Climate change (Mal)adaptation in the Bangladesh Sundarbans – a Systematic Review

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Abstract: Bangladesh is among the countries most vulnerable to climate change. This vulnerability stems not only from its exposure to climate change and intensified extreme weather events but also from the way adaptation policies and projects have been designed using a technocratic, top-down approach. As a result, much of the adaptation has led to negative consequences for certain groups—often the most vulnerable—who depend directly on nature for their livelihoods. This outcome, known as maladaptation, has been particularly pronounced. This paper conducts a systematic review of peer-reviewed literature since 2014, the year when maladaptation first gained significant attention in the IPCC's fifth report. The goal is to assess the current state of research on climate change adaptation in Southwestern coastal Bangladesh, particularly around the Sundarbans, the largest contiguous mangrove forest in the world. The review aims to identify research gaps and discuss key lessons learned. Keywords used in the review include 'maladaptation', 'barriers to adaptation', 'ecosystem-based adaptation', and 'gender', as these concepts are all interrelated to some degree. The review highlights significant research gaps across all topics, as well as a geographical imbalance in the distribution of studies within the region. Given the prevalence of maladaptation in Bangladesh, it is crucial that more research focuses on this issue to gather insights and reduce the risk of maladaptation in future climate change adaptation projects in the country.

Keyword: Bangladesh; maladaptation; barriers to adaptation; gender; ecosystem-based adaptation

1.0   Introduction

Bangladesh is highly vulnerable to climate change due to its geographical location, with floodplains covering no less than 80% of the country's surface area and 70% of the land lying at an elevation of less than 10 meters above sea level (Kibria et al., 2011). Other factors contributing to this vulnerability include the country's very high population density and widespread poverty (Huq, 2001). Additionally, a large proportion of livelihoods depend on climate-sensitive sectors, particularly agriculture and fisheries (Kibria & Haroon, 2017). Bangladesh has been identified as the most vulnerable country to climate change (Mallick et al., 2017; Rakib et al., 2018). Tropical deforestation in Bangladesh has significantly impacted the climate and contributes to climate-related disasters in the country (Islam & Rahman, 2015). Currently, forests cover about 1,429,000 hectares (Reza & Hasan, 2019), corresponding to approximately 11% of Bangladesh's territory. Of this, 801,700 hectares are mangroves (Reza & Hasan, 2019), which store higher densities of organic carbon compared to other forest habitats (Hamilton & Friess, 2018). As a result, when mangroves are deforested, they contribute disproportionately to CO_2 emissions. In addition to their role in carbon storage, mangroves are vital for climate change adaptation by providing protection against storm surges and offering income and medicinal resources for low-income households (Aye, 2019), alongside other ecosystem services.

The Sundarbans, the world's largest contiguous mangrove forest and a UNESCO World Heritage Site, has been experiencing increasing deforestation (Kibria et al., 2011). The portion of the Sundarbans within Bangladesh is classified as a Reserve Forest, covering an area of 6,000 km², of which 4,200 km² are forested, with the remainder consisting of water bodies. On land, the average elevation above sea level is just 1.5 meters (Islam et al., 2021), making the area highly vulnerable to rising sea levels. The combined effects of sea level rise and saline intrusion, attributed to climate change, have already led to a gradual decline in the mangroves' ability to regenerate and provide ecosystem services (Ahammad et al., 2013). As up to 10 million people rely on the Sundarbans for subsistence livelihoods through fishing, wood collection, and honey gathering (Islam & Haque, 2004), the loss of these ecosystem services due to rising sea levels and salinity intrusion could have severe consequences for many marginalized communities (Ahammad et al., 2013).

As a region highly vulnerable to climate change, the Sundarbans requires increased climate change adaptation initiatives. However, there is a risk that poorly designed or implemented projects may shift risks and vulnerabilities to other people and places (Atteridge & Remling, 2018), a phenomenon known as maladaptation. Maladaptation refers to the outcome of an adaptation initiative that, while intentional, harms either the targeted group or other actors (Juhola et al., 2016). Why, then, are certain adaptations consistently chosen despite their maladaptive effects? To some extent, maladaptation is likely to occur when addressing an issue as complex as climate change adaptation, given its spatial and temporal dimensions. Adaptation measures that benefit one group may have adverse effects on others (Adger et al., 2005).

The IPCC has identified an increasing number of maladaptation cases since the release of its fifth assessment report (AR5) in 2014, which was the first IPCC report to examine maladaptation extensively (Pachauri et al., 2014; Pörtner et al., 2022). Maladaptation can worsen vulnerabilities, risks, and inequalities (Pörtner et al., 2022), making it crucial to assess the impact of climate adaptation projects on already vulnerable groups, such as women. When the potential adverse outcomes for different groups are not considered, adaptation efforts can exacerbate inequity, further marginalize communities' dependent on specific livelihoods, and increase exposure to risks (Pörtner et al., 2022). Although the unequal distribution of vulnerability is occasionally mentioned, it is not a key consideration in the design of adaptation policies and projects (Magnan et al., 2016), increasing the likelihood that risks and vulnerabilities will be redistributed to already marginalized and vulnerable groups (Atteridge & Remling, 2018).

