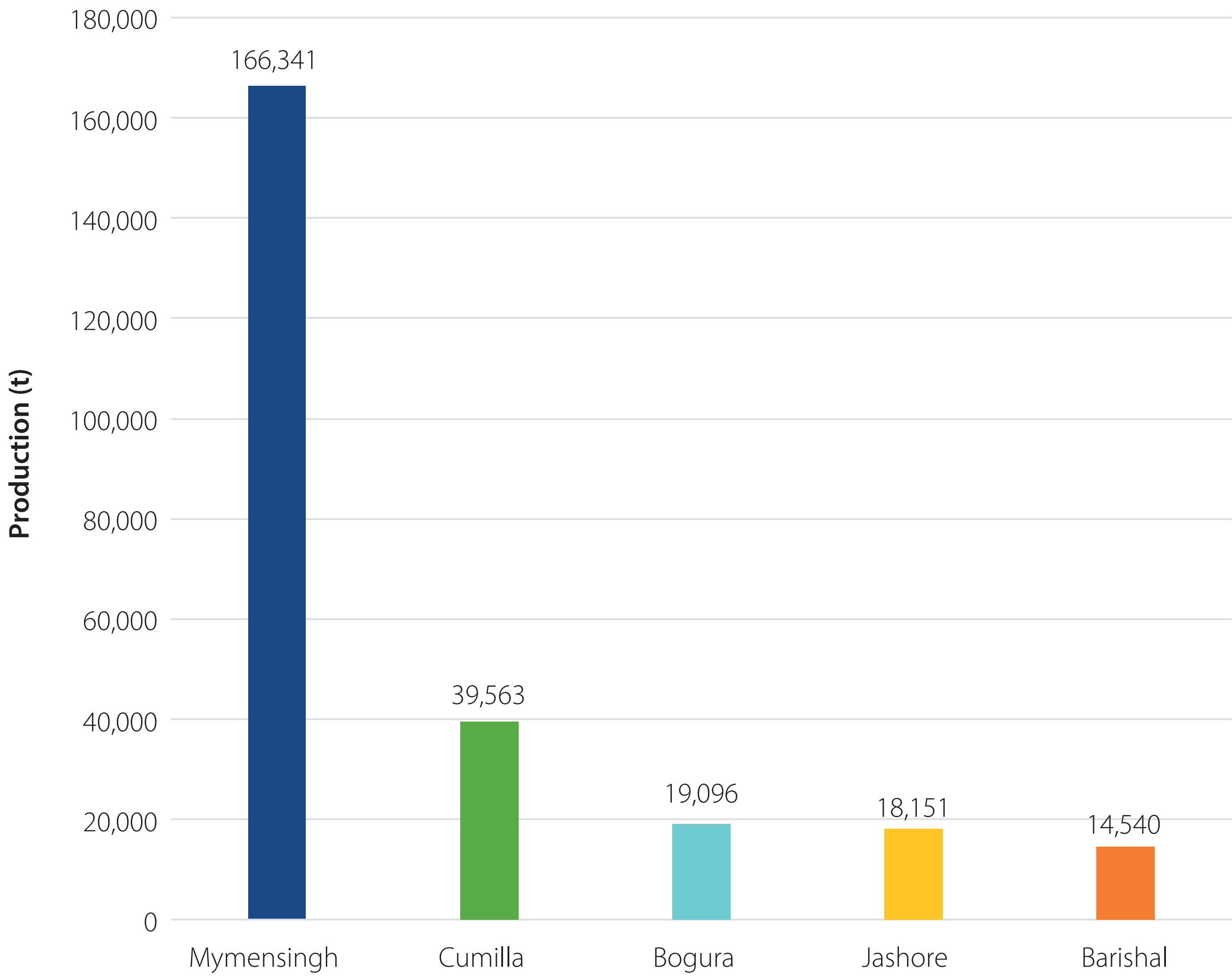
Pangas, known as the "Thai pangas" in Bangladesh, is another exotic species that was brought to Bangladesh from Thailand, during the 1990s. It was introduced as an alternative to farming indigenous pangas (*Pangasius pangasius*), which was hard to grow and domesticate with no hatchery to produce seed.

Given its faster growth rate, access to breeding technology, availability of hatchery fry and relatively easy management, along with its wider acceptability and good market price, pangas has become the most farmed fish species in Bangladesh. In 2019–2020, the country produced 390,000 t of pangas, representing 8.99% of the country's total fish production (DOF 2020). This freshwater species is farmed mainly in perennial ponds, which can hold water year-round, across the country; however, production from Mymensingh District exceeds far beyond those of other districts (Figure 3).

An earlier study showed that farmers mainly practiced pangas monoculture in earthen ponds (Sarkar et al. 2007), but many farmers have since shifted away from monoculture. Currently, 90% follow polyculture techniques (Hossain and Rahman 2018), with pangas being farmed with tilapia, rohu, catla and silver carp. This pangas-carp polyculture is claimed to be a more resilient farming system, as it enhances pond productivity and income without the additional cost of feed for the stocked carp species (Ahmed and Toufique 2015). The unused feed in pangas farms can enhance the nutrient supply and primary productivity of the pond, which in turn serves as feed for the stocked planktivorous carp species.

Pangas is a relatively fast-growing fish species, reaching 1.5–2 kg within 10–11 months. In Bangladesh, pangas become marketable at 500 g, though larger fish are preferred because they fetch a higher price at the markets. The farming period for pangas depends on the targeted market size. Farmers usually stock juvenile pangas in May/June and harvest them in November/January, when the fish reach 1.5–2 kg. Instead of growing large fish, however, some farmers prefer to harvest pangas at an average weight of 500 g and then restock their ponds with new pangas fingerlings. This allows farmers to harvest two crops in a 1-year production cycle. Pangas farming in Bangladesh can be categorized as an input-intensive farming practice, which predominantly follows semi-intensive to intensive production techniques. In general, 30,000–60,000 fingerlings are stocked per hectare (Sarkar et al. 2007) and fed with commercial feed. However, because of the recent price hike in commercial feed, some farmers use farm-made pellet feed instead or along with commercial feed. Reported yields from pangas farms vary widely and depend on many factors. An earlier study estimated production at 20–45 t/ha, with an average of 25 t/ha from pangas farms (Sarkar et al. 2007).

Pangas is a major farmed aquaculture species that contributes greatly to the food security, nutrition, income and livelihoods of millions of people in Bangladesh and has the potential



Source: DOF 2020.

Figure 3. Top-five pangas producing districts in Bangladesh.

to become an export commodity. The species is well known for its ability to tolerate poor water quality. Many farmers grow pangas in sub-optimal environmental conditions, especially in organically polluted waterbodies. This is one of the reasons behind the low acceptability and reduced market price of the species in Bangladesh (Rahman et al. 2021b).

Disease prevalence in pangas farms is one of the main limitations restricting current farming of the species in Bangladesh. A number of health problems have caused major financial loss and threatened the livelihoods of pangas farmers. Clinical signs include red spot, anal protrusion, tail and fin rot, exophthalmia, dropsy, gill rot, ulceration and cotton wool growth (Faruk 2008). In Bangladesh, pangas-carp polyculture is predominantly practiced with high stocking densities despite there being a well-established link between high stocking density and disease outbreak in aquaculture farms (Krkosek 2010).

In addition to disease prevalence, several factors, such as a lack of knowledge and proper diagnostics, act as a driver behind the use of different chemicals and drugs, including antibiotics, in fish farms to tackle disease problems (Chowdhury et al. 2022). Compared to other production systems, a higher proportion of pangas farms use a wide variety of chemicals, such as water treatment products, fertilizers, disinfectants, antibiotics and pesticides (Ali et al. 2016), which are considered important cost items in pangas-carp polyculture farms (Alam et al. 2019). Yet residues of antimicrobial substances and other chemicals can bio-accumulate in fish flesh. Alam and Haque (2021) identified the presence of chemical residues of human health significance, including antibiotics and heavy metals, in the flesh of farmed pangas and tilapia.

In many areas, the recent expansion of pangas farms has come at the cost of the conversion of agricultural land and wetlands. In Trishal, a major fish producing hub of the country, 10.13% of agricultural land has been converted for pangas farming (Ali and Haque 2011). Loss of agricultural land can in turn decrease rice production (Anka et al. 2014).

Intensive dependency of pangas farms on groundwater, particularly during the dry months (Alam et al. 2019), is another concern. On average, one pangas farm in one production cycle (6–8 months) replaces its water twice, with an exchange rate of 20%–70%, and the outflowing water is discharged into nearby wetlands without treatment (Ali and Haque 2011). Releasing untreated nutrient-rich water from fish farms can trigger negative impacts on the environment, which can cause eutrophication in nearby waterbodies. Pangas farms are also known to generate huge amounts of bottom sludge because of the accumulation of unused feed, which needs to be removed to keep the farm fit for fish production (Anka et al. 2014).

2.2.4. Koi farming

At present, there are two exotic strains of koi, also known as climbing perch, that are farmed in Bangladesh: the Thai strain, which was brought to Bangladesh in 2002, and the Vietnamese strain, brought in 2010 (Kohinoor et al. 2016). Compared to native strains, these two strains have various positive attributes that make them suitable for commercial aquaculture, including fast growth, larger size, tolerance to farming at high density, resistance to poor environmental conditions, and attractive local market prices. In addition, the development of induced breeding and the availability of seed have made these exotic strains popular among fish farmers. Species-wise, fish production from pond aquaculture shows that koi is the seventh-most farmed fish species in Bangladesh. In 2019–2020, the country produced 53,227 t of koi, representing 2.6% of total fish production from ponds (DOF 2020).

