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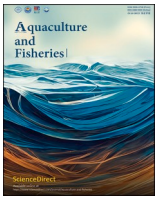

Review article

Status of aquaculture governance in Bangladesh and steps to achieve responsible aquaculture

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ABSTRACT

Aquaculture is the leading animal food-producing sector in Bangladesh and is ranked 5th globally, yielding 2.64 million MT in 2021. Sustainable aquaculture principally relies on an effective governance system that ensures compliance with environmental, social, and food safety standards while managing the risks associated with farming practices. Effective governance significantly influences safe fish production and, thus, fosters sustainability in the sector. Accessing mainstream international markets from developing countries requires addressing challenges such as food safety, traceability, and certification compliance. Secondary data were retrieved from the 'Web of Science' databases and explored for critical analysis to understand the existing aquaculture governance systems in Bangladesh. The study revealed that Bangladesh had enacted various laws and policies to sustain the industry and promote safe fish production. However, the government framework is fragmented, with multiple agencies and departments formulating complex regulations that are challenging for farmers to navigate. Hence, a key recommendation is the development of a collaborative packaged policy, led by the Department of Fisheries (DoF), to harmonize intra- and inter-ministerial efforts. DoF could introduce BanglaGAP, modeled after similar Global South initiatives, to bolster aquaculture governance and provide training for value chain stakeholders. Before adopting such schemes, it is essential to assess the suitability of the initiatives for small-scale farmers and their effectiveness in addressing socioeconomic sustainability issues, such as inequity, exploitation, and injustice in local production and supply chains. Thus, Bangladesh has the potential to develop a tailored aquaculture governance framework, adopt responsible certification schemes, and strengthen its position as a major global fish producer and exporter.

1. Introduction

Aquaculture, the controlled farming of aquatic organisms, is the fastest-growing animal food-producing sector and has become a robust and crucial industry in Bangladesh (Alam & Haque, 2021; Bremer et al., 2016; Heal et al., 2021). Globally, Bangladesh is ranked 5th among countries leading in aquaculture, producing 2.64 million MT of fish in 2021 (DoF, 2022). The massive production is attributed to the farming of the indigenous and exotic carps, pangasius, and tilapia, mostly in polyculture systems, referred to composite aquaculture (Alam et al., 2019; Alam et al., 2022; DoF, 2022). In recent years, the total fish production has approached the fish demand of the entire population of the country, of which aquaculture accounts for 57.1% of the total production of 4.62 million MT (DoF, 2022). Official statistics from the Department of Fisheries (DoF) revealed that Bangladesh had recorded surplus fish production owing to the rapid development of an intensive aquaculture system (Alam et al., 2014; DoF, 2018). However, despite the rapid growth of aquaculture, it is often criticized due to unsustainable production practices, particularly its negative impact on food safety, environmental conditions, and social disruption (Das et al., 2015; Klinger & Naylor, 2012; Osmundsen et al., 2020). Studies in recent years showed that aquaculture is increasingly intensified, and intensive aquaculture poses several sustainability concerns, including resource depletion, environmental pollution, climate change, and sustainability of the systems (Alam et al., 2024; Sampantamit et al., 2020; Sun & van der Ven, 2020).

Aquaculture certification prioritizes effective seafood safety and sustainability practices, which are essential to convince consumers that

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the certified products they buy and consume are safe (Belton et al., 2011; Tran et al., 2022). Certification schemes develop and complement global standards that aim to add to existing national and international regulations, and their essential function is to provide consumers, retailers, and producers with better information, enabling them to make suitable choices regarding environmental impact (Amundsen et al., 2019; Haque et al., 2021; Olsen et al., 2021). An effective governance system in modern aquaculture must synergize environmental, ecological, and social issues and ensure the human well-being of the associated stakeholders (FAO, 2017). With functional aquaculture governance systems, there would be a better allocation of aquatic resources, and irreversible ecological and environmental damage would be ameliorated (Hishamunda et al., 2014). Effective aquaculture governance is essential for the sector to realize its growth and sustainability. It involves formulations and implementation strategies, plans, policies, laws, regulations, and administrative and institutional integration to enable the growth and development of the sector.

In Bangladesh, with a view to implementing aquaculture governance, several rules and regulatory frameworks have been developed. They have been formulated by various organizations and departments of the Government of Bangladesh under different ministries (Haque et al., 2021). Specifically, the Ministry of Fisheries and Livestock (MoFL) is the main agency responsible for formulating, updating, and implementing various policies, legislation, strategies, and other components of the governance to advance the fisheries and aquaculture sector, as well as livestock. Under the MoFL, the Department of Fisheries (DoF), Bangladesh Fisheries Research Institute (BFRI), and Bangladesh Fisheries Development Corporation (BFDC) are key supportive agencies to assist the administrative ministry in formulating policies and acts to boost fisheries and aquaculture production. Various agricultural and relevant universities, organizations within other ministries, and local and international non-governmental organizations are contributing to the development of aquaculture governance in Bangladesh. These organizations contributed directly and indirectly by revising policies, formulating regulations, and introducing technological innovations to promote aquaculture production.

Food and Agriculture Organization (FAO) develops technical guidelines necessary for aquaculture governance towards law adherence, developing standards and procedures, ensuring the credibility and effectiveness of the standards, establishing accountability, and complying with the guidelines for global seafood trade (FAO, 2017). FAO outlines aquaculture governance, offering detailed guidelines with specific points. Many aquaculture-producing countries have developed their governing systems to comply with these guidelines. All the governing systems created in Bangladesh have not been developed according to any kind of standard guidelines. Apart from the DoF, other government and non-governmental organizations have developed many policies related to aquaculture governance, but there is no coordination of the governance system of DoF with these (Haque et al., 2021). That is why the aquaculture governance of Bangladesh is very weak compared to the government system of the leading aquaculture-producing countries (Bremer et al., 2016; Partelow et al., 2023). This article systematically reviews and compares governance systems in leading aquaculture-producing countries with Bangladesh, scrutinizing its institutional functioning, exploring alternatives to the DoF, and discussing strategies to improve aquaculture governance.

Section 2 of the article introduces the methodological framework derived from a comprehensive review of literature that addresses seven key aspects for evaluating aquaculture governance. Section 3 begins by reviewing the institutional structure of aquaculture governance through which the seven points of governance can be implemented. Section 3.1 presents an overview of the zoning plans for aquaculture. Subsequent sections delve into various aspects of farm operations, covering topics such as land and water use, environmental impacts, preservation of genetic integrity of farmed fishes, utilization of fish feed, assurance of food safety, and considerations for human rights and well-being under the aquaculture governance. Section 3.8 discusses other institutional and policy-related considerations pertinent to the previously discussed points. Section 4 wraps up by deliberating on the subsequent actions required for the establishment of effective aquaculture governance.

