Climate change scenarios and adaptation strategies at shrimp farms in the South-west of Bangladesh

A Case Study

M.Sc. Thesis by Mathijs Marinus Augustijn

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Abstract

In the shrimp farming sector of South West Bangladesh, a race is taking place between climate change and adaptation strategies. Currently, climate change has taken the lead, and the shrimp sector is already grappling with its adverse effects. The question of how long shrimp production can sustain as a viable option in the long term remains uncertain. This research aims to explore this viability of shrimp farming in Bangladesh by constructing future climate scenarios, utilizing a combination of climate models and the adaptive capacity framework. Additionally, this study examines potential climate change adaptations that could reduce climate change related vulnerabilities. The results indicate that climate variables, such as temperature, salinization, and precipitation, are projected to worsen under the RCP 4.5 and 8.5 scenarios in the coming 75 years. The issues faced by farmers are complex and diverse, with climate change exacerbating the majority, but not all of these challenges. Climate change adaptations are currently being implemented on farms. However, their use is inconsistent, and scientific evidence supporting their efficacy is lacking. This research concludes that the shrimp farming sector is at significant risk in the future, with climate change being a prominent driver, yet other social and economic factors should not be neglected. While climate change adaptations are crucial for mitigating these risks, additional comprehensive range of solutions, with an increased scope, will be necessary to ensure the sector's survival. A combination of Adaption pathways and demonstration fields with integrated research are recommended as a good starting point.

1. Introduction

In the last decade climate change has emerged as one of the biggest challenges worldwide. In essence developing countries have contributed the least to the problem, yet they are expected to bear the biggest impacts of climate change, threatening to hamper development and livelihoods across the globe (IPCC, 2022).

A developing country that is disaster-prone to climate change is Bangladesh. In the IPCC (2022) report, Bangladesh was stated as one of the most vulnerable countries in the world to both natural disasters and climate risks. The reason for this has to do with a combination of geographical location and socio-economic situation. The country is characterised by an enormous delta, vast plains, and low-lying lands in combination with a monsoon climate and the large river systems flowing through it. This makes the country highly exposed to different natural calamities (Ali, 1999). Examples of natural violence Bangladesh must deal with are droughts, floods, erosion, tropical cyclones, storm surges, and salinization. The impacts of these can be detrimental and will be discussed further on in the following chapter. At the same time, the socio-economic situation is far from ideal to cope with the natural hazards. The country has an extremely high population density, shortage of land, problems with food security, poverty, and so forth (Hossain, 2020). This combination makes the problems as severe and complicated as they can get. Nearly all sectors present in Bangladesh are already experiencing negative effects due to climate change and the prediction is these negative effects will snowball into catastrophic levels.

The focus of this thesis is on the shrimp farming sector. Shrimp farming in brackish water is a prevalent and traditional practice in coastal Bangladesh. Low-lying tidal flats are used for shrimp aquaculture. The country is known as one of the most suitable places in the world for tiger shrimp (*Penaeus monodon*) aquaculture. This cultivation of shrimp has a high potential due to the excellent biophysical resources as well as agroclimatic conditions the country has to offer. The subtropical environment with vast amounts of brackish water of Bangladesh offers special possibilities for shrimp farming. The easy access to wild post-larvae enhances this suitability. It is estimated that in 2020, 260,000 hectares of land is used for cultivation, of which 75% is located in the southwest and the remaining 25 percent found in the southeast (Ahmed, 2015).

Shrimp farms have different practices. By far the most common practice is *traditional (extensive) farming.* This practice is known as highly dependent on the environmental surroundings and has both a low input cost and low management needs. The stocking, seed source and feed used are all natural in this traditional type of farming. Also little to no fertilizer and lime (for disinfecting water) are used. The water exchange is dependent on the tide. This practice has relatively low yields (t/ha/yr) in comparison to other shrimp farming practices (Paul & Vogl, 2011). *Improved extensive farming* is mostly similar to traditional farming but has some moderate inputs additionally. For example, the feed is mostly natural but also contains low-cost additional feeding. Small amounts of fertilizer and lime are added to the water. Water exchange is tidal but also minimal pumping is done. This results in a three to six times higher yield than the traditional practice (Paul & Vogl, 2011). Lastly, *semi-intensive* and *intensive shrimp farming* can be found, which is done on a small scale in Bangladesh (FAO, 2017). These practices have a high number of inputs. Hatcheries for seedlings are in place and the stocking is artificial. Feed is formulated and water exchange pumps are used regularly. The survival rate and yield are significantly higher than that of both extensive farming. (Paul & Vogl, 2011)

In total the farms had a combined production of 125,000 metric tons in 2020 (FAO, 2017). Due to the enormous demand for shrimp on the international market, notably in western countries, the sector has grown to be a multimillion-dollar business in Bangladesh and has given the shrimp the nickname 'white gold'. The export was over 300 million US dollars, making it one of the highest ranked export products in the country, making it highly contributing to the nation's economic expansion. In addition, the industry has given many farmers a livelihood that they can depend on. Next to the farmers' many other locals in the coastal area can profit from the industry, which are being involved in the collecting, selling, processing, and export of shrimp (Ahmed, 2015). Overall, shrimp farming is crucial to Bangladesh's economy since it generates significant foreign cash, increases food production, diversifies the economy, and creates more prospects for employment (Ahmed, 2013), making the industry a crucial lifeline on both national and local levels.

1.1 Problem statement

Despite the numerous economic advantages of shrimp farming, this decade several factors have put Bangladesh's coastal shrimp farming at risk, with climate change being one of the important factors. The possible effects of climate change on shrimp aquaculture might have severe repercussions on Bangladesh's economy (Saha, 2017).

Climate change impacts on shrimp farming in Bangladesh, along with the impacts of the industry itself on the environment are well-documented processes. Several studies (Dash et al., 2021; Islam, 2019; Mahmuduzzaman, 2014; Ruto et al., 2020; Biemans et al., 2019) have researched current and past climate change in Bangladesh, focussing on the variables of temperature, rainfall, sea level rise, drought, salinity, floods, cyclones, and river discharge. These studies have concluded that all variables have been changing in such a way they have had a negative impact on the country (for example Temperature and sea level rise increasing). Further research (Islam, 2019; Ahmed et al., 2013) has been done on how this current change in variables has affected shrimp production. An observation by the two papers was made, in which the last decade and currently the climate variables have severely hampered the production (yield) of shrimp farms. Despite the research done on climate change, there are still some key elements in which a knowledge gap exists.

Firstly, the majority scientific research has focussed on climate change both currently and in the past, and its effects on coastal Bangladesh. Far less is known about future predictions on climate change and how this will process on a farm level, as well as the perspectives of farmers on climate change. Thereby, **Climate scenarios** (Chapter concepts) a tool to explore future predictions are still untouched for shrimp farms. These **climate scenarios** will be essential in scoping out opportunities, and risks, exploring scenarios, potential adaptations, etc. Furthermore, with this knowledge, a part of the uncertainties the farmers must deal with can be mapped, which could act as a starting point for sustainability on these farms.

Secondly, In the report of FAO (2017) issues within shrimp farming were presented. These issues focussed mainly on issues that arise because of farming practices. Setting down shrimp farming as a root cause of the environmental problems in the area. These include the destruction of nature like mangroves, as well as biodiversity loss and landscape deterioration. This same nature is essential for the production of shrimp. Yet, the **issues from a farmer's perspective** are often neglected in research. Mapping out these issues could contribute to more robust findings in the future.

Thirdly, while the environmental impacts are well documented, yet the specific **water management** aspects are often neglected. Water plays, both directly and indirectly, a vital role in both cultivation, environment and is heavily affected by climate change. Looking at the water management could be the red thread in finding opportunities for adaptation.

Lastly, the term **climate change adaptation** has gained traction in the last decade with seeking solutions to climate change. IPCC 2022 defined climate change adaptation as the following: "The process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities. In some natural systems, human intervention may facilitate adjustment to expected climate and its effects.'' Limited research is done on climate change adaptation specifically in the shrimp industry of Bangladesh. The studies that have been conducted, were mostly focused on existing climate adaptions (Islam, 2019). Yet, a knowledge gap is found in using climate scenarios in combination with climate change adaptations. Furthermore, the perspectives of both experts and farmers themselves on using climate change adaptation, and their vision of how to sustain shrimp farming in the future, have not been mapped before.

1.2 Research objective

The main objective of this research is to explore the future viability of the shrimp farming in coastal Bangladesh. By assessing current water management challenges as well as future climate change scenario's, the objective of this research is to identify which climate change adaptation measures may be needed to be able to deal with current and expected challenges for shrimp farming in coastal Bangladesh.

To reach this main objective, the following objectives were formulated:

1. To analyse and develop future scenarios on climate change in the study area using two RCP Scenarios (RCP4.5 and RCP8.5);
2. To map farmers perspective on climate change and their issues;
3. To map current adaptation strategies on shrimp farms;
4. To map both experts and farmers perspective on what adaptation will be essential to sustain yield.

1.3 Research questions

Main research question

- *What are the future scenarios for climate change impact on shrimp farms and what are the potential adaptation strategies, regarding water management, for the farmers in sustaining their livelihood?*

Sub-questions

1. ***To what extent is climate change expected to affect the shrimp farms of Bangladesh in the future?***

1.1. What are projected climate change effects on temperature, precipitation (including droughts), sea level rise, cyclones and salinization dynamics in southwestern Bangladesh according to literature on models?;

1.2. What are perspectives of farmers on current issues and future climate change at shrimp farms?;

1.3. What are plausible climate scenarios for the long term (50 years) in the south-west of Bangladesh for shrimp farms, based on RCP4.5 and RCP8.5?

2. ***Which possible adaptation strategies to climate change can be taken at the shrimp farms?***

2.1. What adaptation strategies have already been taken at shrimp farms?;

2.2. To what extent do farmers share knowledge and help each other with adaptation strategies?;

2.3. What are potential adaptation strategies to sustain livelihood in the future, both from an expert and farmer point of view?

2. Concepts and Theories

2.1 Climate change scenarios

The concept of climate change scenarios can be defined as "'A set of hypothetical events set in the future constructed to clarify a possible chain of causal events as well as their decision points (O'neill, 2020). Because climate change is a hugely complex phenomenon, there is always some degree of uncertainty in climate projections. For this reason, climate scenarios, a strategy that acknowledges the limitations of predictions and uncertainties, has become a popular tool for both researchers and decision makers. In essence climate scenarios, can be used as a guide to get stakeholders ready for future situations outside of already recognized trends (Star et al., 2016).

