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Livestock and aquaculture farming in Bangladesh: Current and future challenges and opportunities

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Abstract: We conducted a comprehensive review of livestock farming in Bangladesh to unveil current challenges and potential opportunities in this agriculture sector. Six challenges were selected as the major constraints to livestock farming in Bangladesh: climate change and natural hazards, poor veterinary care, breeding and management resources, marketing and international trade, and the SARS-CoV-2 pandemic. Solutions to these challenges (such as hazardous weather shelters, intensified surveillance of biosecurity for farms and markets, and non-government, government, and private organizations working together to educate and assist farmers) must target specific regions where the solutions would have the greatest effect.

Subjects: Agriculture; Agriculture & Environmental Sciences; Agriculture and Food

Keywords: livestock; Bangladesh; aquaculture; ruminant; fishery; cattle

1. Introduction

Global agricultural land has remained relatively constant over the past two decades, while the world population has increased (World Bank, 2021a, 2021b). In order to address the increasing demand, the global agricultural yield has increased steadily since the Green Revolution due to the improvements in agricultural efficiency (FAO, 2017). Average annual growth rates for global agricultural output increased from 2.23% in 1981–1990 to 2.68% in 2001–2010; however, this increase in productivity was impeded by a declining growth rate of 2.08% in 2011–2019

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(Alexandratos & Bruinsma, 2012; Fuglie et al., 2021). Therefore, active interventions (e.g., increasing access to infrastructure and taking steps to mitigate the negative effects of climate change) are required to improve future yield growth as a significant expansion of new lands for agricultural production is unlikely (Alexandratos & Bruinsma, 2012; M. Z. Ali et al., 2020).

Bangladesh's livestock and aquaculture production play an important role in maintaining the population's livelihoods. Bangladesh is a densely populated country, which heavily relies on these sectors to meet the growing demand for food, protein, and livelihood opportunities (B. N. Ahmed & Waibel, 2019; Alamgir et al., 2023; M. S. Islam & Hoq, 2019). Livestock production encompasses a diverse range of animals, including cattle, sheep, goats, sheep, poultry, and ducks, while aquaculture focuses on the farming of various freshwater and marine species (B. N. Ahmed & Waibel, 2019; M. Z. Ali et al., 2020; M. Bhuiyan et al., 2017). The Bangladesh livestock sector directly employs 20% and partly employs 50% of the labor force, where it contributes to 1.4% of the total gross domestic product (GDP) and 13.44% of the agricultural GDP (Salim, 2020). Though animal farming contributes to the national GDP is small, it assists residents with meeting their required essential animal protein and additional income (F. Ahmed et al., 2021). Moreover, 78.31% of total households rear livestock (BBS, 2019c). Meanwhile, the aquaculture sector is almost twice in size compared to livestock and contributes 3.52% to the national GDP and 26.37% to the total agricultural GDP (DoF, 2020). In addition, Bangladesh has a thriving aquaculture sector with the third-highest inland open-water capture production and the fifth-highest aquaculture production in the world (F. Ahmed et al., 2021). However, they face many challenges, such as poor infrastructure, disease outbreaks, climate change, and poor access to markets (B. N. Ahmed & Waibel, 2019; M. Z. Ali et al., 2020; M. Bhuiyan et al., 2017; FAO, 2014; M. S. A. Sarker et al., 2020). Moreover, Bangladesh would greatly benefit from the advancement of integrated aquaculture farming systems (B. N. Ahmed & Waibel, 2019; Al Mamun et al., 2011; FAO, 2014).

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In summary, the livestock and aquaculture sectors are critical to both feeding the population and improving economics in Bangladesh. Despite this, little attention has been paid to understanding the challenges and opportunities these agricultural sectors face. Hence, this review aims to provide potential solutions for Bangladesh to utilize against various livestock and inland aquaculture system constraints. This task was accomplished by a vigorous literature search, analysis of available livestock and aquaculture data, and integration of livestock, aquaculture, climate, and weather information through multivariate regression and clustering analysis.

2. Methodology

2.1. Systematic review

This review analyzed livestock production in Bangladesh following the PRISMA statement (Moher et al., 2010). For this study, two major scientific search engines, Google Scholar and Scopus, were

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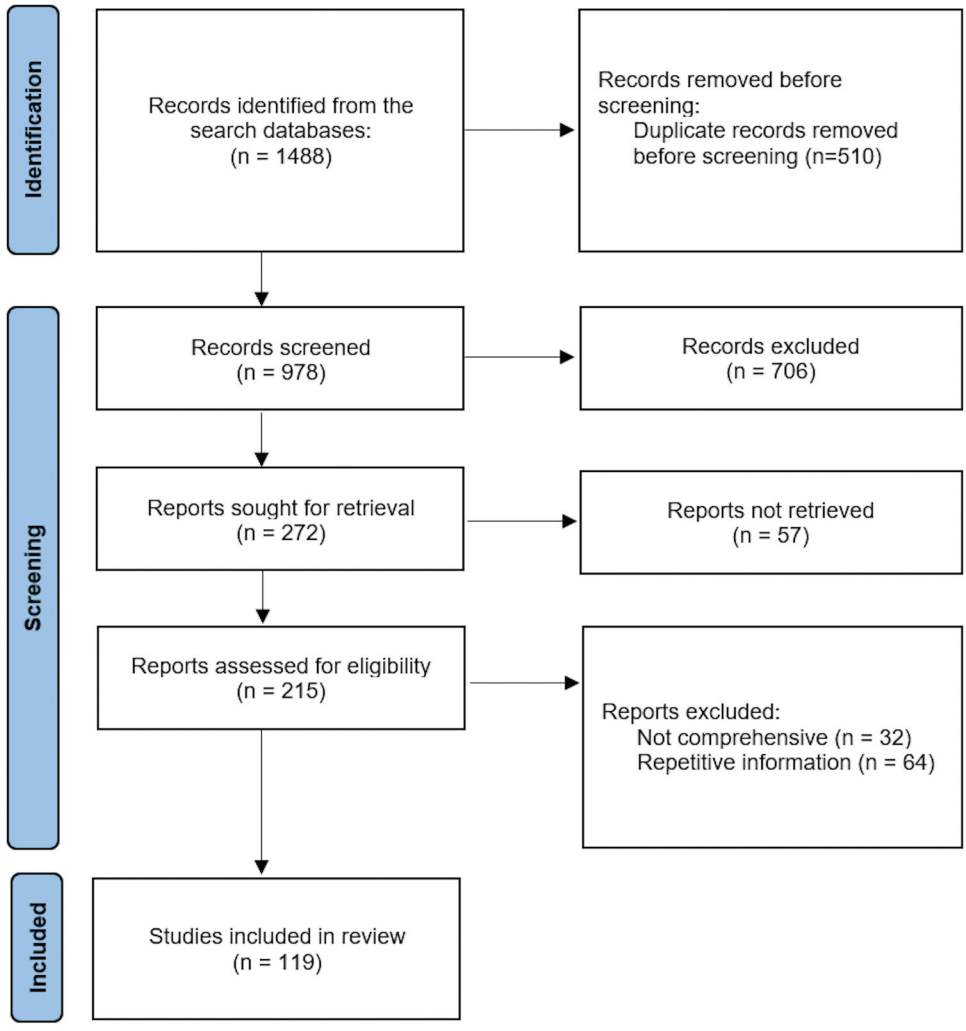

Figure 1. Schematic representation illustrating the systematic review process.

used to complete an exhaustive, comprehensive literature search. Only peer-reviewed journals and reports published in English by reputed government and non-government organizations were used to ensure the quality of the collected information. The major keywords used in this search are as follows: “Bangladesh”, “climate change”, “livestock system”, “agriculture”, “food security”, “nutritional security”, “livestock”, “cattle”, “fishery”, “aquaculture”, “poultry”, “ruminant”, “opportunity”, and “challenge.” The searches included Boolean search commands, principally AND, OR, and NOT to find applicable information and avoid duplications.