2. Methodology: procedure of systematic review

We applied the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol to conduct this review, a powerful tool in social sciences that offers a transparent, rigorous, and methodical approach to summarizing literature (Siddaway et al., 2019; Siddique et al., 2022a). We used relevant keywords to search for the literature on aquaculture governance, following Lebel et al. (2018), who emphasized key governance dimensions, such as institutional arrangements, actor networks, and policy interactions, while the inclusion and exclusion criteria for article selection based on study type, geographical coverage, and methodological quality were applied according to Gambelli et al. (2019). Scientific, peer-reviewed publications were considered and explored to thoroughly analyze the aquaculture governance systems in Bangladesh. Searches were also conducted in the 'Web of Science' databases for journal articles on the governance of aquaculture. To narrow down the search on governance, searches included terms like rules, regulations, policies, legal frameworks, licensing, institutions, administration, participation, property rights, standards, legislation, certification, and laws. For aquaculture governance, keywords included 'aquaculture' plus one: sustainability, green growth, master plan, guidelines, law, rules, regulations, policy, framework, management, and certification. The terms seafood, fish farming, shrimp farming, pangasius culture, tilapia culture, pond culture, and cage culture were considered as alternatives to the term 'aquaculture'. Only peer-reviewed journal articles published in or after 2000 were included. Accordingly, 399 articles in all were retrieved and extracted from the Web of Science databases. A total of 276 studies were excluded due to language problems and lack of full-text access. After the meticulous screening, 123 studies were identified and nominated for verification of appropriateness, among which another 76 articles were eliminated due to being out of the scope of this study or irrelevant to the objectives. Eventually, 47 of the most relevant articles on aquaculture governance systems were included in this evaluation. The findings of the review were recorded, synthesized, and scrutinized for better interpretation.

We analyzed the existing aquaculture governance practices and their alignment with globally recognized responsible aquaculture certification schemes. The key indicators of globally responsible aquaculture certification schemes, used as a framework for this study, were extracted from the ASC (Aquaculture Stewardship Council) (https://www.asc-aqua.org/) and GlobalGAP (Global Good Agricultural Practice) (https://www.globalgap.org/uk_en/). The application of ASC and GlobalGAP certifications is instrumental in promoting good governance practices within the aquaculture sector. These certifications provide comprehensive guidelines and standards that encompass environmental, social, and economic dimensions, ensuring responsible and sustainable aquaculture operations. The details of these indicators are presented in the 'Supplementary Materials' in Appendix A. We also compared the aquaculture governance system in Bangladesh with those of China and Vietnam, which are widely known for their commercial fish production, export, and adoption of sustainability certification schemes, such as the ASC and GlobalGAP. The analytical framework is based on these seven points, drawn from ASC and GlobalGAP in connection with FAO and other responsible aquaculture certifying authorities. Considering seven points, which are as follows, the current status of Bangladesh's aquaculture governance and future actions are analyzed.

a) Zoning of aquaculture: Locate and operate farms within established local and national legal frameworks.
b) Land and water use: Minimize the negative impact of aquaculture farming on water and land resources.

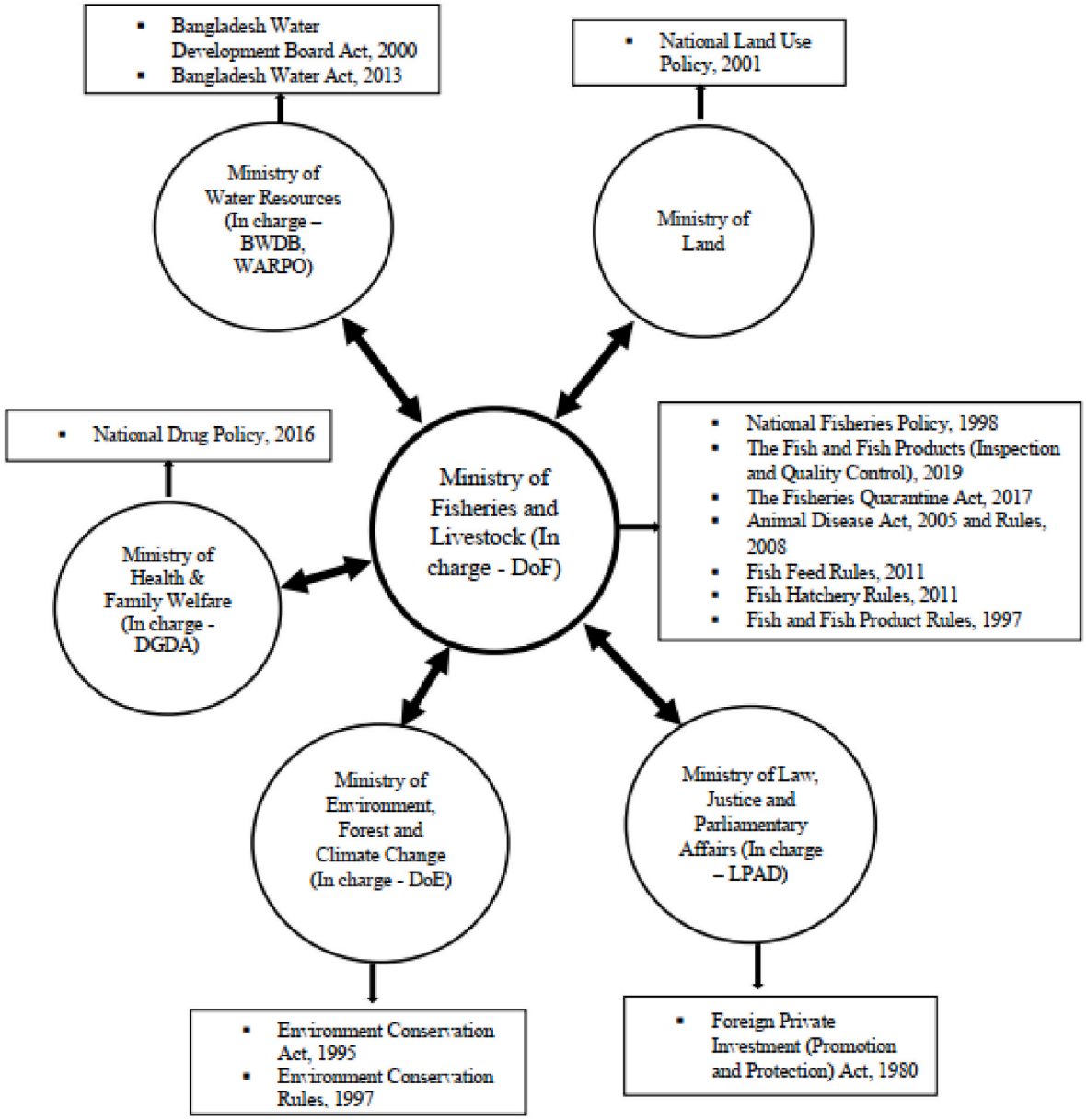

Fig. 1. Administrative authorities of aquaculture governance in Bangladesh.

c) Environmental impacts: Farms must be located, designed, constructed, and operated to avoid/minimize their negative impacts on other users and the environment.
d) Genetic integrity: Minimize impacts of aquaculture on the genetic integrity of local fish populations.
e) Use of feed: Use feed and feeding practices that ensure that feed inputs are sustainable and minimized.
f) Food safety: Minimize ecosystem and human health impacts, while enhancing fish health, welfare, and ensuring food safety.
g) Human rights and poverty alleviation: Develop and operate farms in a socially responsible manner that contributes effectively to community development and poverty alleviation.

