Food Systems in the Bangladesh Delta

Overview of food systems in Bangladesh with a focus on the coastal south west

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Delta's, waar land en water samenkomen, zijn altijd al aantrekkelijke plaatsen geweest om te leven. Ze bieden goede omstandigheden voor landbouw met gemakkelijk toegankelijke transportmogelijkheden over water. Dit is ook zo in de Bangladesh delta: de delta is een belangrijke bron voor voedsel in de regio. Echter, vanwege toegenomen ontwikkelings- en klimaat gerelateerde risico's zoals overstromingen, cyclonen, droogte- en hittestress en zoutintrusie zijn delta's ook in toenemende mate kwetsbare gebieden. Levens van mensen en vee en de productiviteit van de landbouw en aquacultuur worden hierdoor bedreigd. Door veranderingen in zeespiegelstijging, temperatuur en neerslag, verzilting, waterkwaliteitsproblemen, droogte en overstroming, bevolkingsdruk en verstedelijking, staat de landbouwproductie onder druk. Andere factoren die voedselzekerheid bedreigen zijn onder- en overgewicht, en ook voedselveiligheid is een bron van zorg vanwege beperkte handhaving van regelgeving terwijl er wel chemicaliën in de landbouw worden gebruikt. In het zuidwesten van Bangladesh is verzilting van zowel bodem als water een bijzonder aandachtspunt, wat de voedselproductie van de regio ernstig bedreigd.
De vraag is hoe hier mee om te gaan, nu en in de toekomst. Er zijn, naast voldoende voedsel produceren, nog drie doelen: 1. inkomensmogelijkheden voor boeren veilig stellen, 2. gezond voedsel produceren, terwijl vanwege een toenemende stedelijke bevolking de verwachting is dat de vraag naar eiwitten zal toenemen terwijl het landbouwareaal zal afnemen; en 3. tegelijkertijd milieuvervuiling en klimaatverandering het hoofd bieden. In het onderzoek wordt hiervoor een voedselsysteemanalyse gedaan, die in dit rapport wordt beschreven, met nadruk op de zuidwestelijke delta van Bangladesh. Een start wordt gemaakt met de beschrijving van mogelijke veranderpaden richting de toekomst. Er wordt gekeken naar 1. De combinatie mangrove en garnalen; 2. Verbeterd land- en waterbeheer; 3. Aanpassing van veeteelt aan klimaatverandering, inclusief verzilting; en 4. Veranderend gedrag bij boeren. Het onderzoek over veranderpaden staat nog in de kinderschoenen, en vervolgonderzoek met betrokkenen biedt daarom veel perspectief.

Deltas, as areas with both land and water, have always been attractive places to live because they offer good conditions for agriculture, and because navigation was for a long time important for transport. These reasons apply also to the Bangladesh delta, the most important food system for the region. However, the food production system is experiencing (increasing) pressures that threaten food security. The Bangladesh delta has become more vulnerable to development and risks related to climate change, including floods, cyclones, drought, heat stress and salinity intrusion, threatening humans and livestock and reducing agricultural and aquacultural potential. Due to changes in the area of sea level rise, temperature and precipitation changes, salinisation, water quality problems, drying out and flooding, population pressure and urbanisation, agricultural production is becoming more uncertain. Other threats to food security are the prevalence of both stunting and obesity, while food safety standards are rather low due to the usage of (agro) chemicals during or after harvest. A main concern specifically observed in southwestern Bangladesh is the salinisation of water and soil, which threatens the entire food production system of the region. The question is how to deal with this in the future in order to ensure the livelihoods of farmers and to ensure that sufficient, safe and nutritious food is available for the growing and increasingly urban population, while at the same time ensuring that, as protein demand increases and agricultural land decreases, the environment is not compromised and climate change is suitably addressed. This report provides an analysis of the food system in Bangladesh, with an emphasis on the southwestern delta, and, after that, begins by describing possible transition pathways. The pathways explored are i) focus on mangroves in combination with shrimp cultivation; ii) improved water and soil management; iii) climate adaptive livestock management (also linked to salinity), iv) change in farmer behaviour. This is an innovative and interdisciplinary approach still to be developed further; therefore, transition pathways should be further assessed, with the involvement of various stakeholders.

Keywords: Bangladesh, food system, sustainability, water, salinity, livestock, mangrove, transition

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Preface

The strategic research programme 'Food security and water value' (KB35) of Wageningen Research aims to contribute to ending hunger (SDG 2 'Zero Hunger') by combining interdisciplinary agro-food and water to shape the transition to sustainable food systems. The programme works on strategic research, laying the foundation for knowledge that will be relevant to policymakers and industrial partners in the Netherlands and abroad. One of the thematic areas under this programme is the theme 'Deltas under Pressure', which aims to contribute to the development, design and implementation of transition pathways towards sustainable and climate-smart food systems in deltas by combining forces in the agro-food and water domains, taking a production and producer-oriented starting point. Part of this 'Deltas under Pressure' programme, and the subject of this report is to gain more information about delta food systems by looking at food systems in Bangladesh as a whole and focus on the southwestern coastal region of the Bangladesh delta, as local specific issues may be different from national identified priorities. In this research, Wageningen UR closely worked with Solidaridad to jointly learn about food systems at the local level and to provide scientific basis for their work.

Abbreviations

AIS	Agriculture Information Services
AMA	Associated Mangrove Aquaculture
BADC	Bangladesh Agriculture Development Corporation
BARC	Bangladesh Agriculture Research Council
BBS	Bangladesh Bureau of Statistics
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BDP2100	Bangladesh Delta Plan 2100
BWDB	Bangladesh Water Development Board
CBO	Community-Based Organisation
CC	Climate change
CGIAR	Consultative Group for International Agricultural Research
CIP	Country Investment Plan
ES	Ecosystem services
DAE	Department of Agriculture Extension
DAM	Department of Agriculture Marketing
DLS	Department of Livestock Services
DOF	Department of Fisheries
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
FD	Forest Department
FO	Farmers Organisations
FY	Food Year (from July until June)
GCF	Green Climate Fund
GDP	Gross Domestic Product
GK	Ganges-Kobadak
GoB	Government of Bangladesh
HYV	High-Yielding Variety
ICT	Information and communication technology
IUCN	International Union for Conservation of Nature
KB	Knowledge Base (Strategic Research of WUR)
MIS	Management and information system
NAEP	National Agricultural Extension Policy
NAP	National Adaptation Plan
NGO	Non-governmental Organisation
NFP	National Food Policy
NSSS	National Social Security Strategy
NTFP	Non-timber forest products
Ppt	Parts per thousand, indication of salinity
RVO	Rijksdienst voor Ondernemend Nederland (Netherlands Enterprise Agency)
SDG	Sustainable Development Goal
SLR	Sea level rise
SW	Southwest
TEV	Total economic value
UK	United Kingdom
UN	United Nations
USD	United States Dollar
WARPO	Water Resources Planning Organisation
WUR	Wageningen University & Research

Executive Summary

Deltas, as areas with both land and water, have always been attractive places to live, because they offer good conditions for, among other things, agriculture[1]. This characteristic also applies to the Bangladesh delta, which is the most important food system for the region. However, deltas have become more vulnerable to floods and salinity intrusion that are particularly aggravated by climate change, threatening the lives of humans and livestock and reducing agricultural potential. In Bangladesh, agricultural production is becoming more uncertain due to rapid changes in the area of sea level rise, temperature and precipitation changes, salinisation, water quality problems, droughts and flooding. This report studies the Bangladesh food system for the country as a whole and with a specific focus on southwestern Bangladesh, as this is a region under severe water-related stresses. The analyses of the food system provide a basis for initial steps in defining transition pathways to deal with these changes, with the aim of ensuring that food is available for the growing (urban) population, with an increased protein demand and faced with decreasing agricultural land availability.

Five main categories of food systems can be distinguished, ranging from short or basic production chains to industrialised and complex food production systems. All categories of food systems are present in Bangladesh, although food systems based on short production chains are the most dominant forms. Farmers in these systems mainly produce food for themselves and their family, with limited production for external markets.

In general, farmers produce a large variety of agricultural commodities: rice, vegetables, fruits, livestock and aquaculture products. Post-harvest losses are significant due to long transportation times and lack of cold storage and transport. The use of chemicals to preserve agricultural commodities during transport poses serious food safety risks. The natural conditions of Bangladesh provide suitable services for a thriving agricultural system with subtropical temperatures, water availability from both rain and rivers and fertile soil from sedimentation of three major rivers. However, the intensive production system causes soil depletion, thereby hampering production, and significantly reduces the natural biodiversity which is necessary to provide multiple ecosystem services for sustainable agriculture. More recently, high energy prices are affecting farmer income. The largest natural pressure on the entire food system is climate variability and climate change, which is causing floods, cyclones, droughts and salinity intrusion, and thus uncertain income. In particular, farmers in food systems with short value chains are extremely vulnerable to these changes due to lack of information and financial means to take adaptive measures. A main social pressure on food systems is the growing population and economic growth which is causing demand for more food and more inputs under already scarce circumstances. Therefore, Bangladesh's food policies are particularly focussed on optimising and maximising production to be as self-sufficient as possible. More recently, policies also focus on making the agricultural sector more sustainable and climate-resilient. Extension services are used to spread this knowledge to farmers.

There are at least four main outcomes of the current food system for Bangladesh: i) both undernutrition (stunting) and overnutrition (obesity) are commonly present in Bangladesh within particular rural and urban regions, respectively; ii) food safety is a concern in particular due to (agro) chemical usage during production and post-harvesting stages; iii) Bangladesh experiences major pressures on its food system because of salinisation of soil and water resources due to climate variability and climate change; iv) increased GDP brings about an increased intake of protein, which explains increased numbers for fish and meat consumption, and this trend may continue further.

Southwestern Bangladesh[2] is extremely vulnerable to climate change due to a combination of low elevation lands and a short distance to the sea. The region is characterised as the main agricultural area for rice and vegetables and, since the 1990s, has also been known for intensive aquaculture activities such as shrimp and

[1] Please note that the word 'agriculture' is used in the widest sense of the word, including production of cereals, vegetables, pulses and other crops, as well as livestock and aquaculture.

[2] There are many variations to indicate 'southwest' Bangladesh (south west Bangladesh, southwest Bangladesh, Southwest, Southwestern, southwestern, south-west, south-western, and perhaps a few others). All of these uses have some validity, but the authors mostly use 'southwestern' throughout the text, strictly for the sake of simplicity and consistency.

carp. Being a coastal area, mangrove-shrimp combinations are also observed. Livestock rearing is challenging due to climate stresses (heat in particular) and the lack of availability of freshwater, especially during the dry season. Sea level rise combined with reduced runoff causes salinity intrusion, which in turn causes crop stress, while shrimp and fish also (partly) rely on freshwater sources. Sedimentation further hampers drainage capacity of soils, resulting in waterlogging. Other climate change-related risks are increased heat stress, changes in rainfall pattern and reduction of freshwater availability, all of which have predominantly negative impacts on the agricultural production area as a whole. To protect the agricultural lands against flooding, the region entails many polders. However, the construction of polders in combination with reduced freshwater flow from the main rivers is causing major siltation problems that result in flooding and waterlogging and lack of clean-up of pollutants. Land use has also been changing, and a pattern towards increased urbanisation is observed. As a result of these pressures, the food system is affected as crops, fodder and livestock are not sufficiently drought and/or salt tolerant, leading to uncertain quality and quantity of products and negative consequences for food security. From an aquaculture perspective, the changes in temperature and seasonality can potentially negatively impact the growth rate, reproductive capacity, health, mortality and migration of fish and pose another risk to food security.

Potential transition pathways to address the major pressures on the food production system in Bangladesh may focus on i) mangrove restoration in combination with shrimp cultivation; ii) improved water and soil management; iii) adaptive livestock management (also addressing salinity); and iv) changing farmer behaviour. The restoration of mangroves combined with aquaculture has the potential to increase fisheries and maximise agricultural production in brackish saline environments. Research has found that increased numbers of mangroves positively impacts coastal safety and the food system as a whole. From a water and soil management perspective in Bangladesh, a promising transition path lies in rejuvenating rivers and canals to prevent clogging by water plants and siltation, while linking this local-level activity to national-level water management institutions. The path to transition is then focussing on combining national-level with field scale and is based on water storage, modern irrigation and agricultural practices that are maximising agricultural production under brackish to saline environments. Transition pathways in livestock should focus on more resilient animals through adapting genetic resources, increasing supply and capacity of veterinary services and, for more advanced livestock systems, improved animal housing to provide sufficient and good quality water and, preferably, controlled air temperatures. In all transition pathways, social aspects related to farmer behaviour should be considered in order to allow sufficient adoption of measures and innovations and to ensure institutional embedding at the national level.

More research is required to assess with stakeholders the feasibility of applying transition pathways under real-life conditions. For example, pilots could be defined which should focus on socio-economic and environmental adaptiveness potential and upscaling strategies. The latter, upscaling strategies, are required to include feasible interventions in future investment strategies in Bangladesh, e.g. in the context of BDP2100, but also for application in deltas elsewhere. Pilot interventions should also be assessed regarding the potential to contribute to Zero Hunger objectives. With such pilots and, eventually, evolving policy directions, deltas can move towards a sustainable future while contributing to SDG 2 (Zero Hunger) objectives in an integrated manner.

1 Introduction: Delta Food Systems

1.1 Food systems approach

Deltas, as areas with both land and water, have always been attractive places to live because they offer good conditions for agriculture, with high potential for handling logistical challenges, such as navigation through canals. Deltas are therefore the main food production systems for countries and encompass various food systems from basic (with short value chains) to complex (with long value chains) systems. This applies also to the Bangladesh delta, which provides livelihood and food for its 166 million inhabitants (World Bank, 2021). However, deltas have become more vulnerable to floods and salinity intrusion, threatening the lives of humans and livestock and reducing agricultural potential (Hossain et al. 2012). In Bangladesh, because of rapid changes in sea level rise (SLR), temperature and precipitation, salinisation, water quality, drying and flooding, agricultural production is becoming more uncertain (GoB, 2018). The main challenge for the future is to ensure that food is and remains available for the growing and increasingly urban population, as protein demand increases while pressure on agricultural lands and systems also increases. Thus, a transition to other sustainable food production and systems is necessary.

A sustainable food systems approach to addressing these issues has gained prominence in recent years, as discussed during the 2021 UN Food System Summit. A food systems approach aims to ‘ensure food security and nutrition for all in such a way that the economic, social and environmental bases to generate food security and nutrition of future generations are not compromised’ (HLPE, 2017). Food systems encompass all people, institutions and processes by which agricultural products are produced, processed and brought to consumers, including the internal and external drivers that impact food-related value chains. They also include the public officials, CBOs, researchers and development practitioners who design the policies, regulations, programmes and projects that shape food and agriculture (FAO, 2014a). Food systems analysis goes further than value chain and agricultural production analysis on its own. As an example, analysis of the value chain and agricultural production system is traditionally performed to answer questions regarding how to deal with the growing population. If such a question were answered through a food systems approach, attention would also be paid to other relevant issues such as dietary quality, food security, environmental constraints or socio-economic effects of the food chain itself (Béné et al. 2019). Therefore, food systems analysis provides a holistic approach which encompasses all relevant internal and external processes and leads to better-informed strategies towards more sustainable food production. For this reason, the food systems approach has been used more frequently in recent years to assess and improve food production systems.

One of the recently developed frameworks for the food system is shown in Figure 1. In the middle, the figure shows the food systems activities in the value chain, from production through marketing and processing to consumption, as well as the socio-economic and environmental driver groups that cause food systems to transform. Around it, four outcome groups are represented: 1) food security, 2) safe and healthy diets, 3) inclusiveness and equal benefits, and 4) sustainability and resilience (also including biodiversity). System transformation, deliberate or not, causes outcomes to change. An improvement in one may go at the expense of the other (trade-offs), but a transformation may also imply improvements in more than one outcome area (synergies) (Van Berkum et al. 2018).