Furthermore, these scenarios are a tool to explore future states and map alternative response options. The process generates a small number of potential futures (scenarios) that include major uncertainties and can serve as a starting point for conversations on management decisions and community visions. It is important to note that the process does not assign probabilities to specific future conditions, making scenarios non predictive. Instead, it broadens discussions to cover a variety of possible answers, urging institutions to move forward in the face of uncertainty and keeping a flexibility when preparing for these uncertainties. (Moore et al., 2016)

Scenario planning is a technique which is used for medium to long term planning, where storylines are defined that explore future developments, based on interpretations of the present. Such interpretations are about key uncertainties, for example the severity of climate change or how society will develop socio-economically (Seijger et al., 2017). In Figure 1, a template for scenario planning is shown.

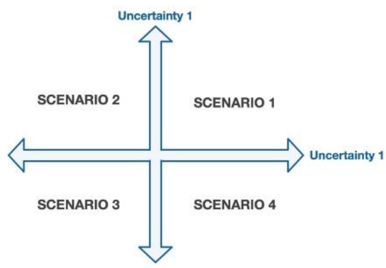

Figure 1: Climate scenario template

2.1.1 Process and type

Within the concept distinctions can be made between the process and type of scenario planning. In the process there are two distinctions: Research driven process and participatory process. In this paper the research driven process will be used, therefore only this will be further explained.

- Research driven process: The creation of scenarios is driven by experts, with the goal of producing thorough descriptions of possible futures that include information that is backed up by the most relevant scientific findings. For studies on climate change, climatic model projections of changes in temperature, precipitation, and other climate variables are used for the scenarios (Star et al., 2016). **In this research quantitative data out of climate models will be used to eventually make a qualitive narrative as scenario.**

Next to process, there also is a distinction in the type of planning. Three categories are present: Present, explorative, and normative. For this research the explorative category will be used to get the best representative scenarios. The explorative type presents a variety of distinct, conceivable futures, attempting to weigh the effects of certain course of action. Such scenarios are primarily intended to highlight the potential repercussions that various futures may have. When a changed strategy, policy, or perspective is the desired result, all developed scenarios are deemed equally realistic and taken into account (Star et al., 2016).

As can be seen in Figure 1, at the climate scenario template, the graph consists of an x-axis as well as an y-axis. In this research the following uncertainties are used:

x-axis: **Climate change severity (RCP)**

y- axis: **Adaptive capacity**

2.1.2 Representative concentration pathways (RCP)

It is required to make assumptions about potential physical changes to the environment that will affect the impact of future climate change in order to properly simulate climate change developments for the south-west Bangladesh region. For this reason, this research has made use of the representative concentration pathways (RCPs), which is a method to capture those assumptions within a set of pathways for the future (Meinshausen et al., 2011). They include global warming scenarios, based on radiative forcing (in watts/m2).

Two of four RCP scenarios have been used in this research. They include the Business as Usual (BAU) scenario and Extreme (EXT) scenario. The BAU scenario (RCP4.5) assumes that national and international efforts to reduce greenhouse gas emissions are maintained, taking into account a mild climate change scenario. On the other hand, the EXT scenario (RCP8.5) takes into account the scenario of extreme climate change without any regional or national initiatives to mitigate GHG.

With the use of these RCP’s, a lot of scientific research has been done to make climate projections on certain climate variables. These are presented in the methodology.

2.1.3 Adaptive capacity

In this research adaptive capacity is defined as the following: "A (human) system's capacity to react to climate change (including climate variability and extremes), to minimize possible harms, to take advantage of opportunities, and to cope with the consequences"(Siders, 2019).

An important term in adaptive capacities are ‘’coping ranges’’. These can be defined as the conditions that a system can handle, accommodate, adapt to, and recover from. The majority of communities and sectors can adjust to (or cope with) typical climatic conditions and moderate deviations from the norm, although exposures to extreme occurrences may fall outside of this range or may exceed the community's adaptation capacity. The coping range is dynamic. Coping levels are adaptable and alter over time in response to changes in institutional, social, political, and economic circumstances. For instance, resource depletion or population pressure may gradually lower a system's capability to adapt and widen its coping range, but economic expansion or advancements in technology or institutional frameworks may result in a rise in adaptive capacity (Cinner, 2018) (Mortreux, 2017).

Dimensions and indicators of adaptive capacity

Adaptive capacity consists of dimensions and the coherent indicators. Figure 2 shows the dimensions and indicators used in this research for the construction of the climate change scenarios, which are further elaborated in this chapter. It is important to note that the indicators of natural resources are adjusted to fit in the shrimp farm perspective (see *natural resources*).

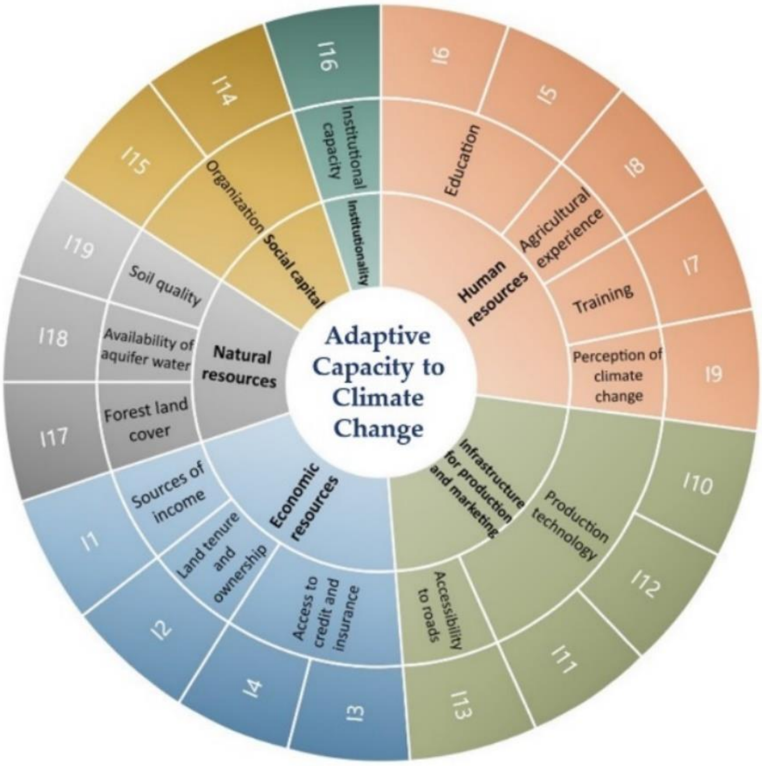

Figure 2: Dimensions and indicators of adaptive capacity (Maldonado-Méndez, 2022)

Economic resources

Farmers' economic situation is crucial for developing adaptive capacity and is closely tied to diversifying their sources of revenue or livelihood. Farms with variable sources of income are better able to make decisions, deal with the difficulties and effects of climate change, and come up with adaption plans (Zanmassou, 2020). Those with fewer options for earning a living, however, have been demonstrated to be more vulnerable. As a result, smallholder farmers who only engage in primary activities frequently have extremely limited potential for adaptation. Furthermore, land tenure is crucial in the agricultural sector because it serves as the foundation for organizing basic operations and enables producers to make decisions and long-term adjustments to on-farm management (Zanmassou, 2020; Maldonado-Méndez, 2022).

Human resources

Improved adaptive capacity is directly correlated with education and the development of people's or communities' capacities (Choden, 2020). The more educated the household members are, the greater the availability of knowledge and information about environmental concerns. The perception of the effects of climate change is more acute. To achieve innovation processes in the agriculture sector, education is a crucial component. There is proof that education is a crucial element and is connected to a number of processes that can lead to better adaptation to the effects of climate change(Lutz, 2014). The preservation of natural resources has a cultural component that enables synergy between people and the environment. Traditional knowledge—the customs, values, and worldview of indigenous and rural communities—is also taken into account when developing measures for coping with climate change. Since it enables them to have a more thorough degree of perception and can create a knowledge wave at the local level, the experience of the farmers is crucial and can benefit their ability to adjust to climate change (Bryan, 2009).

Natural resources

Natural resources serve as the foundation for the construction of other resources and capitals, provide sustenance for all life forms, and help to control the environment (Belle, 2017). This paper uses the indicators of water quantity and quality. The quality and availability of (brackish) water will vary depending on each farmer's production environment; the more water a farm has, the better its potential for adaptability, and the problems associated with implementing adaptation measures will be lower than for a farmer who doesn't have enough water.

Social capital

Networks or groups within a community help to build links in the event of a social or climatic crises and increase the readiness of farmers to develop methods for adapting to climate change or to ask for government assistance. Farmers, according to studies, imitate their neighbours' behaviour and rely on one another for knowledge. Peer-to-peer knowledge replication is more likely when a farmer-to-farmer extension technique is used (Maldonado-Méndez, 2022).

Institutions

The existence of formal and informal institutions in a region or community is significant because they have the potential to positively or negatively affect people's ability to adapt as well as the success of adaptation processes (Berman, 2012). This depends on the power dynamics and degree of interaction between these institutions. Politics and institutionality are just two of the many elements that have a significant impact on adaptive capability. To prioritize institutional efforts and direct them towards the most vulnerable populations or those with the greatest production risks as a result of climate change, good governance is crucial.

Infrastructure for production and marketing

An advantage and factor in having a high adaptive capacity, as well as one that makes it easier to embrace new technologies and adaptation techniques to climate change, is the availability of technology and infrastructure for carrying out basic operations (Maldonado-Méndez, 2022). Farmers that have improved infrastructure tend to be less exposed to the effects of climate change and to experience less hardship.

The previously mentioned dimensions that affects adaptive capacity are linked. Hence, it is impossible to isolate individual factors since the combination of determinants that vary in space and time leads to adaptive capability. The dimensions that influence adaptive capacity exist and behave differently depending on the environment.

2.2 Climate change adaptation

Due to the connections between development and adaptation, efforts have been made to address the two problems jointly and to "mainstream" climate change adaptation into development planning and support (Ayers et al., 2014). The process of mainstreaming entails incorporating data, guidelines, and actions to combat climate change into continuous development planning and decision-making. Instead of creating and managing policies independently from ongoing operations, mainstreaming is thought to be a more sustainable, effective, and efficient use of resources. Theoretically, mainstreaming should prevent potential trade-offs between adaptation and development strategies that might lead to maladaptation in the future and create "no regrets" opportunities for achieving development that is resilient to current and future climate impacts for the most vulnerable (Ayers et al., 2014).