Figure 1. depicts the systematic approach taken to find relevant sources for this study. Part of the identification process eliminated duplicate records. The screening process removed articles that did not address the research questions or objectives. Next, restricted access articles were removed. Finally, the full text of all remaining manuscripts was thoroughly reviewed and, based on our criteria, were further refined where articles were deemed not comprehensive or contained repetitive information. In the end, the remaining articles are included in the systematic review. The focus of this systematic review covered the challenges and opportunities of livestock and aquaculture farming systems in Bangladesh.

The information from cited papers in the references was gathered using a cross-referencing approach. This meant that if we encountered secondary information, the original article was found

and cited through cross-referencing. This review excluded studies with non-comprehensive and repetitive information as well as inadequate sampling. A total of 103 papers were used to shape this comprehensive literature review. Finally, to better synthesize the information and prescribe appropriate interventions related to livestock and aquaculture, a set of maps was produced through geospatial analysis. This will help intervention strategies target the regions that would benefit the most.

2.1.1. Livestock and aquaculture spatial distribution in Bangladesh

There appears to be a lack of updated livestock maps in recent literature. Additionally, agroecological zone maps and agriculture maps do not consider livestock as much as crops. Since a large portion of the Bangladesh population farms livestock and aquaculture, it is critical to understand the main drivers for their spatial variabilities. There are several general livestock distribution maps, which are made with data from the Census of Agriculture 2008 published by the Bangladesh Bureau of Statistics (Huque & Khan, 2017). However, a more specific map with updated numbers from the Preliminary Report on Agriculture Census 2019 issued by the Bangladesh Bureau of Statistics with specific livestock zones would allow for better implementation of targeted strategies to improve livestock and agricultural production (BBS, 2019a).

Here, several maps are created to show the overall spatial distribution of livestock and inland aquaculture. To make the maps, livestock were divided into categories, including total bovine, small ruminant, poultry, and inland aquaculture. The maps include general livestock distribution normalized by area (Figure 2). The data used to create these figures was collected from the Government of the People's Republic of Bangladesh, the World Bank, and GIS file sources provided by the Bangladesh Agricultural Research Council (BARC). In general, it appears to be an extremely high concentration of bovine and a high concentration of small ruminants in the northwestern region of Bangladesh. Poultry has a high concentration in the center of Bangladesh. Inland aquaculture is mainly located in the center and southern regions of Bangladesh.

Multivariate regression determined which variables affect Bangladesh's livestock and aquaculture distribution. The data for each livestock type was scaled using $\log_{10}$ to prevent any livestock numbers from impacting the analysis. Variables that were tested were precipitation, mean temperature, mean elevation, drainage density, and mean poverty rating (on a scale from 1–5 for very low, low, moderate, high, very high). These were identified as potential variables that affect livestock distribution. Next, we used the number of branches on the multivariate regression tree to generate the clustering maps using ArcGIS version 10.8.1. Once the multivariate analysis determines the number of clusters, it will be used to create grouping analysis maps.

3. Results and discussion

3.1. Livestock and aquaculture clustering

The multivariate regression was run with the three livestock, one aquaculture category, and the previously listed variables (Section 2.1.1). Figures S1 to S5 present the results of these analyses. In general, the multivariate regression found total bovine is strongly correlated with drainage density, mean elevation, precipitation, and mean temperature with five distinct groups (Figure S2). Total small ruminants are moderately correlated with precipitation with two distinct groups (Figure S3). Total poultry is moderately correlated with mean poverty and mean elevation with four distinct groups (Figure S4). Total inland aquaculture is moderately correlated with mean elevation and drainage density in three distinct groups (Figure S5).

The multivariate regression found that the three livestock (Figure S1) and aquaculture categories (Figure S5) are moderately correlated with precipitation and mean elevation and have four distinct groups (Figures 2 and S6).

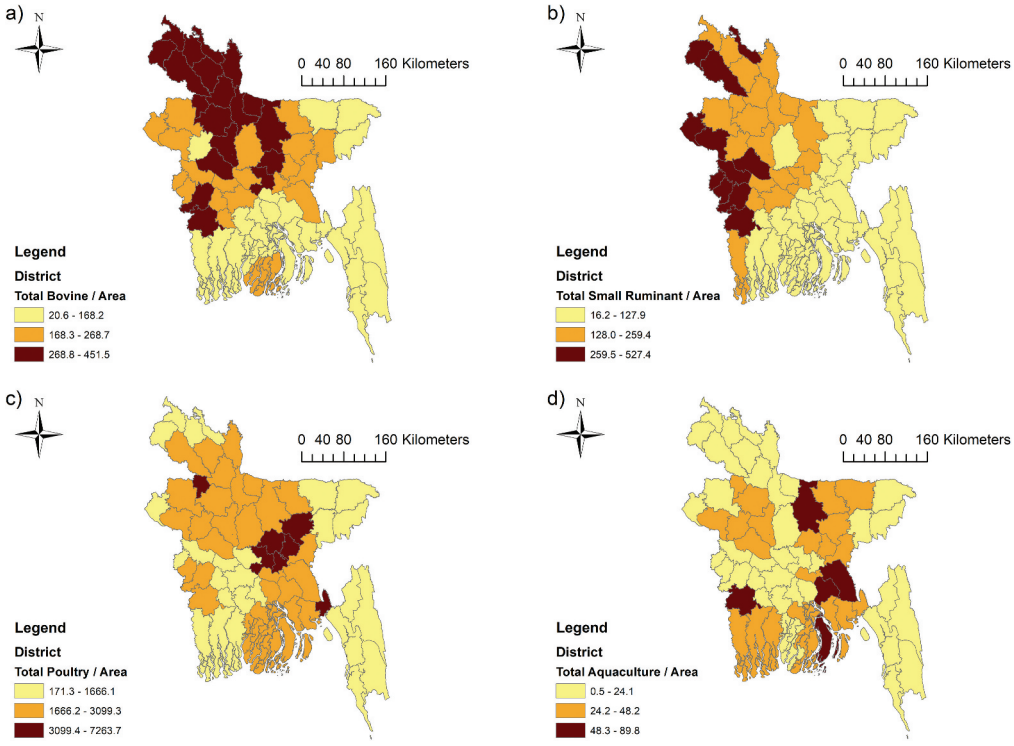

Figure 2. General livestock distribution maps are normalized by area. (a) Total bovine distribution. (b) Total small ruminant distribution. (c) Total poultry distribution. (d) Total inland aquaculture distribution.