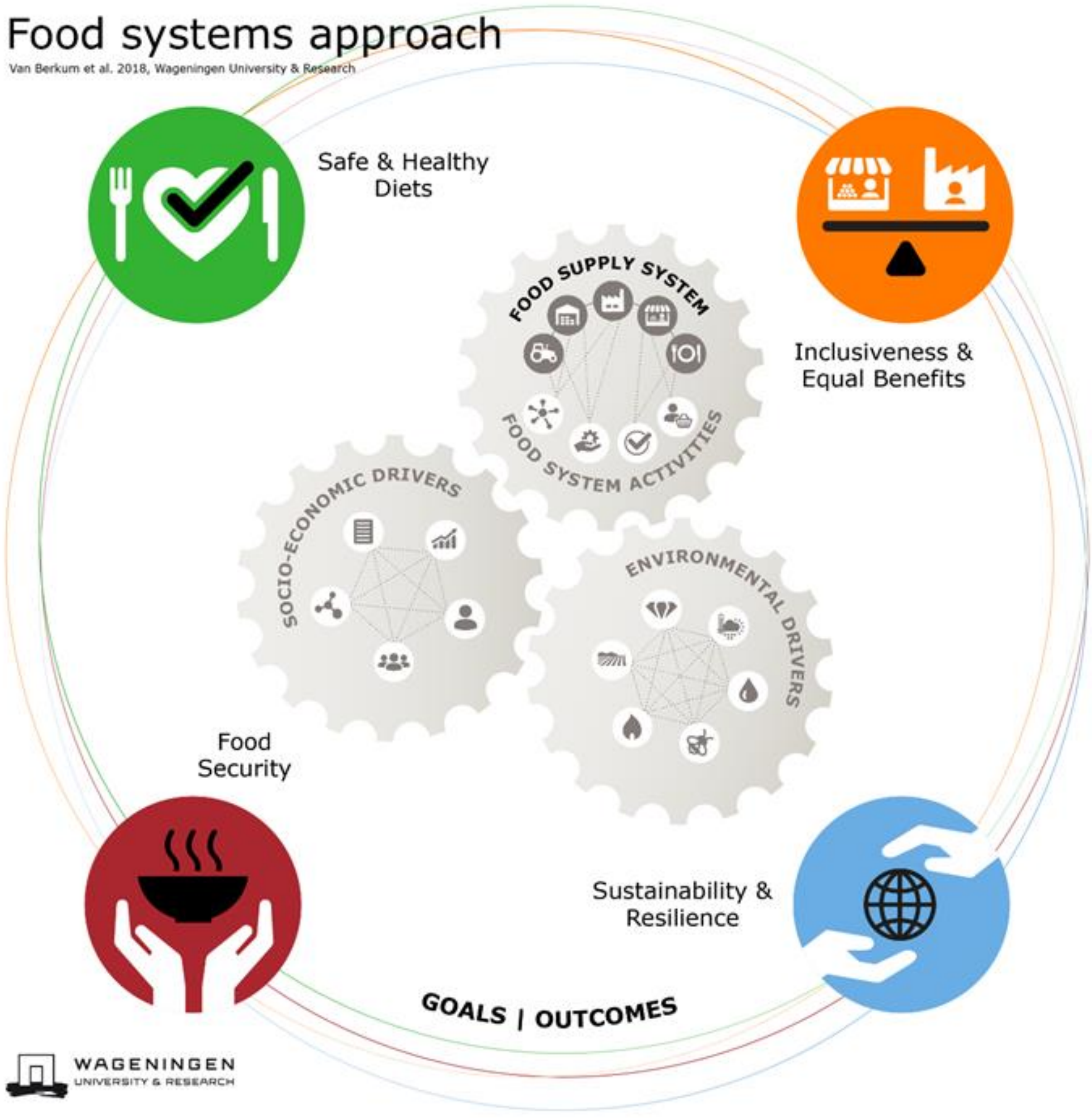

Figure 1 *Food systems approach*

Through interdisciplinary food systems research, challenges in the food system can be addressed simultaneously and in an integrated manner in order to create insight into current and future issues. Such an analysis is the basis for developing sustainable and multi-disciplinary transition pathways for agriculture in Bangladesh.

1.2 Study methodology

In this report, the food system analysis as presented above is applied to describe the main food systems and its challenges, focussing specifically on the agricultural production side and external factors that influence the agricultural production system. This is done in more general terms for Bangladesh as a whole first and then is more focussed on agricultural production in the southwestern part of the country. This region is extremely vulnerable to salinisation due to climate change induced by rising sea levels. Information regarding the description of the food production system and its main issues in Bangladesh generally and southwestern Bangladesh specifically is collected from a literature review using i) published reports and research articles and ii) available online information regarding agricultural, environmental and climate change-related policies.

Expert knowledge of authors who have worked and/or lived in Bangladesh is used to further explain the findings of the literature. Quantified data to present trends for food and agriculture-related indicators were selected from open-source databases from e.g. FAO AQUASTAT, the World Bank and National Bureau of Statistics, among many others.

The directions of the transition pathways were identified in a preliminary and exploratory way. They are (only) briefly described by multi-disciplinary experts from the research team, focussing on mangrove forests (restoration), water and soil management, environmental economics and livestock. Transition pathways have been presented descriptively to explore potentially innovative thinking routes while addressing the main food security risks. This will require further work and provides an initial basis for further feasibility assessments.

1.3 Linking with other outputs of the 'Deltas under Pressure' research programme

Research took place as part of the 'Deltas under Pressure' programme, a strategic research programme of Wageningen University and Research (WUR). In this programme, WUR worked alongside the Safal Programme of Solidaridad, with a focus on strengthening the value chain for small-holder farmers producing a.o. livestock and shrimp.

The research programme has a website (www.wur.eu/deltasunderpressure). The research results of the 'Deltas under Pressure' programme have been made accessible in a storyline available at www.wur.eu/food-in-deltas.

2 Overview: Food Systems in Bangladesh

Following the food systems approach, we first describe the elements of the food system activities in a more general way for the country as a whole, focussing specifically on main food production systems and external pressures from both environment and socio-economic perspective. Based on this analysis, main food systems outcomes are described.

2.1 Food supply system focus on production and consumption

Since its independence in 1971, Bangladesh has faced challenges in how to feed its population. At that time, about 75 million people needed to be fed, although due to war, flooding and drought, widespread hunger occurred. For this reason, the Government of Bangladesh emphasised and successfully increased all types of food production, with rice first and foremost as the staple crop of the nation. As stated in De Brauw et al. (2019), 'The national food system of Bangladesh has made substantial progress since experiencing famine in 1974, soon after independence. After the famine, the government placed a strong emphasis on policies required to attain grain self-sufficiency; since attaining self-sufficiency, the production system, policies related to it and resulting diets have begun to diversify.' Since then, Bangladesh has more than tripled food grain production,[3] and cropping intensity averages 240% throughout the country. Bangladesh is the fourth-largest aquaculture-producing country in the world, while semi-industrial poultry farming for eggs and meat has increased substantially in the past 20 years. Maize production, as a component of poultry feed, has increased from a very low level to more than 1.5 million MT per year (Alam, 2018). Threats to the food system are there as well, as production will be affected by scarcity of good quality agricultural land, the availability of sufficient water resources, the tightening of the agricultural labour market, climate variability, long-term climate change, drainage and salinity (Alam, 2018). More regarding these threats are described in later sections.

2.1.1 Overall food system characterisation

Food systems can roughly be described in five food system categories (Van Berkum et al. 2018): i) basic and rural farming by smallholders with production for their own use or locally sold in open markets; ii) informal and expanding system with formal employment and urbanisation, with basic processing and packaging on a local scale; iii) emerging and diversifying system with a number of medium/large commercial farms linked to markets; iv) modernising and formalising system focussed on large-scale farms with external inputs and year-round availability of imported food items; and v) industrialised and consolidated system with focus on large-scale, input-intensive farms that serve specialised markets. Supermarket density is high, serving most of the population with regulations on food safety and processing standards. In Bangladesh, most landholdings are small and fragmented, with 88.5% of farms having less than 1.0 hectare (ha) and these farms occupying 60% of the agricultural area; the trend is toward greater fragmentation and subdivision, and therefore smaller individual farm units (ADB, 2010). Similarly, a rising middle class (estimated at over 30 million) has fuelled demand for high-quality agricultural products and the need for imported fresh fruits, nuts, dairy products and processed food products (International Trade Administration, 2022). There is also a growing development in more advanced agricultural systems (e.g. aquaculture and livestock rearing). Within larger cities, especially in Dhaka, there is also a growing demand for imported and processed food, which is purchased from supermarkets. The supermarkets started from 2000 onwards and are growing, with 30 companies now having more than 200 outlets (Meena Bazar, Swapno, Agora, Nandan, Prince Bazar, Carre Family, Mart, Bangladesh Rifles, etc.), estimated to be 2% of food retailing, with sales growing by 15-20% according to the Bangladesh Supermarket Owners Association (Alam, 2018). Therefore, Bangladesh has multiple food systems, ranging from basic to advanced, with the vast majority of the population falling within the basic food systems with short value chains. Although the number of supermarkets in cities like Dhaka is increasing, that number still does not cover most people in the urban environment as would be the case in an industrialised food system.

[3] Food grain production refers to grain for human consumption. In Bangladesh: rice, wheat, and maize.

2.1.2 Food production system

The food system has been described by the international CGIAR research team on agriculture for nutrition and health (De Brauw et al. 2019), and they describe the enormous progress that Bangladesh has made in increasing its agricultural production: 34.9 million metric tonnes (MT) in food year (FY) 2018-2019, and 32.6 MT in 2017-2018. The rise in agricultural production can be seen in the food production index, where between 1971 and 2020 the food production index grew substantially, from 29 to 112 (KNOEMA, 2022). The main staple food production is rice, production of which increased from 14.9 million tonnes in 1971 to 54.9 million tonnes in 2020, growing at an average annual rate of 2.84% (KNOEMA, 2020).

In addition to rice, Bangladesh produces over 150 vegetable crops, with onion, garlic, tomato, brinjal, cabbage, cauliflower, gourds and chillies the most important ones. In total, over 6.5 million tonnes of vegetables are produced annually, including 1.9 million tonnes of summer vegetables, 2.5 million tonnes of winter vegetables, 1.8 million tonnes of onion and 466 thousand tonnes of garlic (RVO, 2021a). Fruits are another major agricultural product, mangoes in particular, while papaya, plums, guava and litchi are also cultivated. Fruit and vegetable production are increasing: vegetable production from 3.87 MT to 4.05 MT between 2015-16 and 2016-17 and fruits 4.76 MT to 5.02 MT between 2015-16 and 2016-17 (De Brauw et al. 2019).

Livestock production constitutes an important part of the wealth of the country, with statistics showing that approximately 2.9% of national GDP is covered by the livestock sector, growing at a rate of 5.5% per year (Banglapedia, 2021). The livestock population in Bangladesh is currently estimated at 25.7 million cattle, 0.83 million buffaloes, 14.8 million goats, 1.9 million sheep, 118.7 million chickens and 34.1 million ducks (Bangladepia, 2021). Milk production has increased from 2.95 MT in 2010-2011 to 9.41 MT in 2017-2018 (De Brauw et al. 2019).

Bangladesh is also well known for its intensive aquaculture. The country produced 4.38 million metric tonnes (MN MT) of fish in food year (FY) 2018-19[4], of which over 50% (2.49 MN MT) is cultivated in closed water bodies, and Bangladesh is the fifth-largest producer of aquaculture products. The majority of aquaculture (1.97 MN MT) is cultivated in ponds, particularly focussing on three species: carp (961 kMT), pangasius (447 kMT) and tilapia (321 kMT), which jointly account for 93% of freshwater fish production in ponds. Shrimp was originally introduced by growers in the 1960s as a response to salt intrusion into tidal estuaries. As of 2019, shrimp were the most widely cultured crustacean in Bangladesh, with a production of 125 kMT. Shrimp culture is widely practised in extensive polyculture form, resulting in a high production of fish in shrimp farms (133 kMT), and is currently Bangladesh’s most important agricultural export product (De Brauw et al. 2019; RVO, 2021b).

Food production is varied throughout the country. This has been described per agro-ecological zone, as there are 30 identified by the Bangladesh Agricultural Research Council (BARC), based on land, soil, crops and agro-climate (Brammer et al. 1988). A lot of land is multi-cropped, with two or three crops per year. Still, national production cannot yet cover the requirement for healthy diets as per the WHO guideline, and diets remain unbalanced, with an emphasis on rice consumption.

2.1.3 Food storage, processing and retail

For a large part of the population, food is grown and consumed at the same place (basic food systems with short value chains), either for own consumption or to be sold informally at local markets. In 2021, more than 101.5 million people lived in rural areas, with an annual decrease of around 0.25% (Macrotrends, 2022). In such a case, the value chain is short and not very complex. However, for the more extended food systems which include farmers who produce for regional and national markets (e.g. rice, aquaculture, livestock products), the value chain is more complex, as sorting, grading, packaging, transport and sales location are part of the system as well. This is especially the case for the urban population, which counted 64.7 million people in 2021, with an annual increase of around 3% (Macrotrends, 2022). These processes are challenging in Bangladesh, and a study by the Department of Horticulture indicates that post-harvest management is an important concern (RVO, 2021a). High temperatures, the use of basic packaging materials and (overloaded)

[4] Bangladesh makes plans using the concept of Food Years, which run from July until June.

open trucks for long-distance transport result in large post-harvest losses of fruits and vegetables, ranging from 24% to 44%, depending on the crop (RVO, 2021a). Under the Bangladeshi climate, the lack of cold transports results in a rapid degradation of cultivated crops and fish. In response, formalin or other chemicals are often used during transport of vegetables, fruits and fish to prevent degradation during transport and storage. The use of formalin in food products poses serious health risks to the population (Hoque et al. 2016). Furthermore, some regions in Bangladesh are difficult to reach through limited road and railway capacity and numerous waterways, while traffic near and within cities is affected by high-intensity use of the road network. Transport costs are therefore relatively high (RVO, 2021a). With respect to export of food items, Bangladesh mainly targets the diaspora market in the UK, Middle East and Italy. Although several crops have been identified with good export potential, such as mango, tomato, brinjal and pepper, phytosanitary standards and certification are some of the issues limiting the export to the EU. High cargo charges also contribute to a weak business case for export to overseas destinations (RVO, 2021a).

As such, value chains are mostly national, and the country has developed elaborate systems to provide food to an increasing population. Increasingly, food systems are developing in Bangladesh (increased packaging, increased production of special products, etc.), although there are still many challenges that limit the transition towards more advanced food systems. In addition, there is the challenge that changing circumstances (socio-economic and environmental) may affect the existing food systems.

2.1.4 Consumption

Consumption of food items has changed over time. Table 2 below shows how, over the last 40 years, overall food intake has increased, differentiated for rural and urban populations (Alam et al. 2018).

Table 1 *Consumption of different food items (gram/person/day)*

Food item	**Normal for balanced nutrition**	**Rural area**				**Urban area**			
		1984	**2000**	**2005**	**2010**	**1984**	**2000**	**2005**	**2010**
Rice	500	421	479	477	442	351	377	389	343
Wheat	100	65	24	12	38	79	17	28	51
Vegetable	225	140	196	218	221	179	196	228	241
Pulses	30	26	15	13	13	22	19	19	17
Fruits	50	17	26	33	43	21	27	33	50
Fish	45	29	38	40	46	39	41	50	60
Meat & egg	34	10	15	18	20	22	31	31	42
Milk	50	22	29	31	32	34	33	37	39
Total	934	741	899	986	1005	761	841	999	983

Source: BDP2100, baseline agriculture, Alam et al. 2018, Table 5.4. Please note that not all totals add up exactly; we could not identify the cause of this – the table is identically copied from BDP2100.

Consumption of rice as the major food item is slowly changing, and an increase can be observed for vegetable, fruits, fish and meat products intake. With respect to beef and chicken intake, an increase from 6.8 to 7.5 grams and 11.2 to 17.3 grams per capita per day, respectively, is observed, along with a doubling of egg intake (7.2 to 13.5 grams/capita/day) (BBS, 2017 in De Brauw et al. 2019). On the other hand, the overall daily calorie intake per capita decreased from 2308.1 kcal in 2019 to 2210.4 kcal in 2016 (BBS, 2017 in De Brauw et al. 2019). This pattern is observed in both rural and urban areas and suggests a change towards a more diverse diet. The micronutrient status shows a large prevalence of major deficiencies in, among others, vitamin A, iron, zinc and iodine (Alam, 2018).