For shrimp farming, climate change adaptation will be conceptualized as measures farmers can take to stay resilient to the impacts of climate change, to sustain a livelihood. This will be done by searching for measures to tackle drought, salinization, floods and cyclones, that are already taken, or can still be taken. The dimension will be on plot level of independent farmers and to farm clusters. The timeframe will be climate change in the coming 50 years. As mentioned in the problem statement: In this study the integration of climate scenarios into adaptations will be one factor in the search for potential management practices that will both address current water management problems (such as diseases), and current climate resilience issues, at the same time being relevant for future climate change. Also known as robust, no regret, adaptations.

2.3 Water management

Water management includes various activities like proper planning, efficient distribution, and optimal use of water resources so that it can meet current and future needs.

Water management on shrimp farms is conceptualized as decisions farmers take regarding water in order to sustain a living. These can be decisions on both water quality and quantity. Also, what water management practices have already be taken, and which can still be taken. These decisions will be important to know regarding impacts and adaptations, as all decisions will influence both (Olmstead, 2014). In essence, the research will particularly be looking at these decisions and how they can be used for sustainability.

3. Research methodology

3.1 Study area

The study area of this research is the southwest of Bangladesh (see Figure 3), this is the location where the most shrimp farming takes place in the country. The selection was based on several criteria:

- The abundance of shrimp farming area;
- Shrimp farm production;
- Existence of extensive and semi-intensive farming;
- Exposure to sea;
- Accessibility in terms of existing contacts in the region as well as transport possibilities.

Three sub-districts in the south-west of Bangladesh were deemed suitable for the study: Debhata in Satkhira, Batiaghata in the Khulna district, and Mongla in Bagerhat. For each subdistrict, this study has covered a union. This means, that three unions have been researched, which considered the abundance of shrimp farming, livelihood dependency, and dynamics (Masud, 2022)

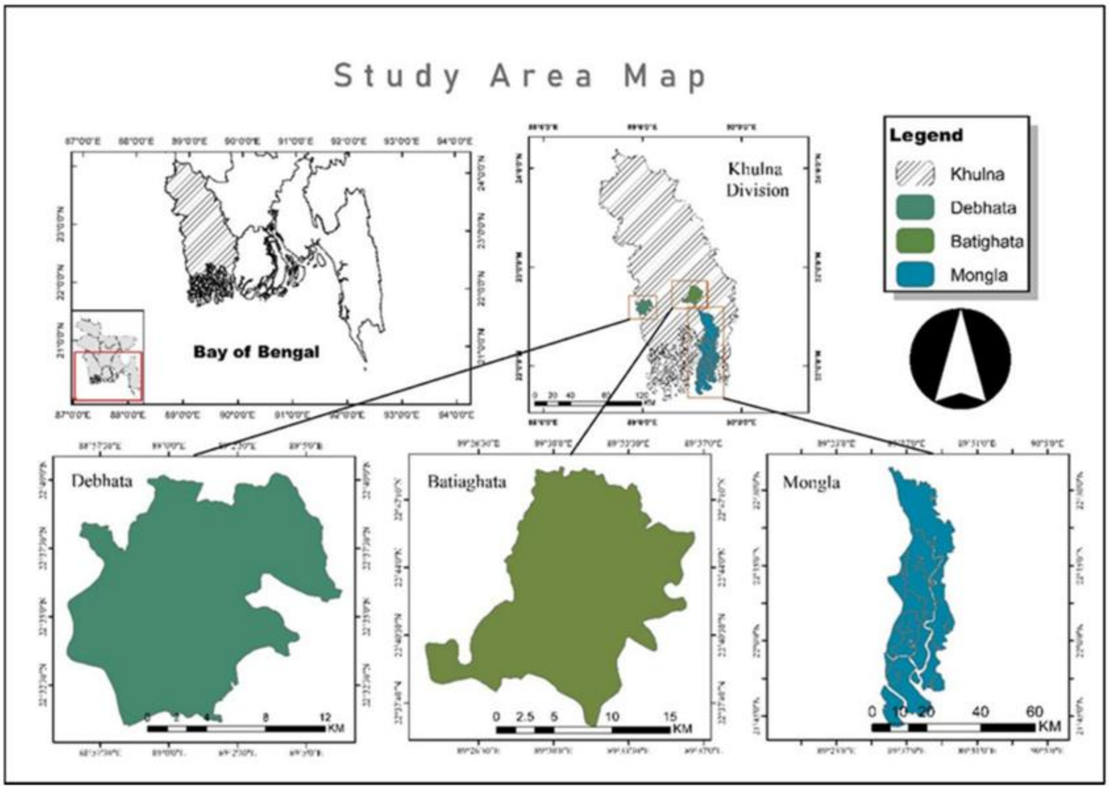

Figure 3: Map of study area (Masud, 2022)

3.2 Structure of Methods

In this chapter the research methodology is discussed in a chronological order. Table 1 and Figure 4 present the order of the research. As can be seen in Figure 4, there are two paths leading to the conclusion, one path in the creation of climate change, and the other path on climate change adaptations. It is important to note the research is a case study, in which both qualitive and quantitative date will be produced and analysed.

Table 1: Structure of methods

Order	Sub question 1. (Climate scenarios)	Sub question 2. (Adaptations)
1.	Literature review climate models	Literature research
2.	Surveys, focus group discussions and interviews	Surveys, focus group discussions and interviews
3.	Climate scenario	

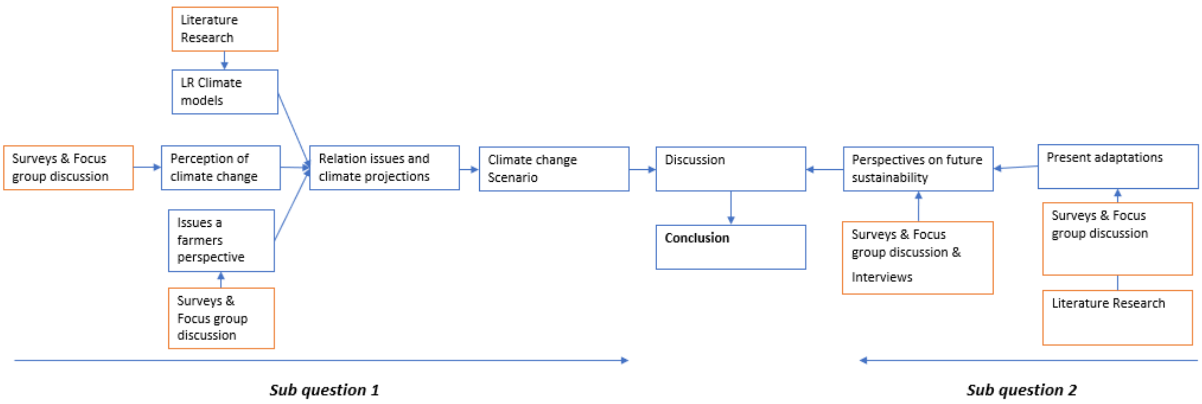

Figure 4: Structure of methods visualized

3.3 Literature review climate models

The climate variables that are used in this research were: Temperature, rainfall, sea level rise, drought and rivers discharge. For these variables literature on models was found, in Table 2 the literature used for each variable is presented. These variables all have direct and indirect effects on shrimp farming.

Furthermore, for salinity, floods and cyclones, literature as well as predictions from the variables presented before were used to get the results.

Table 2: Literature used to make predictions on climate variables for South-west Bangladesh

Title	Reference	Variable
Climate change analysis for Bangladesh using CMIP5 models	(Bosu et al., 2020)	Temperature/rainfall
Downscaling and projection of spatiotemporal changes in temperature of Bangladesh	(Alamgir et al., 2019)	Temperature
Inundation modelling for Bangladeshi coasts using downscaled and bias-corrected temperature	(Hasan et al., 2020)	Temperature/Sea level rise

Model output statistics downscaling using support vector machine for the projection of spatial and temporal changes in rainfall of Bangladesh	(Pour et al., 2018)	Rainfall
Evaluating severity–area–frequency (SAF) of seasonal droughts in Bangladesh under climate change scenario	(Alamgir et al., 2020)	Drought
Impact of climate change on river flows in the southwest region of Bangladesh	(Billah et al., 2015)	River discharge

3.4 Literature research (adaptations)

Literature research has been done as well regarding adaptations. The topics in this research have been answered with the help of both literature research as well as interviews and focus group discussions. Firstly, literature has been analysed regarding adaptations that were already present in the area. Using literature on what adaptations are suitable at farm level, a list was made. This list was used in the field, and further discussed with the farmers in order to map these adaptations. In essence, the literature research done on adaptions was used as a first exploration. Certain standards were deemed applicable, for both the literature review as the literature research, to get well presented and supported arguments.

- More than one source to support a statement;
- Most recent papers on the topic;
- Trying to keep the papers as scientific as possible.

3.5 Surveys, focus group discussions and interviews

As mentioned before, for both the adaptations and future predictions, surveys, focus group discussions (FGDs) and interviews were conducted. This was done in the field with farmers and experts in the area. In all three the following was discussed: Firstly, the perspective of farmers on what the most pressing issues they are facing currently are. Secondly, the perception of farmers on climate change, both looking at the last 10 years, as well as their prediction for the coming 10 years. Thirdly, using the literature from Chapter 3.4, the present adaptations were mapped. On top of this, it was discussed to what extent farmers share knowledge on adaptions as well as help each other out with adapting to a changing climate. Lastly, for both experts and farmers, it was discussed what would be necessary to sustain a sufficient yield in the future. The most prominent ideas were listed.

For all three, a guide was used. This guide can be seen and in *Annex 1.* The guide was used in two different ways, one way for the survey and the other for the FGDs and expert interviews. In the survey the guide had closed questions. For the FGDs and expert interviews the guide was used as a pathway, in which a semi structured type of questioning was applied.

Starting with the focus group discussions: In all three area's (study area) discussions were conducted. In Table 3, the number of participants for each location can be seen.