Figure 3 is a clustering map for all three livestock and aquaculture types with regard to all considered variables. The map is defined by four clustered groups. Analysis of the clustering data compares the groups to each other. This means the numbers being compared might not necessarily be high or low on their own but are high or low based on a comparison between livestock types. The Group 1 region is characterized by low elevation and precipitation with below-average inland aquaculture production. Additionally, the group has above-average bovine, small ruminant, and poultry production. The low elevation and precipitation allow the land-based livestock to reside in high numbers. The Group 2 region has a low elevation and above-average precipitation, where it contains below-average production of small ruminants and above-average production of bovine, poultry, and inland fish. The low elevation allows for the high bovine population. The Group 3 region has significant changes in elevation in its hills found in the Chittagong Hill Tracts located in the country's southeast. The above-average elevation and precipitation contribute to the below-average production of bovine, small ruminants, poultry, and inland aquaculture. The Group 4 region contains the Sundarbans and reserved forests, which are protected mangrove forests located in the south of this region. Additionally, this region has high salinity, which negatively affects agricultural production. These two factors, as well as low precipitation and elevation, contribute to the below-average production of bovine, small ruminants, and poultry; however, there is above-average inland aquaculture production.

3.2. Bangladesh climate and cropping seasons

Bangladesh's subtropical monsoon climate has significant seasonal variations in rainfall, humidity, and temperatures (Mahmud et al., 2018). Bangladesh is composed of several climatic sub-zones, namely, tropical climate without dry season, tropical monsoon climate, and humid subtropical climate with dry winter and hot summer. Bangladesh contains 30 different agroecological zones based on physiography, season, hydrology, cropping patterns, soil types, and tidal activity (BBS,

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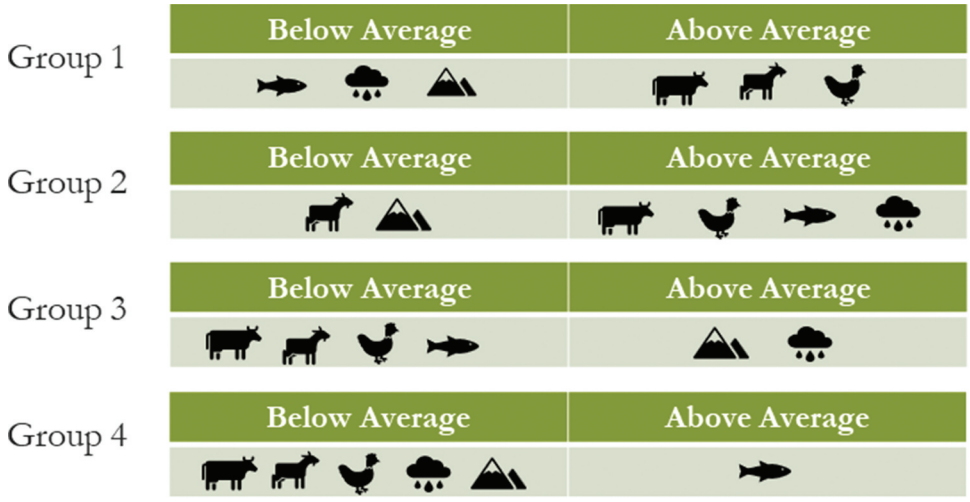

Figure 3. All cluster group's livestock quantities (based on below average or above average) and explanatory variables.

2019b). However, the elevation and regional climatic differences in the country are minimal (BRTC, 2020; Khatun et al., 2016).

Meanwhile, the country is prone to natural climate disasters and is often affected by drought, floods, cyclones, seasonal storms, heavy rainfall, landslides, riverbank erosion, and earthquakes (Amin et al., 2021; Kamruzzaman et al., 2015). Bangladesh is one of the world's most vulnerable countries to climate change's effects due to low income, geographic exposure, and reliance on climate-sensitive sectors (Sikder & Xiaoying, 2014). The level of climate change vulnerability varies greatly from region to region, with the country's coastal region being the most vulnerable (B. Paul & Rashid, 2016). Meanwhile, agriculture is one of the most important climate-sensitive sectors (BRTC, 2020). Erratic rainfall, rising temperatures, and increasing duration and severity of floods and droughts will severely impact smallholder farming communities (BRTC, 2020). The coastal areas of Bangladesh have already experienced several major challenges associated with climate change, such as rising sea levels, coastal flooding, and increased salinity (M. Z. Ali et al., 2020; Mehvar et al., 2019).

Bangladesh has three main cropping seasons: rabi or winter from October/November to February/March, pre-kharif (kharif-1) or spring or pre-monsoon from March/April to June/July and kharif (kharif-2) or aman or monsoon from June/July to September/October (Timsina et al., 2018). Rice (called boro), maize, wheat, pulses, oilseeds, and potatoes are grown during the dry rabi season (Timsina et al., 2018). Kharif-1 sees short-duration varieties of pulses, maize, and rice (called aus) (Aravindakshan et al., 2020; Timsina et al., 2018). During kharif-2, rice (called transplanted aman or T. aman) is predominantly grown under rainfed conditions (Timsina et al., 2018).

3.3. Present status of livestock and aquaculture within the farming systems in Bangladesh

M. Ali (2014) used the FAO definition of the major farming systems and further expanded upon them to describe Bangladesh's agricultural regions (M. Ali, 2014). There are four established major farming systems practiced in Bangladesh: rice, rice-wheat, coastal artisanal fishing, and highland mixed system (Dixon et al., 2001). Indigenous breeds of cattle reared in Bangladesh include North Bengal Grey, Munshiganj, Red Chittagong, Pabna, and Non-descript Deshi (M. S. A. Bhuiyan et al., 2021; Das et al., 2021). Native breeds/types of sheep include Coastal, Jamuna river basin, Barind, and Garole (G. Deb et al., 2019; Rakib et al., 2022) and indigenous breeds of goats include Black Bengal Central, Black Bengal West, Black Bengal Hilly, and Jamunapari (Periasamy et al., 2017; A. Siddiki et al., 2019). Indigenous chicken breeds include hilly, naked-neck, Aseel, and non-descript Deshi (M. S. A. Bhuiyan et al., 2013; Rashid et al., 2020).

3.3.1. Rice system

There are 17.47 million heads of bovines, which are used for meat, milk, manure, and draft power in this system. Additionally, there are a considerable amount of small ruminants in a population of 14.60 million, which are mostly raised by landless marginal farmers (M. Ali, 2014). A high poultry population of 189.23 million resides in the region surrounding Dhaka city areas, where farmers provide white meat and eggs to the city residents. Ducks are raised in the eastern haor areas and receive natural feeding (M. Ali, 2014).