In the future, more analysis is required to define trends in food consumption patterns. However, a first impression from Alam (2018) indicates that, at national level, it is expected that demand for rice in 2050 will increase by 56% from its base (2005); for other cereals like maize and wheat, the demand will be increased by more than tenfold, while the population is expected to increase. The demand for fish and meat will increase by 150%, and potato, which can be expected to act as a substitute for rice, will increase by more than 200%. Milk and egg consumption is expected to increase by more than 500% and 200%, respectively.

The food pattern changes over time towards more protein-rich diets (fish, eggs, meat) and will most likely increase in the future. Therefore, to remain food self-sufficient, Bangladesh will need to produce more protein-rich food items.

2.2 Environmental drivers and pressures of Bangladesh food systems

It may already be clear that, as the downstream riparian zone of three large rivers and on the side of the Bay of Bengal where frequent cyclones occur, Bangladesh as a country has a vulnerable position. The increasing impacts of climate change, combined with the scarcity of land due to the growing population, are the main environmental pressures on Bangladesh's food systems. In this section, an overview of the environmental drivers and their influence on food systems is described.

2.2.1 Land, soils & water

The soil structure and the delta are mainly formed by sediments from three major rivers: Brahmaputra, Ganges and Meghna. These enormous sediment deposits are the major source of soil formation (around 80%), while the remaining soils have been formed in the Tertiary and Quaternary sediments of the hills and in an upper terrace from the Pleistocene period (Banglapedia, 2021). By nature, Bangladeshi soils are very suitable for agricultural purposes, as they are rich in nutrients. These characteristics and flat texture make Bangladesh very suitable for agriculture. According to FAO (2022), 70.1% of land is devoted to agriculture.

The Bangladeshi soil map (see Figure 2) shows the influence of sedimentation processes, as most soils are dominated by alluvial and floodplain-related soils with high clay content. However, acid sulphate soil is also present, which is a risk to agricultural production. Different soil types also partially explain the existence of various agro-ecological zones with different production regimes.

Although soils are fertile by nature, most are depleted and in urgent need of replenishment with manure and fertilisers to enhance productivity, as it is estimated that more than 100kg of nutrients per hectare/year are leaving the soil system (Bayes, 2022).

From a water perspective, Bangladesh receives a large amount of river and groundwater from the three main rivers, with around 1,122 km^3/year. Furthermore, the country receives 2,666 mm/year or 394 km^3/year of rainwater (FAO AQUASTAT, 2019), which falls mainly during the wet season, roughly between April and September (GoB, 2018). Overall water scarcity is 2.9% (FAO AQUASTAT, 2019). However, water consumption is large, mainly due to agriculture, which consumes 80% of total water use, of which 75% is extracted from groundwater (World Bank, 2015). Approximately 5 million out of a total potential of 7 million ha of land is irrigated (De Brauw et al. 2019). The use of groundwater for irrigation is causing a sharp decline in the groundwater table and poses risks with respect to salinisation of the irrigation water. Furthermore, groundwater in Bangladesh is rich in arsenic and other pollutants, and it is unknown how much of those pollutants may reach the food system.

Overall, Bangladesh's soils provide good opportunities for high-productive agricultural systems, but they suffer from depletion. Although Bangladesh is rich in water, the large dependence on groundwater irrigation poses risks to salinisation and exposure of crops to toxic pollutants such as arsenic.

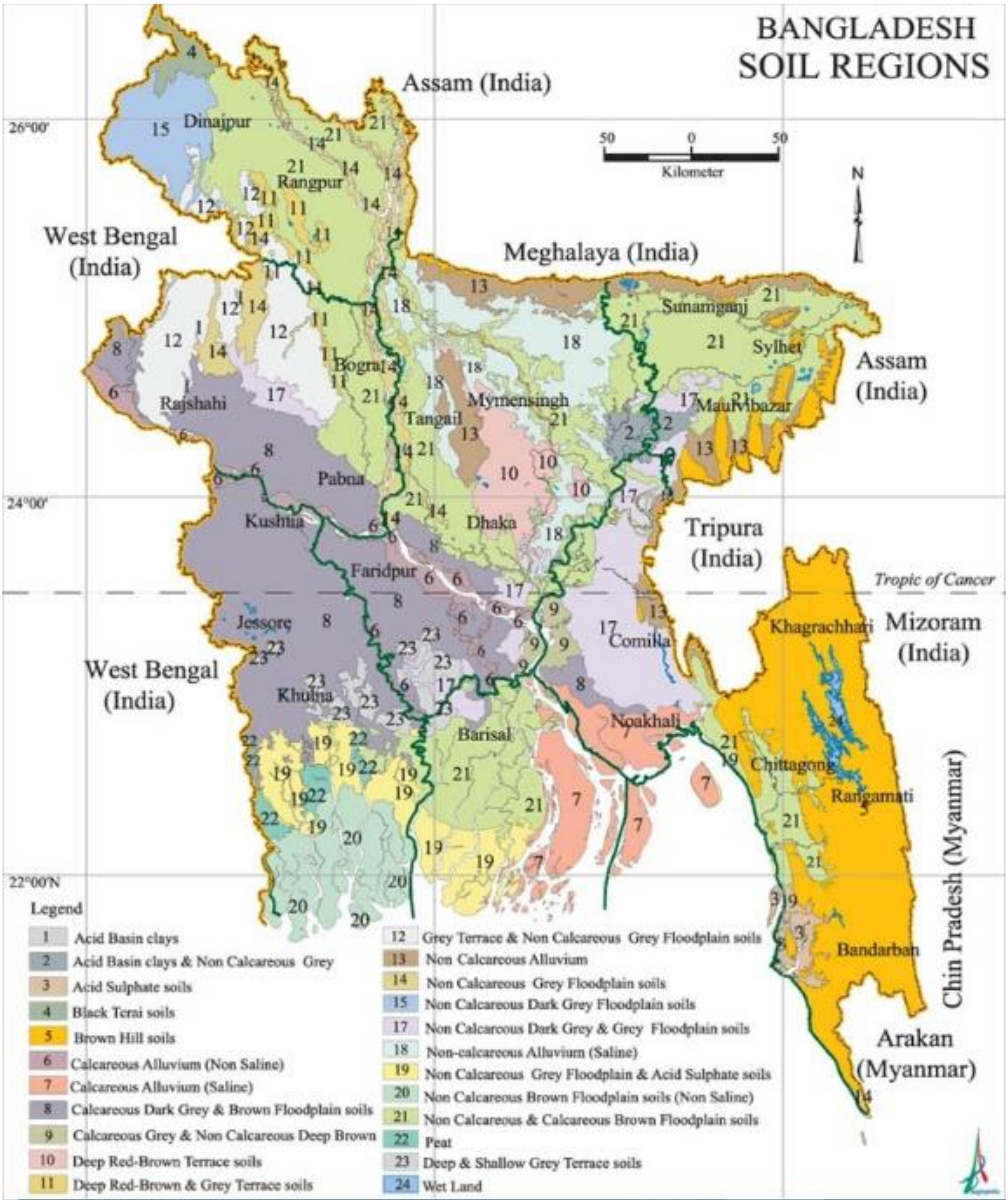

Figure 2 *Soil map of Bangladesh (Banglapedia, 2021)*

2.2.2 Biodiversity

Bangladesh's biodiversity consists mainly of agro-aquaculture and other related species, although there are still many natural species present. The country is rich in biodiversity of crops, fishes, farm animals and forest frees used for food and agriculture and has diverse species of rice, jute, legumes, pulses, oil seeds, taro, sweet potato, litchi, melon, citrus, mango, jackfruit, jamun, guava, plantain, areca nut, coconut and jujube. The animal diversity is mainly with the livestock population, with most being indigenous. Its known water bodies provide habitat for 267 species of freshwater fishes, 475 marine fishes, 24 exotic fishes and a number of other vertebrates and invertebrates. Among the documented aquatic fauna, finfish top the list, followed by crustaceans and molluscs.

Natural biodiversity is under threat in Bangladesh, and natural forests are decreasing, being replaced by planted forests (e.g. rubber), which decreases biodiversity. In addition, a large amount of Bangladeshi forests have been lost due to encroachment on agriculture and agriculture. In recent years, the production of inland open water bodies has been decreasing at an alarming rate. According to the IUCN 2000 Red List, 54 indigenous riverine fishes are threatened, 100 riverine fishes are under threat and several species are already lost (FAO, 2016).

The reduction in natural biodiversity can be seen from the following figures: the production of inland capture fisheries declined from 90% in the 1960s to 42% in 2010-11, while aquaculture contributed about 48%. The total forest in the country is 2.52 million ha, out of which 83% are natural forests and 17% are plantation forests. Evergreen and semi-evergreen forests cover 43% of the total forest land, while natural mangrove forests cover 40% (FAO, 2016).

Therefore, current agriculture and aquaculture practices are a main driver for natural biodiversity. However, this loss of natural biodiversity puts additional pressure on sustainable agriculture and aquaculture production itself, as natural biodiversity provides multiple functions, including pollination, natural pest and disease control and nutrient cycling, among many other services (FAO, 2019).

2.2.3 Energy

Another driver is the use of energy in agriculture, which is increasing in general due to intensification processes. Food systems have become increasingly dependent on fossil fuel inputs for production, processing and transportation. For instance, the cultivation of Boro (winter) rice is largely possible by using pumped irrigation, using diesel or electricity. Natural gas is used for transport of rice via trucks (Alam, 2018). More intensive agriculture consumes large amounts of energy, as such systems rely on external services and input while also having a more complex value chain. Therefore, agricultural value chains are currently sensitive to fluctuating energy prices (Alam, 2018). An overall picture of the energy demand is given in Figure 3, showing that, after industry, the highest demand comes from households, followed by transport and agriculture.

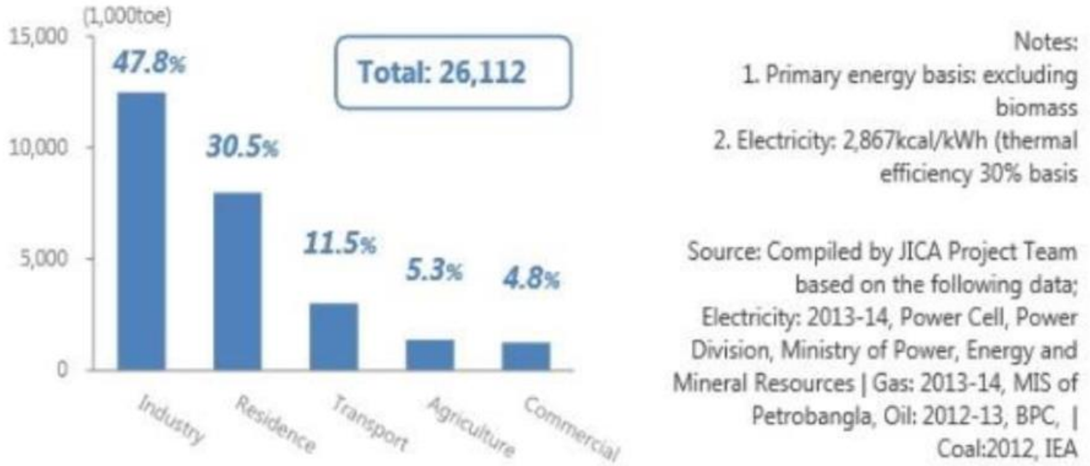

Figure 3 *Energy demand, present scenario (source: JICA study, 2014, in Alam, 2018)*

As the agriculture sector is sensitive to fluctuation in energy prices, a transition towards solar-powered irrigation may provide a solution to reduce the effects of energy price shocks. This option seems feasible in Bangladesh, as sunshine is abundant. Hossain & Karim (2019) found that solar irrigation facilitates an adequate water supply and reduces the cost of production in irrigated agriculture in Bangladesh.

2.2.4 Climate change

Different authors indiated the vulnearability of Bangladesh to climate change. ‘According to the Global Climate Risk Index, Bangladesh is the most climate change vulnerable country in the world’ (Harmeling, 2012; in De Brauw et al, 2019). Likely negative effects of climate change in Bangladesh include:

i) sea level rise and saltwater intrusion in southern Bangladesh
ii) mean temperature increases of 1.7 degrees Celsius by 2050
iii) increased rainfall variability and an increase in the frequency and intensity of extreme weather events

It is evident that these changes pose severe threats to agricultural production systems in Bangladesh, as crops, livestock and freshwater aquaculture are vulnerable to elevated salinity levels. Increases in air temperature cause plant and animal stress and increase water consumption. A brief overview of water productivity and salinity tolerance is presented (Table 2) in order to indicate vulnerability of different agricultural systems to these changes.

Table 2 *Water productivity and salinity tolerance for different agricultural products*

	Vegetables	Fruit trees	Rice	Livestock	Fish/shrimp
Water productivity (kg/m^3)	4.2	1.1	0.7	0.2	0.5
Salinity tolerance level (no reduction in yield mg/L)	383 – 1,984	448 – 1,344	640	2,000 – 4,000[a]	[b]

Water productivity and salinity tolerance levels for main agricultural and livestock production systems in the Mekong Delta of Vietnam (sources for water productivity based on green and blue water: Mekonnen and Hoekstra, 2011; Mekonnen and Hoekstra, 2012; Pahlow, 2015. Sources for salinity tolerance for crops: NSW, 2017).

a: Salinity tolerance levels of livestock are presented in mg/L for poultry and pigs, respectively (Smith, 2021).

b: The salinity thresholds for fish species vary significantly between species and cultivation systems, and therefore no specific range has been identified.

Clearly, dramatic changes in climate may have a direct, long-term effect on Bangladesh’s agricultural system. An analysis of Agricultural Commodities and Trade (IMPACT) for Bangladesh shows that climate change has mixed effects on agricultural production, potentially creating yield increases and therefore land area for some crops, but decreases for others. The specific projected impacts depend on the crop production system in question. The model demonstrates overall yield declines in maize, pulses, vegetables, jute and wheat, but with increases for milk and meat yields, by 2050 (De Brauw et al. 2019).

Overall, particularly in southern Bangladesh, rising soil salinity due to sea level rise is a major challenge (see Figure 4). According to Dasgupta et al. (2018), soil salinity will lead to a 15.6% decrease in productivity of high-yielding rice. Increased salinity can also have other adverse effects, such as reduced water holding capacity in the soil. Shrimp farming in the coastal area may also be affected in the future. Shrimp tends to be cultivated either in a monoculture or after rice.

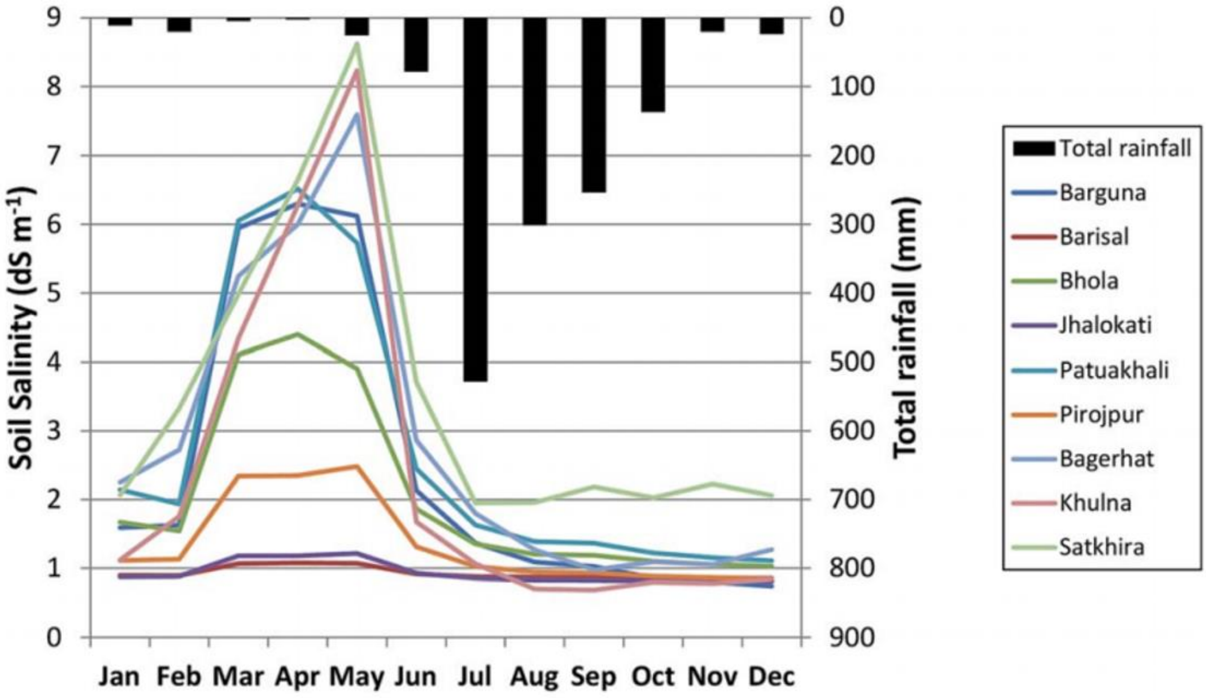

Figure 4 *Rainfall and soil salinity for coastal districts in Bangladesh (Lazar et al. 2015)*

2.3 Socio-economic drivers

Socio-economic drivers influencing the food system are, for instance, GDP, population pressure and urbanisation, as well as the policy framework & strategies and governance structure with respect to water and agricultural organisation and extension services. An overview of those drivers is presented in this section.