Although the species is farmed in many parts of the country, the production data implies that koi farms are mainly concentrated in two districts: Mymensingh and Cumilla. An earlier study reported that farmers started to farm koi following an extensive to semi-intensive polyculture system, where average production can range from 1.5 to 2.07 t/ha (Innovision 2013). Over time, however, farmers have shifted away from this system and have recently started to carry out intensive farming of this species, mainly under a monoculture system, though polyculture with some other species can still be found. In a recent study looking at koi-intensive monoculture systems, the authors reported production of up to 15.35 t/ha for the Vietnamese strain and 9.45 t/ha for the Thai strain (Kohinoor et al. 2016). These strains grow fast and reach market size within 4–5 months after stocking, so farmers are able to culture at least 2 crops a year. In Bangladesh, the koi farming season usually begins with stocking at the beginning of the summer months (March/April) and ends ahead of the start of the winter months (September/October).

2.2.5. Shrimp farming

Shrimp and prawn have become some of Bangladesh's most valuable aquaculture export commodities. In 2019–2020, the country produced 270,114 t of shrimp and prawn (DOF 2020) and earned USD 328.84 million from shrimp and prawn production in the 2020–2021 FY (Taon 2022). Approximately 1.2 million people are directly involved in shrimp production in the country, and a further 5 million are indirectly supported by the industry (Paul and Vogl 2011).

Shrimp are mainly farmed extensively in a gher system where the input supply is minimal. In extensive shrimp farming, farmers rely on natural productivity with little or no management, but reported production from this kind of farming practice is comparatively low. Semi-intensive and intensive shrimp farming practices are relatively less common, and the systems mainly depend on input supplies, such as feed, chemicals and management practices, including pond waste removal, aeration and water supply. Production from extensive shrimp farming is relatively low, at just 160–230 kg/ha, compared to semi-intensive systems, where production ranges between 500 and 5000 kg/ha (Belton et al. 2011).

Shrimp farming in Bangladesh mainly takes place during the dry months, from January to July, when water salinity is relatively high. In the southeastern part of the country, shrimp are farmed alternately with salt production, whereas shrimp farming is alternated with rice production in the southwestern part. During the farming season, farmers usually stock shrimp post-larvae several times; they stock them monthly and then harvest them intermittently throughout the production cycle. Shrimp are predominantly grown in extensive ways in which more land is required per unit of production compared to other prevalent fish farming systems in the country (Jahan et al. 2015; Ali et al. 2016).

Although shrimp farming started many decades ago in Bangladesh, it still faces a number of challenges, including environmental degradation and a high prevalence of disease, raising questions about the long-term sustainability of this industry (Islam et al. 2021). Farming takes place in the south, southwestern and southeastern coastal areas of Bangladesh, where favorable environmental conditions, particularly saline water, are available for production. Earlier, shrimp farming was mainly concentrated in areas that were inundated with saline water. But the industry experienced a boom during the 1980s because of strong international market demand, which acted as an incentive for the rapid expansion of shrimp farms in converted land, especially converted paddy fields and mangrove forests (Azad et al. 2009; Anisuzzaman et al. 2015), which has changed the ecology of the affected area remarkably. Environmental impacts such as mangrove degradation and associated impacts on ecology and biodiversity, salt water intrusion, sedimentation, pollution and disease outbreaks are some of the major obstacles to the development of sustainable shrimp farming in the country (Paul and Vogl 2011).

Disease is one of the main limiting factors to the development of shrimp farming in Bangladesh. A number of diseases, such as white spot syndrome disease (WSSD), yellow head disease, vibriosis, black gill disease and soft shell disease, have all been reported from shrimp farms in the country (Islam et al. 2020). An earlier study reported that about 97% of shrimp farms were affected by diseases and found that 15% of farmers used chemicals to treat shrimp diseases (Faruque et al. 2008). Among these, WSSD causes devastation in shrimp farms, which are reported to have no treatment, and mortality could be as high as 100% (Pradeep et al. 2012). Farmers have tackled the disease burden in shrimp farms by increasing the use of different types of chemical and biological products, leading to a reported 424% average increase in the number of active substances entering shrimp ponds (Heal et al. 2021).

3. Common inputs in commercial aquaculture farms in Bangladesh

3.1. Feeds

Feed is a major input in semi-intensive to intensive aquaculture systems in Bangladesh and accounts for 60%–70% of total production costs. Many extensive farming systems, especially extensive shrimp polyculture in ghers, depend heavily on the natural productivity of the culture waterbody; however, improved extensive, semi-intensive and intensive culture systems depend substantially on supplementary feed for their production.

Farm-made and commercial feeds are both popular in Bangladesh's aquaculture sector. One earlier study estimated that in 2012 the country produced 1 million metric tons of commercially formulated aquafeed and 300,000–400,000 t of farm-made aquafeed (Mamun-Ur-Rashid et al. 2013). Fish production is linked to the number of inputs, especially with the amount of feed used and the number of fish stocked. As such, the recent increase in fish production implies that feed use either could have increased substantially or that more seeds have been stocked.

When making farm-made fish feed, farmers often use various ingredients, such as wheat bran, rice bran, bone meal, soybean meal, mustard oilcake, rice polish, corn, salt, vitamin premix and molasses. The Fish and Animal Act, 2021 prohibits the inclusion of additives in aquafeed in both commercial and farm-made feed. However, it is common for farmers to mix various chemicals, such as hormones, enzymes, growth promoters, antibiotics and other substances when making their own farm fish feeds, and the quality of those feeds, which the relevant authorities cannot control, is often below standard (Innovision 2013). Some local farmers have been reported to mix Doxicap—a broad-spectrum antibiotic of the tetracycline group—when preparing farm-made fish feed to control fungi (Sarkar et al. 2007). Currently, it is unclear the extent to which chemicals are included in commercial fish and livestock feeds produced in Bangladesh, but the industry is not without controversy. A number of studies have confirmed contamination of both commercial and homemade fish feeds with various harmful chemicals, such as antibiotics, heavy metals, hormones, mycotoxins, organophosphates, anthelmintics and dyes (Islam et al. 2014; Ali et al. 2016; Alam and Haque 2021).

In poultry feed, amoxicillin, ciprofloxacin and enrofloxacin have all been routinely used without being declared to the seller (Khan et al. 2018), and many commercial poultry feed manufacturers are also manufacturing commercial fish feed in Bangladesh. Experts believe that locally made commercial fish feed could contain antimicrobials (UOE 2019).

3.2. Fertilizers

Fertilizers are one of the inputs extensively used in most types of small-scale to commercial aquaculture farms in Bangladesh, from pond preparation to the grow-out stage. The main reason for using fertilizers in aquaculture farms is to provide nutrients that enhance the primary productivity of the culture waterbody. This enriches the linked-ecological food chain, such as microbes, phytoplankton and zooplankton, which in turn provides natural food to fish that boosts productivity.

Both organic and inorganic fertilizers are used in aquaculture farms in Bangladesh. During pond preparation, it is common for farmers to partially fill the pond with water and fertilize it with organic and inorganic fertilizers. Three to four days after initial fertilization, farmers fill their ponds with additional water.

To prevent plankton crashes, some farmers fertilize their ponds every fortnight. The rate of pond fertilization varies widely and depends on various factors, such as farmed species, farming systems and how water physicochemical properties respond to fertilization. In general, intensive farmers use more fertilizer than extensive or semi-intensive farmers (Innovision 2013). Fertilizers, both organic and inorganic, are heavily used in semi-intensive carp polyculture systems that largely depend on the primary and secondary productivities of the ponds. Table 1 lists different fertilizers commonly used in different aquaculture production systems in the country. Urea, triple

Type of fertilizer	Name of fertilizer
Organic	Cow dung
	Buffalo manure
	Chicken droppings
	Compost
	Molasses and yeast
Inorganic	Urea
	Triple super phosphate
	Di-ammonium phosphate
	Muriate of potash
	Lime
	Gypsum
	Dolomite

Table 1. List of fertilizers that are commonly used in pond aquaculture in Bangladesh.

super phosphate and cow dung are the most common (Ali et al. 2016). One earlier circumscribed study estimated that semi-intensive fish farms used 8.6 t/ha of organic and inorganic fertilizers annually, of which 88% were organic, mainly cow dung (Karim 2006). In Bangladesh, 3079 t of poultry manure are produced per day (Hossen et al. 2015), and 50% of medium-sized poultry farm owners use their poultry litter for fish culture (Sarker et al. 2009).

Manure from livestock and poultry is a valuable source of nutrient supply for aquaculture systems in Bangladesh and is used as a fertilizer in fish and shrimp production. However, livestock and poultry manure are believed to be a potential major driver of spreading pathogenic bacteria, including antimicrobial-resistant pathogens, in aquatic systems and the environment (Aly et al. 2009; Macedo et al. 2020). The risk could be especially high in Bangladesh, where regulations on the use of veterinary drugs in livestock sectors needs to be strengthened (Jahan et al. 2021).

Although the use of organic manure from livestock origin in aquaculture represents a significant risk in Bangladesh, there are limited national studies on the level of antibiotic residues and antimicrobial-resistant pathogen loads in organic manure. Sarker et al. (2020) reported that out of 120 poultry manure samples, 40.83% had antibiotic residues from ciprofloxacin, 23.33% from oxytetracycline, 17.50% from doxycycline and 8.33% from enrofloxacin. Of these, ciprofloxacin and oxytetracycline are listed in the Watch category on the World Health Organization's (WHO) access, watch and reserve (AWaRe) list for antibiotic classification (WHO 2021). This category contains the highest priority agents among critically important antimicrobials for human medicine that are at relatively high risk of selection for bacterial resistance.