The Mymensingh region, which is located in the southern foothills of the Himalayas, has favorable hydrological conditions for rice-fish farming (N. Ahmed & Garnett, 2011). Rice-fish culture systems have two classifications; the alternate system is where fish and rice are raised in rotation, and the integrated system is where they are grown together (N. Ahmed & Garnett, 2011). Integrated rice-fish farming systems can sustainably produce more rice and fish with less water and land use (A. H. M. S. Islam, 2016). Researchers have found this system to be ecologically and environmentally friendly, work as integrated pest management, improve soil fertility, optimize resource utilization, and improve diversification, productivity, intensification, and profitability (N. Ahmed & Garnett, 2011; N. Ahmed et al., 2007, 2011; Frei & Becker, 2005; A. H. M. S. Islam, 2016; Nhan et al., 2007). Despite the potential of integrated rice-fish farming, the system is not widespread in Bangladesh as it is impaired by high production costs, lack of technical knowledge of farmers, and risk posed by drought and flood (N. Ahmed & Garnett, 2011; N. Ahmed et al., 2011; A. H. M. S. Islam, 2016).

3.3.2. Rice-Wheat system

There are 6.69 million bovines used for milk, beef, manure, and draft power in this system (M. Ali, 2014). Resource-poor farmers work with a population of 7.88 million small ruminants and 47.93 million poultry for meat production, but also rely upon them as a cash income during the time of need (M. Ali, 2014).

Like many countries around the world, Bangladesh has increased market demand for maize from the livestock sector (cattle, poultry, and fish feed) and domestic and international markets such as feed, food, and fuel (M. Y. Ali et al., 2009; Gathala et al., 2015; Timsina et al., 2010). Farmers feed ruminants utilizing crop residuals and agro-industrial by-products (Ahuja, 2013). For example, farmers in the Indo-Gangetic Plains region use rice and wheat straw as cattle feed, livestock bedding, biofuel, mulching material, and thatching material for houses (Bijay-Singh et al., 2008; Chauhan et al., 2012; M. S. Hossain et al., 2016; Samra et al., 2003).

3.3.3. Coastal artisanal fishing

A bovine population of 2.65 million reside in the area, but most suffer from poor health due to the scarcity of natural grass and straw (M. Ali, 2014). The region also contains 1.46 million small ruminants and 12.61 million poultry (M. Ali, 2014). A major source of livelihood for residents, chiefly poor households, is off-farm and is made up of catching natural prawn and fish from coastal rivers, boat pulling on rent, working in shrimp gher, and working in the Sunderban forest area (M. Ali, 2014).

Gher farming is a system of farming that utilizes High Yielding Variety (HYV) Boro (dry season) rice, carp, and freshwater prawn (A. K. M. A. Rahman et al., 2020). A gher is characterized by several dikes surrounding an area that is filled with monsoon season rainwater, which resembles a typical pond (S. Rahman & Barmon, 2012). The gher system is increasing in popularity in Bangladesh as the growth rate has constantly outpaced overall Bangladesh agriculture (A. K. M. A. Rahman et al., 2020). Gher farming improves income for farmers in the area, with 97% of the produced shrimp being exported (A. K. M. A. Rahman et al., 2020;

Washim et al., 2020). On average, around 0.12 million tons of shrimp are produced annually in this farming system (M. Ali, 2014).

The coastal artisanal fishing region has a high availability of water bodies, creating the potential for increased duck farming (M. Ali, 2014). Meanwhile, ducks also have a good scope to enhance the livelihoods of farmers in northwest Bangladesh as there is an expansive foraging area available in the haor water for 6 to 7 months (M. Ali, 2014). Furthermore, proper management working with improved duck breed introduction could improve duck survivability and productivity (M. Ali, 2014).

Meanwhile, there is a deficiency of fodder crops and grazing land in the coastal regions of Bangladesh as a result of increased salinity (M. Z. Alam et al., 2017). In the southern coastal region of Bangladesh, the scarcity of quality year-round feed has led to cattle being undernourished and decreased milk, meat, and cow dung availability due to a lack of fertile soils and limited available land (N. Ahmed et al., 2010; USAID, 2021). Of the farmers in the districts Feni, Lakshmipur, and Noakhali, about a third rear cattle, 12% rear sheep, 81% rear chickens, and 63% rear ducks (Rahim et al., 2013). The average household has 2.5 cattle and 2.1 goats per household (Rahim et al., 2013).

3.3.4. Highland mixed system

The region contains about 0.41 million bovines, 0.8 million small ruminants, and 2.52 million poultry (M. Ali, 2014). The livelihood of people who live in this system can not only be described by their farming systems as the residents' culture and food habits require gathering various animals, plants, fruits, and roots which support the farmers' livelihood. However, they are difficult to measure adequately. Nevertheless, over-exploitation due to the increasing population has caused the quantity and diversity of flora and fauna to decrease swiftly, forcing people to earn more from off-farm ventures (M. Ali, 2014). The Chittagong Hill Tracts have 1% of the country's population and 9% of the area (Government of Bangladesh & FAO, 2013).

Pig rearing is common in the Chittagong Hill Tracts, where it is a crucial asset to the household (Government of Bangladesh & FAO, 2013). Cattle in this region suffer from an insufficient grazing area where the land has the potential for improved fodder production (Government of Bangladesh & FAO, 2013). The Red Chittagong is a variety of cows that are primarily found in the Chittagong district (A. Z. Siddiki et al., 2010). While the Red Chittagong cattle have a lower milk production than crossbred cows, their resistance to disease, calf production per year, and feed conversion ratio are superior (Hasanuzzaman et al., 2012).

3.4. Major constraints for livestock farming in Bangladesh

3.4.1. Climate change and natural hazards

Natural hazards such as cyclones, thunderstorms, hailstorms, floods, droughts, waterlogging, and tornados pose a great danger to livestock rearing in Bangladesh. Depending on the location of the country, damage from natural hazards can cause a loss of 2 to 46.8 million US dollars (Biswas et al., 2019). Climate change increases temperatures and causes extreme weather events to occur more frequently. Hotter temperatures and increased humid weather can have the potential impact of increased disease and vectors/parasites (whose life cycle is partly outside of the host) prevalence, which negatively affects livestock (S. N. Ahmed & Islam, 2013; Harvell et al., 2002; Karl et al., 2009; Patz et al., 2000; Rojas-Downing et al., 2017). This will make livestock more at risk of heat stress, oxidative stress, and metabolic disorders while decreasing reproductive performance, immune suppression, and mortality (M. Z. Ali et al., 2020). A study found on average, 43.7% of cattle farmers were unable to protect their animals from natural disasters, with only 6.9% of them reporting some level of success (Amin et al., 2021). Indirect health challenges exacerbated by climate change include parasitism, virulent pathogens, and vector-borne pathogens (M. Z. Ali et al., 2020). Increasing temperatures boost body metabolism while reducing feed intake, resulting in reduced

livestock growth and lower meat, milk, and egg production (Mack et al., 2013; MoEF, 2009). Meanwhile, shrimp can experience heat-related stress due to the rise in surface water temperature with a threshold of 32 degrees Celsius, where small shrimp fries exhibit very high mortality rates (A. U. Ahmed, 2006). These problems will need to be addressed with planned strategies.

Sea level rise predominantly affects the coastal areas of Bangladesh by increasing salinity levels, which will reduce feed quality and forage production area (Biswas et al., 2019; Thomas et al., 2013). Coastal embankments have an increased risk of saline water surpassing them due to stronger surges and tidal bores (A. U. Ahmed, 2006). Livestock can have negative reactions to high salinity in fodder crops, such as loss of weight, liver fluke, skin diseases, diarrhea, and the breakdown of the immune system (M. Z. Alam et al., 2017).