2.3.1 Population and economic growth

Bangladesh is the eighth-most populated country in the world (WorldoMeter, 2020), having approximately 165 million inhabitants, and it is one of the most densely populated. The population has been growing at a yearly average rate of 6% since independence, when the national population growth rate was 2.2% (De Brauw et al. 2019). This means that roughly 2 million more mouths are to be fed every year. The urban population has grown much faster, and currently about 25% of the people live in urban areas (De Brauw et al. 2019). Currently, population density is estimated to be around 34,000 persons per square km (Alam, 2018), with Wikipedia reporting 46,997/km^2 and World Population Review reporting 23,234/km^2.

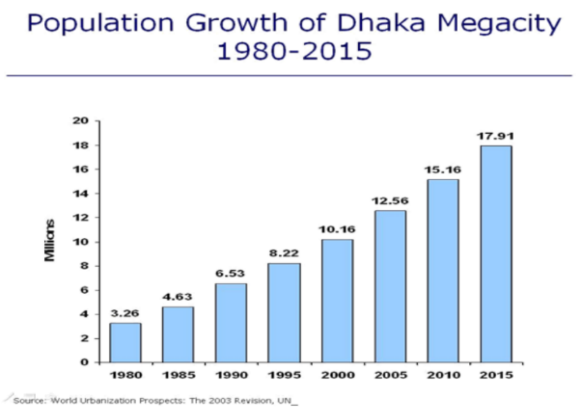

Figure 5 *Population growth of Dhaka megacity 1980 – 2015 (source: Alam, 2018)*

The national economy of Bangladesh has been continuously growing, and exponentially so since 2010. This can be seen in Figure 6, which shows the GDP, as the main indicator of economic development, for Bangladesh as a whole (World Bank, 2022). The figure shows a development from a GDP of 4.27 billion USD (2022 values) in 1960 to 416.26 billion USD (2022 values) in 2022.

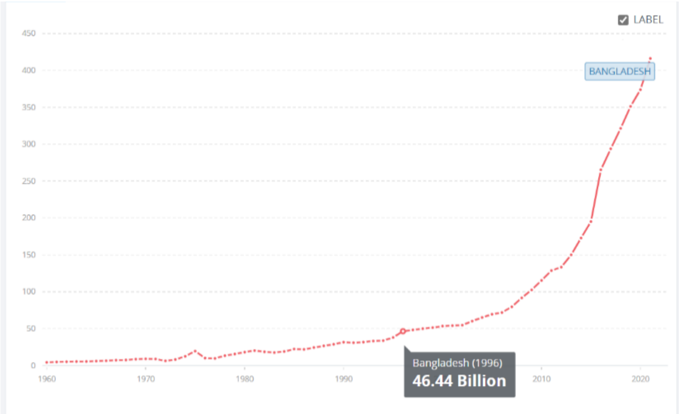

Figure 6 *GDP (current USD values) for Bangladesh 1960 – 2022*

Population growth put increased pressure on the level of food self-sufficiency and therefore a need to keep enhancing domestic food production. This is challenging, as land fragmentation continues, mainly due to the effects of population growth. Economic developments, in turn, cause changes in dietary patterns. In general, the populations of increasingly developing countries tend to consume more protein and fats such as fish and meat (products) and processed foods. These foods must be (at least partly) produced within Bangladesh in order to prevent excessive food import expenditures and dependence on foreign markets.

2.3.2 Policy framework

Bangladesh has a wide array of food and agriculture-related policies that are a main driver for agricultural production. These policies include, for instance, the Perspective Plan 2021-2041, the Bangladesh Delta Plan 2100; the Eighth Five-Year Plan 2020-2025, the National Food Policy of 2006, the National Food Policy Plan of Action (NFP PoA 2008-2015), the National Social Security Strategy (NSSS) and various climate change plans. A brief description of three main and recent plans is presented below:

Perspective Plan 2021-2041: The focus of this plan is to cope with rapid transformational shifts in, among others, agriculture by internal and external causes like climate change. The main objective of this plan is to ensure that key natural resources like land, water, forestry, natural habitat and air are used in a manner that avoids depletion and degradation. The plan has defined six strategic approaches: i) bringing unfavourable agro-ecosystems under productive sustainable agricultural practices; ii) intensifying crop cultivation in productive agricultural land, and thereby maintaining sustainability of soil health; iii) sustainably intensifying agricultural production systems without bringing new land under cultivation; iv) increasing resilience of crop and livestock production systems in the face of climate change; v) diversifying in agricultural production and livelihoods, involving more plant species or varieties, or animal breeds, off-farm activities and employment; and vi) coping with uncertainty in developing responses due to uncertainty about the scale and eventual nature of adaptation needed to address climate change.

In addition, Bangladesh has multiple Country Investment Plans (CIP) that support investments in these fields, such as the Plan on Forestry, Environment and Climate Change issues and on Agricultural Development.

Bangladesh Delta Plan 2100: This plan addresses the whole nation as a 'delta', encompassing 'all districts of Bangladesh because they face numerous weather and climate change risks related to their location either around the sea, around major rivers or in water scarce zones' (GoB, 2018).

The plan highlights that ‘The soil and water combination of Bangladesh makes it a highly fertile land with multiple cropping opportunities.’ Bangladesh has wisely combined this natural advantage with seed fertiliser irrigation technology to intensify land cultivation and expand food production, mainly rice. The plan emphasises four main challenges: i) climate change (temperature, rainfall, etc.); ii) upstream developments; iii) water quality; and iv) waterlogging. The plan comprises a vision, mission, goals and strategies (see Table 1 for an overview) to address each. Basically, the government aims to ensure long-term water and food security, economic growth and environmental sustainability, while effectively reducing vulnerability to natural disasters and building resilience to climate change and other delta challenges through robust, adaptive and integrated strategies and equitable water governance (GoB, 2018).

Table 3 *Bangladesh Delta Plan 2100 in summary (GoB, 2018)*

BDP 2100 is envisioned as an integrated and holistic plan that takes a long view on water resource management, climate change and environmental challenges with a view to support long-term development of Bangladesh. **Vision**: Achieving a safe, climate-resilient and prosperous delta **Mission**: Ensure long-term water and food security, economic growth and environmental sustainability, while effectively reducing vulnerability to natural disasters and building resilience to climate change and other delta challenges through robust, adaptive and integrated strategies and equitable water governance. These long-term needs have been translated into specific goals or targets for its implementation. This is done by combining long-term development outcomes in terms of economic growth and poverty reduction in the Perspective Plan of 2041, with targets for reducing long-term vulnerability from water and climate change-related hazards, plus targets for environmental conservation. BDP 2100 approach to long-term **goals**: The BDP 2100 proposes three higher-level national goals and six BDP goals that contribute to achieving the higher-level goals. Higher-level goals: Goal 1: Eliminate extreme poverty by 2030 Goal 2: Achieve an upper middle-income status by 2030 Goal 3: Become a prosperous country by 2041, and remain prosperous beyond BDP 2100 specific goals: Goal 1: Ensure safety from floods and climate change-related disasters Goal 2: Enhance water security and efficiency of water usage Goal 3: Ensure sustainable and integrated river systems and estuary management Goal 4: Conserve and preserve wetlands and ecosystems and promote their wise use Goal 5: Develop effective institutions and equitable governance for in-country and transboundary water resource management Goal 6: Ensure optimal and integrated use of land and water resources The goals are then translated into various **strategies**: two national strategies (one for flood management and one for freshwater management), with six regional specific strategies (coast; Barind (prone to drought); Haor (flash flood); CHT (eastern hills); river systems and estuaries; and urban) and seven cross-cutting strategies (sustainable land use and spatial planning; agriculture, food security, nutrition and livelihoods; transboundary water management; dynamising inland water transport system; advancing blue economy; renewable energy; and earthquakes).

The Eighth Five-Year Plan 2020 – 2025: compiles the main areas of interest where developments and improvements are required. For the agricultural sector, concrete plans and strategies are developed for marine and freshwater fisheries, livestock, crop sector and for the agricultural sector in general. The emphasis on all these domains is to further increase production while halting or reducing pressure on natural resources, with a main focus on sustainable production. Also, addressing the effects of climate change impacts is a main priority of this plan.

The agricultural and food-related plans of Bangladesh have a main link between increases in agricultural production and climate adaptation. In addition to the three plans mentioned above, Bangladesh is rich in many sector and topic-specific policies and plans, as well as investment plans with the purpose of operationalising concrete activities contributing directly to the policies. In general, the policy scene in Bangladesh is a main driver of transformation to increased sustainable and climate-resilient agriculture. However, concrete funding and operationalisation of plan objectives on a large scale remains a challenge.

National Adaptation Plan 2022
Bangladesh has already taken significant steps in climate adaptation planning over the past decade, by implementing the Bangladesh Climate Change Strategy and Action Plan (BCCSAP) and National Adaptation Plan of Action (NAPA) through the establishment of climate change trust funds and pioneering community-based adaptation approaches. However, institutional arrangements and a coordinated strategy for mid- and long-term climate change adaptation investment are not yet in place. To meet this gap, formulation and advancement of the National Adaptation Plan (NAP) process is being executed by the Department of Environment and financed by the Green Climate Fund (GCF). NAP will allow Bangladesh to identify country-specific adaptation needs and has four objectives: i) strengthened institutional coordination and climate change (CC) information and knowledge management for mid- to long-term planning; ii) evaluated and prioritised adaptation options, and a formulated National Adaptation Plan; iii) climate risk-informed decision-making tools, developed and piloted by planning and budget departments at national and sectoral levels; and iv) nationally appropriate adaptation, investments-tracking mechanism setup and a financial plan for mid- and long-term CCA implementation (UNDP, 2022).

2.3.3 Agricultural governance

Bangladesh has a National Agricultural Extension Policy (NAEP) set out by the Department of Agricultural Extension. The mission of NAEP is to provide efficient, effective, coordinated, decentralised, demand-responsive and integrated extension services to help farmers in Bangladesh access and utilise better knowhow, improve productivity, optimise profitability and ensure sustainability, thus ensuring the wellbeing of their families. Since 2012, the NAEP’s focus has been particularly on use of ICTs to link marketing and production systems and establish digitised databases and management and information systems (MIS) down to the upazila (district) level, better coordination between public and private sector actors and increased women’s participation. The extension service has multiple institutes (GFRAS, 2022):

- Department of Agricultural Extension (DAE), www.dae.gov.bd
- Department of Fisheries (DOF), www.fisheries.gov.bd
- Department of Livestock Services (DLS), www.dls.gov.bd
- Agricultural Information Service (AIS), www.ais.gov.bd
- Department of Agricultural Marketing (DAM), www.dam.gov.bd
- Bangladesh Agricultural Development Corporation (BADC), www.badc.gov.bd

In addition, Bangladesh is also rich in farmers organisations (FOs). According to FAO (2014b), the country has 198,114 FOs of various types being formed by government agencies, (inter)national NGOs and, in some cases, autonomously. Most FOs are small, with 25 – 50 members each, which makes it difficult to connect national and regional investment planning. A majority of FOs function more to deliver activities and services (e.g. training, inputs) and less as partners or stakeholders capable of partnership with other development actors.

In general, Bangladesh has many services to share knowledge, practices etc., from top level (national government) to field scale, through extension services and farmers organisations. These services enable farmers to gather new knowledge and tools to increase (sustainable) agriculture while securing or improving farmer income. However, extension services and farmer organisations could be used more as equal partners to identify agricultural development strategies.

2.4 Outcomes

Bangladesh has a productive agricultural sector, mainly due to multiple supporting climate services such as weather, water availability and nutrient-rich soils from sedimentation processes of three large rivers. Furthermore, the country has multiple policies, extension services and farmers organisations to support (sustainable) production of food. However, there is significant pressure to produce enough food for the population due to the continuous increase in population, in particular in cities. Economic growth is another pressure on food consumption. With regard to sustainability and resilience, it needs to be noted that, therefore, there is a pressure on land due to urbanisation (reducing the area of land available to agriculture, but also reducing forest and nature area) and there are important combined impacts of development and climate change.

Both undernutrition (stunting) and overnutrition (obesity) are commonly present in Bangladesh, showing the diverse food systems present in the country. Rural areas in Bangladesh can be characterised as mostly basic food systems with short value chains, while within cities more advanced food systems with complex value chains are present. In particular, undernutrition remains a problem in rural areas, and fruit and vegetable consumption is inadequate for most people relative to international recommendations. Obesity, on the other hand, is mostly observed in cities with higher processed food intakes, which are more rich in fat and can be linked to rising overweight and obesity status.

Food safety is another concern, particularly due to agro-chemical usage during production, substandard microbial standards and usage of chemicals like formalin, which is applied after harvest. The latter is practised to preserve food during long transport times, in combination with lack of cold storage and transport facilities.

GDP is increasing, as is consumption of livestock and aquaculture products, which corresponds to international trends of increasing protein consumption with increasing income. It may be expected that this trend will continue in the years to come, thereby putting more pressure on land for this purpose, but also providing income opportunities in rural areas.

One of the main pressures of the food system in Bangladesh is the salinisation of the soils from the rise in sea level induced by limited runoff and climate change. This is particularly the case in the southwestern part of the country and affects farmers who rely on farming as the main family income (basic food systems). This group of farmers have very limited resources for adaptation with almost no opportunities for alternative income generation, and these farmers are thus extremely vulnerable to this climate change-induced impact. Most crops, freshwater aquaculture and livestock are (very) limited in their resilience towards increased soil and water salinity. Therefore, the identification of sustainable transition pathways is required to maintain or even enhance the income of these farmers, as well as to produce sufficient food (food security) to feed the growing population of the country. The next chapter will focus specifically on the southwestern region of Bangladesh, which is one of the most vulnerable regions with respect to soil salinity caused by sea level rise.

3 Southwestern Coastal Bangladesh

In this chapter the focus is on the coastal districts Khulna, Satkhira and Bagerhat, which represent the southwestern part of the Bangladesh delta. This region is extremely vulnerable to development and climate-induced impacts such as soil and water salinity on agricultural production systems. This chapter describes the main production systems of this region, the pressures it is facing and socio-economic and environmental impacts.

3.1 Food production system in southwestern coastal Bangladesh

The southwestern (SW) region of Bangladesh stretches from the Ganges River in the north to the Bay of Bengal in the south and West Bengal of India in the west to the districts within the catchment of the Arial Khan River and its tributaries in the east (WARPO, 2001). The southwestern region comprises two distinct zones: the inland zone, extending from the Ganges River in the north to around Khulna in the south; and the coastal zone, which consists of the Khulna, Satkhira and Bagerhat districts (Figure 7) (WARPO, 2001; FAO, 2013). The coastal zones of the SW region lack freshwater flow in the rivers due to anthropogenic changes upstream such as the Farakka Barrage, the Ganges-Kobadak (GK) irrigation project and polderisation, which consequently resulted in sedimentation of the river bed, waterlogging and increased salinity (Higgins et al. 2018; Islam et al. 2021; Goes et al. 2021). Salinity intrusion, river bed sedimentation, flooding and waterlogging will all be exacerbated by climate change, which also increases the probability and intensity of extreme events such as cyclones and storm surges (Oppenheimer et al. 2019). Sundarbans, the largest mangrove forest in the world, located in the southwestern region of Bangladesh, is also threatened by climate change and human interventions (Loucks et al. 2010; Anwar & Takewaka, 2014).