3. Institutions related to aquaculture governance in Bangladesh

In Bangladesh, various aquafarming implementation practices, including regulations based on formulated policies, are mainly overseen by the MoFL (Fig. 1). The DoF under the MoFL is the competent agency for fisheries and aquaculture, exerting critical functions in formulating national fisheries development strategies and regulations to facilitate the development. The UFOs (Upazila Fisheries Officers) in the local sub-districts (Upazilas) are liable for monitoring and enforcing the fisheries regulations and establishing local regulations to address regionalized concerns. Government administrative agencies, among other organizations and institutes, also contribute intrinsically to fisheries and aquaculture development, such as the BFRI, BFDC, MFA (Marine Fisheries Academy), etc. Additionally, the BWDB (Bangladesh Water Development Board) and WARPO (Water Resources Planning Organization) under the MoWR (Ministry of Water Resources), DoE (Department of Environment) under the MoEFC (Ministry of Environment, Forest and Climate Change), DGDA (Directorate General of Drug Administration) under the MoHFW (Ministry of Health and Family Welfare), LPAD (Legislative and Parliamentary Affairs Division) under the MoLJPA (Ministry of Law, Justice and Parliamentary Affairs) and MoL (Ministry of Land) are indirectly linked with fisheries and aquaculture governance in Bangladesh (Fig. 1). The institutional arrangements for fisheries and aquaculture sector provide an organized administrative body for the advancement of aquaculture. The collective institutional governance for

fisheries and aquaculture in Bangladesh is extensive and variegated, which can be an organized administrative body by integrating seven points, as discussed below.

3.1. Zoning plan of aquaculture

The aquaculture zoning plan has drawn global attention to sustainable growth, minimizing conflicts, and environmental integrity (e.g., China, Australia, Norway, and New Zealand). These countries have designated regions for investment in aquaculture and do not permit aquaculture in other zones (Aguilar-Manjarrez et al., 2017; Pueppke et al., 2020). Aquaculture zoning has advantages, including identifying the best potential areas, controlling disease, reducing environmental impact, and protecting habitats and species in authorized zones. National or local governments direct the zoning process with significant stakeholder involvement, fed by relevant information and supported by relevant regulations (Aguilar-Manjarrez et al., 2017). Published literature reported that a proper zoning system fosters sustainable aquaculture development and expansion (Lauer et al., 2015). Aquaculture in Bangladesh has flourished in an unregulated way without any organized zoning plan (Shamsuzzaman et al., 2022). Nevertheless, the aquaculture zone has naturally unbridled development in several parts of Bangladesh through the farmers' experience, willingness, and observation of neighboring farms, including Mymensingh, Jashore, Bogura, Khulna, and Cumilla regions (DoF, 2022). Aquaculture advancements have brought both advantages and challenges to these regions in the absence of zoning. The advantages include the development of fish farms, hatcheries, feed mills, aqua pharmaceuticals stores, and fish processing factories, which have enhanced food security and created numerous employment opportunities. The challenges, on the other hand, are caused by the rapid growth of aquaculture, which has led to the indiscriminate conversion of agricultural land and wetlands into fish ponds, resulting in a change in the landscape, environmental degradation, ecosystem destruction, and biodiversity loss (Abdullah et al., 2017). Lack of an effective zoning plan, aquaculture spreading sporadically and rapidly to other regions of Bangladesh, which could spread the potential negative impacts of the aquaculture industry more widely. Aquaculture in Bangladesh is predominantly pond-based small to medium-scale farms that produce a variety of carp, tilapia, catfish, and crustaceans (Haque, 2007). The adoption of a zoning plan may restrict small-scale farmers' access to appropriate sites for aquaculture activities, as certain areas may be reserved for larger, industrial-scale operations. Moreover, zoning without proper planning and appropriate policies may abruptly cease aquaculture in different regions, posing a threat to sustainable practices and production. This disruption in fish production trends could lead to financial challenges for farmers and stakeholders. A comprehensive survey and data synthesis are essential to identify appropriate areas for a well-planned aquaculture zoning system. The Bangladesh government should establish a well-structured zoning plan explicitly for aquaculture. Establishing an aquaculture zoning system requires considering the following factors: farmers' clusters, production volume, geographical location, species availability, and farming practices. Such a plan would reduce negative impacts, ease compliance with certification requirements, ensure safe and sustainable production, enhance the global image of Bangladeshi aquaculture products, and bolster local and international trade (Haque et al., 2021).

3.2. Land and water use

Globally, land-based pond aquaculture is the most typical and established method of fish production. The literature reported that science had been applied to pond aquaculture in the last 100 years, but this technique has been used for at least 2000 years (Boyd & Chainark, 2009). Over time, pond-based aquaculture will lead to a boom as global capture fisheries production stagnates (Naylor et al., 2021). Land and water resources are important components of pond-based aquaculture,

Table 1
Present status of the aquaculture governance system and the responsible authority in Bangladesh.

Sl. No.	General areas	Specific regulations	Responsible authority
		Policy/Act/Law/Rules	Ministry/ Departments/Agencies
A.	Basic legislation & policy	i) National Fisheries Policy, 1998	Department of Fisheries
B.	Accessibility legislation	i) National Land Use Policy, 2001	Ministry of Land
		ii) The Fish and Fish Products (Inspection and Quality Control) Act, 2019	Department of Fisheries
		iii) Bangladesh Water Act, 2013	Ministry of Water Resources
		iv) Bangladesh Water Development Board Act, 2000	Ministry of Water Resources
C.	Environment influence assessment	i) Environment Conservation Act, 1995	Ministry of Environment, Forest and Climate Change
		ii) Environment Conservation Rules, 1997	Ministry of Environment, Forest and Climate Change
		iii) Environment Court Act, 2000 (as amended in 2002)	Ministry of Environment, Forest and Climate Change
D.	Fish movement	i) The Fisheries Quarantine Act, 2018	Department of Fisheries
E.	Disease control	i) Animal Disease Act, 2005	Ministry of Fisheries and Livestock
		ii) Animal Disease Rules, 2008	Ministry of Fisheries and Livestock
F.	Drugs and chemicals rules	i) National Drug Policy, 2016	Directorate General of Drug Administration
G.	Fish feed act and rules	i) The Fish Feed and Animal Feed Act, 2010	Ministry of Fisheries and Livestock
		ii) The Fish Feed Rules, 2011	Department of Fisheries
H.	Fish hatchery act and rules	i) The Fish Hatchery Act, 2010	Department of Fisheries
		ii) The Fish Hatchery Rules, 2011	Department of Fisheries
I.	Food safety	i) The Fish and Fish Product (Inspection and Quality Control) Ordinance, 1983	Department of Fisheries
		ii) Fish and Fish Product (Inspection and Quality Control) Rules, 1997	Department of Fisheries
J.	Aquaculture investment	i) Foreign Private Investment (Promotion and Protection) Act, 1980	Ministry of Law, Justice and Parliamentary Affairs