In Bangladesh, the northwest area is the most drought-prone in the country; therefore, remedies should be targeted in this region. Drought and periods of extreme rainfall variability can trigger extreme food scarcity with disastrous effects on livestock production (Biswas et al., 2019). Drinking water is limited during drought years and cannot meet livestock requirements (Biswas et al., 2019). Drought decreases grass growth and can dry grass in extreme conditions, thus losing its availability to livestock (Biswas et al., 2019). Dry weather reduces livestock grazing areas, leading to a decrease in animal weight gain and less milk production (Biswas et al., 2019). Drought also decreases the reproductive capacity of poultry and cattle (Habiba et al., 2013). Additionally, lack of water and poor quality drinking water increases livestock's vulnerability to diseases decreasing their economic efficiencies, such as milk production and draught power (A. U. Ahmed, 2006). During the dry season in Northwest Bangladesh, main rivers and channels dry off, making farmers rely completely on groundwater, further straining aquifers.

Floods predominantly affect the central, northeast, and charlands regions in Bangladesh, where waterlogging and flooding damage grazing land, as excess water hurts grasses in any growth stage (Biswas et al., 2019; Thomas et al., 2013). Embankment breaches from outside water easily overpass them and can wash off culture ponds and release fish to open water, which can occur during high-intensity flooding (A. U. Ahmed, 2006). Longer flood and waterlogging periods damage the livestock sector even more due to the unavailability of quality feed. Poultry production diminishes due to natural hazards, which limit scavenging areas (Biswas et al., 2019).

Cyclones' vulnerable areas of Bangladesh include the coastal area and the southwest (Thomas et al., 2013) Cyclones hit the country about every other year, which often leads to serious damage and loss of human and livestock life (Miyaji et al., 2020). Cyclones not only damage livestock populations directly but also contribute to the distribution of infectious diseases like foot and mouth disease, which is very contagious and easily transmittable by floodwaters (Karl et al., 2009; Miyaji et al., 2020).

3.4.2. Poor veterinary care

Poultry farming has several constraints that limit its potential to expand. Most of the poultry production in Bangladesh is handled by poorly supported and inexperienced residents who lack the ability to improve conditions to decrease disease risk and maneuver through volatile markets (Hennessey et al., 2021). There could be an increased risk of disease from medium and small-scale poultry production development without proper efforts taken to contend with underlying structural factors such as inadequate access to independent credit, lack of capital, and poor farmers' bargaining power (Hennessey et al., 2021). Insufficient income is also the limiting factor involved with the adoption of new technology to address these issues. Sick poultry is sold in the market to avert economic losses due to weak regulation and small profit margins (Hennessey et al., 2021; Høg et al., 2019; Zhou et al., 2009). This potentially increases disease transmission within poultry populations and between poultry and humans (Hennessey et al., 2021; Høg et al., 2019; Zhou et al., 2009). Poor

livestock production and veterinary services, which impede the proper discovering and handling of infection, have contributed to making bird flu endemic in Bangladesh (M. Islam et al., 2014).

Seasonal outbreaks in cattle occur primarily in the rainy season (76.19% of the disease outbreaks) due to poor nutritional status and the marshy environment (Simul et al., 2012). However, a separate study found cattle diseases to occur most frequently in the summer (40.45%), followed by the rainy season (34.37%) and winter season (25.19%) (M. Sarker et al., 2014). Several categories of diseases/disorders include general and systemic, reproductive and production, surgical, and infectious (M. Sarker et al., 2014). The most common diseases/disorders for the general and systemic category are fever, anorexia, weakness, and bloat; the infectious category are mastitis, foot-and-mouth disease, black quarter, and ephemeral fever; the production and reproductive category are milk fever, retained placenta, repeat breeder, and anestrous; and the surgical category are navel ill or omphalitis (M. Sarker et al., 2014). Some zoonotic diseases of the highest priority to address in Bangladesh are rabies, zoonotic influenza (including avian and swine), zoonotic tuberculosis, anthrax, brucellosis, and Nipah (Government of Bangladesh et al., 2017). There are preventative and managerial methods for each of these diseases except for Nipah, which has no licensed treatments for infection, so treatment is limited to addressing symptoms as they occur (CDC, 2020; Government of Bangladesh et al., 2017).

Pig rearing had multiple constraints in the Rangamati and Khagrachari districts (M. Hossain et al., 2011). Some of these include insufficient and low-quality feed, limitations in vaccination knowledge, and diseases such as foot-and-mouth, hemorrhagic septicemia, and anthrax (M. Hossain et al., 2011).

3.4.3. Breeding and management resources

Like other developing countries of Asia, Bangladesh has a high genetic variation in its farm animals, such as chicken, geese, duck, pigeon, buffalo, cattle, horse, sheep, goat, and pig, where a majority of the livestock are an indigenous except for about 30% cattle and 75% chicken, which are commercial and exotic cross types (Siddiky, 2018). The goat breed population is 90% Black Bengal, and the Native Bengal species holds the largest portion of sheep in Bangladesh (A. K. M. Rahman et al., 2021). The indigenous breeds have substantial adaptability to poor nutrition, light or no care management system, the harsh climate, and resistance to domestic parasites and diseases; however, the indigenous breeds have lower productivity than improved breeds of livestock utilized in the country (Siddiky, 2018). The increasing population of crossbred cattle sacrifices the indigenous cattle's genetic resources by dilution for increased milk and meat production (M. Bhuiyan et al., 2017). Improving the genetics of livestock species is a high-input, long-term, labor-intensive program, which is challenging for developing countries owing to a lack of supportive infrastructure, personnel, and institutional arrangements (M. Bhuiyan et al., 2017). The development of livestock in Bangladesh is further constrained by rudimentary science-led breeding methods, such as inappropriate breeds and limited technical knowledge (Siddiky, 2018). Small ruminant breeding is mainly performed by inferior quality bucks and rams due to continuous poor selection, which has led to decreased performance (M. Bhuiyan et al., 2017). Limiting factors of a self-sufficient breeding program in Bangladesh include lack of knowledge on indigenous genetic resource value, limited market opportunities for selling their products at a premium price, absence of a formal breed society for a particular population or breed, and inadequate/unavailable necessary support services from relevant national and local institutions (M. Bhuiyan et al., 2017). Bangladesh lacks a national breeding act or regulatory body to regulate breeding materials and services, breeding materials prices, breed imports, and breed quality and merits (Siddiky, 2018). The existing Bangladeshi breeding services (including artificial insemination) for cattle, goats, and buffalos have made it such that farmers either do not know or do not fully understand the quality of the semen provided by

breeding service providers (Siddiky, 2018). Coastal fishing resources are threatened by overfishing, morphological changes in the estuary, conservation regulations being poorly enforced, and increasing pollution in the coastal waters (B. Paul & Rashid, 2016).