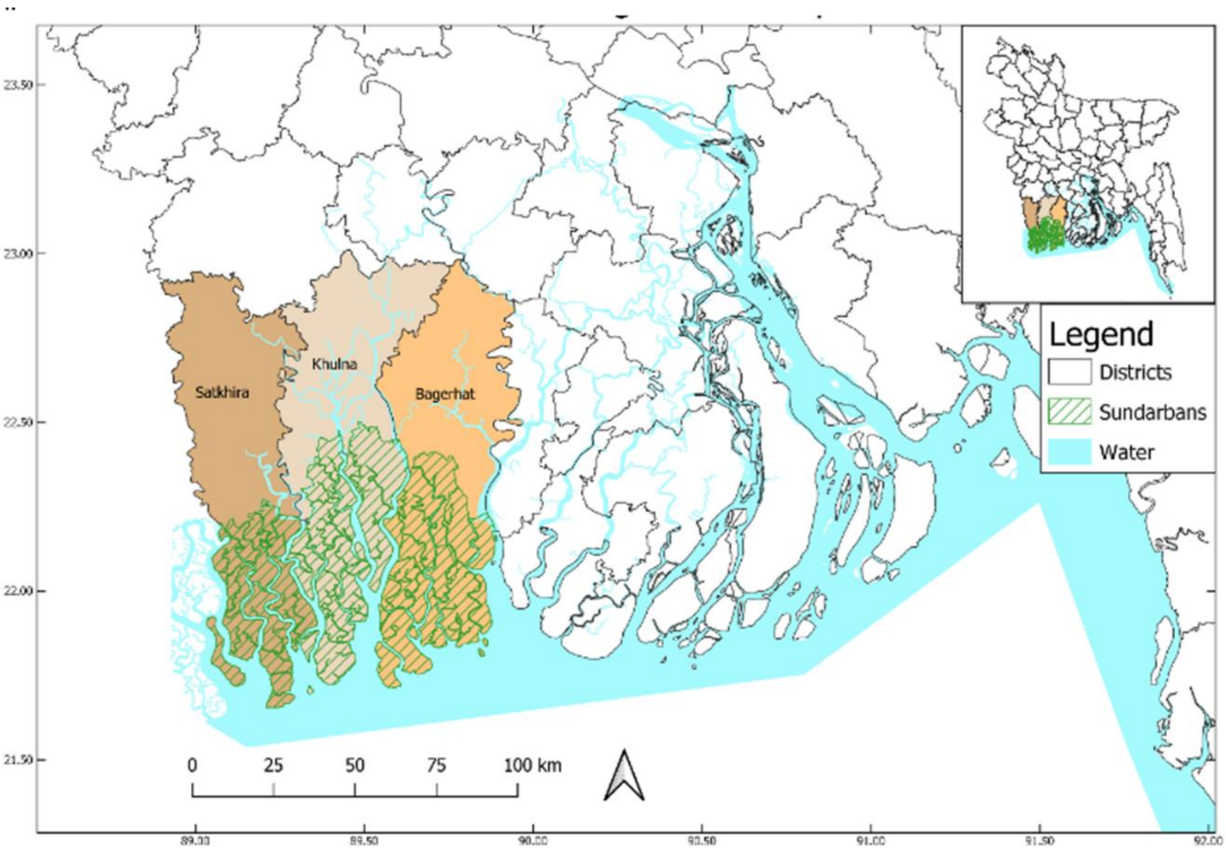

Figure 7 *Southwestern coastal Bangladesh with districts and Sundarbans*

For the food system, this implies that agricultural production is facing uncertainties, as it is adversely impacted by natural hazards and climate change, which will increase even more in the future. Therefore, climate change will have an impact on the economy as the agriculture sector contributes approximately 14.1% of the gross domestic product (GDP) and employs about 40.6% of the country's labour force (Habiba & Abedin, 2021).

What a sustainable food system will look like in the (near) future is not yet known. Salinity in the coastal region will increase, as will protein consumption due to the potential increase of income per capita with changes in land use and urbanisation. The change in pressures and the drivers of the food system such as regional climate, water availability, salinity, land use and sea level will influence farmers' decisions about common goods, water and salinity management, livestock, mangroves and aquaculture and will shape the future.

3.1.1 Agricultural production

Farmers in the SW region of Bangladesh produce rice, vegetables and fruits, in addition to being involved in aquaculture and livestock rearing (Uddin and Nasrin 2013). Agriculture contributes 19.3% of the gross domestic product (GDP) of Bangladesh (Shelley et al. 2016). Rice contributes to 70% of this agricultural GDP and one-sixth of national income. Rice cultivation accounts for 48% of total rural employment. It provides two–thirds of the caloric needs of the nation, along with one-half of the protein consumed. Therefore, rice cultivation plays a critical role in Bangladesh. More than 13 million farms grow rice covering some 10.5 million hectares, which is 75% of the total cropped area and 80% of the irrigated land (Sayeed and Yunus, 2018).

Most farmers in the three districts of coastal zone of the SW region cultivate local and HYV Aman rice in the Kharif-II season (mid-July to mid-October), and as the salinity during the Kharif-I (mid-March to mid-July) and Robi (mid-October to mid-March) seasons intensifies, farmers grow vegetables such as tomato, bean and pumpkin for both domestic consumption and for sale in local markets (Chowdhury and Hassan, 2013; Uddin and Nasrin 2013; Hoq et al. 2021). Vegetables are mainly produced during winter. The average annual rice production is 34 million metric tonnes, and for wheat it is 0.88 million metric tonnes (BBS, 2012). However, salinity intrusion is affecting rice production in the SW region. Due to the increased salinity, some farmers are moving from rive to shrimp farming with saline water, and as a result the salinity is seeping to adjacent areas, increasing soil salinity (Lam et al. 2022).

3.1.2 Aquaculture

After rice, fish and shrimp farming is the second most valuable agricultural crop (Belton et al. 2011). Total fish production (including shrimp) is estimated to exceed 2.56 million tonnes, of which aquaculture accounts for 39%. Almost all (94%) of the (wild-caught) fish and aquaculture production is consumed locally (Hernandez et al. 2018) and constitutes more than 60% of all animal-sourced food in the country (Belton et al. 2011). Between 2000 and 2005, urban fish consumption increased 17.5% to 18.1kg, while consumption in rural areas increased 4.8% to 14.5kg. Low-value wild fish and cultured carps remain the most common fish consumed in rural areas, whereas pangasius, tilapia and climbing perch and high-value wild fish are increasingly dominant in urban markets (Belton et al. 2011).

Shrimp production is largely focussed on the production of the black tiger shrimp *Penaeus monodon* and giant freshwater prawn *Macrobrachium rosenbergii*, while fish production today involves several carp species for local consumption, along with commercially more interesting species such as tilapia and pangasius catfish. According to Belton et al. (2011), about 399,000 tonnes of aquaculture production come from homestead ponds; 390,000 from commercial semi-intensive carp culture; 395,000 tonnes from intensive systems; and 98,000 tonnes of shrimp and prawn, for a total of 1.35 million tonnes (27% higher than the 1.06 million tonnes of aquaculture production reported in official statistics).

Pond culture appears to be dominated by carp production, followed by tilapia and pangasius (Belton et al. 2011). About 4.27 million households (20% of rural inhabitants) operate a homestead pond, covering a combined area of 265,000 ha. Commercial semi-intensive carp culture amounts to about 110,000 ha, and intensive forms of pond culture to about 15,000 ha. Other aquaculture systems account for around 2% of total aquaculture production (Belton et al. 2011). Ali et al. (2016) document the use of 46 chemical and biological products in aquaculture in Bangladesh. They found large differences between the different types of aquaculture but concluded that the use of these agents is relatively low compared to many other countries in Asia. Black tiger shrimp and giant freshwater prawns are the second most important export commodity after ready-made garments, but they suffer from many environmental and market problems. The rapid development of private sector hatcheries and nurseries has been a decisive factor in aquaculture expansion (Belton et al. 2011).

Due to the environmental impact of shrimp farming, farmers are adopting integrating shrimp (or prawn) and fish with rice and vegetables, alternating between rice cultivation and aquaculture seasonally and floating agriculture and livestock (Uddin and Nasrin, 2013). Increasing salinity and waterlogging is and will influence agricultural production and human life (migration, availability of drinking water and health) negatively (Uddin and Nasrin, 2013). The change will also effect the agricultural production of the region.

3.1.3 Livestock

The contribution of livestock to the GDP of Bangladesh is approximately 2%, which is almost 13% of agricultural GDP (Iqbal et al. 2016). Most farmers in Bangladesh have livestock such as cows, goats, lambs, ducks and chicken on their homestead, mostly for domestic consumption. Farmers also produce for commercial purposes. In the last few decades, poultry farming has had a significant impact on the income of farmers (Dolberg, 2008). Poultry farms have offered more opportunities for marginal and small farmers. Das et al. (2020) estimate that there were about 345 million poultry in 2018, with an annual growth rate of 4.5%. Egg production is currently estimated at 15.5 billion per year. The Khulna region has about 22% of the total number of poultry farms in Bangladesh (Ministry of Foreign Affairs, The Netherlands, 2020). Cattle also form a large part of livestock production by farmers. The livestock density in Bangladesh is about 376 heads/km^2 (Das et al. 2020). Das et al. (2020) also estimate the total number of cattle, sheep and lamb to be 24.16 million, 26.18 million and 3.5 million, respectively. Livestock also has had a considerable contribution to the income of rural households. Iqbal et al. (2016) reported that, considering meat and milk production, households who raise livestock earn on average about 4000 to 9000 BDT as profit annually.

However, farmers of southwestern Bangladesh face difficulties in breeding cattle, as the availability of feed grain for the livestock is reducing due to salinity (Lam et al. 2021). Lam et al. (2021) also reported that due to the lack of freshwater to drink, cattle are getting more sick and physically weaker. Farmers in the southwestern region are therefore moving away from raising cattle (Lam et al. 2021).

3.1.4 Mangrove and aquaculture

Mangrove forests support livelihoods by providing food, timber and charcoal materials to local inhabitants, as well as ecotourism possibilities to outsiders (Armitage, 2002). More importantly, the forests also provide coastal protection, fulfil essential ecological functions, such as trapping pollutants, nutrients and sediments, providing a nursery and spawn habitat for important coastal fishery resources and building and protecting fertile land (Nagelkerken et al. 2008; Kimirei et al. 2013; Hutchinson et al. 2014) (Figure 8).

Several studies document the current economic importance of mangroves to the inhabitants of rural coastal villages in Bangladesh. For instance, around 30% of people in the Sundarbans landscape zone depend on mangrove NTFPs (FD 2010). For villages in Khulna, mangrove forest income represents 24%, 48% and 74% of total household income, respectively, for upper, middle and lower-income village households (Abdullah et al. 2016). Direct use values of non-main wood and leaf litter extraction alone (not counting all the other extractive or indirect services) already economically justify the planting of mangroves in Bangladesh (Chow, 2015) and the harvest of a single seasonal forest product (in this case, Nypa) may provide 28% of annual household income in the Sundarbans (Islam et al. 2020). In the Satkhira district, adjacent to the Sundarbans forest, 80% of households depended on mangroves for all or part of their income, while nearly 35% of households depended entirely on mangroves (Rahman et al. 2018).

Figure 8 *Mangrove roots serve to build and protect land by entrapping sediments in their root systems, which also serve as shelter for the young of many commercially important fish, shrimp and crustacean species (Photo: A.O. Debrot)*

3.2 Pressures and drivers on the production system

3.2.1 Climatic conditions and seasonality

The climate of southwestern Bangladesh is tropical, with considerable influence from the monsoon season (Abedin et al. 2019). The region has three seasons: dry (November to February), pre-monsoon (March to May) and monsoon (June to October) (Islam et al. 2021). The temperature of the region ranges between 8 °C and 35.5 °C, with an annual average of 24.5 °C. The temperature is highest during the pre-monsoon season and lowest during the dry season (Abedin et al. 2019) (Figure 9a). The average annual rainfall in the southwestern coastal region is about 1,750 mm, with 70% of that rainfall occurring during the monsoon season and the lowest amount of rainfall during the dry season (Kabir and Golder, 2017; Amin et al. 2014). Similar to rainfall, humidity varies seasonally, at it is lowest during the dry season and highest during the monsoon season, with humidity increasing along with increasing rainfall (Amin et al. 2014) (Figures 9b and 9c). Monthly average evaporation is highest during the pre-monsoon season, when the humidity and rainfall are low and radiation and temperature are high (Figure 9d). Average evaporation is lowest during the monsoon season, when radiation is relatively low and humidity and rainfall are high (Figure 9d). During dry season, the monthly average radiation is lowest, but the evaporation (Figure 9d) is not considerably lower than during the monsoon season, as the humidity, rainfall and temperature during dry season is the lowest (Figures 9a, 9b and 9c). These factors influence water availability in the rivers and in the region. The change in climate will impact these variables and drivers, especially seasonality. Climate projections suggest that Bangladesh is likely to experience more hot days and heat waves, longer dry spells and higher risk of drought. Rainfall variability is projected to increase significantly due to climate change. Rain events will likely be more intense and dry spells will increase, while precipitation is likely to increase during the summer seasons (Amin et al. 2014). These trends will make water management more challenging in the future.

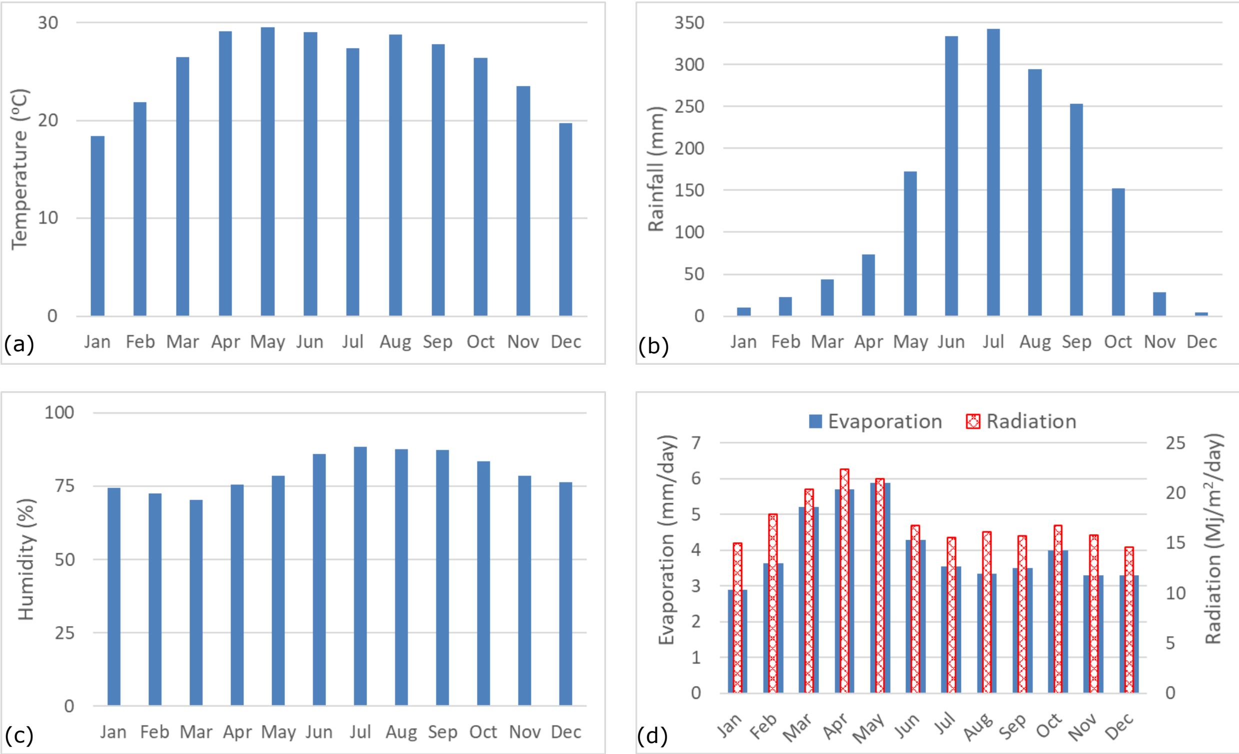

Figure 9 *Climatic variables and drivers of southwestern Bangladesh: (a) monthly average temperature, (b) monthly average rainfall, (c) monthly average humidity and (d) monthly average evaporation and radiation*

3.2.2 Water management and salinity

The southwestern coastal region of Bangladesh (Figure 10) is relatively flat and low-lying, has an elevation up to 3 metres and lies about 1.5 metres above the mean sea level (Hossain et al. 2012; GoB, 2018). Therefore, it is also significantly vulnerable to natural hazards such as cyclones and tidal floods.