3.3. Aquamedicines, drugs and supplements

Over the past few decades, the aquaculture sector in Bangladesh has gone through a number of transformations in terms of its expansion, intensification, diversification and the adoption of new fish farming technologies. In the past 12 years, the sector has managed to achieve consistent growth of 8.59% annually (DOF 2020).

To support this transformation, various support services in the industry have been established, especially services relating to health management and disease treatment of farmed fish species. Approximately 100 pharmaceutical companies are marketing about 400 different types of aquamedicines in Bangladesh (Alam and Rashid 2014). These companies, as well as importers, sell various aquamedicines, drugs and chemicals either directly or indirectly through livestock feed dealers and input shops in the country. In turn, farmers purchase various chemicals and drugs to manage the health of their ponds and fish, such as antibiotics, probiotics, growth promoters, insecticides and herbicides.

It is well established that the overuse and abuse of these chemicals poses a significant threat to the health of humans, animals and the environment. Most of the existing literature from Bangladesh on aquamedicines mainly lists the different types that are available in the domestic market. The effectiveness of these drugs in terms of improving water quality, treating diseases and enhancing production is obscure and not scientifically tested. The potential human health hazards associated with the impractical use of these chemicals by farmers also pose some great concerns.

The most common aquamedicines and chemicals used in Bangladesh are disinfectants, antibiotics, probiotics and chemicals for water quality management, nutritional supplementation and pesticides. A survey of 1890 aquaculture farms covering major aquaculture producing areas of the country listed 45 chemical and biological products that were used (Ali et al. 2016). And a recent study in the Mymensingh region reported that antibiotics were the most used drugs (80.85%) in fish farms, followed by disinfectants and nutritional supplements (6.38% each). The study also reported that salt, ammonia removal agents, probiotics and pesticides were also commonly used in fish farms (Faruk et al. 2021).

3.4. Disinfectants

Disinfectants are chemical compounds that are commonly used in aquaculture to kill microorganisms on inert surfaces such as nets, equipment, concrete tanks and hatchery production systems. However, they are also used for other reasons. Commercial fish farms in Bangladesh mainly use disinfectants to treat soil, water and fish infections, while farmers use them to manage water quality by reducing pathogen loads in culture waterbodies and controlling algal blooms as well as to treat diseased fish. Yet most farmers do not have adequate knowledge about these chemicals (Faruk et al. 2004), and it is usually the drug sellers, or input sellers, who advise them to buy and apply these disinfectants in their aquaculture farms (Kawsar et al. 2019). Farmers usually dilute these disinfectants in water, as instructed by the drug seller or input dealer, and then manually spray the solution over the waterbody. Different brands of disinfectants commonly used in aquaculture systems in Bangladesh are listed in Table 2.

3.5. Antibiotics

One of the main concerns of using antibiotics in agri-food systems, including aquaculture, is that using them irrationally and inappropriately can accelerate AMR in pathogenic bacteria, which can spread through the human-animal-environment interlinked interface. In the aquatic system, antibiotics can persist for a longer period, so the risk of developing resistance in pathogenic bacteria in water and in close contact with aquatic animals is high.

In Bangladesh, the use of unapproved drugs in aquaculture is rising tremendously. A recent study estimated that the country is now the third-highest user among the world's top major aquaculture producing countries in the world in terms of the number of antibiotic compounds (21) used (Lulijwa et al. 2020). According to sales data, antibiotics were the most sold item, with about 49% of total aquamedicines sold (Jahan et al. 2021). A countrywide literature review on aquamedicines, drugs and chemicals identified 58 antibiotics that have been used in Bangladesh's aquaculture sector (Asif et al. 2021). Oxytetracycline, a broad-spectrum antibiotic, is the most common (Ali et al. 2016), while others include chloro-tetracycline, amoxicillin, erythromycin, ciprofloxacin, co-trimoxazole, sulfadiazine, sulfamethoxazole, chloramphenicol and prefuran, as shown in Table 3. Oxytetracycline, chloro-tetracycline, ciprofloxacin and erythromycin in particular belong to the Watch category on the WHO's AWaRe list, which is also known to contain important antimicrobials in human medicine (WHO 2021).

Table 4 lists some of the AMU in commercial aquaculture in different regions of Bangladesh. A more recent cross-sectional study on the antibiotic use practices of 672 inland and coastal aquaculture farms in the country found that farmers mainly followed instructions from feed dealers or drug sellers (54%), local service providers (23%) or other farmers (23%), with the most common antibiotics being oxytetracycline, ciprofloxacin and amoxicillin (Chowdhury et al. 2022).

3.6. Other chemicals

Besides feeds, fertilizers and antimicrobials, other groups of chemicals are often used in semi-intensive and intensive aquaculture systems in Bangladesh, including probiotics, nutritional supplements, growth promoters, hormones, enzymes, insecticides and pesticides. A list of these chemicals is included in Appendix 1.

Trade/generic	Active ingredients
Safegard	Vitamins, enzymes and probiotics
Timsen	n-alkyl dimethyl benzyl ammonium chloride (40%) + inert urea (60%)
Albeas	Vitamins, minerals and an antimicrobial agent
VIREX	Potassium peroxymonosulfate (50%)
POLGARD+	3-methyl and 4-methyl two chain brominated compounds
Microdine iodine 20%	Povidone iodine
Bioclean Aqua	n-alkyl dimethyl benzyl ammonium chloride (40%) + stabilized urea (60%)
Sansure	Benzalkonium chloride (80%)
Micronil	Benzalkonium chloride (80%)
VIROCID	Didecyldimethylammonium chloride, alkyldimethylbenzylammonium chloride, isopropanol
Virusnip	Potassium permanganate (50%), sodium dichloroisocyanurate (5%), exipients (45%)
Aquakleen	Brominated organic salt, ammino nitrogen, benzalconium chloride
BKC	Benzalkonium chloride
Bleaching powder	Chlorine
EDTA	Sodium thio-sulfate
Efinol	Efinol
Formalin	Formaldehyde (38%)
Waterclear	Sodium thio-sulfate
Omicide	Benzil ammonium chloride + urea
Salt	NaCl
Lime	$CaCO_3$, CaO
Potassium permanganate	$KMnO_4$
Copper sulfate	$CuSO_4$

Sources: Hoq et al. 2011; Ali et al. 2014; Akter et al. 2020; Das et al. 2020; Jahan et al. 2021.

Table 2. Disinfectants and their active ingredients used in aquaculture systems in Bangladesh.

Trade name	Active ingredients	Trade name	Active ingredients
Renamox	Amoxicillin trihydrate	Moxillin Vet DS	Amoxicillin
Renamycin	Oxytetracycline	Colimox	Amoxicillin
Bactiab	Oxytetracycline (20%)	Mimox	Amoxicillin
Cotrim-Vet bolus	Co-trimoxazole	Renamox	Amoxicillin
Otetra-Vet power 50	Oxytetracycline	Cipro-A Vet	Ciprofloxacin
Cotrim Vet	Sulphamethoxazole + Trimethoprime	Ciproflox	Ciprofloxacin
Oxin WS	Oxytetracycline (20%)	C-FLo	Ciprofloxacin
Fish Cure	Chlotetracycline HCL	Cibro-Plus	Ciprofloxacin
Chlorsteclin	Chlotetracycline	Renaflox	Ciprofloxacin
Orgacycline 15%	Chlotetracycline	Ciprocin-Vet	Ciprofloxacin
Eskamycin	Oxytetracycline (50%)	CIPRO-A VET	Ciprofloxacin
Chemycin	Oxytetracline HCl BP	Cfcin Vet	Ciprofloxacin
Aquamycin	Chlortetracycline	Ciptec 10%	Ciprofloxacin
Oxy-D Vet	Oxytetracycline (20%) + Doxycycline (10%)	Cirolin- 20	Ciprofloxacin
Urocot	Erythromycin	Eryvet	Erythromycin
Acimox (Vet)	Amoxicillin trihydrate BP (30%)	EST-Vet	Erythromycin
Otetra Vet 50	Oxytetracycline (20%)	Erazine Vet	Erythromycin
Oxysentin 20%	Oxytetracyline HCl BP	Micronid	Erythromycin
Sulfatrim	Sulphadiazine and Trimethoprim	Enstrimb	Erythromycin
Moxilin Vet	Amoxicillin	ERAPRIM VET	Erythromycin
Acimox	Amoxicillin	Erisen-Vet	Erythromycin
Navamox VET	Amoxicillin	Azi-Vet	Azithromycin
Azin Vet	Azithromycin	Oxy-D Vet	Oxytetracycline
Tylo Doxi Plus	Doxycycline hydrate, Tylosin hydrate, Bromhexin hydrochloride	Doxy-Oxy	Doxycycline
TYLOVET	Tylosin	Oxin	Oxytetracycline
Tidoxy	Tylosin	Bactilab	Oxytetracycline
Pefloxe	Pefloxacin	Teradox	Oxytetracycline
Eskatrim	Sulfonamides	Oxysentin	Oxytetracycline
S-trim Vet	Sulfonamides	Oxy-D Vet	Doxycycline
Renatatrim Vet	Sulfonamides	Oxy-Doxy	Oxytetracyline
Ativet	Sulfonamides	Teradox	Doxycycline
Cotrim Vet	Sulfonamides	Captor	Chlortetracycline
TETRAVET WSP	Oxytetracycline	Eon CTC	Chlortetracycline
Renamycin	Oxytetracycline	Cotra Vet	Chlortetracycline

Sources: Hoq et al. 2011; Ali et al. 2014; Akter et al. 2020; Das et al. 2020; Jahan et al. 2021.