Table 3: Participants focus group discussions

Number	*Location*	*Participants*
Focus group discussion 1	Debhata	11
Focus group discussion 2	Batiaghata	24
Focus group discussion 3	Mongla	9
		Total: 44

The goal of the FGD was to involve people from the same background, in this case, shrimp farmers. Only farmers participated in the FGD, experts were individually interviewed. The topics discussed are mentioned earlier in this chapter. Qualitative data was produced by asking the farmers' perceptions, opinions, and ideas, on the topics asked. The discussion among participants was encouraged. For the construction of the climate scenarios, the most pressing issues, as well as their perspective on climate change were discussed. For the adaptions a list was made of possible adaptions, this was discussed by the participants, along with discussing what was needed to sustain their livelihood in the future.

At the same three areas, surveys were conducted. These surveys were taken with farmers who had not participated in the FGDs. In Table 4 , the number of surveys taken can be observed.

Table 4: Surveys taken for each location

Survey	*Location*	*Surveys taken*
Round 1	Debhata	9
Round 2	Batiaghata	10
Round 3	Mongla	10
		Total: 29

Lastly, four different experts were interviewed. The emphasis of the interviews lay in getting their view and ideas on sustaining yields in the future. In Table 5 , the different experts have been listed.

Table 5: Expert interviews

Expert
Professor aquaculture and fisheries department
Professor environmental science department
Government official/ WUR PhD graduate aquaculture and fisheries
Head Management shrimp hatchery Cox's Bazar

4. RESULTS

4.1 Literature review climate models South-west Bangladesh

In this chapter future projections on different climate variables including temperature, rainfall, sea level rise and salinity are made, considering climate change. This was done by reviewing previous scientific papers in which different climate models have been used and analysed. In this research the RCPs 4.5 and 8.5 have been used.

4.1.1 Temperature

The first climate variable projected is temperature. Three papers have made projections for both RCPs, as shown in Table 6. The range of spatial locations varies from the whole of Bangladesh to specifically Khulna. All projections are done for 2100, with an increase per decade included. The range of decades starts at 1980 till 2100. In two papers the increase in temperature is taken for both maximum and minimum daily temperatures, in Hasan (2020) an average is shown, as well as the increase per decade. All account for the annual average daily temperature (Celsius).

Table 6: Projected changes in annual average daily temperature (°C), as well as the change in temperature per decade under RCP 4.5 and RCP 8.5, using three Scientific climate modelling papers.

	Location	**RCP 4.5 (2100)**	**RCP 4.5 (1980-2100, per decade)**	**RCP 8.5 (2100)**	**RCP 8.5 (1980-2100, per decade)**
(Bosu et al., 2020)	Bangladesh	Max 1.9°C Min 2.1°C	0.17°C	Max 4.0°C Min 4.0°C	0.33°C
(Hasan et al., 2020)	Coastal Bangladesh	Avg 1.7°C	0.15°C	4.4°C	0.37°C
(Alamgir et al., 2019)	Khulna	Max 2.7°C Min 2.7°C	0.23°C	Max 4.2°C Min 4.1°C	0.35°C

All climate projections predict an increase in temperature which ranges from 0.17°C per decade for the Bangladesh overall, and 0.23°C Khulna for RCP 4.5, respectively 0.33°C for Bangladesh and 0.37°C coastal Bangladesh for RCP 8.5. This means the shrimp farmers can expect the temperature to further rise this and coming decades. As well as future projections, it can also be seen that the temperature from 1980 until now has also steadily increased.

4.1.2 Sea level rise

Hasan et al(2020), further argues that the temperature and sea level show a significant positive relationship.RCP8.5, the pace of yearly sea-level change will dramatically increase, under RCP4.5, it begins to decline around 2070 and reaches a rather stable condition by the end of the 21st century, as can be seen in Figure 5. According to this annual sea-level change rate, the mean sea level has changed in comparison to the years before it. By 2100, it may reach 21 mm/year, up from less than 1.5 mm/year in 1980 (RCP8.5 based on the anticipated temperature using enhanced quantile mapping). According to the model employed in the study, the mean sea level will rise by 0.77 to 1.15 meters by the end of the 21st century compared to the period from 1986 to 2005. According to projections, the mean sea level rise by 2050 will be between 0.30 and 0.35 meters, or 30 and 39% of the expected SLR at the turn of the century. For the years 1980 to 2100, the annual average rate of sea-level rise ranges from 6.69 mm (RCP4.5) to 9.88 mm (RCP8.5).

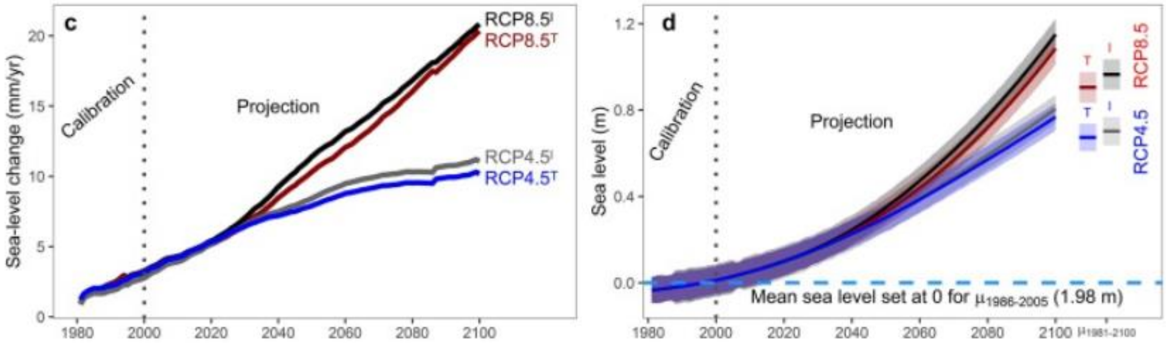

Figure 5: Projected sea-level rise, Bangladesh.

4.1.3 Rainfall

Rainfall has a way more diverse projection in comparison to temperature. This counts for both temporal and spatial predictions. Table 7 shows the projections from the region of Khulna based on two articles.

Table 7: Projections on annual rainfall in Khulna

	Location	RCP 4.5	RCP 8.5
Bosu et al., 2020	Khulna	2025-2049: -3% 2050-2074: 1% 2075-2100: 6%	2025-2049: 4% 2050-2074: -2% 2075-2100 : 1%
Pour et al. 2018,	Khulna	2025-2049: 5% 2050-2074: 4% 2075-2100: 6%	2025-2049: 9% 2050-2074: 12% 2075-2100: 14%

Even though the projections are more diverse for rainfall, both papers (Bosu et al., 2020) (Pour et al., 2018) agree on the following: For RCP 4.5 and 8.5 there will be rising yearly rainfall levels throughout the whole of Bangladesh. The spatial distribution of annual rainfall changes revealed that rainfall will rise more in the western section, which includes Khulna, where annual average rainfall is lower, and less in the northeast corner, where annual average rainfall is higher. This would increase the homogeneity of the annual rainfall's spatial distribution in Bangladesh.

Thereby, both papers projected that precipitation varied over different time periods. The seasonal changes in mean rainfalls showed that the monsoon season will experience a bigger rise in rainfall than other seasons, which would cause Bangladesh's rainfall to be concentrated more during the monsoon. In essence the rainfall is projected to increase, yet this increase is concentrated during the monsoon, which would make dry periods drier and the monsoon wetter.

4.1.4 Droughts

Alamgir (2020) further proves previous statements on rainfall, by projecting droughts. The findings in the paper find that overall droughts in Bangladesh were projected to both become more severe as well as more frequent, under both RCP scenarios. For RCP 8.5 the changes in the areas impacted by drought were the most present. Relative increases in areas affected by higher return period droughts were predicted to occur during the middle of the current century (2040–2069)

4.1.5 River discharge

In Billah (2015) et al., simulations have been performed, showing that the southwest river network model of Bangladesh can expect significant changes in both discharge and water level. In the study the ten most important rivers in the south-west of Bangladesh were chosen, all rivers are projected to have significant increases in both water level as well as discharge. The projections for 2030 showed an increase between 4.59 and 9.28% (starting from the taken baseline of 1996) in discharge. The projections for 2050 showed an increase between 4.96 and 13.23% in discharge.

4.1.6 Salinity, floods, and cyclones

As salinity, floods and cyclones are climate variables that are initiated and effected by previous climate variables, they have been grouped in one chapter. They do not have their own modelled projections, but the predictions are derived from other climate variables. In Table 8 the prediction for all three climate variables is stated.

Table 8: Future predictions on Salinity, floods and cyclones. derived out of literature.

Climate event	Prediction
Salinity	Due to an increase in sea-level rise, unequal rainfall distribution and increased temperature (evapotranspiration), the salinity in both soil and water is predicted to increase. (Dasgupta, 2015)
Flood	Due to the combination of rising sea-level and an increase in river discharge, floodings both from river and sea are predicted to increase in the coming century
Cyclones	The frequency of cyclones and associated storm surges in the Bangladesh delta are increasing and are predicted to further increase in the future (Oppenheimer, 2019), due to increases in sea surface temperature. Thereby the intensity will also increase, with more cyclones in a short amount of time.

4.2 Perception of climate change

In this research surveys with farmers in three locations were taken to get a view of their awareness of the climate and to get their perception of how different climate occurrences will progress in the future, as well as questions on adaptations. It was found that farmers generally only have a perspective on variables that are not too far in the past as in the future. For this reason, the question asked were 10 years in the past as well as 10 years in the future. In Figure 6, the results of this are shown.