From June to October, freshwater flows during the monsoon season, thereby causing the soil and river salinity to remain relatively low (Clarke et al. 2015). However, climate change impacts such as sea level rise, seawater intrusion, waterlogging and increased flooding have made low-lying areas subject to saline water intrusion (Bhowmik et al. 2021; Hossain et al. 2012). This occurs especially during the dry season between November and March, where reduced flow in the Ganges River results in increases of the soil, surface and groundwater salinity (Faruque et al. 2017). The increasing salinity in the soil and irrigation water reduces plant growth and decreases overall agricultural productivity (Bhowmik et al. 2021).

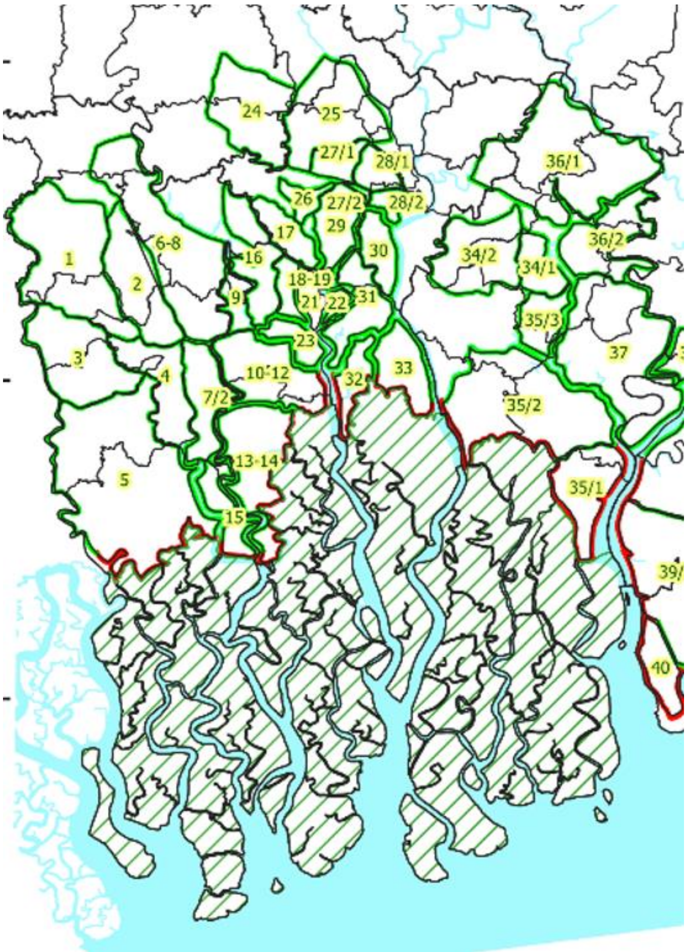

Figure 10 *Polders in southern Bangladesh*

Agriculture is the main economic activity in southwestern Bangladesh, where approximately 49% of the population is engaged in agriculture (Bhowmik et al. 2021). Subsistence-oriented rice production with additional crops, low-intensity aquaculture (fish farming) and livestock are all traditional for the region (Faruque et al. 2017; Lazar et al. 2015). Today, the region is mostly comprised of 'polders', low-lying cropland areas protected from tidal inundation and salinisation by man-made dikes and drainage sluices (Faruque et al. 2017). These polders have been constructed through a top-down approach in the 1960s with the goal to manage water levels and improve agricultural productivity of the region, without taking social, ecological and economic systems into account (Faruque et al. 2017; Hossain et al. 2012).

However, polder embankments obstruct the flow of water and sediment from tidal rivers to floodplains and low areas. This obstruction, combined with the decrease in the freshwater flow upstream to push the sediment bought by flood tide toward the sea, has resulted in siltation of the river channels (GoB, 2018; Van Staveren et al. 2017). Siltation of sluices, inability of the drainage network within the polders to drain excess water from rainfall with gravity (due to the land elevation inside the polder being lower than the river bed), tectonics, sediment compaction, changes in farming practices (e.g. irrigation) and groundwater extraction also progress subsidence and can cause waterlogging in polders and upstream of polders (Faruque et al. 2017; Brown and Nicholls, 2015). Recurring salinity events in polders degrades soil quality and drainage becomes more difficult, which will complicate the operation of traditional agricultural practices.

During the 1970s, the progressive salinisation and improved access to global markets converted the traditional agriculture to an export-oriented shrimp aquaculture (Faruque et al. 2017). And it is this change in land use that not only hampered the traditional agricultural practices and, in addition to generating income, also inflicted further salinisation of areas previously used for rice cultivation (Faruque et al. 2017; Hossain et al. 2012). Commerce-focussed aquaculture offers limited employment to locals and is not particularly sustainable, since soils become salinised within a few years of aquaculture and shrimp farming (Rahman et al. 2020).

Altogether, the water system is quite complex and in the following pages will be explained in detail, as well as the water and soil salinity, the sea level rise and land use change.

3.2.2.1 Understanding the water system

The coastal zone of Bangladesh is a disaster-prone area. Cyclones, storm surges, droughts, floods, waterlogging and salinity intrusion cause significant damage to people, animals, crops, fishery and vegetation (BDP). The challenges facing Bangladesh are closely related to the water system.

The Ganges River is the main source of freshwater flow in the rivers of the southwestern region of Bangladesh. The SW region once received freshwater flow from the Ganges River through a two-river system: Gorai-Modhumati-Nabaganga and Mathabanga-Bhairab-Kobadak (Monirul and Sarker, 2004) (Figure 11). However, the Mathabhanga River was disconnected from Ganges due to anthropogenic changes such as barrages upstream, diversion of the Ganges River and sedimentation resulting from lack of flow during dry seasons (Kwadijk et al. 2020).

The Gorai River flows south as the Modhumati River and splits at Bardia, then continues to flow southeast as the Modhumati River and southwestern as the Nabaganga River (Figure 11). The Modhumati River flows south as the Baleswar and finally meets the sea (Figure 11). The Nabaganga River flows south as the Rupsa River and the Pasur River and meets the sea at the Pasur estuary (Figure 11). The Pasur River is strategically and economically important, as it has the second-largest port of Bangladesh, Mongla, on it (Figure 11). The tributaries of the Mathabhanga River and Kobadak River flow south, becoming the Sibsa River, which meets the Pasur estuary as well (Figure 11). The Kobadak, Bhairab and Sibsa are tidally influenced and are mainly saline throughout the year, as they lack freshwater flow from upstream. The only freshwater for these rivers is the overland flow from monsoon rain. The rivers in the southwestern region are important, as they supply freshwater flow during monsoon seasons and are used for navigation. The flow and salinity of the Gorai River vary seasonally, but for the most part river dominated flow (Islam et al. 2021). In contrast, the rivers located south of the region are tidally influenced throughout the year. However, the middle part of the region is influenced by both freshwater flow during the monsoon and tidal flow during dry and pre-monsoon seasons (Islam et al. 2021). The flow in the SW region is highest during the monsoon, as the high flow from the Ganges River is distributed through the Gorai River system, which results in flooding of parts of low elevation areas. During dry and pre-monsoon seasons, the freshwater flow is low and so is the water level of the rivers, which results in a drier season and lack of freshwater flow.

The Sundarbans is located in the southwestern part of Bangladesh, extending 60 to 80 km inland from the coast and providing considerable degree of protection to the areas north of the Sundarbans from storm surges which occur almost annually. This region of the delta has long low-gradient drainage routes and receives insufficient freshwater flow from the parent river (the Ganges) through the Gorai River (Islam et al. 2021). To protect the low elevation coastal areas from tidal flooding, more than 100 polders were constructed in the 1960s and 1970s (Van Staveren et al. 2017). Tide dominates the flow in the rivers along most of these polders, of which a few are located more than 150 km from the coast (Islam et al. 2021). The dikes and the infrastructure of the polders control the flow of water between rivers and canals inside the river to drain flood water and reduce flooding and salinity inside the polders. The canals inside of some of the polders, especially under the Blue-Gold project, are used to store freshwater from overland flow from access rainfall during monsoon and utilise this freshwater during dry season when the freshwater in the rivers is scarce.

For the southwestern region of Bangladesh, the lack of drainage capacity of the tidal rivers is the primary concern. The area is also attributed to depressions (beels) running roughly parallel to the coast. These areas are especially difficult to drain for agriculture. Along with river floods, waterlogging is a growing concern for the region.

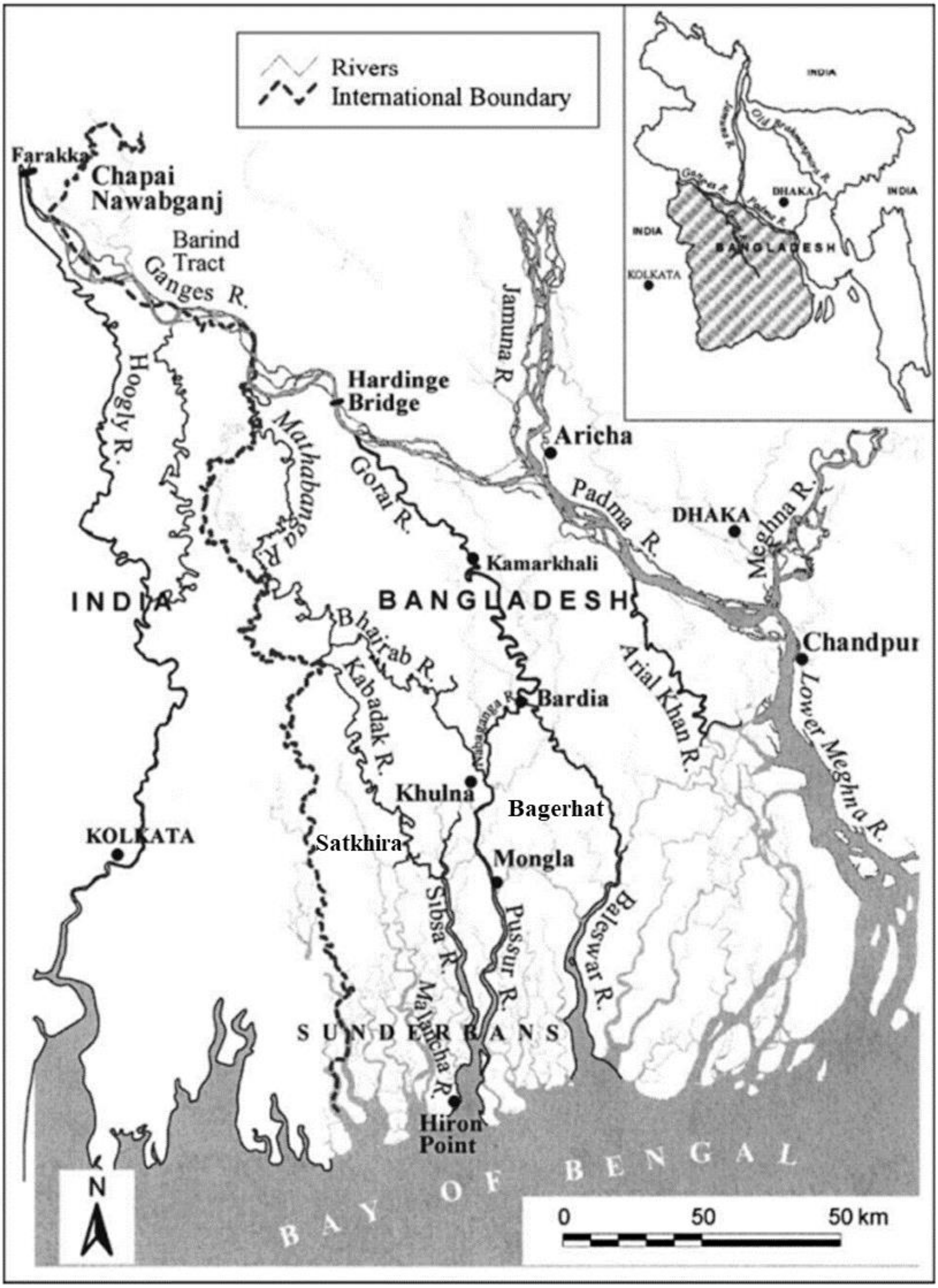

Figure 11 *Network of primary rivers of southwestern Bangladesh (Monirul and Sarker, 2004)*

3.2.2.2 Water and soil salinity

A reduction in freshwater inflows from the transboundary Ganges River, siltation of the tributaries of the Ganges and siltation of other rivers following the construction of the polder system has resulted in a significant increase in river salinity in coastal Bangladesh during the dry season. The average salinity concentrations of the rivers in the coastal area are higher in the dry season than in the monsoon due to the lack of freshwater flow from upstream. Salinity levels in water generally increase almost linearly from October to late May, with a gradual reduction in the freshwater flow from the upstream. Observations of water salinity show an increase in salinity at Khulna, from 0.7 ppt to 16.8 ppt in the Rupsa River from 1962 to 2011 (IWM, 2013). The variation in water salinity over the years at Khulna is shown as function of upstream flow and is presented in Figure 12.

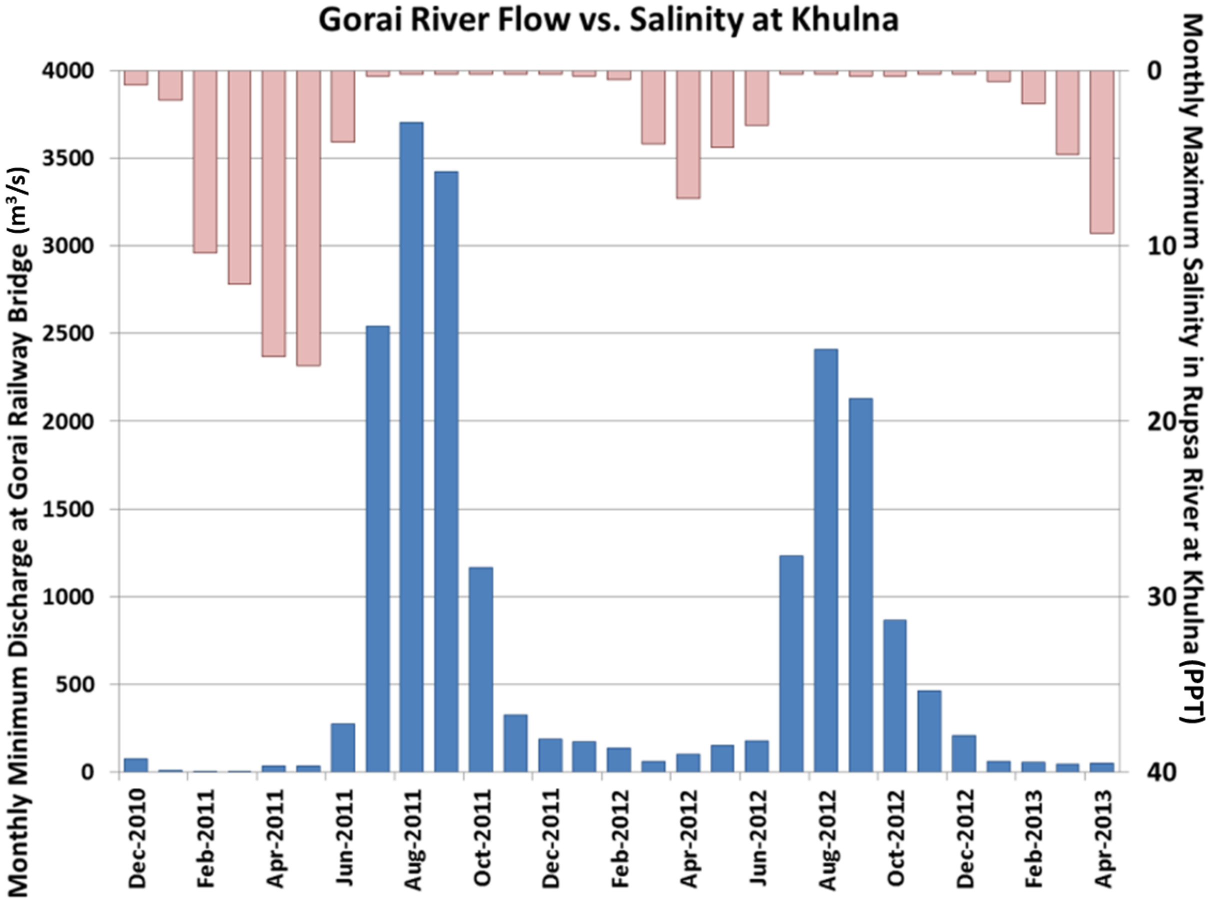

Figure 12 *The variation in water salinity over the years at Khulna is shown as a function of upstream flow (IWM, 2013)*

The bifurcation between the Ganges and Gorai Rivers influences the freshwater flow in the SW region. During the non-monsoon seasons, the Gorai inflow is severely hampered, creating scarcity of downstream freshwater availability.