Table 3. Antibiotic brands and their active ingredients used in aquaculture systems in Bangladesh.

Reference	Study description	Farming system/settings	Key findings	
			Disinfectants	Antibiotics
Chowdhury et al. 2022	Large-scale cross-sectional study on antibiotic use in aquaculture farms	• A total of 14 sub-districts from 6 major fish farming districts were covered. • A total of 672 fish farmers, 14 large feed dealers and 70 fish farmer clients were interviewed.	-	• A total of 478 farms (71%) reported using antibiotics at least once since the start of their production cycle. • Oxytetracycline, ciprofloxacin and amoxicillin were the most frequently used antibiotics.
Khan et al. 2022	Cross-sectional study on AMR bacteria in shrimp and shrimp farms	• Shrimp and prawn farms in the region of Bagerhat, Khulna, were covered. • Sediment and prawn samples were analyzed.		• *E. coli, Salmonella* and *Vibrio* spp. were absent. • Approximately 78% of the identified Enterobacterales isolates showed resistance to at least one antimicrobial. • 29.3% of all isolates showed multidrug resistance.
Hasan et al. 2022	Cross-sectional study to evaluate antibiotic residues	• Live fish and water samples were taken from wet markets in Mymensingh District.	-	• Oxytetracycline residue was detected in 5.42% of fish samples and 8.33% of water samples.
Faruk et al. 2021	Cross-sectional study to understand the effectiveness of veterinary drugs	• Freshwater aquaculture in the Mymensingh region was covered. • A total of 50 commercial fish farms and 25 drug shops were surveyed.	Disinfectants were the second-most used antimicrobials (6.38%) mentioned by farmers.	• Antibiotics were the most used drugs (80.85%) mentioned by the farmers. • Oxytetracycline (25.59%) and amoxicillin (25.05%) were the most sold antibiotics, followed by ciprofloxacin (17.79%), sulfadiazine (14.68%) and other antibiotics, such as chlortetracycline (6.37%) and azithromycin (5.26%). • The effectiveness of veterinary drugs varies between 10% and 60%.
Asif et al. 2021	Literature review to understand the current status of aquamedicines used in aquaculture	• Published articles from 2011 to 2020 relating to Bangladesh were reviewed.		• A total of 58 antibiotics were reported from different regions in 2020. • Farmers in the Chattogram region were the main users of antibiotics (56 antibiotics).
Faruk and Azad 2021	Cross-sectional study to know the use of “extra-level” drugs not originally designed for aquaculture but used in commercial aquaculture	• Freshwater aquaculture farms in the Mymensingh region were covered. • A total of 30 commercial fish farmers and 30 drug sellers were interviewed.	• Disinfectants were the fifth-highest selling aquadrugs (5%). • Five different “extra-label” disinfectants were found in the surveyed shops.	• Six groups of antibiotics were reported from surveyed drug shops: beta-lactams, macrolides, fluoroquinolones, tetracyclines, sulfonamides and quinolones.

Reference	Study description	Farming system/settings	Key findings	
Das et al. 2020	Cross-sectional study to know the pattern of use of antibiotics and other chemicals in aquaculture farms	• Freshwater aquaculture was covered. • A total of 100 fish farmers, 12 medical representatives and 17 drug shops were interviewed.		• Ten brands of antibiotics were available in local markets and used by fish farmers. • Active ingredients in these antibiotics were oxytetracycline, chlortetracycline, doxycycline, sulphamethoxazole, trimethoprim and erythromycin.
Kawsar et al. 2019	Survey to assess aquadrugs and aquamedicines in aquaculture	• Upazilas in the districts of Chattogram and Cox's Bazar were selected. • Data was collected from fish hatchery owners, nursery and grow-out farmers, aquamedicine retailers and medical representatives.	• Approximately 38% of farmers were using different commercial disinfectants to treat diseases. • Approximately 40% of farmers were using potassium permanganate to disinfect their ponds.	• A total of 14 different brands of antibiotics were used by the fish farmers. • About 52% of farmers used erythromycin, 18% used ciprofloxacin and 10% used oxytetracycline.
Ferdous et al. 2019	Cross-sectional laboratory observations	• Observations were made in Chittagong District. • Fish samples collected from wet markets were analyzed in a laboratory for antibiotic residues.		• Amoxicillin and oxytetracycline residues were identified in wet market samples of koi, rohu, tilapia, loitta (*Harpadon nehereus*) and shrimp (*Penaeus monodon*). • Amoxicillin in fish tissues was higher than the maximum residual limit.
Hossain et al. 2017	Cross-sectional laboratory observations	• Water samples were taken from freshwater and brackish water aquaculture farms.		• Residues from seven antibiotics were identified from water samples collected on freshwater finfish farms and four on brackish shellfish farms.
Ali et al. 2014	Cross-sectional study	• Data was collected from 1890 fish farms in 6 major fish production-hubs: Barishal, Mymensingh, Jashore, Khulna, Faridpur and Rangpur. • Both freshwater and brackish water farming systems were surveyed.	• A total of 46 chemical and biological products, including 13 disinfectants, were used in aquaculture farms.	• Seven antibiotics were applied in aquaculture farming systems. • Use of disinfectants and antibiotics was the highest in intensive koi and pangas farms.
Chowdhury et al. 2015	Cross-sectional study	• Fish farmers, aquamedicine sellers and medical representatives in Zakigonj, Sylhet, were interviewed.	• Bleaching powder, Timsen, EDTA, POLGARD+, VIREX, Aquakleen, Germnill, and Pond safe widely used by farmers as disinfectants. • Health management and disease treatment were the main reasons for using chemicals on surveyed fish farms.	• The most used brands of antibiotics were Renamycin, Oxysentin (20%), Chlorsteclin, Oxy-D Vet, Aquamycin, Orgamycin (15%), and Orgacycline(15%). • Major active ingredients of these antibiotics were oxytetracycline, chlortetracycline, amoxicillin and doxycycline.

Reference	Study description	Farming system/settings	Key findings	
Innovision 2013	Prospects and problems of farming high-value species	Tilapia, pangas and koi semi-intensive-intensive farming systems were covered.	• Aquakleen, Zeo-Fresh, Oxylife, Aquamix, Gastrap, Cevit-Aqua, Panvit-Aqua, antivirus were some of chemicals, disinfectants and additives commonly used in tilapia farms for higher production, environmental management, maintaining water quality and disease control. • Hormones, enzymes, growth promoters and other substances not certified by the relevant authorities were used in pangas feed.	• Mixing antibiotics in pangas feed was a common practice.
Chowdhury et al. 2012	Cross-sectional survey	• Freshwater aquaculture, including hatcheries, nurseries and culture farms, were covered in Noakhali District. • Data was collected through a questionnaire interview, personal contact, a market survey and a participatory rural appraisal, such as focus group discussion.	• A total of 22 different chemicals were used for artificial breeding, pond preparation, water quality management, fish poisoning, killing insects and treating fish diseases in this region. • Formalin was the most widely used (43%) disinfectant, but bleach and EDTA were also used.	Oxytetracycline was the most widely used (47%) antibiotic, other than farmers using chlortetracycline and amoxicillin to treat diseases.
Uddin and Kader 2006	Cross-sectional study to know the pattern of use of antibiotics and other chemicals in shrimp hatcheries	The study covered shrimp hatcheries.	Five disinfectants were used to treat diseases, including formalin, malachite green and potassium permanganate.	• Eight different antibiotics were identified from 80% of surveyed shrimp hatcheries. • Chloramphenicol (40%), erythromycin (25%), nifurpirinol (Prefuran 20%) and oxytetracycline (15%) were the commonly used antibiotics in broodstock management to prevent diseases in shrimp.

Table 4. Evidence of AMU in commercial aquaculture in different regions of Bangladesh.

4. Linking prevalent fish diseases and AMU in Bangladesh's aquaculture sector

Similar to the global trend, experts believe that the increased demand for fish in Bangladesh will mostly come from the aquaculture sector, particularly through the intensification of inland freshwater aquaculture. Many of the currently popular aquaculture systems in Bangladesh were first started as extensive farming systems and, over time, farmers started to apply semi-intensive to intensive farming techniques to the same systems. This intensification is often linked with an elevated risk of disease occurrence in Bangladeshi aquaculture (Hossain and Rahman 2018), and high stocking density often leads to increased use of therapeutics to reduce the risk of pathogens and infectious diseases (Henriksson et al. 2018).

According to one study, the most common response of Bangladeshi fish farmers to disease outbreaks is the use of different chemicals (46.16%), including antibiotics (6.15%), and farmers tend to use a combination of chemicals together (Uddin et al. 2016). Based on responses from farmers, a comparatively recent study reported that antibiotics were the most used drugs (80.85%) in Mymensingh District, a major fish production hub in Bangladesh (Faruk et al. 2021). On Bangladesh's shrimp farms, the number of active substances entering the farm has reportedly increased 424% to combat disease problems (Heal et al. 2021).

A number of fish and prawn/shrimp diseases are currently prevailing in Bangladesh's aquaculture sector, as shown in Table 5. These are considered a major threat to the sustainability of the industry. However, many of these disease problems are reported based on their clinical signs, not on a confirmatory diagnosis of the exact etiology agent. This is due to a lack of financial ability among farmers to access those tests, as well as limited laboratory facilities and trained operators.