as well as key issues to be incorporated into responsible aquaculture certification (Boyd et al., 2007). Bangladesh has no particular governance system in the land and water use to support aquaculture. However, the MoL adopted the 'National Land Use Policy,' Bangladesh, issued on June 21, 2001 (Table 1). The policy's primary purpose is to terminate agricultural land conversion, optimize land use in agroecological zones, discourage urbanization on agricultural land, and improve environmental sustainability for land utilization. The existing 'Land Use Policy of 2001' scarcely specified aquaculture and did not map land zoning areas for aquaculture to avoid conflict with other sectors. Aquaculture producing country like Vietnam has established a regulatory framework (Law on Land, Law No. 13/2003/QH11) guiding land use zoning and plans, aligning with master zoning strategies, socio-economic development, and national defense and security. This regulation addresses the provisions and procedures for land access, such as allocation, leases, and revocation, specifically for aquaculture. Moreover, China has adopted a law to formulate a comprehensive land utilization plan, categorizing agricultural, fisheries, aquaculture, construction, and unutilized land.

For successful water use and management, the 'Bangladesh Water

Development Board Act, 2000' and 'Bangladesh Water Act, 2013' were adopted by the MoWR in Bangladesh (Table 1). The MoWR is considered the competent authority and heads the policy formulation, monitoring, and implementation of plans pertinent to water. The MoWR oversees water policy in Bangladesh while supporting organizations, such as BWDB and WARPO, responsible for implementation. Indeed, 'Bangladesh Water Act, 2013' was developed to provide integrated development, management, distribution, utilization, protection, and conservation of water resources. Additionally, it involves implementing groundwater irrigation, making it mandatory for individuals and organizations to obtain a license/permit for extensive groundwater withdrawal extending beyond domestic and agricultural (including aquaculture) use (Qureshi et al., 2014); . Extensively, 'Bangladesh Water Development Board Act, 2000' focuses on constructing embankments, dams, barrages, reservoirs, and other structures for the development of rivers. Neither regulation specified nor elucidated water utilization for aquaculture purposes. Therefore, aquaculture farmers largely ignored wastewater treatment and most often directly discharged it into the nearby croplands, rivers, and canals. Nutrient-rich water and sludge can lead to plankton blooms, degrade water quality, cause mortality of aquatic animals, as well as a decline in biodiversity. Aquaculture wastewater discharge has the potential to transmit pathogens and diseases, endangering wild aquatic populations. Various aqua medicines, chemicals, pesticides, and feed additives applied in aquaculture are directly incorporated into the environment, causing antimicrobial resistance in nontarget species and posing risks to human health (World Bank, 2007). To mitigate this problem, the DoF should provide training and education to the farmers to raise awareness about responsible water use and wastewater management, as well as robust monitoring and surveillance to track aquaculture activities and ensure compliance with regulations at the farm level. China formulated a water policy (The Water Law 1988; as amended in 2002) that governs water bodies' development, utilization, protection, allocation, and management, playing a crucial role in fish production, particularly in freshwater aquaculture. For wastewater treatment, the MoWR announced the administrative regulation of the 'Bangladesh Water Act, 2013' in November 2013 (Table 1). The 'Water Act' widely oversees several key water lapses; however, there are no guidelines relating to non-point water polluting sources like fertilizer and pesticides, nor a specific description of environmental protection from industrial pollution, and there is quite a deficit of provisions for aquaculture farmers. They are the principal water regulatory body, but face limitations in implementing regulations as the MoEF acts as the chief water mediator. Specifically, for water pollution, the DoE is responsible for pollution control, standardization of water utilization and effluent, elucidation of environmental impact assessment, issuance of environmental clearance permits, and declaration and protection of degraded ecosystems (UNEP, 2001). The DoE established standard guidelines for sludge management in Bangladesh, addressing industrial waste disposal under environmental rules and regulations to meet water quality objectives and human health issues. However, the guideline lacks clarity on the aquaculture waste management system, despite being of major concern in all the aquaculture certification schemes. Aquaculture waste includes sludge, animal-tissue waste, plastic waste, animal urine, feces, manure, as well as agrochemical waste containing dangerous substances (DoE, 2015). Hence, it is necessary to revise the guidelines for aquaculture waste management, prioritizing environmental management systems to regulate water use, optimize effluent discharge, protect natural waters, and ensure appropriate disposal of pond sludge. Aside from the MoWR and MoEF, five more ministries are involved in the country's water management: the Ministry of Local Government, Rural Development & Cooperatives (MoLGRD&C), Ministry of Industries (Mol), Ministry of Textiles & Jute (MoT&J), and Ministry of Disaster Management & Relief (MoDM&R). Therefore, for responsible aquaculture, a clear guideline is a prerequisite, encompassing all relevant authorities within the executive committee of the 'Water Act, 2013', with a designated institution for effective coordination.

3.3. Environmental impacts

Aquaculture has been intensely criticized since 2000, particularly by various environmental organizations, and is visible in mass media (Naylor et al., 2021; Osmundsen & Olsen, 2017). The rapid expansion of aquaculture farms being constructed haphazardly poses environmental challenges: habitat conversion, pollution, eutrophication, pathogen transfer, emissions, dependency on wild fisheries for feed, animal welfare issues, and food-safety concerns (Afewerki et al., 2023; Luo et al., 2022). Earlier literature has documented genetic pollution, invasive species introduction, and indiscriminate use of antibiotics and other medicines in aquaculture (Gephart & Golden, 2022; Hall et al., 2011). Traditional aquaculture in Bangladesh, starting in the 1980s, rapidly evolved, doubling production in the last decade due to intensive techniques (DoF, 2022). However, unplanned intensification of aquaculture and operation raises concerns about environmental sustainability, particularly in coastal shrimp and prawn farming, causing negative impacts on soil salinity, mangrove destruction, waterlogging, biodiversity degradation, ecosystem loss, climate change, and societies (Ahmed & Turchini, 2021). Researchers already addressed the possibility that long-term shrimp farming may lead to severe salinization of lands, rendering them unusable for rice farming or even shrimp cultivation (Ahmed, 2018). The intensification of aquaculture has escalated fish disease rates, causing a surge in the use of indiscriminate antibiotics and pharmaceuticals for treatment (Alam & Haque, 2021; Bondad-Reantaso et al., 2023). The residues of these antibiotics accumulate in fish, organisms, and aquatic environments. Antibiotic use and misuse have driven the emergence of antimicrobial-resistant (AMR) microbes, consequent to zoonotic pathogens and AMR genes spreading through the food web (Bell et al., 2023; Kumar & Pal, 2018; Mannan et al., 2020). It is evidenced that AMR pathogens are transmitted between aquatic and terrestrial organisms, which pose a severe threat to human and animal health (Chowdhury et al., 2022; Lassen et al., 2022; Thornber et al., 2022). The above discussion makes it evident that the unplanned aquaculture in Bangladesh harms the aquatic environment and keeps spreading. Many countries worldwide have undertaken various initiatives and adopted policies to minimize the negative environmental impacts of aquaculture. China has adopted environmental laws, like the 'Environmental Protection Law, 1989', and 'Environmental Impact Assessment Law, 2002', aiming to prevent and control environmental pollution and conservation of natural resources (Zou & Huang, 2015). The MoEFC in Bangladesh enacted the 'Environment Conservation Act, 1995 and Rules, 1997' to achieve goals such as environmental conservation, environmental standard improvement, and environmental pollution regulation and mitigation (Table 1). The administrative DoE under the MoEF is responsible for implementing the law; however, it has scarcely adopted it in aquaculture practices under this law. Several lapses in these laws clarified that they are inexhaustible and incompatible regardless of time (Saleh, 2015). Presently, the globally sustainable utilization of aquaculture techniques has the predominant objective of different certification schemes. However, it is very weak due to the lack of proper governance and poor implementation of regulations in Bangladesh (Haque et al., 2021; Jolly et al., 2023; Sohel & Ullah, 2012; Uddin et al., 2019). Hence, it is imperative to undertake revisions and reforms in the policies to establish aquaculture farms judiciously, ensuring the sustainability of aquaculture in Bangladesh.