3.4.4. Marketing and international trade

Urbanization leads to increased demand for milk, meat, and eggs which means that processing plants and marketing systems must keep up (B. Paul & Rashid, 2016). Unfortunately, rural farmers cannot access organized marketing linkage, so they sell their products in the local market (B. Paul & Rashid, 2016). Meanwhile, urbanization, industrialization, population growth, and the expansion of aquaculture, agricultural, and recreational activities have all contributed to intensified competition for coastal land (B. Paul & Rashid, 2016). Bangladesh has land use zoning regulations for its coastal land; however, they are not strictly enforced (B. Paul & Rashid, 2016). Powerful elite groups have been acquiring land, and poor governance and public corruption deny landless farmers and agricultural laborers from being allocated land. The shrimp sector is export-oriented, leading to many poor coastal residents lacking food security (B. Paul & Rashid, 2016). Border points lacking physical and clinical inspection and the informality of the cattle trade between Bangladesh and its neighbors contribute to the high probability of breakouts of foot-and-mouth disease and anthrax (M. Rahman & Bari, 2018). A study interviewed cattle rearers and found several challenges to the cattle market, such as unhygienic conditions of the marketplace, lack of place in the market, price fluctuation, high transportation costs, no market rules and regulations, no grading system of cattle, and unfair prices from dalal (N. Ahmed et al., 2010).

3.4.5. SARS-CoV-2 Pandemic

The novel coronavirus disease (COVID-19) has altered many ways of life across the globe. Bangladesh entered its first lockdown due to SARS-CoV-2 on 26 March 2021 (Shammi et al., 2021). This mitigation method placed a massive strain on livestock production and marketing in Bangladesh (M. S. Rahman & Das, 2021). An absence of labor was instigated by social distancing and restrictions on movement (M. S. Rahman & Das, 2021). Additionally, a transport ban has contributed to animal feed and other logistical supplies shortages while also limiting veterinary services. A drop in demand for fish, chicken, and eggs can be attributed to misinformation proposing that COVID-19 can be spread through chicken and eggs (Khan et al., 2021). Additionally, restaurants, dairy food outlets, and super shops have faced closures which have led to a decrease in the consumption of milk, eggs, and meat (Khan et al., 2021). The fish sector has experienced complications such as difficulty importing inputs and rising prices due to the COVID-19 pandemic (Khan et al., 2021).

3.5. Strategies and actionable ideas for improvement

3.5.1. Climate change and natural hazards

Bangladesh is extremely vulnerable to its own variable weather, which is exacerbated by the effects of climate change, with extreme weather conditions occurring more frequently and causing more damage. Potential mitigation techniques to reduce livestock damages from natural disasters include coastal embankments, earthen platforms, and fodder production programs (Biswas et al., 2019). The Bangladesh government has already developed and executed effective policies to proactively combat climate change with adaptation and mitigation measures for the coastal region with financial aid from the European Union and other European countries (B. Paul & Rashid, 2016). Grazing land in the coastal region of Bangladesh is either limited to certain areas or not available. Therefore, the establishment and expansion of feed mills is a viable solution while inspiring and training veterinary professionals and paraprofessionals (B. Paul & Rashid, 2016). To mitigate livestock damages from natural disasters, the livestock sector could construct shelters, establish a flood zone, popularize irrigated fodder production in drought years, ensure feed supply during floods, and establish an early warning system (Biswas et al., 2019).

To combat water scarcity in Bangladesh, farmers commonly use groundwater to cope; however, increased reliance on irrigation by groundwater is not a sustainable long-term remedy (K. Alam, 2015). Therefore, water resource management needs policy action through research and extension of drought, disease, and saline tolerant in addition to high-yielding rice and fodder varieties, low-water consuming crops, and soil and water conservation (S. N. Ahmed & Islam, 2013; K. Alam, 2015; M. Z. Ali et al., 2020). Irrigation water management can be improved through sustainable irrigation water management as it can potentially combat long-term droughts by expanding surface water irrigation and limiting groundwater infrastructure (S. N. Ahmed & Islam, 2013; K. Alam, 2015). In addition, local non-government organizations can play an important role by encouraging conservation practices, such as conservation tillage working in tandem with mulching, to decrease crop failure in dry years by enhancing soil moisture (K. Alam, 2015). Initiatives like this need cohesion between government and non-government organizations to make an effective action plan.

Anticipatory flood defense actions, such as embankments, can be preemptively built and maintained to protect crops and fodders from a harsh rainy season or deliver technical support and agricultural inputs to boost food production before a potential food crisis (S. N. Ahmed & Islam, 2013; FAO, 2021). This requires a reliable forecasting warning system and pre-agreed warning thresholds (S. N. Ahmed & Islam, 2013; FAO, 2021). Early action benefits families as they may not have to take on debt, take children out of school, sell agricultural assets, or reduce the quality and quantity of meals. When heavy monsoon rain descends upon the country, families can prepare themselves by packing food, fodder, and other essential belongings as they travel to higher ground where livestock can be placed in community livestock shelters (Ayeb-Karlsson et al., 2016; FAO, 2021).

A good method to combat cyclones is the use of shelters (S. N. Ahmed & Islam, 2013; B. Paul & Rashid, 2016). These are already in use in Bangladesh though there are an inadequate number to provide enough space for people, and only some shelters can house livestock (B. Paul & Rashid, 2016). The shelters that protect animals are called killa, which are located on elevated grounds (S. N. Ahmed & Islam, 2013; B. Paul & Rashid, 2016). Additionally, an early warning system and the construction of dykes and embankments can work as adaptation strategies (S. N. Ahmed & Islam, 2013).

Regardless of the effects of climate change, farmers in Bangladesh are not passive victims as they react and adjust to adverse climate events and changes (Delaporte & Maurel, 2018). They react by utilizing risk coping factors such as changing field location, changing the crop consumption pattern, changing the amount of land under production, seeking off-farm employment, and/or migrating to a new location (S. N. Ahmed & Islam, 2013; Delaporte & Maurel, 2018). While these actionable ideas could help agricultural workers, some constraints limit farmers' ability to utilize mitigating strategies due to lack of access to electricity and wealth, such as changing crop type and variety, changing irrigation amounts, and switching from livestock to crop production. Poor households have limited access to mitigation strategies for climate hazards, so proper wealth distribution with access to education and electricity will allow poor households to adapt to the effects of climate change (Delaporte & Maurel, 2018).

3.5.2. Poor veterinary care

Poultry farming could benefit from improved access to professional organizations/associations where medium and small-scale poultry farmers could get information on the market price of various inputs and outputs as well as poultry biosecurity and production (Akwar et al., 2018; Zhou et al., 2009). However, public education to improve awareness of bird flu and biosecurity is a long process that is anticipated not to succeed rapidly (Parvin et al., 2020). To improve poultry disease control in Bangladesh, several methods are required, such as intensified surveillance of biosecurity, trading control, and biosecurity at live bird markets, the sensible implementation of cost-effective

avian influenza vaccinations, and increasing veterinary capacity (Akwar et al., 2018; M. Z. Ali et al., 2020; Orubu et al., 2020; Parvin et al., 2020). Moreover, for all herd animals, it is important to maintain proper farm practices, strict biosecurity, and health management (M. Z. Ali et al., 2020). Foot-and-mouth disease is endemic in Bangladesh and primarily affects cattle and buffalo, with the disease morbidity affecting 36% of cattle, 23.3% of buffaloes, and 4.8% of sheep/goats (Mostary et al., 2018). To combat the virus, buffalo and cattle should be vaccinated before other species, such as goats, sheep, and pigs (A. K. M. A. Rahman et al., 2020).