Sometimes, co-infection with multiple agents can be behind a disease outbreak. Incorrect disease diagnosis can lead to inappropriate use of antimicrobials. Some of the major damage-causing diseases in many farming systems in Bangladesh are non-bacterial but caused by viruses and fungi such as WSSV in shrimp, TiLVD in tilapia farms and EUS in many finfish species. But in many of these viral and fungal outbreaks, antibiotics that are only able to treat bacterial diseases are used as treatment products. In shrimp aquaculture, although the most devastating diseases are viral, antibiotics are commonly used to prevent and treat diseases (Thornber et al. 2020). The lack of adequate diagnostics, knowledge and a clear understanding of the risk factors associated with AMU can lead to the development of antimicrobial-resistant pathogens.

In 2022, WorldFish, in collaboration with the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDRB), conducted a study on AMU in aquaculture and its drivers The findings coincide with previous observations of wider antibiotic use in the country's aquaculture sector, particularly in freshwater finfish culture and revealed a significant connection between the presence of sick fishstock and the use of antibiotics (Chowdhury et al. 2022).

Diseases/clinical signs	Main infected species	Causative agent	Antimicrobial used
Fin and tail rot	Tilapia, carp, pangas, koi	Symptoms are associated with multiple bacterial agents	Ciprofloxacin with disinfectant
EUS	More than 32 susceptible species, including carp and koi	Fungus	Oxytetracycline or amoxicillin with disinfectant
WSSV	Shrimp	Virus	Various antimicrobials used, including lime
White spot disease (Ich)	Catfish	Parasite	Oxytetracycline, ciprofloxacin or enrofloxacin
TiLVD	Tilapia	Virus	-
Dropsy	Carp, pangas	Multiple agents, including bacteria, fungi and parasites	Oxytetracycline with enzyme
Rectal and anal protrusion	Pangas	-	-
Red spot disease	Carp, pangas, tilapia	Symptoms associated with multiple bacterial agents	-
Saprolegniasis	Koi	Fungus	Amoxicillin with disinfectant
Pop eye	Carp, pangas, koi	Not known	-
Argulosis	Carp, pangas, tilapia	Parasite	Trichlorfon or ivermectin with oxytetracycline
Lernaeasis	Carp	Parasite	Ivermectin or deltamethrin with oxytetracycline
Bacillary necrosis of pangasius	Catfish	Bacteria	Sulphadyazine and trimethoprim with disinfectant

Sources: Faruque et al. 2008; Uddin et al. 2016; Kawsar et al. 2022.

Table 5. Common antimicrobials used in Bangladesh's aquaculture sector.

5. Linking AMR and aquaculture in Bangladesh

Antimicrobial and agrochemical use in aquaculture can lead to AMR. The interconnected nature of agri-food systems means that AMR can spread, posing a major health threat to the health of people, animals, plants and their shared environment, as well as the structure and sustainability of food production systems. A number of drivers make the aquaculture sector a hotspot for the emergence and transmission of antimicrobial-resistant pathogens. These drivers include (i) disease burden and health management practices, (ii) purposeful and inadvertent use of antimicrobial treatments, (iii) feeding practices and the use of waste organic materials and inputs from other farming sectors, and (iv) the transfer of water between neighboring farms (UOE 2019).

Information relating to the presence of antimicrobial-resistant pathogens in aquaculture in Bangladesh is limited, as most studies are mainly focused on AMU rather than AMR, but several previous studies have confirmed the presence of AMR bacteria in fish and aquaculture systems in the country. Siddique et al. (2021) analyzed 216 samples from fish, shrimp, water and sediment from three sampling sites located in Satkhira Sadar Upazila of Satkhira District and reported that 94% of isolated pathogenic *Vibrio parahaemolyticus*, an important human pathogen, were resistant to ampicillin and amoxicillin, while 29% were resistant to cefotaxime and 18% to ceftriaxone. Hossain and Rahman (2018) reported that 80% of *Staphylococcus aureus, Escherichia coli* and *Pseudomonas* spp. isolated from fish samples collected from antibiotic-treated ponds showed resistance to 16 commonly used antibiotics in eight classes, namely tetracyclines, aminoglycosides, fluroquinolones, cephalosporins, carbapenems, penicillins, macrolids and sulfolinamides. A separate study by Foysal et al. (2012) showed that 80% of *Pseudomonas fluorescens* bacterial isolates recovered from hemorrhagic septicemia-infected carps and catfish were resistant to multiple antibiotics, including chloramphenicol.

In a recent study, WorldFish confirmed the presence of AMR bacteria in tilapia and shrimp samples purchased from a number of retail and wholesale wet markets located in Dhaka and Khulna. Initial results of whole genome sequencing of representative bacterial isolates (i.e. *E. coli, Salmonella* spp.) conducted at the Bangladesh Livestock Research Institute (BLRI) using Oxford Nanopore Technologies indicated the presence of multidrug resistant pathogenic bacteria at the point of human consumption (Rheman et al. 2022). Based on 16S rRNA sequences, the putative identity of samples was largely in agreement with their initial classification at the genus level and some at the species level. Antimicrobial-resistant genes were identified in nearly all genomes assembled, which is somewhat alarming for aquatic food products sold at wet markets but not unexpected given the historical use of antibiotics in the agri-food and environmental sectors. For example, a number of the strains harbor the tetracycline resistance gene, and this is an extremely common antibiotic used to treat or prevent bacterial infections in fish and shrimp. However, it was beyond the scope of the study to point out the source of the identified antibiotic-resistant bacteria, as it could also generate from post-harvest contamination during transportation from farm to wet market.

6. One Health metrics in sustainable aquaculture

In section 2, we introduced the fish farming systems and finfish species that are predominantly practiced and farmed in different regions in Bangladesh. Commonly used inputs in finfish aquaculture systems were discussed under section 3. In sections 4 and 5, we linked AMU in particular with disease occurrence in fish farms and evidence of AMR in Bangladeshi aquaculture. In this section, we review the major aquaculture systems and species farmed in Bangladesh from broader One Health principles and sustainability measures.

The sustainability of agricultural systems can be assessed following different frameworks and methods. However, most of the prevailing frameworks assess the sustainability of production systems from an atomistic angle, such as livelihoods, natural resources, input use, agriculture practice, assessment of farms and value chain sustainability (Haque et al. 2021). In contrast, the One Health framework in aquaculture is a multidisciplinary and multisectoral approach that conceptualizes many metrics of the interlinked human-animal-environment triad from health, social and economic aspects to achieve enhanced sustainable production (ESP) from this industry. The One Health approach in aquaculture aims to produce safe food efficiently by identifying gaps and adopting research, evidence, policy and legislative measures to design sustainable production systems.

Stentiford et al. (2020) introduced a metrics-based framework to implement the One Health approach in aquaculture, which can be tailored to industry subsectors to address specific sustainability requirements. The framework supports the design of policy and legislation in aquaculture and scores each metric from 0 to 5 based on its successful or unsuccessful application in policy and legislation development. The highest score (5) of a success metric (SM) indicates a consistent application of policy and legislation, while the lowest score (0) means there is no evidence of policy and legislation design. Considering the input and output characterization of diverse farming systems and the unique character of farmed species in section 6, we have made a preliminary assessment of farming systems and farmed species using the SMs, as shown in Table 6.

Sector	One Health metric	Homestead pond	Carp polyculture (pond)	Tilapia polyculture (pond)	Pangas polyculture (pond)	Shrimp (gher)	References
People	SM1: Nutritious and safe food	Food produced by this system is nutritious and safe to consume. It increases household fish consumption greatly, as about 50% of fish are used for household consumption.	Food produced by this system is nutritious and safe to consume.	Food produced by this system is nutritious and safe to consume.	Food produced by this system is nutritious and safe to consume.	Food produced by this system is nutritious and safe to consume.	Castine et al. 2017; Shepon et al. 2020
	SM2: Equitable income generation	This improves the quality of household diets, alleviates poverty and limits income generation from the sale of surplus fish after household consumption, with 20%–40% fish sold to markets. The contribution to total household income is low (4%).	This is commercial in nature and mainly targeted for local markets. About 80%–90% of the total harvested biomass is sold to markets. The contribution to total household income is moderate (49%).	This is commercial in nature and mainly targeted for local markets. About 80%–90% of the total harvested biomass is sold to markets. The contribution to total household income is moderate (42%).	This is commercial in nature and mainly targeted for local markets. About 80%–90% of the total harvested biomass is sold to markets. The contribution to total household income is high (72%).	The production system is commercial in nature, and shrimp are produced mainly to be sold on the international market. About 80%–90% of the total harvested biomass is sold on the international market. The contribution to total household income is moderate (42%).	Naureen et al. 2006; Jahan et al. 2015; Karim and Little 2018; Ahmed and Waibel 2019
	SM3: Gender equalization	This is uniquely accessible to women to engage and participate in fish culture compared to other farming systems. About 80% of women actively or somewhat actively participate. Women need greater access to high quality food.	Approximately 57% of women actively or somewhat actively participate in commercial fish farming.			The participation of women in shrimp farming is relatively low (19%).	Siddiqa et al. 2017; Castine et al. 2017