Soil salinity has also increased over the years in the coastal area. The observed data show an increase of soil salinity over the years in the southwestern zone (Figure 13). Monsoon rainfall is generally sufficient to reduce topsoil salinity, but crops on the non-embanked coastal fringe can be affected by saline water incursions during exceptional high tides (Bhuiyan, 2012). However, the area affected by salinity is increasing in the coastal districts of the SW region of Bangladesh (Table 4).

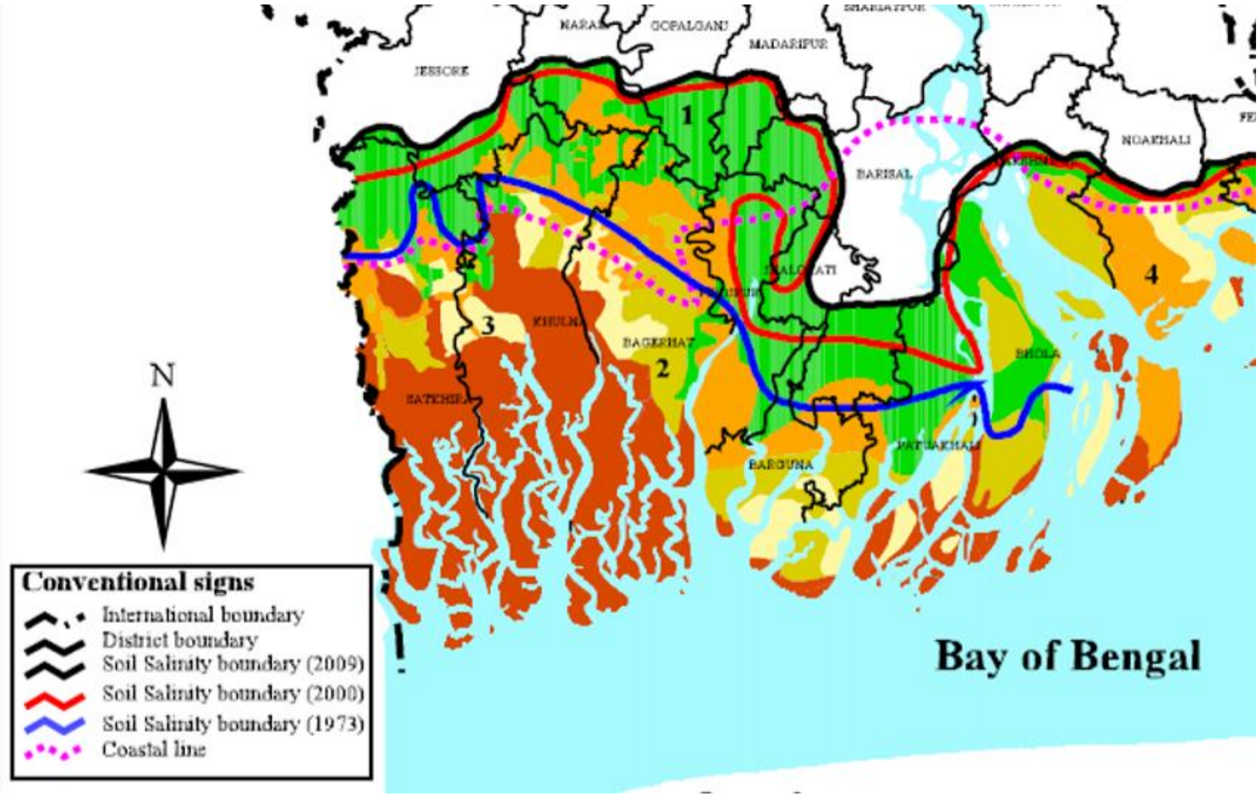

Figure 13 *Soil salinity propagation 1973 – 2009 (from BDP 2100 - GOB, 2018)*

Table 4 *Salt-affected area in southwestern Bangladesh (in thousands of hectares)*

	Salt affected area (10^3 ha)		
District	**1973**	**2000**	**2009**
Khulna	120.04	145.25	147.96
Bagerhat	107.98	125.13	131.12
Satkhira	146.35	147.08	153.11
Total	374.37	417.46	432.19

3.2.2.3 Sea level rise and climate change

Simulations of salinity intrusion with sea level rise of 52 cm in 2050 shows that the freshwater zones in Bagerhat, Barguna, Barisal and Bhola are likely to be lost. The Khulna, Jhalokati, Pirojpur and Satkhira districts will also be most adversely affected by the increase in river salinity in times of climate change. An area of 7000 sq km is likely to be affected by more than 1 ppt, and about 8400 sq km would be affected by more than 2 ppt salinity in the southwestern and south central zones by 2050, with a 52 cm sea level rise (IWM, 2013). The 2 ppt salinity front may then move about 65 km into Barisal Division, as shown in Figure 14. With freshwater flow projected to be reduced in the Ganges River, the sea level projected to increase and subside in the future, larger areas will be negatively affected by salinity and lack of freshwater availability. This freshwater reduction can potentially create a tipping point for many agricultural activities in this zone, i.e. many farmers have to choose a new farming strategy (Hossain, 2012). To understand the impact and explore the effect of water availability, water and soil salinity in the future, hydrodynamic models may provide insight.

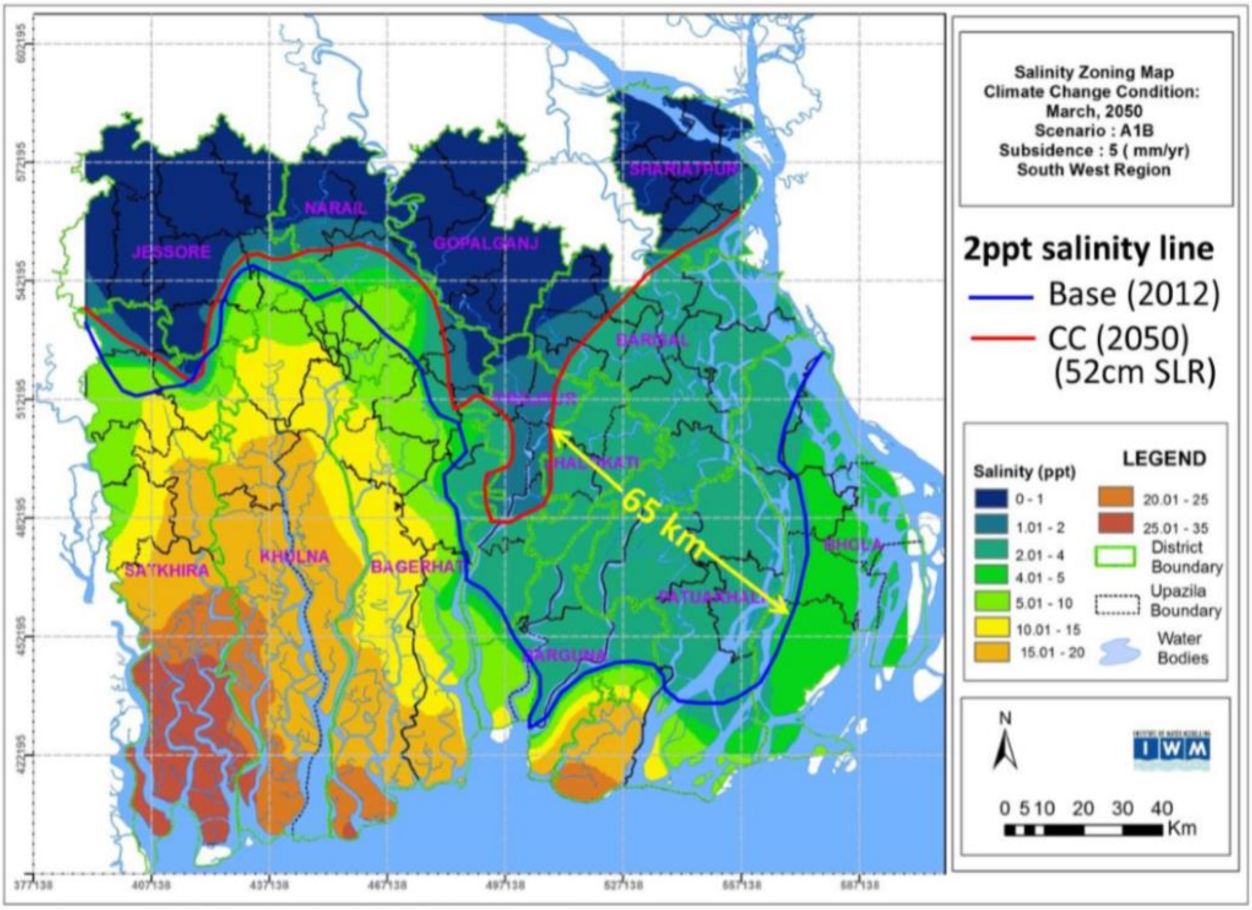

Figure 14 *Salinity propagation (Dasgupta et al. 2018)*

3.2.2.4 Land Use change and its impact on food system

The land use of the southwestern region is changing, and the completion of the bridge on the Padma River in 2022 will accelerate the rate of change. The urban centres, the district cities of Khulna, Satkhira and Bagerhat are all growing. With the completion of the bridge, better connectivity with economic centres and improved infrastructure will increase urbanisation and industrialisation in the region. These areas will compete with for the available agricultural land and resources for agricultural production in a region which is already facing scarcity of resources.

With the completion of the bridge on the Padma River, the travel time by road from Dhaka to Khulna is halved to about five hours. This time savings provides great opportunities for farmers to transport their agricultural product much more quickly to Dhaka. This bridge can potentially boost the agricultural production in the region and increase demand for labour which can potentially counter the climate-related outmigration. However, to make this vision a reality, the existing agricultural system must adapt to climate change, as it will face complex (climate and development) challenges in the future.

3.3 Effect of the pressures and drivers on food systems

3.3.1 Agricultural production

Climate change, sea level rise, salinity intrusion and land use change will affect the agricultural sector as a whole in the future. The cost of natural disaster and environmental degradation is predicted to increase due to higher heat, humidity, salinity intrusion and frequent flooding, thereby hampering production of rice, vegetables and other agricultural production sectors. As such, 9% of total GDP can be lost due to severe flooding in the future, which is especially the case in southwestern Bangladesh. These factors will not only have a negative impact on the economy; they also increase the risk of food security and might result in climate migration.

From an aquaculture perspective, changes in temperature and seasonality can potentially negatively impact the growth rate, reproductive capacity, health, mortality and migration of fish. With salinity intrusion further inland, the existing ecosystem might be altered, thereby affecting fish production. Although salinity intrusion can create more opportunities for shrimp culture, it can also adversely impact the existing freshwater aquaculture adversely. Due to the potential increase in natural hazards such as droughts, floods, river bank erosions and storm surges, the aquaculture infrastructure can be damaged, hampering existing aquaculture practices (Ministry of Foreign Affairs, 2018). The intensity of extreme weather events such as cyclones is projected to increase in the future and, due to climate change, the sea current can potentially change. These changes will endanger the lives of fishermen and their livelihood in the future.

The effect of climate change directly and indirectly impacts livestock production and health parameters. Several biophysical parameters are affected: growth milk and meat yield and quality; egg yield, weight and quality; and reproductive capacities (Ali et al. 2020). These changes will impact the current animal production systems in Bangladesh. Animals can get sick, or their productivity can decrease, due to heat stress or abundant salt intake through drinking water and/or feed. Moreover, the combination between both pressures is known to have worse effects than if they exist separately. Additionally, due to drought, salinity intrusion, waterlogging and frequent flooding, the availability of feed is decreasing, while demand is increasing already. Specific crops and fodder are not drought and/or salt tolerant; consequently, low quality and quantity influences the possibility to generate production or high productivity of animal production.

3.3.2 Mangrove and aquaculture

Mangrove forests are also threatened by climate change and its effects, which include rise in sea level, rise in air and water temperature and change in frequency and intensity of precipitation and storms. Among these effects, rise in sea level poses the greatest challenge to survival of the mangrove, as inland migration of mangroves is obstructed if there is a lack of available suitable land and if the rate of migration is slower than the rate of sea level rise (Dasgupta et al. 2017). Salinity intrusion and lack of nutrient supply will further increase the threat. All of these challenges will have implications for the survival of mangroves and the Sundarbans. Dasgupta et al. (2017) suggested that the poorest coastal districts of Bangladesh will have the greatest negative impacts due to aquatic salinity driven mangrove migration, as the standing timber value and honey production will decrease, and the risk of human-wildlife conflict will increase. The Sundarbans also contribute about 53 million USD per year through tourism (Mohammad et al. 2021).

The loss of mangroves and substitution by aquaculture have translated, among others, into faltering fisheries and a net loss of food, micronutrient and nutrition security for Bangladesh, for the poorest consumers in particular (Belton et al. 2014). The loss of mangroves has also been shown to have increased vulnerability of low-lying coastal areas to climate and weather-related phenomena (Marois and Mitsch, 2015). Thus, the loss of mangroves not only impacted coastal safety for man and infrastructure, but also impacted the food system. For instance, the ever important and extensive shrimp farming in the southwestern part of the country is highly vulnerable to natural weather-related phenomena, cyclones and flooding, diseases, excess water temperature, salinification, water contamination and unstable product prices (Paul and Vogl, 2013). Deb and Ferreira (2017) show that the degradation of mangroves in grassland could raise the surge elevation by 57% and increase flood waves by up to 2730% for Category 3 cyclones. Inland penetration and total flooded area would, respectively, increase by an estimated 10 km and 18%, even for low-intensity cyclones (Deb and Ferreira, 2017).

4 Transition Pathways: Initial Directions for Southwestern Bangladesh

The research explores potential transition pathways for a resilient and sustainable food system in deltas. Several parts of the food system and water food nexus are addressed and combined, connecting field, farm, regional and national levels in deltas. The description of transition pathway directions is specifically focussed on the southwestern region of Bangladesh, which is extremely vulnerable to salinity intrusion from sea level rise. The transition pathways directions are clustered into four themes: mangroves, water and soil management, livestock and human behaviour. These four themes link to possibly interesting directions for the food system, such as more protein production, which thereby addresses demand, and at the same time ensures income for farmers, while a need to address climate change and sustainable development remains. Eventually, if stakeholders are interested in exploring paths further, there will be more research needed to explore what could be sustainable. This chapter explores first initial steps on possible transition pathways for mangrove/aquaculture, improved water management, salinity and livestock and farmer behaviour.