3.5.3. Lack of technical expertise

Farmers make adaptation decisions based on their household's farm and socioeconomic characteristics, infrastructure access, institutional setting, and perception of extreme climate events (K. Alam, 2015). To target the farmer's adaptive capacity, non-government, government, and private organizations must coordinate and improve farmer access to education, electricity, land tenure, institutions, and infrastructure resources (K. Alam, 2015). Adopting and intensifying the semi-intensive method of coastal artisanal fishing could double cultivation production and generate more employment opportunities. However, as culture intensity increases, so too does the required capital and risk, which makes it difficult for small-scale producers to adopt these techniques. Meanwhile, off-farm activities maintain a key role in supplementing farmers, especially smallholder, marginal, and landless farmers, as a big portion of their income needs to come from off-the-farm to significantly reduce poverty (M. Ali, 2014).

3.5.4. Breeding and management resources

Breeding program sustainability mainly depends on farmers' willingness to work according to planned objectives (M. Bhuiyan et al., 2017). Community-based breeding programs have been revealed to be a viable and sustainable approach to the conservation and simultaneous genetic improvement of indigenous livestock for smallholder farmers (M. Bhuiyan et al., 2017). To preserve the sustainability of breeding programs, it is necessary to form farmers' organizations and support services from research institutes, the government livestock development office, agribusiness agents, and cooperatives, as well as the long-term commitment of farmers' participation (M. Bhuiyan et al., 2017). Bangladesh has several good native livestock breeds, which can be developed into high-yielding breeds with the help of a systematic pure breeding program (Amin et al., 2021; Government of Bangladesh et al., 2017). Most livestock breeds are indigenous and are reared in the traditional subsistence mixed farming systems, while a small proportion of the poultry and cattle industry is run commercially. Therefore, future efforts should target developing and preserving local potential breeds. To overcome the inferior ruminant quality breeding challenge, the Bangladesh Livestock Research Institute has established goat and sheep farms to distribute quality bucks and rams to community farms. However, this contribution is not impacting a large population (M. Bhuiyan et al., 2017).

Pig rearing in the Chittagong Hill Tracts could benefit from developing good indigenous species, establishing a breeding program to achieve adequate stock, and utilizing scientific husbandry such as improved feed management (Government of Bangladesh & FAO, 2013).

Currently, there is a goal to improve the performance of local chicken breeds in Bangladesh (Besbes, 2009). Programs such as this should focus on specific attributes of indigenous/local breeds to enhance the productivity of the animals when raised under village conditions (Besbes, 2009).

Aquaculture production in the coastal region could be improved by increasing pond culture productivity and expanding cage/pen culture, which will employ coastal residents. Coastal aquaculture production could also benefit from the establishment of fish and shrimp processing and preservation plants, modern fish hatcheries, and aiding positive environmental, high-quality fish-drying plants (B. Paul & Rashid, 2016).

3.5.5. Marketing and international trade

Integrated shrimp-rice farming is more sustainable than exclusively shrimp farming (B. Paul & Rashid, 2016). Therefore, the integration of rice and shrimp would not only be better for the environment than just shrimp farming but would also increase food security, create employment opportunities for the poor, and improve human welfare (B. Paul & Rashid, 2016). Meanwhile, shrimp yield can improve by changing current management practices and the enforcement of land zoning (B. Paul & Rashid, 2016). Shrimp farming has the potential to massively increase smallholder income and/or provide an opportunity for well-paid employment at large operations (M. S. Hossain et al., 2013). However, a study found shrimp farming had no significant association with poverty even though shrimp farming has the potential to improve the livelihood of the poor and marginalized in the delta area (Johnson et al., 2016). This absence of association could be attributed to larger and more profitable farms owned by external investors, which creates fewer economic benefits for local farmers and residents (A. K. Deb, 1998; Ito, 2002; Johnson et al., 2016; B. G. Paul & Vogl, 2011). These results raise the possibility of high profits driving saline shrimp farming and only being branded as adaption while neglecting the needs of the poorest in Bangladesh (Johnson et al., 2016). Crab farming in the coastal artisanal region has the potential for expansion as there are located in saline and water-logged areas, which provide profitable livelihoods with low investment and high demand in Dhaka and/or exports abroad (M. Alam et al., 2013; M. Ali, 2014; Sutradhar et al., 2015).

A study interviewed cattle rearers in Bangladesh to find what they thought were problems and potential solutions to their marketing of livestock (N. Ahmed et al., 2010). The cattle rearers chose several marketing solutions to improve the cattle market, such as improvements to market facilities, checking price fluctuations, government legislation on market price, and management of proper capital (N. Ahmed et al., 2010).

3.5.6. SARS-CoV-2 Pandemic

To combat the emerging threats to marketing channels brought on by the COVID-19 pandemic, it is necessary to support farmers to maintain the production cycle, flourishing market demand, and alternative supply chains (M. S. Rahman & Das, 2021). Milk processing farmers can take the lead in utilizing a strategic action plan for the dairy industry by increasing household consumption, investment in liquid milk processing technology adoption at the farm level, farm economic knowledge, and increased feed management efficiency to reduce milk production costs (Uddin et al., 2021). Government and non-government organizations must collaborate with industries and academic institutions to promote effective decision-making (M. S. Rahman & Das, 2021). Consequently, the Bangladesh government announced an approximately USD 589 million stimulus package to support non-crop farmers (livestock rearing, seasonal fruit and flower cultivation, poultry, fisheries, and dairy) critically affected by the COVID-19 pandemic (M. T. Islam et al., 2020).

A summary of all challenges and opportunities discussed above is presented in Table 1.

4. Conclusions

In Bangladesh, livestock farming and aquaculture are critical for the economy, farmer livelihood, and food and nutritional security. The sector provides direct employment for 20% of the population and indirect employment for 50% of the population. Major challenges to livestock farming in Bangladesh include weather variability, lack of available arable land, and poor veterinary care. Moreover, Bangladesh is one of the most at-risk countries for the effects of climate change, where low income, geographic exposure, and reliance on climate-sensitive sectors exacerbate the effects of climate change. The country is prone to floods, droughts, and cyclones, which have become more frequent and intense in recent years. The livestock sector is climate-sensitive and will be heavily affected by climate change. Bangladesh can utilize a plethora of options to combat the challenges it faces, such as expanding access to infrastructure and educating farmers on techniques to help with mitigating weather damage, as well as breeding, marketing, and veterinary care. Government, non-government, and private organizations must coordinate to improve the livelihood of livestock farmers through suggested potential interventions. These intervention methods must target regions where they will have the most significant impact.