Sector	One Health metric	Homestead pond	Carp polyculture (pond)	Tilapia polyculture (pond)	Pangas polyculture (pond)	Shrimp (gher)	References
People	SM4: Quality employment	Income does not significantly contribute to employment.	Income contributes to employment and wealth generation.	Income contributes to employment and wealth generation. A total of 167,089 fish farmers are involved in tilapia farming.	Income contributes to employment and wealth generation. About 54,000 farmers are involved in pangas farming. Non-compliant working conditions were reported in pangas farms.	This is the second-largest export industry of the country, employing about 840,000 people. It has significant influence on the socioeconomic elevation of coastal communities. Work in the working conditions and environment is risky.	Innovision 2013; EJF 2014; Haque et al. 2021; Ray et al. 2021
	SM5: Knowledge and skills generation						
Organism	SM1: Healthy stock	The level of disease occurrence in farms is comparatively lower (6%). There is little initiative to promote environmental conditions conducive to limiting disease susceptibility.	The level of disease occurrence in farms is comparatively low (8%). There is little initiative to promote environmental conditions conducive to limiting disease susceptibility.	The level of disease occurrence in tilapia farms is low (5%). Average mortality is 23.2% There is little initiative to promote environmental conditions conducive to limiting disease susceptibility.	The level of disease occurrence in pangas farms is comparatively higher (11%). There is little initiative to promote environmental conditions conducive to limiting disease susceptibility.	The level of disease occurrence in shrimp farms is higher (34%). There is little initiative to promote environmental conditions conducive to limiting disease susceptibility. The supply of specific pathogen-free (SPF) shrimp post-larvae is limited.	Pradeep et al. 2012; Hossain et al. 2015; Jahan et al. 2015; Debnath et al. 2016; Faruk et al. 2017

Sector	One Health metric	Homestead pond	Carp polyculture (pond)	Tilapia polyculture (pond)	Pangas polyculture (pond)	Shrimp (gher)	References
					A number of diseases currently prevailing in pangas farms cause economic losses of 3.6% of farmers' total income.	The prevalence of WSSD in the shrimp farming industry is high, can cause 100% mortality and is able to contaminate almost the entire farming system.	
Organism	SM2: Minimal chemical hazards	The production systems have minimal use of chemicals and biological products. Instead, they mainly use water and soil treatment products and fertilizers.	There is a low number of chemicals and biological products used. Instead, mainly water and soil treatment products, disinfectants and fertilizers are used.	The percentage of tilapia farms that use different chemicals and biological products is lower than pangas farms.	A wider variety and higher percentage of chemicals and biological products are used compared to other farming systems, including a number of antibiotics.	Water are soil treatment products, disinfectants and fertilizers are commonly used in shrimp farms.	Jahan et al. 2015 ; Ali et al. 2016; Alam and Haque 2021
		Only 0.26% of producers use antibiotics.	Only 3% of carp farms use antibiotics.	Only 1% of farms use antibiotics.	Approximately 12% of farms use antibiotics.	Only 3% of farms use antibiotics.	
		Culture waterbodies are used for a range of domestic activities, such as bathing, washing clothes and cleaning pots.					

Sector	One Health metric	Homestead pond	Carp polyculture (pond)	Tilapia polyculture (pond)	Pangas polyculture (pond)	Shrimp (gher)	References
	SM3: Biosecure farms	There is little or no control over the entry of pathogens and few prevention measures to control contamination from disease.	There are limited biosecurity measures over the entry of pathogens and few prevention measures to control contamination from disease.	There are limited biosecurity measures over entry of pathogens and few prevention measures to control contamination from disease, contributing to outbreaks in the farms.	There are limited biosecurity measures over entry of pathogens and few prevention measures to control contamination from disease.	Ghers are large low-laying converted paddy fields that usually share water with neighboring farms that source water from nearby canals/rivers. There is literally no control over entry of pathogens into the ghers.	Jahan et al. 2015; Rahman et al. 2022; Debnath et al. 2022
Organism	SM4: Safe farm	There is no active AMU and AMR surveillance, so the risk of transfer of zoonotic, environmental and AMR pathogens from stock to humans is high.	There is no active AMU and AMR surveillance, so the risk of transfer of zoonotic, environmental and AMR pathogens from stock to humans is high.	There is no active AMU and AMR surveillance, so the risk of transfer of zoonotic, environmental and AMR pathogens from stock to humans is high.	There is no active AMU and AMR surveillance, so the risk of transfer of zoonotic, environmental and AMR pathogens from stock to humans is high.	There is only passive surveillance of antibiotic residues in exportable shrimp items, and a complete absence of active AMR surveillance.	Thornber et al. 2022; Rheman et al. 2022
	SM5: Optimized farm systems	Species appropriate for the conditions are farmed.	Species appropriate for the conditions are farmed. Different carps species are stocked to use all trophic levels and spatial niches of the pond ecosystem optimally.	Species appropriate for the conditions are farmed.	Species appropriate for the conditions are farmed. Optimization of farming systems in terms of species combination and density is lacking.	Species appropriate for the conditions are famed.	Alam et al. 2019

Sector	One Health metric	Homestead pond	Carp polyculture (pond)	Tilapia polyculture (pond)	Pangas polyculture (pond)	Shrimp (gher)	References
Environment	SM1: Optimal water use	The primary water source is rainfall. Dependency on groundwater and surface water is low.	The main water sources are rainfall and groundwater.	The main water sources are rainfall and groundwater.	Dependency on groundwater is high. This requires an intensive water supply during the dry season, from February to May.	Dependency on surface water is high, mainly saline river water.	Jahan et al. 2015; Alam et al. 2019
	SM2: Optimal water quality						
	SM3: Protected biodiversity and natural capital	-	-	There is a risk of establishing the species in natural waterbodies and influencing native fish populations.	The major changes associated with this farming system are rapid loss of agriculture land, water quality deterioration, eutrophication, and production of comparatively huge amounts of pond sludge.	Shrimp farming is linked with large-scale mangrove and biodiversity degradation, salinity intrusion, sedimentation and pollution.	Canonico et al. 2005; Paul and Vogl 2011; Anka et al. 2014
	SM4: Energy production	Mostly homemade feed is used. Use of commercial pelleted feed is minimal. The feeding rate is low.	Both homemade and commercial feed are used. Dependence on commercial feed is moderate (42%).	Dependence on commercial feed is high. About 70% of farms use commercial feed.	There is a heavy dependence on commercial pellet feed (80%). Homemade pellets are used in the production system.	The farming system mainly depends on natural productivity. Use of commercial pellet feed is minimal.	Jahan et al. 2015
	SM5: spatial footprint	The production system is extensive to semi-intensive. Pond surface area ranges from 0.04 to 0.06 ha. Yield is 1.6–1.7 t/ha.	The production system is predominantly semi-intensive. Pond surface area is 0.27 ha. Yield is 4.7 t/ha.	The production system is semi-intensive to intensive. Pond surface area is 0.18 ha. Yield is 8.8 t/ha.	The production system is intensive. Pond surface area is 0.23 ha. Yield is 32.6 t/ha.	An improved extensive production system is practiced in large converted rice fields. Pond surface area is 1.86 ha. Yield is 0.86 t/ha.	Jahan et al. 2015; Ali et al. 2016

Table 6. Major aquaculture species and systems in Bangladesh through One Health SM for ESP.

7. AMR research trends and gaps in aquaculture in Bangladesh

AMR is a major public health concern globally, but the impacts are felt most in low- and middle-income countries such as Bangladesh, where the public has limited access to many essential facilities, including medical access. In view of the national burden of AMR and the importance of tackling this emerging issue, AMU and AMR issues have been getting more attention from the scientific community in Bangladesh, and with it more and more scientific research.

This review was carried out to address the incidence of AMU and AMR specific to aquatic food production systems in Bangladesh based on previous studies and to highlight the gaps and potential areas for further investigations. Although AMR is a One Health issue, previous research has mainly documented AMU and AMR independently in humans, livestock and poultry, with limited emphasis on aquaculture, which is an important link connecting the aquatic food supply, water bodies and the millions of people who depend on them. Most of the available literature on AMU in aquaculture in Bangladesh consists of cross-sectional studies listing the antimicrobials, including antibiotics, that are commonly used by farmers and available to purchase over the counter in various regions. Few studies characterize the sensitivity profile of pathogens to key antibiotics, nor do they identify the potential drivers leading to the misuse and overuse of antimicrobials in aquaculture settings.

Recently, a study was conducted to determine the effectiveness of veterinary drugs, antimicrobials, and supplements on fish health and growth, but the study results were based on the perception of farmers and drug sellers (Faruk et al. 2021). To the best of our knowledge, there is no controlled research available on the efficacy of drugs in the treatment of fish diseases and the financial benefit of using antibiotics in aquaculture in Bangladesh.

8. Government initiatives to reduce AMU and AMR in the aquatic food sector

The Department of Fisheries (DOF), the agency responsible for fisheries development in Bangladesh, is also a competent authority for governing AMU and AMR in aquaculture in the country. The organization is structured under three components: the Central, Regional and Local Competent Authorities.

Currently, several legal frameworks are in place to govern the use of aquamedicines in aquaculture in Bangladesh. The Fish and Fish Products (Inspection and Quality Control) Act, 2020 is one of the main legal frameworks that directly aims to control their use in the sector. The act bans the use of prohibited aquamedicines in aquaculture and emphasizes following good aquaculture practices to produce safe food. The Fish and Fish Products (Inspection and quality control) Rules, 1997 (amended in 2008, 2014, 2017) lists antibiotics that are prohibited for use in aquaculture, with a provision for a handful of antibiotics, including tetracyclines and sulphadimithoxin, and with acceptable limits of antimicrobial substances in fish flesh. The Fish Feed and Animal Feed Act, 2010, and the Fish Feed Rules, 2011, are other sets of rules that prohibit manufacturing, distributing and using medicated feed in aquaculture settings.