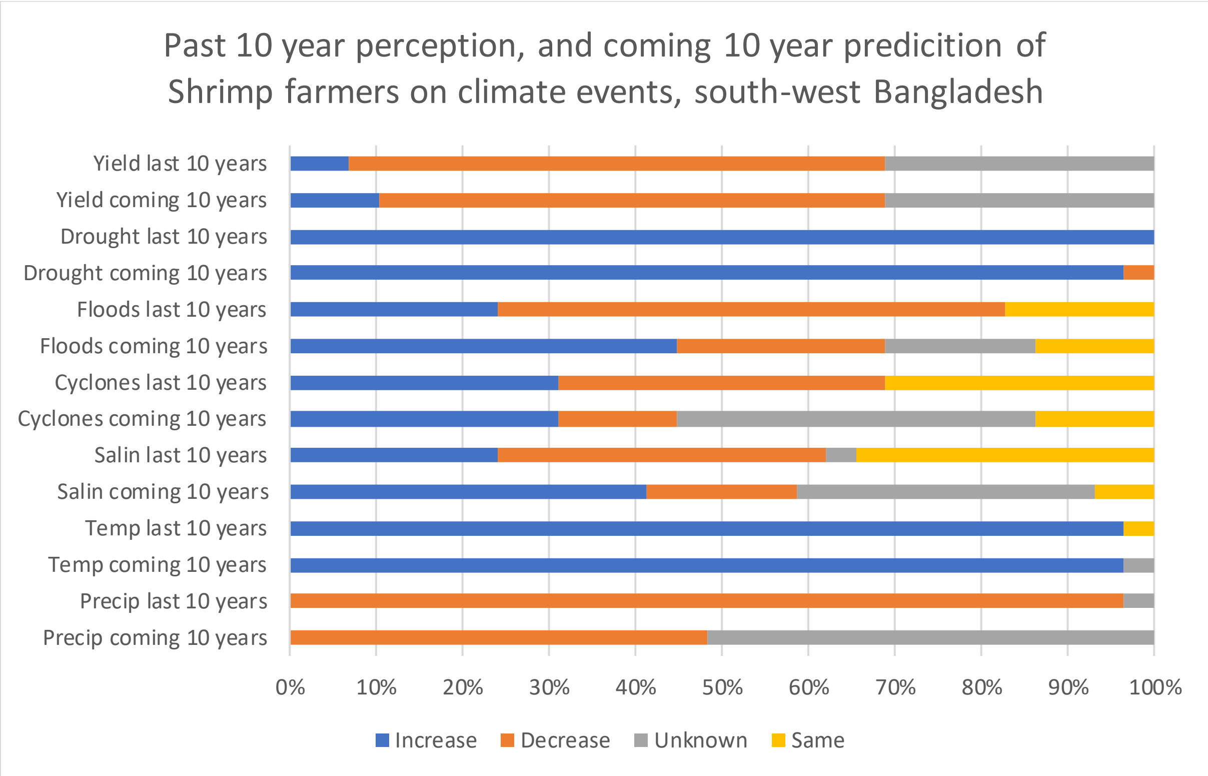

Figure 6:Past 10 year perception, and coming 10 year prediction of Shrimp farmers on climate variables (surveys)

In general, looking at all climate variables there is a high degree of variation and inconsistency in the perception of farmers on this, both for the past 10 years as their opinion on the coming 10 years. The inconsistencies are mainly present in floods, cyclones, and salinity. For three climate variables the perception is clearer, these are:

- *Drought*: All farmers said that they had experienced an increase in severity and periods of droughts in the past 10 years, thereby nearly all farmers thought this drought would further escalate in the coming 10 years;
- *Temperature*: For temperature also nearly, all farmers experienced an increase in the past 10 years, as well as predicting a further increase in the future;
- *Precipitation:* Lastly farmers nearly all saw a steep decline in precipitation in the last 10 years, most farmers are however unsure on the course in the future, part of the farmers think it will decrease further.

4.3 Issues, a farmer perspective

In this chapter the most pressing issues by the perspective of a shrimp farmer are mapped. In Table 9, these issues are listed and described. For each issue the locations that have recognized this this have been mentioned.

Table 9: Most pressing issues by the perspective of shrimp farmers in the south-west Bangladesh

Issue	Location	Description
Diseases/viruses	Debhata/ Batiaghata/ Mongla	The most important issue farmers recognized at all study sights was the occurrence of diseases in the shrimp. With disastrous consequences for both yields and livelihood. Many farmers acknowledged that both the frequency and severity of virus attacks on farms got worse over time, stating that in the past the virus attacks on farms only attacked certain age groups, as during farming there were more age groups present on the farm. However, nowadays the attacks have progressed to attacking all age groups and not being bound by a group. Consequently swiping out complete ponds full of shrimps. These present diseases is the most concerning issue among farmers. Confusion is present among farmers about the causes of the disease. Most farmers think the disease is present in the shrimp fry they buy for their farms. This fry is bought from middlemen who again buy them from hatcheries in the east of Bangladesh, this is seen as the main reason. The suspicion towards these middlemen is high, with some farmers even accusing the producers of injecting timely medicine in which the fry looks healthy at first sight but becomes sick at a later timeframe. Also, slightly below half of these farmers thinks water quality could also be a factor in the spread of diseases, mainly connected to the number of pollutants and the high degree of salinity in the water.
Education & knowledge	Debhata/ Batiaghata/ Mongla	Several farmers at all study sights have expressed their concerns regarding the lack of knowledge and education they have in reducing climate hazards as well as basic on-farm practices. This can result in mismanagement and maladaptation's on the farm, which can both harm the environment further as well as cause low yields, resulting in a low livelihood for the farmers.
Increase Salinity	Debhata/ Mongla	A major issue identified in two locations was the increase in salinity. In general, moderate amounts of salinity is not a problem, and are even needed for the cultivation of shrimp in brackish water. But farmers have observed that increasing salinity has negative effects on their production to the point that all shrimp get killed due to the chloride levels being too high. Furthermore, farmers link a decrease in rainfall with increasing salinity. Rainfall would dilute the water in the pond and therefore reduce salinity, something that is in their opinion is again linked to seasonality.

Decrease in rainfall	Shatkira/ Mongla	Another issue identified in the same two locations is the decrease in rainfall. Farmers said that rainfall has become an abnormal occurrence. Both decreased and falling at illogical times, mostly not falling when it was needed, and falling when it was needed. Seasonally during the dry season when rain is needed the most, it was not present. The decrease has led to several problems. Firstly, as mentioned earlier, the salinity increases. Thereby, the water level in the ponds was low. This has several consequences for the production of shrimp and decreases the yield. One of these consequences is that as the number of pollutants stays the same, yet the amount of water decreases, resulting in a relative increase in the amount of pollutants. Also, farmers who have mixed cultivation in order to protect their livelihood during virus attacks were not able to cultivate with fish as this requires more water and higher water levels. This made their income on the farm have a higher degree of risk.
Sedimentation	Shatkira	In one of the locations, the sedimentation deposited by the river was seen as a significant issue. This sedimentation enters the ponds which thereby increases the pond bed and therefore decreases the water levels of the pond. At the same time, the layer of sedimentation covers the food of the shrimp, hampering the shrimp growth.
(Salt) water scarcity	Batiaghata	The farmers of Batiaghata have a major issue in their location. Which was the limited accessibility to salt water, which they require in order to cultivate the shrimp. The issue was even seen by several farmers in the area as more pressing than shrimp diseases. In general, an upstream-downstream water conflict is present, in which the farmers close to the river get enough water, but do not pass enough water through for the farmers further away from the river. Thereby crop farmers often try to block saline water from entering , as the water can harm their crops.
Marketing	Batiaghata	One economic issue farmers had concerns about was the marketing and price of Bangladesh shrimp. A large portion of shrimp in Bangladesh gets exported to other countries. The reputation of the shrimp has suffered a lot in the last few years. Suspicions of certain chemicals and medicine that have been added to the value chain of shrimp have led to this reputation. The consequence is that the demand for shrimp from Bangladesh specifically has decreased, resulting in a reduction in price, having financial consequences for the farmers.

4.4 Relation Issues and climate projections

In this chapter the relation between the future climate projections and the current identified issues by the farmers, are crossed with each other and further analysed. This will make estimations on how certain issues might progress in the future and were the emphasis in solutions should lay.

- **Diseases/viruses**: Literature has shown that water quality is well connected with the spread of diseases and viruses. All projected climate variables will have negative consequences on the water quality. Therefore, its predicted that the number of diseases from this standpoint will further increase. Most farmers are aware of this predicted rise, yet often are not able to identify where it comes from.
- **Education & knowledge**: N/A
- **Salinity:** As can be seen in chapter 4.1.6, the salinity is predicted to increase. Therefore, this issue will also become more severe in the future. The perception of farmers on salinity is location bound, but much is still unsure in their eyes.
- **Rainfal**l: Even though rainfall annually is projected to increase, farmers have said that they need more precipitation during the dry season. It is projected that rainfall will decrease in the dry season and increase during the monsoon season. For this reason, problems with decreased rainfall will further escalate in the future. This is also predicted by farmers, who are aware of this growing issue.
- **Sedimentation**: Projected is that river discharge will increase in the coming decades. An increased discharge also means an increase in sediment transportation and displacement, and therefore the sedimentation is expected to increase as well. This will mean that in the future the farmers will experience more issues related to sedimentation.
- **(Salt) Water scarcity**: Water scarcity is more of a social issue, rather than an issue related to climate change. All farmers who experienced water scarcity said that it was due to other agricultural sectors not passing the water to them: a classic up-stream versus down-stream water conflict. Yet, with the droughts increasing, which the farmers are aware of, the water scarcity problem might also increase.
- **Marketing**: N/A

4.5 Climate change scenarios

Climate scenarios are a technique that is used for medium to long term planning, where storylines are defined that explore future developments, based on interpretations of the present. In this research, four scenarios are constructed based on the following information, both quantitative and qualitative, obtained from all previous chapters in the results.

For the construction of the climate scenario map two axes have been chosen: Climate change severity and adaptive capacity.

x-axis: **Climate change severity (RCP 4.5 & 8.5)**

y- axis: **Adaptive capacity**

In Figure 7 the four chapters are presented.

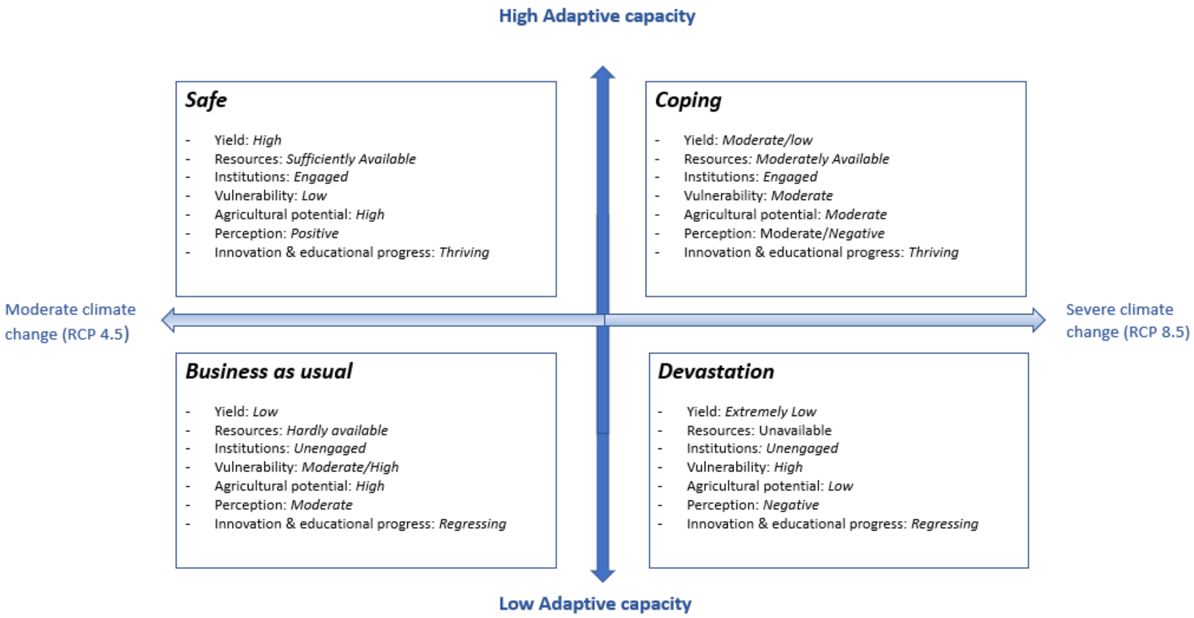

Figure 7: Four climate scenarios based on climate change and adaptive capacity.