3.4. Genetic integrity of farmed fish

Aquaculture in Bangladesh is entirely dependent on hatchery-based seed production (Haque et al., 2014). Before 1990, seed production was based on spawns collected from natural sources (i.e., rivers, canals, estuaries). The situation changed after 1990, leading to an increased number of hatcheries and production with the successive introduction of

exotic carp, catfish, tilapia, and shellfish in various parts of the country (Siddique et al., 2022b; Siddique et al., 2022a). Over 1000 fish hatcheries have been established in Bangladesh, of which 103 are government and 963 are privately owned, according to DoF (2020). The government hatcheries, scattered nationwide, are administered by the DoF to distribute high-quality seeds to aquaculture farmers. However, their contribution (only 3 %) does not impact a large number of farmers due to a lack of adequate quantity of seeds compared to farming demand. In contrast, private hatcheries substantially impact seed production; approximately 97 % (648,486 kg) of fish seed is produced in private hatcheries (Mahalder et al., 2023). Because of the scarcity of seed production in government hatcheries, monitoring and surveillance are poorly governed in this sector; therefore, most private hatcheries disregard the standard seed production protocols and prioritize their own experience. To resolve this drawback, the Bangladesh government formulated the 'Fish Hatchery Rules, 2011', ensuring registered and certified hatcheries follow standard procedures and management practices to produce good quality fertilized fish eggs, fry, and fingerlings. The rules prohibit undesirable practices, including inbreeding, hybridization, negative selection, and improper broodstock management, to sustain aquaculture production. The enactment of the 'Fish Hatchery Rules, 2010' is a unique and significant process and the first in Southeast Asia to ensure quality in fish seed production (Table 1). According to the enactment, the hatcheries must be registered by the DoF and comply with the legislation. Although the regulation for hatchery operation in aquaculture is very much specified, some criteria have remained negligible in the rules, such as transgenic fish, GMO (Genetically Modified Organisms), etc. Limited skilled manpower, institutional resources, and support services hinder the genetic integrity, broodstock management, and seed quality of hatchery operations. Most hatcheries use the same broodstock without renewing year after year, resulting in deteriorating genetic integrity and increasing the risk of inbreeding, negatively impacting aquaculture (DoF, 2020; Sarder, 2007). Ingram and Nguyen (2014) claimed that improperly planned genetic management of broodstock and breeding results in declines in stock quality over several generations, leading to low fecundity, hatch rates, growth rates, high mortality, as well as an uptick in deformities and disease susceptibility. Fish breeding and quality seed production largely depend on the willingness of the hatchery owner/operator to work according to planned objectives. Therefore, to maintain the genetic integrity of farmed fish and overcome the inferior quality breeding challenges, it is necessary to increase the support services and training facilities from the DoF and BFRI to private hatcheries on systematic pure breeding techniques. China has adopted 'Measures for the Management of Aquatic Fingerlings, 2005' on hatchery operation, aiming to protect and utilize aquatic germplasm, strengthen selective breeding, regulate seedling production, trade, and import/export of aquaculture species, improve the quality of fish seed, and protect the legal rights of aquaculture seedling producers, traders, and users. The law clarified the aquaculture seedlings, such as broodstock, juveniles, larvae, fertilized eggs, spores, and materials for genetic breeding of aquatic organisms for reproduction, release, or grow-out, and scientific experiments (Liu, 2016).

Broodfish and millions of fish seeds (i.e., fry, fingerling, and shrimp PL) of various fish species are being imported into Bangladesh without a proper quarantine system or even any inspections (Sarder, 2007). In these cases, various novel diseases are likely to be introduced, and maintaining genetic integrity is extremely challenging at the hatchery level. To address these issues, different countries have launched several initiatives, such as China adopted administrative regulation on 'The Entry and Exit of Animal and Plant Quarantine Law, 1991', focusing on aquaculture, to maintain genetic integrity, prevent infectious and parasitic diseases, pests, and other harmful organisms from spreading into or out of the nation. For the same purposes, DoF introduced 'The Fisheries Quarantine Act, 2017' to restrict the entry of fish, fish products, and related microbes, requiring government approval and licensing to curb invasive fish species and pernicious bacteria in imported fish and fish seeds. As required by law and directed by the competent authority, the imported fish, fish products, economic microorganisms, or packaged fish items are temporarily inspected at designated 'Fisheries Quarantine Stations'. The quarantine tool is crucial for national fish health strategies, as it increases farm-level biosecurity and fosters sustainability. Overall, addressing the challenges surrounding genetic integrity and quarantine systems in Bangladesh's aquaculture industry requires the establishment of a suitable governance and certification framework. Such a framework would not only safeguard genetic diversity but also bolster the country's aquaculture sector, ensuring sustainable and secure fish production.