4.1 Nature-based transition pathways in aquaculture with mangroves

The important and extensive shrimp and fish farming in the southwestern part of the country is highly vulnerable to natural weather-related phenomena, cyclones and flooding, diseases, excess water temperature, salinification, water contamination and unstable product prices (Paul and Vogl, 2013). To reduce natural vulnerabilities, mangrove reforestation will be needed. In addition, mangrove non-timber forest products can help to diversify farm production, reduce expensive feed input, improve water quality and reduce vulnerability to disease (Debrot et al. in review). Production of organic shrimp, even without the additional benefits of mangroves, also serves to decrease livelihood vulnerability (Paul and Vogl, 2013). Mangroves regenerate rapidly and furthermore have a high ability to adapt to sea level rise (RSLR) (Bomer et al. 2020). In addition, mangroves are extremely productive systems that provide many ecosystem services. While shrimp culture may yield 8,000 to 30,000 USD ha^{-1} yr^{-1}, the total economic value (TEV) of mangrove forests is much higher, between 15,937 – 57,000 ha^{-1} yr^{-1} (Russi et al. 2013; Rumahorbo et al. 2019).

Transition pathways within the scope of decreasing vulnerability of aquaculture production systems in southwestern Bangladesh should therefore focus on a) mangrove restoration and b) (re)introducing mangroves into the shrimp farming system (e.g. Hai and Yakupitiyage, 2005, Gatune et al. 2012, Tendencia et al. 2012, Tuan et al. 2013, Bosma et al. 2016, Rahman et al. 2020, Alam et al. submitted). A schematic overview of benefits for shrimp farmers regarding this transition pathway is presented in the figure below.

Figure 15 *Overview of the many benefits of mangrove presence on pond aquaculture production (Photo: A. Debrot)*

Recent research suggests that mangrove aquaculture systems should be limited to less than 30% of the total surface area to ensure sustainability (Bosma et al. 2016, Luom, 2019). To help achieve greater socio-economic resilience and reduce environmental degradation, Paul and Vogl (2012) have further pointed to opportunities in expansion of organic shrimp aquaculture in Bangladesh. Organic shrimp aquaculture can be characterised as relatively high yield, low production cost and high market prices. Furthermore, small holder farmers are likely to earn more income benefits from organic shrimp aquaculture than their larger-scale counterparts, making it highly suitable for typical small-sized family farms (Paul and Vogl, 2012).

Figure 16 shows an example how a mangrove-shrimp system can be developed.

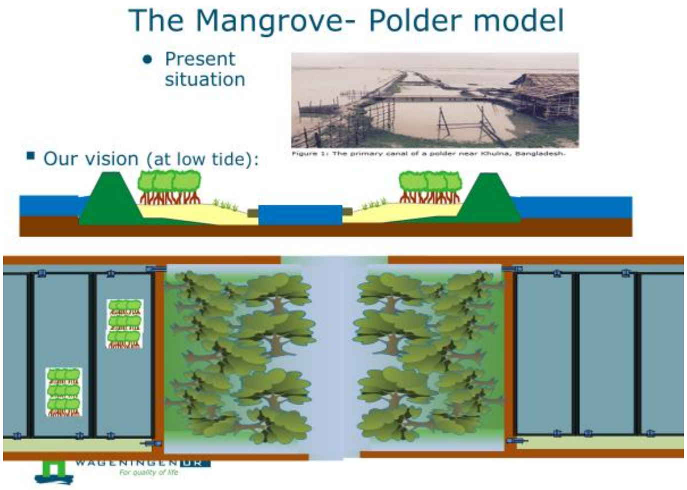

Figure 16 *How mangroves can be incorporated into the aquaculture landscape to simultaneously serve both pond aquaculture and broader ecosystem services using the Associated Mangrove Aquaculture (AMA) approach (Figure: Roel Bosma)*

In general, mangrove forests support livelihoods and, more importantly, also provide coastal protection among various other ecosystem services. The restoration of mangroves combined with aquaculture has the potential to increase fisheries and be a net gain in food production, micronutrient and nutrient security for Bangladesh. Restoration of mangroves has been demonstrated to reduce vulnerability of low-lying coastal areas to climate change, such as salinity intrusion from sea level rise. Thus, increase of mangroves positively impacts coastal safety as well as the food system as a whole.

4.2 Improved water and soil management

Water management is one of the key elements of the agricultural system. In southwestern Bangladesh, canals (locally called *khals*) are crucial for supplying irrigation water to fields and ponds, but also serve as drainage to discharge surplus water. However, due to sedimentation of canals and excessive growth of water hyacinths, these water-related functions are hampered. In dry seasons, water scarcity is prevalent, which limits agricultural and aquacultural production. In some areas, only one growing season is possible. During wet seasons, waterlogging and flooding events occur, which are pressures in particular for agricultural production.

A potentially attractive transition pathway is to systematically improve the regular and systematic excavation and maintenance of small waterways and the removal of water hyacinth. Six pilots conducted by Solidaridad (documented in Mornout et al. 2022) assess the preliminary impacts on agricultural production systems from dredging at micro-watershed level. The first results indicate an increase in rice production when the possibility emerges of growing rice in two seasons instead of only one. In addition, vegetable cultivation increased in some of the pilots, as the irrigation and drainage demand was better matched with the crop requirement. Another benefit was observed for aquaculture production, in particular shrimp. Aquaculture in southwestern Bangladesh relies on sufficient freshwater to remove accumulated pollutants from ponds, which was hampered when the canals were sedimented. Due to project interventions, though on a limited scale, more regular water refreshment became possible, leading to increased shrimp production. Continuation of maintenance (beyond the one time only) will be critical, as will be scaling to the landscape and national level, which is currently being explored.

Another transition pathway is increased agricultural water and soil management on field level, and two categories can be distinguished: i) water storage and retention and ii) modern irrigation techniques and agricultural practices. In our research, this pathway was not covered for Bangladesh. Wilbers studies this in the context of Vietnam (Wilbers et al. in preparation). Regarding storage, jars and tanks provide opportunities to store water in the wet season for usage during dry season. Quantities are limited, but may be sufficient, e.g. as a water source for livestock. Larger basins are also possible and can provide a buffer capacity for irrigation during the dry season. However, this is probably only feasible when storage water can simultaneously also be used for other economic purposes, such as fish cultivation, since the claims on land are substantial and land is already very scarce in Bangladesh. Another option is sub-surface storage through controlled sub-surface drainage systems or managed aquifer recharge (Hasan et al. 2019). An advantage of such a system is also to control groundwater and salinity levels enhancing crop yields. However, the drainage system itself can be used as a freshwater storage buffer when the outlets to main drainage canals are controlled. Experience on groundwater use and storage has been documented in Ahmed et al. 2022.

Improvements in land and soil management on field scale, aimed to reduce usage of brackish to saline irrigation water, can also be an interesting transition pathway. Irrigation techniques such as drip irrigation help to achieve this goal. It should be noted that leaching should be done regularly with such interventions to eliminate accumulated salts. Another approach is to increase the organic content which enhances the capacity to hold soil moisture and thus can reduce irrigation needs. This can be achieved by fertilising the soils with compost. Prevention of deep tillage during the dry season prevents accumulated salts from deeper soil layers to be brought upwards and enter the root zone. The creation of raised beds during the dry season may also provide an adaptative measure during the dry season for e.g. vegetable production. As salts tend to accumulate at the sites of beds, lower salinity levels in the centre provide the opportunity for crops to be cultivated under brackish/saline conditions. Additionally, furrow irrigation in relation to raised beds can be applied to stimulate salt accumulation on one side of the raised bed only, while crops are grown on the other side (with lower salt concentrations into the soil).

In general, transition pathways from a water and soil management perspective in Bangladesh can only work if they focus on combining local-level solutions with landscape-level and national-level solutions. In this way, rejuvenating rivers and canals to prevent clogging by water plants and siltation, field-scale water storage, and irrigation and agricultural practices focussed on maximising agricultural production under brackish to saline environments can contribute to larger policy goals like e.g. BDP2100 and NAP.

4.3 Innovations in livestock sectors

The effects of climate change challenge current animal production systems in Bangladesh. Animals can get sick, or their productivity can decrease due to heat stress or abundant salt intake through drinking water and/or feed. Moreover, the combination of both pressures is known to have worse effects than if they exist separately. Additionally, due to drought and salinity, there is limited feed available. Specific crops and fodder are not drought and/or salt tolerant; consequently, low quality and quantity influences the possibility of generating production or having high productivity of animal production.

At the same time, the market for dairy products increases as the income of the population increases. This is the case in Bangladesh. At the same time, more people live in cities, which requires the development of a good value chain to bring milk to cities. The limitation in Bangladesh is that the cost price of milk in rural areas, including transport costs, has to compete with (subsidised) imported milk powder. Furthermore, cold storage facilities are still few in number, thereby limiting marketing possibilities. Through its Safal project, Solidaridad is supporting farmers in enhancing production and further developing market opportunities.

With regard to climate change, the following is already available from livestock literature:

The main transition pathways for the livestock sector to deal with climate change impacts (heat stress, decreased water quality) are the following (Hoving et al. 2014):

- *Improvement of livestock genetic resources.* What is needed is livestock which are genetically efficient and well adapted to extreme temperatures and low quality diets and which have greater disease resilience. Climate-resilient breeds can improve and maintain food production, but in practise those breeds often cannot keep their expected productivity in more extreme climatic or endemic disease situations. Therefore, one should avoid quickly replacing locally adapted breeds with ‘indiscriminate’ crossbreeds, due to the loss of adapted traits and lower economic benefits. Well-considered breeding programmes adapted to local environments must be seen as long-term investments.
- *Health*. Climate change is likely to affect the distribution and seasonality of important infectious diseases, which impacts animal health. Not only higher temperatures, but also heavy precipitation events and flooding, will increase the risk of outbreaks of diseases transmitted by arthropod and water-borne vectors. Although climate change can increase the need for animal health care, it does not directly lead to need for new veterinary knowledge. Developing an effective veterinary service is probably the most important strategy for dealing with climate change in developing countries, and it is also essential to improve livestock production, thereby contributing to food security.
- *Housing.* Housing and management measures can prevent problems due to extreme climate conditions, like heat stress, but they are only feasible in capital-intensive livestock systems. The function of housing is to match the needs of animals and humans to reach higher livestock productivity with reduced inputs. As a consequence of housing, the demand for labour is changing, and capital is needed to acquire supplementary feed and fertiliser and to invest in buildings, storage and transport. Expert knowledge is needed for feed conservation, animal nutrition and manure treatment.

Further work exploring a transition path to create employment for farmers will need to take all these aspects into account.

4.4 Farmer behaviour

The transformation of smallholders is vital to achieving the desired development goals. However, how to efficiently encourage the transition to resilient and sustainable farms, with an efficient farm size, and especially how to reach the number of farmers needed for efficient food production, is still underexplored. Solidaridad targets farmers with different strategies according to their expected behaviour and circumstances. For example, in the case of technology adoption, it is common that farmers identified as followers would need another approach than those who are front-runners.

Therefore, to achieve a behavioural change, it is critical to understand how farmers learn from each other. A package of different incentives/approaches is required to make behaviour change for farmers more attractive. For example, a new rice variety has a higher yield and a shorter duration, which is better with regard to climate resilience.

For transition pathways that focus on farmers' behaviour, supporting local-driven processes and the agricultural transition toward a sustainable food system will be important elements. The existing food system is the result of the activities of various stakeholders in the system, and changing it requires (some of) these actors to change their behaviour. Stimulating change requires an understanding of the role of these actors, their objectives, and how their activities can support change (Van Berkum et al. 2018).

Following the guidelines to facilitate transition pathways, the transition process can be seen as a process that encompasses several activities (Verhagen et al. 2022). Research needs to be embedded in ongoing and planned activities, and interaction with local stakeholders is critical, such as presented in the transition guidelines developed under this project. In collaboration with Solidaridad in the study region, we plan to identify the relevant particularities, for example, for Associated Mangrove Aquaculture (AMA) in southwestern Bangladesh, as a starting point for developing transition paths. The aim is to understand the goals for change and then prioritise them.

5 Conclusions and Recommendations

5.1 Conclusions

The Bangladesh delta, which receives nutrient-rich sediments from three large rivers, is a productive agricultural system that provides fisheries, livestock products, rice, vegetables and fruit among many other food items to feed the country's large population. Most of the people in Bangladesh rely on their own cultivated food items for daily consumption, with poor farmers lacking access to markets and having minor financial means to purchase external goods and services; these are typical characteristics of basic food systems with short value chains which are dominant in Bangladesh. However, the delta is facing multiple pressures that make agricultural productivity and food self-sufficiency now and in the future more uncertain, and these changes affect farmers. Although population growth and economic developments put pressure on food systems from a consumption side, they also create opportunities for employment and income. The production side is faced with multiple environmental pressures, uncertain prices and large losses in the value chain after harvesting. A large external pressure on Bangladesh's food system is climate variability and climate change, which increase floods and droughts, cyclones, changes in water availability and, last but not least, sea level rise. The latter, combined with upstream (over) use of water, results in increased soil and water salinity. This affects crops, freshwater fisheries and livestock production. As a result, this climate change-related impact, combined with development-related pressures, is threatening the future production of major food items for which the country is dependent, and viable transition pathways and adaptative measures to address this are urgently required. Transition pathways must connect national policy priorities with viable local-level adaptation strategies and measures. This is especially the case in southwestern Bangladesh, which is characterised as a low-lying land near the coast and encompasses various food production systems within particular and often combined aquaculture, rice and livestock rearing. This region is extremely vulnerable to climate change-induced soil and water salinisation, but also has to deal with waterlogging, flooding, cyclones and droughts. Adaptive measures or strategies, also called transition pathways, directed at multi-disciplinary interventions towards a sustainable future food system, are required. The report explores four initial directions for transition pathways:

- Mangrove forest restoration: Mangrove forests in combination with shrimp cultivation provide a positive business case for farmers while enhancing multiple other ecosystem services. It also provides an opportunity to create organic shrimp cultivation with higher market prices, a main benefit for farmers. A main advantage also lies in mangroves providing protection against natural shocks such as cyclones and tidal waves. Furthermore, mangrove/shrimp production systems are resistant to increased water and soil salinisation. Therefore, this option is particularly relevant for southwestern Bangladesh.
- Improved water and soil management: this should be done through improved management of waterways, with a focus on sediment removal of waterways, to allow for better irrigation and drainage possibilities. However, sediment and water management practices should be improved to prevent continuous siltation of waterways. These interventions can also be combined by planting mangroves on the river and the pond. Other promising transition pathways lie in usage of modern irrigation techniques, (sub-surface) water storage and changes in agricultural practices such as tillage management. These measures are particularly relevant to better cope with increased water and soil salinity, waterlogging and flooding problems in southwestern Bangladesh.
- Livestock: increased heat stress and changes in water availability and quality are main risks for animal health, production and thus food security. Adaptive measures should focus on adjusting genetic resources for animals that are more resilient towards climate-induced changes. Increasing veterinary services and capacities are also important to address animal diseases. Housing of animals focussed on providing sufficient and safe water and controlling temperatures are also affective adaptive measures, although such investments are mostly feasible for industrialised and large-scale livestock farms.
- Farmer behaviour: Farmer behaviour is an important aspect in driving changes. Interventions can be feasible from a technological point of view, but they only work when executed, adopted and accepted appropriately by farmers. In this context, the identification of relevant particularities, for example, for Associated Mangrove Aquaculture (AMA) in southwestern Bangladesh is required.

5.2 Recommendations

The above-mentioned transition pathways, and possibly other, need to be further elaborated and explored, together with stakeholders. Along with implementation, further research can be helpful to scientifically underpin such pilots and demonstrate solutions. When interventions prove to be successful under field conditions, further feasibility assessments are required which are specific to social-environmental and economic impacts, now and in the future. These interventions should happen in co-creation with farmers, taking into account possibilities for farmer adoption and collaboration, impacts on crop and water production among other ecosystem services and cost-benefit analysis. Upscaling strategies should be explored for the most promising routes looking at the policy framework that exists in Bangladesh. More specifically, upscaling of innovations at pilots can only be successful when those contribute to national and regional development objectives. The relevant stakeholders responsible for the operationalisation of policies should be involved in an early stage.

Currently, pilots have been developed in southwestern Bangladesh at the micro-watershed level, sometimes combined with mangrove plantations, linking water management to value chain improvements. These pilots are in a demonstration phase and have yet to be linked to water management at the landscape and national level. Further impact assessment will benefit the further development of such pilots. Pilots should also focus on socio-economic and environmental adaptiveness potential and the identification of upscale potential. Synergies and trade-offs need to be further understood for scaling of pilots and making such piloted interventions helpful in contributing towards the Zero Hunger objectives (SDG 2).

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