The indicators that were used to create these scenarios are as follows:

- **Yield:** The amount of shrimp (kg) farmers gets from their farms (ha).
- **Resources:** Access for farmers to economic, human and natural resources (see chapter concept).
- **Institutions:** The engagement of institutions, such as the government and universities, with shrimp farms.
- **Vulnerability**: the degree to which shrimp farms are susceptible to and unable to cope with adverse effects of climate change, including climate variability and extremes.
- **Agricultural potential**: Productivity of shrimp farms.
- **Perception**: The opinion and visions of farmers on the future.
- **Innovation & educational progress**: The growth in both innovations, for shrimp farms, as well as the growth in education, acquiring knowledge on farms.

Scenario descriptions

4.5.1 Safe

Rafi was a successful shrimp farmer in Bangladesh. He had always been aware of the potential impacts of climate change, and he had taken steps to mitigate them. His yields were thriving, and his livelihood had increased. He made enough to provide for his family, and to even invest in a couple of innovations to keep his yields high.

Rafi had taken advantage of innovative farming techniques, such as cluster farming, in which the water was equally distributed along the farms. He had attended educational workshops on climate-resilient farming practices and had implemented them on his farm. Any problems encountered on his farm were met with knowledge from these workshops as well as knowledge shared with other farmers.

Despite the challenges that came with moderate climate change, Rafi was glad the climate had not further escalated as it did in the past. He had managed to adapt and thrive. He was thinking of further expanding his farm in the future, so that his children in the future could take over.

4.5.2 Coping

As extreme climate change set in, Rafi knew that he had to take drastic action to save his farm. He had invested in many adaptions in order try to keep his yield up. These were harsh times for him and his family, but he managed to get around and make ends meet.

He had attended educational workshops on cutting-edge farming techniques, such as implementing mangroves around his farm, ensuring that his shrimp thrived even in the harshest conditions. The adaptation was a success in which shrimp were protected from the climatic elements. Symbioses also took place, where shrimp ate food from the mangrove, and the mangrove used nutrients from the shrimp.

Despite the challenges that came with extreme climate change, Rafi had managed to adapt and thrive. His farm was an example of how high innovative and educational progress can help farmers overcome even the most severe impacts of climate change.

4.5.3 Business as usual

Rafi had always been a traditional shrimp farmer, relying on the same techniques and practices that had been passed down for generations. He had never thought much about the potential impacts of climate change, and he had not invested in any innovative farming techniques.

As moderate climate change set in, Rafi began to see the impacts on his farm. The saltwater intrusion made it harder for his shrimp to survive, and the storms were getting more frequent and more severe. Despite this, Rafi was not changing his ways. He was not sure what he should have done to combat these climate variable, nor was he aware of the dangers. He had tried some traditional methods but was not sure which worked, and which did not.

Over time, Rafi's farm began to suffer. His yields decreased, and he struggled to make ends meet. Yet, he would never stop working as farmer, as it was in his blood.

4.5.4 Devastation

As extreme climate change set in, Rafi struggled to keep his farm alive. He had no knowledge and not enough resources to invest in the use of innovative farming techniques, and he had not attended any educational workshops on climate-resilient farming practices.

The saltwater intrusion had become so severe that it was almost impossible to keep his shrimp alive, and the storms were so frequent and so severe that his ponds were destroyed almost every year. Rafi was distraught in what he should have done to stop this from happening, thereby he started to panic at his situation.

Over time, Rafi's farm collapsed. He lost everything, and he was forced to leave his home and move to the Dhaka in search of work. There he became a rickshaw driver, trying to provide for his family. He had become a climate refugee, with little hope for the future. He wishes to be back in the calm countryside.

4.6 Present adaptations

To map the present adaptations and farm management strategies taken by farmers at this moment, a survey was done with 29 farmers in 3 regions. Questions were based on adaptation strategies found in four key papers (Islam,2019; Jayasinghe,2019; Jamal,2023; Do, 2022), as well as on open questions asked beforehand. In Figure 8, the results of the survey that show which adaptations are (not) present can be seen.

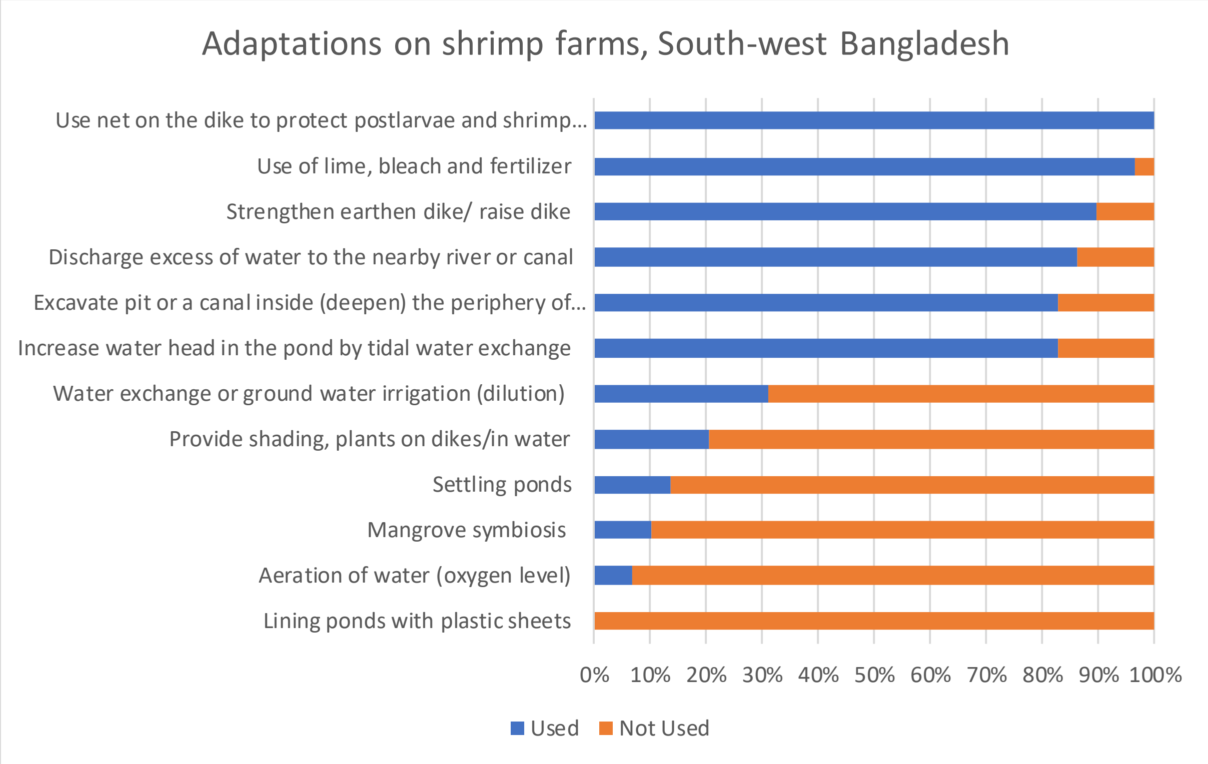

Figure 8: Graph of adaptations taken by shrimp farmers, south west Bangladesh

Most farmers made use of the first 6 adaptations in the graph, while much fewer farmers used the 6 lower adaptions. The fact that the yield has been going down year by year, despite the use of these adaptations, suggests that these adaptations will in the future not be enough to sustain livelihoods. Therefore, new and innovative adaptations should be implemented.

In focus group discussions, an adaptation that was not used in the survey was mentioned. This was the use of polyculture, in which white fish and shrimp are both cultivated in the same pond. This is an adaptation that is implemented in order to reduce risk. In chapter 8.9, polyculture is further explained.

Sharing knowledge and working together

Most farmers (83%) stated that they did share knowledge within their communities on both adaptations and farm practices. Yet, they also stated that knowledge on adaptations was often not present. Fewer (64%) farmers said that they worked together. In general, farmers seem well willing to help each other out within their communities. Therefore, for future implementation of adaptations, opportunities arise.

4.6 Perspectives on future sustainability

4.6.1 Farmers

In both focus group discussions and surveys farmers were asked what was needed (focussed on climate change and adaptions) in order to sustain a living in the future. The following answers were most prominent: financial support, education, medicine and management for shrimp disease, deepening of the canals and utilising better drainage systems, and a sluice. Below, a more detailed explanation of these answers can be found.

Financial support

By far the most frequent answer to the question was getting financial support in several forms from the government.

Farmers mentioned they wanted financial support to invest in infrastructure, on and surrounding their ponds. With this they would improve and better maintain the ponds and canals around them. For example, deepening both in order to achieve better water quality and flow. This deepening is further explained below.

A small part of the farmers said they needed subsidy for the fuel of ground water pumps. This because the use of the pumps is necessary at their farms, yet the costs of fuel is high, and continues to rise. Therefore, their profits are shrinking by the day. In addition, the same group of farmers wanted financial support to buy ground water pumps that reached significantly deeper than the current pumps used. This would help them to get more and, in their view, less polluted ground water to be used on the farms.

Lastly, another part of the farmers stated that they needed financial support in order to be part of the electrical grid, to get electricity on the farms that do not have this yet. The use of electricity is a basic development goal, that can help to improve many tasks on the farm.