3.5. Use of fish feed

Commercial aquaculture in Bangladesh heavily relies on formulated feed, and usage has grown substantially over the years. The fish feed industries massively expanded to meet the increasing demand, developing about 1000 local feed mills, 100 commercial mills, and ten multinational feed additives companies. Approximately 60% of the feed ingredients utilized in aquaculture have to be imported from abroad (Mamun-Ur-Rashid et al., 2013). There are multiple drawbacks of import-dependent feed ingredients. For example, the importers' syndicate raises feed prices at will, farmers become hostage to them, and often use poor quality ingredients or adulterate to reduce feed expenses. Therefore, the growing concern over import dependency on feed ingredients, fish feed quality, and its impacts on aquaculture yield stems from the fact that adulterated aquafeed degrades fish meat quality and color, and raises food safety issues (Hoque et al., 2021; Iheanacho et al., 2020). Certified fishmeal and fish oil applications are poorly operated in the Bangladesh aquaculture sector. Feed millers or companies often mix various antimicrobials, parasiticides, feed additives, and probiotics to enhance fish health and disease prevention (Rico et al., 2013). As documented in investigations, aquafeeds and fish species contain toxic heavy metals and contaminants (Alam & Haque, 2021; Bhowmik et al., 2023). Adulterants and unauthorized aquaculture medicines jeopardize food safety, hindering responsible aquaculture certification, export, and sustainability (Alam et al., 2024). Some Asian countries, like China and Vietnam, enforced strict regulations on aquaculture feed for sustainability. China formulated the 'Feed and Feed Additives, 1999' regulation, overseen by the MoA (Ministry of Agriculture), that improves fish feed for food safety (Liu, 2016). Vietnam introduced a regulatory framework (Decree No. 01/2008/ND-CP) calling aqua feed mills to register, adhere to feed standards, and regularly monitor products (Nguyen et al., 2017). The responsible authorities approve and monitor the feed quality and production conditions of each manufacturer. Bangladesh introduced 'Fish Feed Rules, 2011,' aimed at promoting the management of producing quality fish feed and feed additives to ensure the safety of aquaculture products and consumer health (Table 1). The DoF is the responsible authority for ensuring the quality use of feed and feed additives and guiding their safe and rational application in aquaculture. The fish feed standard aligns closely with China and Vietnam regulations and covers moderate global sustainability certification schemes. The use of antibiotics, growth hormones, and pesticides in animal and fish feed is prohibited by law in Bangladesh (MoFL, 2011). Specifically, the rule addressed the use of drugs and chemicals in aquafeed and listed several non-permitted chemicals in feed, including hormones, some antibiotics, organophosphates, environmental contaminants, heavy metals, mycotoxins, anthelmintics, and dyes. A few antibiotics, such as the tetracycline group, are allowed, but the rates and dosages in the feeds are provided by the rules. According to the rules, the feed producers, processors, and traders must obtain a license from DoF. Implementing the fish feed rule in Bangladesh's aquaculture remains challenging despite existing regulations. A more robust enforcement mechanism is necessary to ensure the production of safe, high-quality fish feed and to promote sustainable practices throughout the aquaculture industry.

3.6. Food safety

Aquaculture has raised food safety concerns due to the risk of contamination and adulteration of products (Khan et al., 2023; Okocha et al., 2018). Effective governance can ensure sanitation, food safety, and sustainable aquaculture. The unregulated use of drugs and chemicals in aquaculture production leads to contamination and poses human health and food safety issues (Alam & Haque, 2021; Thornber et al., 2022). In Bangladesh, farmers have limited knowledge and poor awareness about the usage of drugs and chemicals (Rico et al., 2013). Farmers usually apply aqua medicines based on their experiences and recommendations from neighbor farmers, local chemical and feed shop sales staff, and corporate representatives. Another big issue is that veterinary surgeons prescribe drugs and chemicals for livestock and poultry, but are not officially authorized to deal with them for aquaculture. Like veterinary surgeons, DoF wants to initiate the prescription of drugs and chemicals for aquaculture farmers via local officers. However, DoF's local officers limited pharmacological knowledge is a historical drawback, but recent academic curricula at the University level now cover medicine use for disease treatment and other applications. Compared to Bangladesh, China and Vietnam have enacted comprehensive legislation for drugs and chemical use in aquaculture (FAO, 2013). Under this legislation, China forbade the use of most unapproved or banned chemicals, and all medicines are strictly monitored for use in aquaculture ponds. Since 2002, over 40 new standards or specifications for drug residues in aquatic products and inspection techniques have been developed or updated (Li et al., 2011). Local standards for veterinary medications have also been eliminated or converted to national standards, subject to re-examination and approval (Wang, 2009). Vietnam developed a strong policy prohibiting unapproved drugs, and records must be kept on the use of all aqua drugs and medicines. Active ingredients, usage, dosage, duration of use, and withdrawal periods are specified and must be adhered to (DERG and CIEM, 2010). Bangladesh enacted the 'National Drug Policy, 2016' under the MoHFW via DGDA (Table 1), which ensures food safety, prevents animal disease, and protects public health through quality and safe veterinary drugs and vaccines. The main objectives of the national drug policy are to control aquaculture drugs and chemicals in Bangladesh, safeguard human health, enforce residue limits, prevent illegal or unauthorized drug use, and ensure adherence to best practices throughout the manufacturing, importation, distribution, retailing, and utilization stages (DGDA, 2016).

Disease control and prevention are crucial for maintaining the utilization of resources and a sustainable aquaculture sector because good health conditions are key for the welfare of farmed animals (Gudding, 2012). Certification schemes, such as ASC and GlobalGAP, emphasize animal health and responsible practice, serving as tools to promote good governance in aquaculture. China formulated the 'Law on Animal Diseases, 1997', which aimed at preventing, controlling, and eliminating animal diseases, as well as the measures of animal quarantine, including fisheries and aquaculture (FAO, 2005). In light of the implementation of certification schemes, Bangladesh adopted the 'Animal Disease Act, 2005' and 'Animal Disease Rules, 2008' to control animal disease, promote breeding industry growth, and maintain public health and safety. The administrative DoLS (Department of Livestock Service) under the MoFL oversees the law, specifically for livestock animals. However, no legislative body was specified for the regulation of disease within aquaculture facilities. Several effective disease management systems, such as measures to minimize the risk of disease entry, the capability to diagnose disease, and emergency preparedness, were absent in aquaculture production owing to a lapse in governance. The absence of specific legislation on fish health and disease leads to the misuse of drugs, hormones, therapeutics, and antibiotics in aquaculture activities. Therefore, these lessons could be used to establish effective legislation and regulation for fish health, mitigate disease prevalence, reduce drug misuse, and ensure the aquaculture products.