Table 1. Potential interventions to challenges facing livestock and aquaculture farming in Bangladesh

Challenge	Sub-Category of Challenge	Interventions for Improvement	Reference
Climate change and natural hazards	General	Wealth distribution.	(Delaporte & Maurel, 2018)
		Increase in access to education.	(Younus et al., 2018; Delaporte & Maurel, 2018)
		Increase in access to electricity.	(Younus et al., 2018; Delaporte & Maurel, 2018)
		Coping factors such as changing field location, changing crop consumption patterns, changing the amount of land under production, seeking off-farm employment, and/or migrating to a new location.	(S. N. Ahmed & Islam, 2013; Delaporte & Maurel, 2018)
	Drought and Water Scarcity	Policy action through research and extension of high yielding, saline-tolerance, and saline tolerant rice and fodder varieties, low-water consuming crops, and soil and water conservation	(S. N. Ahmed & Islam, 2013; K. Alam, 2015; M. Z. Ali et al., 2020)
		Expansion of irrigation water management techniques (increased surface water irrigation and limited groundwater infrastructure).	(S. N. Ahmed & Islam, 2013; K. Alam, 2015)
		Conservation tillage and mulching.	(K. Alam, 2015)
		Effective planning between government and non-government organizations.	(K. Alam, 2015; Ayeb-Karlsson et al., 2016; Younus et al., 2018)
		Popularize irrigated fodder production in drought years.	(Biswas et al., 2019)
	Flood	Build and maintain anticipatory flood defenses (such as embankments.	(S. N. Ahmed & Islam, 2013; FAO, 2021)
		Reliable forecasting, warning system, and pre-agreed warning thresholds.	(S. N. Ahmed & Islam, 2013; FAO, 2021)
		Early preparatory and anticipatory actions such as packing food, fodder, and other essential belongings, traveling to higher ground and placing livestock in shelters.	(Ayeb-Karlsson et al., 2016; FAO, 2021)
		Establish a flood zone.	(Biswas et al., 2019)
	Cyclone	Increase number of cyclone shelters.	(S. N. Ahmed & Islam, 2013; Biswas et al., 2019; B. Paul & Rashid, 2016)
		Early warning system.	(S. N. Ahmed & Islam, 2013; Biswas et al., 2019; B. Paul & Rashid, 2016)
		Construction of dykes and embankments.	(S. N. Ahmed & Islam, 2013; Biswas et al., 2019; B. Paul & Rashid, 2016)

(*Continued*)

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Table 1. (*Continued*)

Challenge	Sub-Category of Challenge	Interventions for Improvement	Reference
Poor veterinary care	General	Intensified surveillance of biosecurity.	(M. Z. Ali et al., 2020)
	Poultry	Increase in access to professional organizations/associations that provide information on market prices of inputs and outputs and poultry production and biosecurity.	(Hennessey et al., 2021; Orubu et al., 2020)
		Intensified surveillance of biosecurity.	(M. Z. Ali et al., 2020; Parvin et al., 2020; Orubu et al., 2018)
		Tightening of trading control and biosecurity at live bird markets.	(Akwar et al., 2018; Parvin et al., 2020; Orubu et al., 2018)
		Sensible implementation of cost-effective avian influenza vaccinations.	(M. Islam et al., 2014; Parvin et al., 2020)
		Increase in veterinary capacity.	(M. Islam et al., 2014; Parvin et al., 2020)
		Public education to improve awareness of bird flu.	(M. Islam et al., 2014; Parvin et al., 2020; Orubu et al., 2018)
	Ruminant	Foot-and-mouth disease vaccinations should be given to buffalo, cattle, goats, sheep, and pigs.	(A. K. M. A. Rahman et al., 2020)
Lack of technical experience	General	Non-government, government, and private organizations must increase access to and knowledge of education.	(K. Alam, 2015; Delaporte & Maurel, 2018; Younus et al., 2018)
		Non-government, government, and private organizations must increase access to and knowledge of electricity.	(K. Alam, 2015)
		Non-government, government, and private organizations must increase access to and knowledge of awareness of climate variability.	(K. Alam, 2015)
		Non-government, government, and private organizations must increase access to and knowledge of tenure status.	(K. Alam, 2015)
		Non-government, government and private organizations must increase access to and knowledge of institutions and infrastructure.	(K. Alam, 2015)
		Adoption and intensification of the semi-intensive method of coastal artisanal fishing.	(M. Ali, 2014)

(*Continued*)

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Table 1. (*Continued*)

Challenge	Sub-Category of Challenge	Interventions for Improvement	Reference
Breeding and	management practices	General	Community-based breeding programs.
	(Bhuiyan, 2017)		
	Formation of farmers' organization and supporting services from research institutes, the government livestock development office, agribusiness agents, cooperatives, and farmer's participation.		(Bhuiyan, 2014)
	Development of promising native livestock breeds through systemic pure breeding programs.	(M. Z. Ali et al., 2020; Siddiky, 2018)	
	Small Ruminant	Bangladesh Livestock Research Institute has distributed quality bucks and rams to community farms.	(Bhuiyan, 2014)
	Aquaculture	Improvement of pond culture productivity and expanding cage/pen culture in the coastal region.	(B. Paul & Rashid, 2016)
		Establishment of fish and shrimp processing and preservation plants, modern fish hatcheries, and supporting positive environmental, high-quality fish drying plants.	(B. Paul & Rashid, 2016)
	Pig	Development of good indigenous species.	(Government of Bangladesh & FAO, 2013)
		Establishment of a breeding program.	(Government of Bangladesh & FAO, 2013)
		Utilize scientific husbandry (improved feed management).	(Government of Bangladesh & FAO, 2013)
Poultry	A focused breeding program of indigenous/ local breeds.	(Besbes, 2009)	

(*Continued*)

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Table 1. (*Continued*)

Challenge	Sub-Category of Challenge	Interventions for Improvement	Reference
Marketing and	international trade	Aquaculture	Integration of shrimp and rice farming to increase job opportunities.
	(B. Paul & Rashid, 2016)		
	Enforcement of land zoning and changing current management practices.		(B. Paul & Rashid, 2016)
	Expansion of crab farming due to export market.	(M. Alam et al., 2013; M. Ali, 2014; Sutradhar et al., 2015)	
	Cattle	Improvement of market facilities.	(N. Ahmed et al., 2010)
		Check price fluctuations.	(N. Ahmed et al., 2010)
		Government legislation of market price.	(N. Ahmed et al., 2010)
		Management of proper capital.	(N. Ahmed et al., 2010)
SARS-CoV-2 Pandemic	General	Support of farmers to maintain the production cycle, flourishing market demand, and alternative supply chains.	(M. S. Rahman & Das, 2021)
		Collaboration of government and non-government organizations with industries and academic institutions to promote effective decision-making.	(M. S. Rahman & Das, 2021)
		Bangladesh government announced a USD $589 million stimulus package to support non-crop farmers critically affected by the COVID-19 pandemic.	(M. T. Islam et al., 2020)
	Dairy Farming	Increase household consumption.	(Uddin et al., 2021)
		Increase investment and adoption of liquid milk processing technology at the farm level.	(Uddin et al., 2021)
		Increase farm economic knowledge.	(Uddin et al., 2021)
		Increase feed management efficiency.	(Uddin et al., 2021)

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For example, bovine-specific solutions should be implemented in the regions where the most cattle could benefit. The livestock maps provided in this report can be used in tandem with the recommended intervention methods outlined in Table S1 to best improve livestock farming in Bangladesh.

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