Currently, direct AMU surveillance in the aquaculture sector is lacking; however, the competent authority mainly conducts passive surveillance of AMU through surveillance of antibiotic residues in aquaculture products under the National Residue Control Plan (NRCP). The plan was developed as a statutory requirement to export fisheries products from Bangladesh to countries in the European Union (Suman et al. 2021) and aims to protect consumer safety. The plan is in place to ensure appropriate controls and practices are employed to prevent pharmacologically active or other harmful substances from entering the food chain from aquaculture products. The NRCP aims to test, find the source and prevent the entry of contaminants, including some antibiotics, from various points of the aquatic food chain. In 2021, a total of 424 samples were tested in the DOF's quality control laboratory (QCL) for residual analysis of banned antibiotics (chloramphenicol, nitrofurans and metronidazole), and 463 samples were analyzed for residues of authorized antibiotics. Under this NRCP program, the DOF has a future plan to conduct AMR surveillance of pathogens of One Health significance from aquatic food systems.

9. AMR projects, collaboration and outcomes in aquaculture led by WorldFish

In an effort to reduce the burden of AMU and AMR in Bangladesh's aquatic food systems, WorldFish teamed up with the Centre for Environment, Fisheries and Aquaculture Science (Cefas), the Animal and Plant Health Agency (APHA) of the UK government, the Fleming Fund, the Food and Agriculture Organization's (FAO) Emergency Centre for Transboundary Animal Diseases (ECTAD), and the University of Exeter (UOE). These organizations are working closely together with competent national authorities, research institutions, farmers and other stakeholders to understand AMU, promote AMR awareness, develop AMR surveillance schemes for aquaculture and build antimicrobial susceptibility testing (AST), whole genome sequencing and bioinformatics capacity in laboratories.

9.1. Production without medicalization

Funded by the UK Economic and Social Research Council, WorldFish implemented this multidisciplinary collaborative project in partnership with Cefas, the UOE, the Veterinary Medicines Directorate (VMD), APHA and FAO in Dhaka from January 2018 to December 2020. The goal was to generate knowledge about the use and socioeconomic drivers of AMU in aquaculture in Bangladesh. On February 12–13, 2019, an AMR workshop, called Production without Medicalization: AMR, One Health and Aquaculture, took place in Dhaka. The workshop aimed to disseminate and discuss lessons from various AMR-related projects and to develop priorities for future work (https://hdl.handle.net/20.500.12348/3135).

9.2. Cefas collaboration on One Health

9.2.1. Embedding One Health to support aquatic food production during COVID-19

From December 2020 to December 2021, WorldFish implemented this new project in Bangladesh in partnership with Cefas. The project, funded by the UK's Official Development Assistance aid program, aimed to build capability and educational tools by promoting a One Health approach to the aquatic food system in Bangladesh. The project consisted of the following five work packages.

9.2.1.1. Bangladesh-UK engagement activities

Engagement with responsible authorities covering the broad policies associated with aquatic food production (environment, animal health, human health, trade, etc.) was a central part of this project.

9.2.1.2. Food from water in Bangladesh: A One Health analysis

A comprehensive analysis considered the ongoing impacts of COVID-19 on aquaculture and supply chains in Bangladesh's aquatic food sector against defined success metrics spanning the health of the environment, people and organisms, collectively called One Health.

9.2.1.3. Animal and human health hazard assessment and risk profiling

This attempted to understand the risk to stocks within the production cycle, such as animal health risks, and to consumers of the end-product, such as human health risks.

9.2.1.4. Global Aquatic Microbial Hazard Portal

This provided access to information data and analyses through Cefas' FAO Reference Centre and the World Organization for Animal Health's (WOAH) Collaborating Centre on key hazards associated with current and future aquatic food production.

9.2.1.5. Establishing SARS-CoV-2 virus testing methods in seafood and wastewater

This developed a robust SARS CoV 2 testing methodology in seafood and wastewater which was transferred to the appropriate responsible authorities' laboratory networks in Bangladesh to support public safety and protect national and international trades.

Under this project, WorldFish and Cefas jointly led a workshop on March 22–23, 2021, with its partners, including national competent authorities in Bangladesh, universities and research institutions, FAO and the UOE (https://mel.cgiar.org/reporting/report/id/10551/del_id/27164). The workshop summarized previous and current collaborative projects in Bangladesh associated with aquatic animal health, food safety and AMR, all with a One Health research and development focus. Delegates at the workshop also discussed the current partnership, including the opportunity to interact directly with the UK-based leads of the WOAH's Collaborating Centre for Emerging Aquatic Animal Diseases, as well as the FAO Reference Centre for AMR and the FAO Reference Centre for Bivalve Mollusc Sanitation. Cefas experts also introduced a framework of One Health metrics for aquaculture that would inform national and international science and policy strategies to support improved design of aquatic food systems.

9.2.2. AMR: Facilitating future collaboration on COVID-19 responses through capacity building on AMR livelihoods

From January 2021 to March 2022, WorldFish implemented this project in collaboration with Cefas. This pilot project aimed to strengthen AMR surveillance by providing technical assistance and diagnostic services and establishing AMR surveillance of key pathogens from farmed fish. Under this project, WorldFish engaged relevant competent authorities and stakeholders, including the DOF, Department of Livestock (DLS), Khulna University, Jahangirnagar University, and Fleming Fund Country Grants Bangladesh (FFCGB), to enhance their own initiatives to reduce the AMR burden in Bangladesh. WorldFish also established a pilot system of AMR surveillance in aquaculture in two laboratories—Khulna University and the Animal Health Laboratory at the BLRI—by providing training in fish sampling techniques, rapid diagnostics and AST of key pathogens recovered from wet markets. To generate evidence of AMR at the point of consumption, WorldFish collected samples of tilapia and shrimp from four wet markets in two districts of Bangladesh and conducted laboratory analysis in two laboratories at Khulna University and the BLRI. Under this program, WorldFish also delivered training programs to develop the capacity of technical staff from a number of relevant government and autonomous institutions to conduct bacteriological sample processing from aquatic foods, AST in the laboratory, and genome sequencing.

9.3. Collaboration with the Fleming Fund

One Health and AMR experts from WorldFish mentored two Fleming Fund Fellows from the QCL at the DOF, who conducted piloting research on AMR surveillance in aquaculture in Bangladesh.

9.4. Collaboration with the University of Exeter

WorldFish, in collaboration with the UOE, supported two PhD candidates in 2022 working on pond microbiomes and their dynamics in relation to various antibiotics in Bangladesh and abroad. Under the Hatchery Biosecurity Project, the collaboration led to the production of best management practices and biosecurity training materials.

9.5. Joint development and dissemination of learning resources

WorldFish, in collaboration with partners, produced a number of learning resource materials to disseminate scientific guidelines to conduct diagnosis along with AMR surveillance in aquaculture settings.

The following are the learning resource materials developed:

- Antimicrobial resistance (AMR): A major challenge for the aquaculture industry in Bangladesh (fact sheet) (https://hdl.handle.net/20.500.12348/5272)
- Quick protocol for AST in aquatic animal species from aquaculture and fisheries (https://hdl.handle.net/20.500.12348/4862)
- Sampling materials for fish disease diagnostics (https://hdl.handle.net/20.500.12348/4836)
- Wet mount sampling guide for ectoparasites and fungi (https://hdl.handle.net/20.500.12348/4837)
- Microbiome sampling guide (https://hdl.handle.net/20.500.12348/4838)
- Blood sampling guide (https://hdl.handle.net/20.500.12348/4839)
- Bacteriology sampling guide (https://hdl.handle.net/20.500.12348/4840)
- Histology sampling guide (https://hdl.handle.net/20.500.12348/4842).

10. Other major projects addressing AMU and AMR in aquaculture in Bangladesh

The FFCGB, led by the Development Alternatives Incorporated (DAI), has been supporting the national effort to develop a specific surveillance strategy in Bangladesh since 2020. WorldFish is closely supporting the FFCGB programs, which support Bangladesh's AMR strategy in aquaculture by generating specific data on AMU and AMR, and developing a series of standard operating procedures for sample collection, processing and AST testing. To understand AMU and its drivers in Bangladesh's aquaculture sector, WorldFish, in partnership with the ICDDRB, which is one of the FFCGB's partners, conducted a countrywide AMU and AMR point prevalence survey in commercial aquaculture farms in the country in 2021.
Under this program, a total of 672 commercial aquaculture farms were surveyed, and 14 feed dealers and 70 customers were interviewed with a structured questionnaire. The FFCGB program, led by DAI, is also directly working with a number of relevant government agencies, including the DOF, DLS, the Institute of Epidemiology Disease Control and Research, the Directorate General of Drug Administration, and the Directorate General of Health Services.

WorldFish is co-leading and supporting FAO's effort to develop finfish disease management and treatment guidelines with scientists and experts from the DOF, BFRI, Dhaka University, Bangladesh Agriculture University, Cefas, National Parks in Singapore and a number of other organizations. The aim is to reduce inappropriate use of antibiotics in finfish aquaculture farms in Bangladesh.

Some of the major projects and programs addressing AMU and AMR issues in aquaculture in Bangladesh are summarized in Table 7.