Nevertheless, the effectiveness of sustainability certification schemes in promoting good governance is contested. Recent studies suggest that many prominent transnational certification schemes and their standards, benchmarking criteria, and governing principles remain overwhelmingly fragile in promoting responsible and socio-culturally sustainable seafood production practices (Saha, 2022, 2024). These schemes include, for example, Naturland, GlobalGAP, and Friend of the Sea. While these standards emphasize health and environmental criteria, they often overlook ethical and social dimensions, including the rights of indigenous peoples and small-scale farmers. Although addressing these issues could enhance the inclusiveness and acceptability of certification standards, such reforms are unlikely to enhance the sociocultural sustainability of aquaculture, as these schemes are primarily designed to serve business interests and increase market access (Samerwong et al., 2018; Vormedal & Gulbrandsen, 2020). Moreover, high certification costs and stringent criteria further marginalize small-scale farmers, reinforcing existing social inequalities (Saha, 2022). Similar concerns have been raised by Vandergeest (2007), Tran et al. (2013), Marschke and Wilkings (2014), and Gulbrandsen et al. (2022), who critically assess the actual effectiveness of certification schemes to sustainable seafood governance. In terms of product safety and traceability, China formulated the 'Aquaculture Product Quality and Safety, 2003' laws to improve aquaculture product quality, protect fisheries ecosystems, and regulate feed, medicine, labeling, drug residue, and responsible usage. Vietnam, like China, upholds strict safety regulations for quality seafood export controlled by the Food Safety Authority, addressing aquatic animal health and disease prevention with hygiene standards (DERG and CIEM, 2010). Bangladesh announced the administrative regulation of 'The Fish and Fish Product Ordinance, 1983', and subsequently, the ordinance was further implemented by the 'Fish and Fish Product Rules, 1997' (Table 1), improving fisheries and aquaculture product quality and safety. They uphold the overall liability for fish inspection and quality control vested in the DoF, managing testing laboratories for exportable fish products. DoF examines sensory, chemical, and microbiological samples at the FIQC laboratory before exporting seafood from Bangladesh. The act also includes basic food processing, storage, packaging, labeling, and transport provisions. The rule forbids exporting fish and fishery products without a health/-salubrity[1] certificate from the DoF. The legislation lacks comprehensive coverage, focusing mainly on laboratory aspects rather than addressing the field level in food safety and export, especially in farms, hatcheries, and feed mills. The traceability system in the aquaculture sector is in disrepair due to the absence of a legal framework and a lack of government efforts. Despite the efforts of DoF to improve traceability for shrimp exports, the system is currently dysfunctional, posing a significant challenge to a complex network of intermediaries, highlighting the critical need for a legal framework and effective governance. Therefore, developing a comprehensive governance system is crucial for enhancing food safety, animal health, and the overall sustainability of aquaculture. Bangladesh must adopt successful models, implement robust regulations, standards, and compliance measures for safe fish production, and ensure global market access.

3.7. Human rights and poverty alleviation

Human and labour rights concerns in aquaculture are increasingly being highlighted and criticized internationally (FAO-ILO, 2013). Aquaculture is a potentially significant economic sector, employing an estimated 20.5 million people worldwide as full-time, part-time, occasional, or unspecified workers, including approximately 21 % women

[1] Health/salubrity certificate means that the consignment of fish and fish products is certified from DoF which examines and inspects several export criteria based on EU guidelines complying with the fitness for human consumption.

(FAO, 2022). In Bangladesh, over 20 million people, including subsistence and secondary sector workers and their families, are directly and indirectly engaged in fisheries and aquaculture sectors (DoF, 2022). Commercial aquaculture supports to alleviate poverty and hunger, and malnutrition by creating new employment opportunities, increasing fish supply for the underprivileged at lower prices, and generating consumption linkages. Globally, the aquaculture sector is increasingly relying on responsible aquaculture i.e., aquaculture certifications, which evolved to embrace some social and welfare issues, albeit slowly or superficially. The certification standards include several social and labor rights criteria, including justice, equity, dignity, ethics, minimum wages, decent work, forced labor, child labor, employment conditions, freedom of association, occupational health and safety (Brugere et al., 2023). In response to these concerns, Bangladesh formulated 'Labor Act, 2006′, under the Ministry of Labor and Employment (MoLE), and amended it three times in 2009, 2010, and 2013. The act focuses on the labor recruitment process, labor-employer relationships, minimum wages, wage payment, incidental expenses, occupational risks, collective bargaining, dispute resolution, and workplace environment. In 2012, the Bangladesh government introduced the 'Labor Policy' to ensure a productive, non-discriminatory, non-exploitative, and healthy work environment for all engaged citizens. The policy emphasizes decent work, workers' rights, labor dignity, and their bargaining abilities. Additionally, Bangladesh launched the 'National Child Labor Elimination Policy, 2010′ to eliminate risky child labor by 2021 and all child labor by 2025, safeguarding children (MoLE, 2013). The government acts and policies were enacted primarily based on apparel industry employees, while also supporting aquaculture development and addressing common ILO standards. However, the compliances with labor rights are poorly followed in the Bangladesh aquaculture sector, including informal recruitment, irregular payment, sudden termination, wage discrimination, excessive work, and abuse of child labor (Haque et al., 2021; Rashid et al., 2023). Recruitment policies are highly informal, and there are no written formal contracts and appointment letters in place. Brugere et al. (2023) reported critical labor rights issues and substandard working conditions in Bangladesh's aquaculture value chain (e.g., hatcheries, feed mills, farms, processing plants, etc.). A stringent aquaculture governance is needed to create an environment where all aquaculture workers can enjoy fair treatment, social protection, and decent working conditions. This approach promotes workers' well-being through alleviating poverty and backs the industry's sustainable expansion, establishing a global reputation for responsibility and respect.

3.8. Other regulations and institutional issues

Bangladesh has developed other laws and policies to establish a sustainable, export-oriented, and institutional framework for the aquaculture sector. The ‘National Fisheries Policy (NFP), 1998’ formulated by the MoFL, aims to boost fish production, increase foreign exchange revenues, and support economic growth while sustaining ecological balance and biodiversity. The policy incorporated government and non-government organizations, autonomous organizations, multi-national institutions, and voluntary organizations to develop seafood farming strategies, improve harvest and preservation techniques, add value, and boost export potential. Its broader objectives include boosting fish production, alleviating poverty, creating self-employment, improving the socioeconomic status of farmers, and ensuring national food security. However, the over 25 year old NFP 1998 placed greater emphasis on capture fisheries, offering limited attention to aquaculture development, due to a lack of a precise definition and proper categorization of aquaculture in national statistics. This neglect is exacerbated by a shortage of comprehensive statistical data, particularly in the "Yearbook of Fisheries Statistics of Bangladesh" since 1983, which inadequately reports species-specific farming areas, distribution of culture systems, registered aquaculture farms, feed production, and export values. Therefore, the policy requires amendments to reflect the rapid growth of aquaculture, ensure sustainability, and align with the best practices from leading aquaculture-producing countries. Notably, China's ‘Fisheries Law’, first promulgated in 1986 and subsequently amended in 2000 and 2004′, provides a strong model for regulating aquaculture and inland fisheries, emphasizing fishery resources protection, farmers' legal rights, and boosting overall fish production (Liu, 2016).

Bangladesh enacted the ‘Foreign Private Investment (Promotion and Protection) Act’ 1980, under the MoLJPA, which plays a vital role in encouraging investment in hatcheries, feed industries, and fish processing plants. The act safeguards protection against expropriation, guarantees non-discrimination between foreign and national investors, and allows repatriation of profits. However, to attract greater investment in sustainable aquaculture, Bangladesh must solidify taxation and trade policies, ensure consistency in tariffs, avoid foreign exchange restrictions, and reduce unnecessary trade union involvement.