Education

As seen in chapter 8.2 on issues, farmers had expressed concerns regarding the lack of knowledge and education. This has resulted in mismanagement as well as in the implementation of mal-adaptations. A part of these same farmers acknowledge that both trainings and further education will be needed in order to keep yields at sufficient levels and to sustain themselves in the future.

Therefore, they further said that if certain trainings and education would be given to them, they would all be willing to participate, and actively engage. This would then also result in them applying the new found knowledge to their fields.

Medicine and management for shrimp diseases

The most pressing issue, as seen by farmers, are shrimp diseases and viruses (chapter 8.2). Farmers often pray that some sort of medicine gets developed, which is affordable, that will cure shrimps that are affected. They see innovation in the drug sector as their hope. Thereby, they would like to get better knowledge on what farm management they can use to both prevent, as well handle, the diseases when they strike.

Deepen the canals and utilise better drainage systems

Another measure farmers came up with, was to both deepen the canals between the ponds as well as implement improved drainage systems. This in order to sustain a water flow in all the ponds, and also to combat sedimentation, by maintaining the canals.

Sluice

Lastly, at FGD 3 all farmers agreed that a sluice being built between the river and the channel would have great positive effects on their yield. The sluice would be able to mitigate saltwater intrusion as well as keeping the water in the channel when needed.

4.6.2 Experts

From four interviews with experts, the same question as for the farmers was asked: what would it take to sustain shrimp farming in the future, focussing mostly on climate change. In this chapter, their answers to this are listed, as well as several ideas and visions.

Awareness and education

Experts were unanimous in the fact that both awareness and education for shrimp farmers must increase. If applied successfully, this knowledge can be applied to any farm-related activity. These include: salinity control, mixed farming, disease outbreak control, and water quality management. All promote better production, thus increasing their adaptive capacity. Also, experts advised that farm owners should be informed in advance of any natural disasters. Being informed means farmers are getting timely weather updates and can use the appropriate adaption techniques, assisting in reducing the loss of yield.

Cluster farming

Another idea brought up by experts was the use of cluster farming between shrimp farms. In cluster farming, several small-scale shrimp farmers spread out across a big area to grow shrimp, working together, and becoming a whole. The key advantages of cluster farming include jointly managing biosecurity, improving feed input methods, adopting specialized pathogen-free shrimp PL, and ensuring water quality. The goal of cluster farming is to also involve other stakeholders in the food chain, including terminal and shrimp farm operators. This tactic could lead to the establishment of a fixed shrimp market chain, by combining stockholders through a chain of knowledge in a farmer cluster. Climate adaptation will be aided through knowledge exchange and group initiatives.

With cluster farming on a sizable river water channel with sluice gates, farm water quality is preserved through maintaining tidal action without using any water pumps. Implementation of this technique can result in a large rise in the production of fish of all types, including shrimp. Thereby, cluster farming can lower the risk of natural catastrophes and make better use of government assistance.

Mangrove symbioses

At this moment, pilots are being researched in which a symbiosis between mangroves and shrimp farming is realized. Experts are hopeful many benefits can arise from this system when implemented. The resistance of mangroves to climatic effects on shrimp farming is significant. Shrimp farms are shielded from tidal surges by mangrove forests, because they can operate as an active cyclone barrier and absorb wave energy. Due to their ability to absorb wave energy and support coastal soil, mangroves can minimize coastal flooding, shoreline erosion, and effects of cyclones on shrimp farms. Mangroves might expand the variety of climate change response and adaptation options. Floods, sea level rise, salinity variations, and elevated water temperature might have a reduced impact on farms when mangroves are present. Because of their ability to absorb pollutants, sediments, and harmful elements, mangrove could also aid to sustain better water quality.

Polyculture

The increased implementation of polyculture was seen as a potential adaptation by experts. This is the production of two or more fish species in a specific aquaculture setting. Ponds are where most polyculture occurs. Paddlefish, tilapia, and other fish species are some of the species that can be cultivated in shrimp ponds. Shrimps may be impacted by illness outbreaks under the fish, causing them to eventually perish. This means that the entire production cycle could result in a loss. In this instance, fish output from other species provides extra financial assistance during unfavourable conditions. It can help meet the farmer's daily protein needs and lessen the impact of economic losses brought on by calamities, reducing risks.

The use of integrated methods (rice/shrimp or shrimp/salt.) is advised as well. This is in accordance with the agro-ecological conditions in each area, to ensure the coexistence of various cropping systems. To improve agro-ecological benefits, the Bangladeshi government is already promoting farmers to switch from monoculture to polyculture of shrimp.

Increase depth of entire pond

Shrimp diseases/viruses are affected by extreme heat and heavy rainfall. The pH, temperature, and salinity of the water may alter as a result of unfavourable environmental factors, which can reduce shrimp survival rates, if the pond depth is significantly reduced. Shallow water also reduces pond productivity. When pond depth rises, shrimp may adjust better to environmental changes. Hence, increasing the shrimp farms' depth is seen as a crucial measure by experts.

5. Discussion

This research explored how several climate events are likely to develop under RCP 4.5 and 8.5 in the coming 50 years. Additionally, the most pressing issues that shrimp farmers are experiencing were mapped. By combining the projected climatic changes, according to the literature and according to the farmers, and the issues as identified by shrimp farmers, four climate scenarios were produced. Moreover, an inventory of existing climate change adaptations and farm strategies for sustaining shrimp production was made. Finally, both the perspective of farmers as well as of experts was taken into account, to evaluate which farm practices constitute the most promising climate change adaptation strategies to sustain shrimp farming livelihoods in the future.

The main findings of the research were that all climate variables will increase in the future with negative implications for shrimp farming. The list of issues faced by shrimp farmers was diverse and their priorities differed per study area, including diseases/viruses, salt water scarcity, salinization, and marketing. Four climate scenarios were constructed, using the variables of climate change on the x-axis, and adaptive capacity on the y-axis. It was found that six adaptations were already being used by many farmers, while other adaptations were not widely adopted. Both farmers and experts had different perspectives on what adaptations strategies should be used in the coming 10 years, though both agreed that training and education is a key strategy.

5.1 Interpretations & implications

Sub question 1: *To what extent is climate change expected to affect the shrimp farms of Bangladesh in the future?*

To answer the sub-question, exploring future predictions regarding climate change and shrimp farming, climate scenarios were constructed. This was done by several steps that all supported the narrative, as well as the claims written on the four scenarios.

The first step in the process was reviewing the literature on climate models, to get information on the future predictions on different variables and the x-axis of the scenarios (climate severity). For this, several sources were used, with often multiple sources for one variable. These overlapping papers had slight differences in exact predictions, but all presented similar trends in how the variables would progress in the future. Literature (Pielke, 2021) suggests that RCP 4.5 (moderate) will be the most likely scenario to happen, yet RCP 8.5 (severe) is far from unthinkable. The importance of taking RCP 8.5 into account, is the fact it prepares farmers for the worst. This opens up the path of having to think about and implement robust, no-regret adaptions. In essence, climate change adaptions that are prepared for the worst, and still are applicable with lesser climate severities. Important is, as can be seen in chapter 4.1, that for both RCP's the results show that the climate variables are all increasing, except for the variable of rain. With this knowledge this paper builds and provides further evidence on the direction that climate change is heading in the future of Bangladesh. Which will undoubtedly further pressure shrimp farming at an alarming rate in the coming 50 years, for both RCPs.

The second step was to map the existing issues, from a farmer's perspective. This step is an in-between step, as it does not directly answer the future predictions, yet it is an important way to see what could potentially occur in the future. A high variety of issues were presented by farmers. These issues were often location bound, while major issues, such as diseases and lack of education, were observed in every location. The fact that the issues showed so much variation per location, indicates the complexity of the issues and that robust solutions may have to vary as well. These results build further on the paper of the FAO, 2017, wherein issues that have arisen due to shrimp farming are discussed. These results give an extra perspective from the farmers' side.

Furthermore, for the issues mentioned by farmers that are directly connected to climate change (increased salinity and a decrease in rainfall during the dry season), this research builds further on the papers of Dash et al (2021), Mahmuduzzaman (2014), Ruto et al (2020). These papers state that the shrimp farms were currently experiencing these problems. At the same time, a contradiction was found with Islam, 2019, which stated that farmers were also experiencing flooding. Contradictory to paper of Islam floodings in this research were called insignificant by farmers, with most farmers even experiencing a decrease in floods. A reason for this could be the locations of the study areas. Some had no issues with flooding, yet other areas may experience them. Lastly, water scarcity is often masked as a climate change problem. While it often is, it can also be part of upstream-downstream water conflict. This seemed to be the case here as well, as shrimp farmers accused other agricultural farms (e.g. for rice production) of not letting water through.

This part of the study contributes to scientific knowledge, by taking a view from a farmer themselves on the issues. With all the issue considered in the results, this paper argues that the issues are much bigger and more complex than only focussing on issues caused by climate change. Even though climate change does play a significant role in these issues, both now and in the future, a bigger scope must be used for shrimp farming. This scope should take more social and economic issues into consideration. Thereby, also looking at both the local level and the national level. Both a top-down as well as a bottom-up approach will be needed to map these issues out.

In the next part, the perceptions of the farmers on climate variables were asked. The farmers had a coherent opinion on three variables: an increase in temperature, an increase in droughts, and a decrease in precipitation. A decrease in rainfall was also already mentioned in the issues, yet a contradiction exists with an increase in salinity. Farmers from two locations mentioned salinity as a concerning issue, but with the perception of farmers, there is no clear increase mentioned. A reason for this could be that in the third location, salinity was not that much of a problem.

This research cannot conclude if the farmers were aware of the fact that a change in climate variables were one of the reasons for the reduction in yield, as farmers' answers varied too greatly. For this reason, this paper provides evidence that farmers are aware of the changing climate to a certain extent, mostly focussing on the three variables. Yet the awareness of farmers on climate variables influencing their productions remains questionable.

Finally, from all these steps, climate scenarios were constructed. These climate scenarios answer the research question by making an exploration of future possibilities. Under the 'safe' scenarios, in which the climate change RCP 4.5 is moderate and the capacity to adapt is high, the environmental pressure is moderate and the way to cope with them is quite simple, due to the high capacity to adapt. This also results in a high yield. The opposite of the 'safe' scenario is the devastation scenario, in which there is severe climate change as well as a low adaptive capacity. The result of this is that the climate variables impact the farms so severely, that yields will be too low to maintain a livelihood. As a result, people have to become climate refugees and move to the city.