Name of the program/project	Lead implementing organizations and partners	Year	Location	Scope of the program/project
A Guide for the Prevention, Control and Treatment of Common Bacterial, Fungal and Parasitic Diseases in Freshwater Fish	FAO ECTAD, WorldFish, Cefas	2022	-	• Identify a probable list of drugs against identified finfish diseases following the WHO's AWaRe categorization by relevant experts to reduce the misuse of antibiotics in finfish aquaculture. • List the dose, duration, withdrawal period and other important information of these drugs by experts. • Develop pond biosecurity guidelines for infection prevention and control to reduce the disease burden in finfish farms.
Active AMR Surveillance in the Animal Health and Aquaculture Sectors of Bangladesh	DAI	2022	Dhaka and Chottogram	• Test 1200 isolates of five targeted bacterial pathogens per year for AMR. • Recover bacterial pathogens from wild-caught and cultured fish species and shrimp.
Strengthen AMR and AMU Surveillance Capacity in the Animal Health and Aquaculture Sectors	DAI	2020–2022		• Develop a national and sector-specific surveillance strategy. • Strengthen AMR surveillance in the aquatic sector. • Strengthen AMC and AMU surveillance in the human, animal and aquaculture sectors.
AMR Surveillance in Aquaculture	DOF (Fleming Fund Fellows)	2022	Mymensingh and Gazipur districts	• Conduct a pilot program of AMR surveillance in the aquaculture sector. • Test a panel of 16 antibiotics for susceptibility. • Targeted pathogens for AST were *E.coli, Salmonella and Vibrio* species. • Analyze 35 fish samples and 35 water samples.
AMR: Facilitating Future Collaboration on COVID-19 Responses through Capacity Building on AMR Livelihoods	WorldFish and Cefas	2021–2022	Khulna and Dhaka districts	• Assess AMR of bacterial isolates recovered from sampled fish and crustacean species from four wet markets. • Build capacity through training for AMR surveillance, focusing on fish and crustacean species sourced from retail wet markets.
Point Prevalence Survey of Antimicrobial Use in Human, Commercial Chicken and Aquaculture Using the One Health Approach in Bangladesh	ICDDRB, WorldFish, DAI	2021	Mymensingh, Cumilla, Bagerhat, Jashore, Khulna and Satkhira	• Estimate the prevalence of AMU in commercial aquaculture. • Identify factors related to AMU in commercial aquaculture.
Surveillance of Antibiotic Residues in Aquaculture Products (NRCP)	DOF	2021	Countrywide	• Conduct antibiotic residue surveillance in aquaculture products. • Test 424 samples for residual analysis of banned antibiotics. • Analyze 463 samples for residues of authorized antibiotics.
Production without Medicalization in Bangladesh	WorldFish, Cefas, UOE, VMD, APHA, FAO ECTAD	2018–2020		• Generate knowledge about the uses and socioeconomic drivers of AMU in aquaculture in Bangladesh.

Table 7. Major AMU and AMR-related projects and programs in Bangladesh's aquaculture sector.

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Appendix 1. Other chemicals

Trade name	Active ingredients	Purpose/type
Oxyrich	Sustained release of O_2 (13.5%)	Dissolved oxygen supply
Oxyrich Tab	Sustained release of O_2 (12%)	
Oxymore	Sustained release of O_2 (13.5%)	
Oxylife	Sodium percarbonate	
OXYMAX	Sodium percarbonate	
Oxy-A	Sustained release of O_2 (13.5%)	
Oxy-Ren	Sodium carbonate peroxyhydrate	
BIO-OX	$2Na_2CO_33H_2O_2$	
OXY-GOLD	Sodium percarbonate	
Best Oxygen	Sodium percarbonate	
Oxygen Plus	O_2 promoter	
Oxyflow	H_2O_2 (10%)	
Oxygrow	O_2 promoter	
Oxyplus	$Na_2O_{2+}AlOHNa_2O_2$ (90%)	
ACI-Ox	Sodium percarbonate $2Na_2CO_33H_2O_2$	
Oxy Aqua	Sodium percarbonate	
Oxyflox	Sodium percarbonate	
OXY-CARE	Active chemical and food products	
Geo-rich	Natural geolite (100%)	Removal of harmful gases
Yucca	*Yucca cidigera* extract	
Geo-prime	Natural green geolite (100%)	
Gasonil	Probiotic and yucca (30%)	
Geopel	Natural green geolite 100%	
Bio-pond	Geolite and probiotic	
Bio-grow	Vitamins, minerals and probiotics	
Aqua Pure	Natural sodium aluminum silicate	

Trade name	Active ingredients	Purpose/type
Gasstrap	Enzyme and probiotics	Removal of harmful gases
Metrix	Al_2O_3, CaO, SiO_2, ferrosoferric oxide	
Bio-aqua 50	Extract of *Euka cidijera*	
Geo-ren	Aluminum sodium silicate	
MEGAZEO PLUS	SiO_2, Al_2O_3, Fe_2O_3, CaO	
Ammonil	Yucca plant extract, *Bacillus subtillis, Candida utilis*	
Gas Stop	*Bacillus subtillis* Al_2O_3 SiO_2	
Aqua Magic	*Azotabactor chorococcum, Bacillus subtillis, Candida utilis*	
Bio-Aqua-50	Yucca plant extract, saponin components	
GASONEX (+)Y	*Pseudomonas* sp., *Bacillus subtilis, Nitrococcus* sp.	
Yucca gold	Yucca schidigera extract	
Gasonil	Yucca plant extract, saponin components, Glyco components	
Pondkleen	*Yucca schidigera* plant extract	
Ammo Check	Extract of *Yucca schidigera*	
Megazeo Plus	SiO_2, Al_2O_3, Fe_2O_3, CaO	Probiotics
Megazeo Gold	SiO_2, Al_2O_3, Fe_2O_3, CaO	
Aquastar Pond	Probiotics	
JV ZEOLITE	Natural zeolite	
Zeo-Fresh	Standard zeolite	
Aqua Green	Seaweed extract and organic micronutrients	
AQUA PURE	Natural sodium aluminum silicate	
Biomax	Aluminum sodium silicate	
Zeopel	Zeolite (100%)	
Green Zeolite	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2	
Pontox Plus	SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O	
Profs	*Bacillus* sp., *Padiococcus* sp.	
Aqua Photo	*Bacillus subtilis*, *Rhodoseudomonas*	
pH Fixer	*Bacillus* spp.	
Eco Marine	*Bacillius subtilis, B. pumilis, B. mylolichenifacions, B. megaterium*	

Trade name	Active ingredients	Purpose/type
Aqua Gold	*Rhodopseudomonas* sp.	Probiotics
Procon-PS	*Bacillus* sp. *Rhodococcus, Rhodobacter*	
Super Biotic	*Bacillus* sp.	
Super PS	*Rodobacter* sp., *Rodococcus* sp.	
Pondcare	*S. faecalis*, other bacteria	
Safegut	Probiotics, vitamins and enzymes	
Saltose	Probiotics and enzymes mixed	Growth promoters and vitamins
Panvit Aqua	Liquid multivitamin	
Spa Gelly	Omega-3 fatty acids	
Vitamix- F Aqua Premium	Vitamins, minerals, amino acids	
Charger Gel	1-3 D glucan, olysaccharides, btain, beta glucan	
Aqua Boost	Organic acid, ss-glucan	
Megavit Aqua	Vitamin, mineral and amino acid supplement	
Orgavit Aqua	Vitamin, mineral and amino acid supplement	
ACI Mix Super Fish	Vitamins, trace elements, amino acids	
Megavit Aqua	Vitamins, minerals, amino acids	
Square Aquamix	Vitamins, minerals, amino acids, prebiotics, antioxidants, yeast	
Aqua Boost	Organic acid, β-glucan, mannan oligosaccharide	
Aquagro G	DHA-enriched micro dietary supplement	
Aquagro L	DHA-enriched micro dietary supplement	
Aquanone	Rotenone	Pond preparation
Bio Aqua	Extract of *Uka cidizera* tree	
Gastrap	*Bacillus, Bacillus subtilis, amylase, cellulose, lipase*	
Geotox	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na_2O	
Green Zeolite	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na2O	
Lime	CaO, $Ca(OH)_2$	
Mega Zeo	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na_2O, Mn	
Zeocare	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na_2O	

Trade name	Active ingredients	Purpose/type
Zeo-Fresh	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na_2O, K_2O	Pond preparation
Zeolite	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, MgO, Na_2O	
Zeo Prime	SiO_2, $A1_2O_3$, Fe_2O_3 CaO, LoI, K_2O	
Albez	Doxycycline, colistine sulfate + vitamin premix + minerals	
Eco-solution	-	
Malthion	Malathion	
Registrol	Betain, calcium, P, vitamin C	
Salt	NaCl	
Engreb	Cypermethrine (10%)	
Nigotox Aqua	Trichlorphon (40%)	
Rota Plus	Rotenone (9%)	
Sanmarine	Cypermethrine 10 E.C.	
Sumithion	Fanitrothion	
Tea Seed Meal	Seponin (15%–16%)	
I-mec	Ivermectin	
Zeorich Megazeo Plus	SiO_2, $A1_2O_3$, Fe_2O_3, CaO, MgO, Na_2O, K_2O, Mn	
Zeolite Gold	SiO_3, MgO, CaO, etc.	
Acme's Zeolite	Aluminum sodium silicate	
Acp Yucca	Extract of *Yucca schiigera* that contains saponin and glycocomponent	
Ammocure Vet	Extract of *Yucca schiigera* (500 mg)	
Dolo-lime	Dolomite (Mg and Ca enriched lime)	
Rotenone	Derris root ($C_{23}H_{22}O_6$)	

Sources: Hoq et al. 2011; Ali et al. 2014; Akter et al. 2020; Das et al. 2020; Jahan et al. 2021.

Table 8. List of chemicals commonly used in aquaculture systems in Bangladesh.

About WorldFish

WorldFish is an international, not-for-profit research organization that works to reduce hunger and poverty by improving aquatic food systems, including fisheries and aquaculture. It collaborates with numerous international, regional and national partners to deliver transformational impacts to millions of people who depend on fish for food, nutrition and income in the developing world.

The WorldFish headquarters is in Penang, Malaysia, with regional offices across Africa, Asia and the Pacific. The organization is a member of CGIAR, the world's largest research partnership for a food secure future dedicated to reducing poverty, enhancing food and nutrition security and improving natural resources.

For more information, please visit www.worldfishcenter.org