Despite these legal instruments, policy implementation in aquaculture remains plagued by fragmentation, weak coordination, and gaps in enforcement. The divergence between policy objectives and practical implementation underpins persistent regulatory weaknesses in shrimp/prawn aquaculture, the country's primary export sector. Many shrimp/prawn farms have low compliance with “Good Aquaculture Practice” criteria, especially regarding chemical and antibiotic use, post-harvest handling, and water quality monitoring. Documented issues include adulteration in supply chains, weak traceability, and occasional rejection of export consignments due to non-compliance (Islam et al., 2022). Although multiple actors are engaged, governance frameworks lack robust mechanisms for sustainable coastal management. These frameworks are often exclusive, inequitable, and unjust in design and implementation (Saha & Masud-All-Kamal, 2023). While they generate profits for producers and investors, they largely ignore issues such as exploitation, dispossession, human rights violations, and environmental degradation. Local civil administrations frequently favor politically and financially powerful groups, further exposing coastal communities to socioecological risks. Consequently, these policy gaps undermine the adaptive capacity of coastal residents to cope with climatic and anthropogenic stresses, particularly in vulnerable low-lying and island regions (Saha & Masud-All-Kamal, 2023).

To address these challenges, Bangladesh needs to update the NFP 1998 and develop a comprehensive master policy package that promotes sustainable aquaculture, economic prosperity, and environmental responsibility. However, such a framework alone is not a panacea for ensuring effective governance. Local power politics, the influence of political elites, and bureaucratic barriers often hinder successful policy implementation in the fisheries and aquaculture sector (Adnan, 2013; Saha & Masud-All-Kamal, 2023). Therefore, while a comprehensive policy package provides a necessary foundation, it must be complemented by institutional reforms and accountability mechanisms to mitigate these socio-political constraints and ensure equitable and sustainable sectoral growth.

4. Conclusion and recommendations

Effective aquaculture governance plays a pivotal role in managing risks associated with profitability, environmental impact, and societal acceptance, leading to industry sustainability. Bangladesh lacks a comprehensive governance package for the development and sustainability of the aquaculture sector, relying instead on sporadic rules and complex regulations that have not yielded clear goals. In contrast, aquaculture-producing countries in the global south, such as Vietnam, China, and Thailand, have initiated efforts to improve aquaculture governance to enhance the reputation of their aquaculture products and expand their seafood trade in both existing and new markets (Sun & van der Ven, 2020). They also reported that the Vietnamese government launched VietGAP to address various concerns and ensure safe, sustainable aquaculture practices, supporting compliance through robust

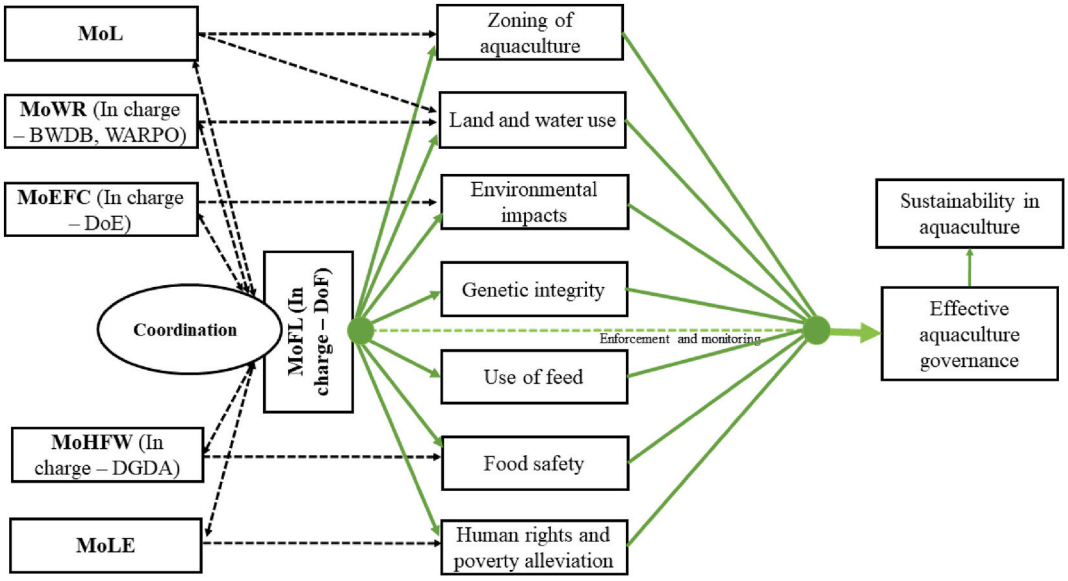

Fig. 2. Diagram showing the effective aquaculture governance systems for adopting responsible aquaculture.

policies, funding, training, and certification subsidies. The Chinese government launched ChinaGAP to enhance food quality, build consumer trust, and promote the export of aquaculture products. The DoF of Thailand issued a code of conduct for sustainable aquaculture to upgrade fish farming, such as shrimp farming, to meet international standards. It also established a clear standard for Good Aquaculture Practice (GAP) to regulate hygiene and drug use at farms and hatcheries, and created a comprehensive national network to introduce these standards to farmers, provide training, and conduct monitoring. Given the aforementioned conditions and the primary responsibility of Bangladesh's DoF, it can lead the development of a comprehensive platform for effective aquaculture governance that harmonizes intra- and inter-ministerial contributions, aligning them with existing laws and policies (Fig. 2). Based on the discrepancies identified between existing Bangladeshi laws and international aquaculture standards, the government should formulate transparent and consistent policies to enhance regulatory coherence.

To consolidate aquaculture governance, Bangladesh could introduce its own sustainability governance initiative, "BanglaGAP", similar to the GAP programs of other countries in the region. This initiative could serve as a master plan for responsible aquaculture, enabling easier adoption of certification schemes and improving market competitiveness. However, before adopting such schemes, it is essential to assess their suitability for small-scale farmers and whether they adequately address sociocultural sustainability issues such as injustice, exploitation, and inequity in local production and supply chains. Priority areas of BanglaGAP should include a comprehensive zoning plan or governance framework for land and water use to address landscape changes, water quality degradation, and ecosystem destruction. Regular farm monitoring should be emphasized despite diverse regulations from the DoF covering genetic integrity at hatcheries, feed quality, and fish health. Additionally, labor laws, primarily developed for the apparel industry, are not applied in aquaculture, need to be adopted in the aquaculture sector. These initiatives should provide technical assistance and continuous training for aquaculture farmers and relevant stakeholders through extensive networks led by the DoF.

CRediT authorship contribution statement

Md. Mehedi Alam: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Mohammad Mahfujul Haque:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Data availability statement

The data presented in this study are available on request from the corresponding author.

Ethics approval

Not applicable.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this manuscript, the authors used ChatGPT to enhance the clarity and readability of the text. The tool was applied only for language editing and did not generate or modify the scientific content. All AI-assisted outputs were carefully reviewed and revised by the authors, who take full responsibility for the accuracy and integrity of the final manuscript.

Declaration of competing interest

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

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Appendix A. Supplementary data

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