This research predicts that in the future, without drastic changes, Bangladesh will stay in the low adaptive capacity scenarios. These are devastation and business as usual, depending on the RCP's, with RCP 4.5 being the most likely. This is an extremely concerning prediction. Farmers will have low yields and not much of a future perspective, as well as low progress and development rate. Further reasoning for this future perspective is given at the end of this chapter.

Climate scenarios for shrimp farmers in Bangladesh are a tool that has not been used before in other research. This contributes to the field of research by showing several possibilities of what can happen in the future. It can also be used as a wakeup call that shows that the alarming rate of climate change in combination with no increase in adaptive capacity, might mean the end of shrimp farming in Bangladesh. At the same time, these scenarios can be used as one of the steps in making adaptation pathways, which will be essential in ensuring sustainability for farmers in the future.

Sub question 2: *Which possible adaptation strategies to climate change can be taken at the shrimp farms?*

Firstly, to answer this sub-question, the existing adaptations were mapped. To know which strategies can be taken, one must know which are already being taken. The results found were in line with the paper of Islam, 2019. Additionally, the future view on the sustainability of both experts and farmers was explored. A list was made for both the expert's ideas and the farmers. The lists were completely diverse from each other, except for education. The reason for this could be a knowledge barrier for the farmers (for example: Not being aware of the existence of mangrove symbioses), as well as the possibility that the experts are not connected well enough with the farmers to see their issues.

In the end, both lists created a new perspective on this knowledge gap. All knowledge produced by other papers was based on existing climate change adaptation and had not taken a view into the future from these two perspectives. This new knowledge can be used by institutions for the implementation of climate change adaptations. Next to this, it can also be used in further research on adaptation pathways.

Results have shown that most farmers' yields are decreasing. This indicates that the present adaptation strategies that are taken are not enough. On top of this, scientific evidence and qualitative data on the affectability of these adaptation strategies are lacking. Which makes it impossible to know which adaptation strategies to use for which issue. Furthermore, this research questions if adaption strategies are enough as a whole to sustain yields in the future. Rather, a broader pack of solutions, with adaption strategies as part of it, might be necessary. To achieve this, institutions such as the government, non-governmental organizations, and universities will have to work together in order to tackle the issues. This will be challenging, but not impossible.

At the same time there are promising pilots, such as mangrove symbioses, that have the potential to mitigate climate variables as well as increase production, to sustain a decent yield. But these will only prosper in combination with broader solutions. A rise in education and awareness could be a potential key element in sustainability, with further research on this topic being advisable.

5.2 Limitations

The two most significant limitations in the study were in the climate models, and surveys, focus group discussions and interviews.

5.2.1 Climate models

The use of climate models brings a set of standard limitations with it. These include model uncertainties, scenario uncertainties and internal variability.

Model uncertainties

When given the identical initial conditions, such as air pressure and temperature, the several climate models created to estimate future climate scenarios each produce unique projections based on their assumptions. These initial conditions include things like temperature. For this reason, models from several papers were used in this research, in order to see the trends overall.

Scenario uncertainties

Estimates of the future amounts of climate models from human sources are needed for climate forecasting models. These future concentrations must be projected based on evaluations of the social, political, and economic aspects that affect the models' emissions and land-use changes, because they cannot be predicted by physical laws. In order to predict future model emission levels, a number of socioeconomic hypotheses must be made, including adjustments for population growth, economic output, energy usage, land use, and technology. Model emission scenarios range widely because of how quickly and unexpectedly these conditions might change. As this research did a literature review on papers on models, these hypotheses were not made themselves, which could have effected the outcomes on the variables. This was tried to be mitigated by using several papers to support arguments made.

Internal variability

Internal climatic variability emerges in response to interactions and feedback among internal components of the climate system itself. The chaotic behaviour of the climate system leads to further internal unpredictability. This can be seen on a global level, although it is most noticeable on a regional level. Short-term impact is the largest. As this research looked at regional level as well as short-term impact, this has some implications on this research in which the accuracy could potentially lack.

5.2.2 Surveys, focus group discussions and interviews

Farmers found it easier to answer the questions on the past 10 years, than about the future 10 years. Many farmers have a day-to-day lifestyle, in which they are not very engaged with the future reality. For a part of farmers, it appeared that the interview was the first time they actively thought about the climate from a future perspective. Part of this might be because of the high level of religion in the region, which for the farmers was predominantly Islam, followed by Hindu. These religious farmers regarded the future as something only God could influence. Despite this, many still answered what they thought. One limitation was the lack of knowledge of certain climate events. Drought and salinization were terms that some farmers had a hard time understanding, though these terms were often simplified, this was done by using terms they do understand to describe the not understandable term as good as possible.

The focus group discussions were attended by a high variety in ages, with the youngest farmer being in their 20s and the oldest in their 70s. As respect for elders is a strong tradition in Bangladesh, the elders were the people who dominated the discussions the most, and who were always the first to answer the questions. To adapt to this, often younger farmers were picked out individually by the researcher, to answer questions before the elderly took over. Thereby, at the end of each FGD farmers were put in smaller groups, where the younger farmers were sat with each other, to get their views on certain questions without the elders taking over.

Even though there were translators with a high level of the English language, sometimes answers got lost in translation and therefore simplified, though the most important points that farmers spoke about were still noted.

6. Conclusion & recommendations

This study aimed to explore the future of shrimp farming in Bangladesh, by answering what future scenarios for climate change impacts on shrimp farms could be, as well as by exploring potential climate change adaptations that could reduce vulnerabilities.

This research concludes that shrimp farming is already at great risk, and more so in the future. Climate change is an important factor in this, but not the only one, other economic and social factors such as overall production mismanagement due to a lack of knowledge, tough market competition and water conflicts (potentially enhanced by climate change), play roles as well.

Within climate change, for both RCP 4.5 and 8.5, all climate variables will in the future heavily impact and threaten shrimp farming practices in Bangladesh. Farmers are realizing that temperature, droughts, and perception are changing for the worse. Yet, for other variables, as well as the relationship between climate variables and yield, the awareness is questioned and doubtful. The issues mapped by farmers are highly diverse and not all directly or indirectly related to climate change. Further, this research predicts that in this current solving rate, the climate scenarios with low capacity, namely business as usual and devastation, are most plausible. This means low yields and farmers barely being able to sustain their livelihoods.

The current adaptation strategies used are not enough to sustain a livelihood in the future. As not all issues are related to climate change, a broader spectrum of solutions will be needed for future sustainability. Yet, adaptation strategies might play a big role in them. These solutions must be explored both bottom-up, from a farmer's perspective, but also top-down, with the government, non-governmental organizations, and universities working together to tackle these issues and to ensure sustainability in the future. Progress in education and awareness might be a key element in these solutions. A race between solutions and climate change is currently happening, with climate change having a head-start.

This research recommends to further research the following aspects:

Adaptation pathways

The concept of adaption pathways has gained traction in scientific research in the field of water management. Adaptation pathways are a planning approach addressing the uncertainty and challenges of climate change in decision-making. It allows for the study of several potential futures, as well as the analysis and exploration of the flexibility and robustness of diverse alternatives within those numerous futures.

Adaptation often uses climate scenarios, as well as making multi-criteria analyses on which climate change adaptations can be used at a certain turning point. This research can be utilised as a first exploration of both the scenarios and possible climate adaptations.

Demonstration fields with integrated research

Since a lack of knowledge was identified by farmers and experts, it is recommended that universities, government and NGO's work together to produce new and applicable knowledge by researching and demonstrating best practices in farmers' conditions. This could help the collection of biophysical data as well as farmer's perception on the viability of certain climate adaptions.

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Annex 1

Annex 1 contains the guide used for surveys, interviews as well as the focus group discussions. The guide consists of three parts:

1. Getting to know practices of shrimp farmers
2. Perception on climate change / other issues present
3. Climate change adaptation

Important note: The interviews and FGD's were semi structured, for that reason the guide was used as a pathway going through questions.

A1. Guide for survey, interview and focus group discussion

1.Getting to know practices of shrimp farmers
In this part the characteristics of shrimp farmers are mapped, note these down.

- Size (ha) and number of ponds	
- Farm type intensive/ (semi) extensive/traditional	-
- Yield (if possible)	-
- Educational level	-
- Age of farmer	-
- Other interesting things to mention	-

Extra space for notes:

2.Perception on climate change / other issues present

Ask the farmer: *What are the most pressing issues you are facing on your problem?*

What farming strategies do you use to reduce these issues? How do you cope?

Issues	Description	Farming strategies used to cope	To what extent do you think this is linked to climate change?
…			
…			
…			
…			

For each event ask:

- *To what extent have the following events changed in the last 10 years?*
- *How do you think these events will change in the coming 10 years?*

Events	To what extent have the following events changed in the last 10 years?	How do you think these events will change in the coming 10 years?
- Yield of farm (not a climate event)		
- Drought -		
- Floods		
- Cyclones -		
- Salinization		
- Temperature		
- Precipitation (rainfall)		

3.Climate change adaptation

- *What adaption/farm strategies do you use to cope with these climate events?*
- Use last table to ask for certain adaptations (also includes questions that can be asked for each adaptation)

Adaptation/risk management strategies		Reason (yes)	Possibilities to implement (No)
	-	- Which issue tackled - Known adaption for climate change? - Noticed effects of adaptation?	- Do you see any benefits adaption? - If the adaption would be explained, how could the adaption benefit the farm? - What could be certain resources to implement this adaption? Is this present?
Increase water head in the pond by tidal water exchange	Temp		
Provide shading, plants on dikes/in water	temp		
Excavate pit or a canal inside (deepen) the periphery of the pond to retain water during high temperature	temp		
Use of lime bleach fertilizer	Temp/salinity/extreme		
Aeration of water (oxygen level)	temp		
Water exchange or ground water irrigation (dilution)	salinity		
Strengthen earthen dike/ raise dike	Extreme rainfall/cyclone		
Use net on the dike to protect post larvae and shrimp from escaping with overflow of water	Rainfall/cyclone		

Discharge excess of water to the nearby river or canal	Rainfall/cyclone/floodings	
Settling ponds	-	
Lining ponds with plastic sheets	-	
Mangrove symbiose - Pilot is going on, in which it seems that the use of mangrove trees at the sides of the ponds	Several	
Other Dilution practices (salinity)		
Adaptations present, not mentioned above.		

Question to also ask:

To what extent is knowledge on climate change adaptations shared, and do the farmers (you) work together to tackle issues?

What must be done in order to sustain a livelihood in the future?