One of the causes of maladaptation is that decisions regarding climate change have mostly been made by experts, while local communities—who may possess knowledge that could offer alternative adaptation strategies—have had little influence (Falzon, 2021; Naess, 2013). Without a proper understanding of the root causes of vulnerability, adaptation strategies are likely to address only the symptoms, not the underlying issues (Schipper, 2020). Additionally, perceptions of climate change and strategies for adaptation are largely shaped by the values, cultural practices, and worldviews of individuals or groups (Antwi-Agyei et al., 2018). To reduce the risk of maladaptation, climate change adaptation efforts must be inclusive, drawing on cultural values, as well as Indigenous and local knowledge. In Bangladesh, a systematic review of climate resilience in coastal agriculture identified maladaptation, along with gender and inequality, as two areas with significant research gaps (Kundu et al., 2022). Maladaptation was not addressed systematically due to faulty adaptive measures. This paper examines the current state

of research on maladaptation in the Sundarbans, along with the impact of gender on adaptation strategies. In addition, the paper also explores related topics, such as employing ecosystem-based adaptation (EBA) to reduce the risk of adverse outcomes, as well as barriers to adaptation. Maladaptation reduces the resilience of ecosystems to climate change and negatively impacts ecosystem services (Pörtner et al., 2022). EBA is a relevant adaptation strategy for the Sundarbans because it promotes sustainable and productive land use while diversifying livelihoods (Ahammad et al., 2013). However, there is a lack of research that systematically examines the role of EBA and the factors influencing its effectiveness in coastal Bangladesh (Saroar, 2018).

There are many different definitions and typologies of barriers to adaptation, but they are commonly defined as factors that impede adaptation, yet can be overcome with effort (Barnett et al., 2015). Barriers to adaptation have been primarily studied in developed countries, often within the context of the water sector (Biesbrock et al., 2013). Despite the growing literature on this topic, there are few explanations for why barriers exist and how they change over time. This highlights the need for research that focuses on how different barriers interact, as well as why they arise and persist (Eisenack et al., 2014). Such research can also provide insights into how to overcome these barriers.

2.0 Study Area

Most of the studies discussed in the systematic review focus on three districts in Southwestern Bangladesh including Khulna, Bagerhat, and Satkhira as shown in Figure 1. All of these districts include parts of the Sundarbans, one of the regions in Bangladesh most affected by natural disasters, such as Cyclone Aila (Ela et al., 2021). In addition to the loss of human lives and destruction of property, the flooding has led to increased salinization levels (Rahman, 2018). This, in turn, has negatively impacted crop production, forcing many farmers to seek alternative livelihoods (Paul, 2013). A significant portion of the population also suffers from inadequate sanitation, healthcare, and access to safe drinking water (Islam et al., 2013).
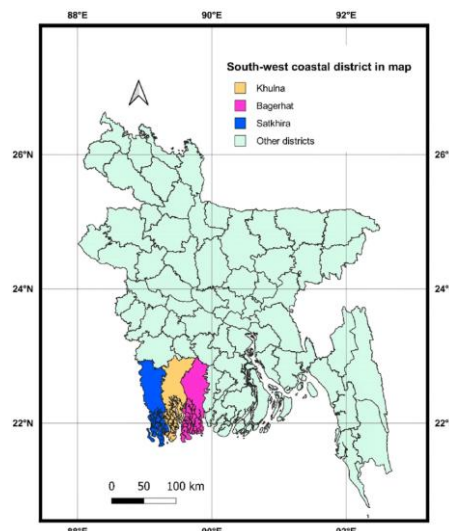

Figure 1: Southwest Coastal Bangladesh (Source: Wikipedia)**.**

3.0 Materials and Methodology

To improve the often-varying quality of systematic review reports in healthcare, Moher et al. (2009) introduced a revised set of guidelines known as Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PRISMA defines a systematic review as a 'review of a formulated question that uses systematic and explicit methods to identify, select, and critically appraise relevant research, and to collect and analyze data from the studies included in the review.' The process employs a flow diagram consisting of four phases: identification, screening, eligibility, and inclusion criteria. By using an approach that is both robust and replicable, the likelihood of biases that might otherwise affect literature reviews can be minimized (Raad & Burke, 2018). The structured methodology of systematic reviews is applicable to both natural and social sciences and has become increasingly used to map and summarize existing knowledge (Ford & Pearce, 2010) and identify research gaps (Pickering & Byrne, 2014). While most systematic reviews have been conducted in healthcare fields, their use has expanded to other disciplines, including the study of climate change adaptation (Berrang-Ford et al., 2015; Antwi-Agyei et al., 2018; Shepard et al., 2011). Recent studies focusing on Bangladesh include Hoque et al. (2019), Kundu et al. (2020), and Ahmed & Khan (2023).

The systematic review aims to address the following key research questions:
1. How prevalent is maladaptation in climate change adaptation projects in coastal Bangladesh?
2. What barriers to adaptation have been identified in the region?
3. To what extent is an Ecosystem-based Approach (EBA), involving local communities and their knowledge, being applied to adaptation projects?
4. Are there gender differences in terms of climate change impacts and adaptive capacities, and how are these differences addressed in climate change adaptation projects?"

3.1 Document Selection

Identification Phase: A search was conducted between August 30 and September 7, 2022, in the Scopus and Web of Science databases. Google Scholar was not utilized, partly due to concerns about its citation accuracy (Falagas et al., 2008). Only peer-reviewed literature was included to ensure that the selected papers adhere to research standards. The search focused on literature published between January 1, 2014, and September 1, 2022. The year 2014 was chosen as the starting point because it marked the release of the IPCC Working Group 2's 5th Report, which extensively addressed the importance of maladaptation in climate change adaptation. The keywords used were

"Adapt*" AND "Climat* Change" AND "Sundarbans" AND "Bangladesh" in the title, keywords, and abstracts, as well as "Climat* Change" AND "maladaptation" AND "Bangladesh."

Screening Phase: During the screening process, papers were excluded for various reasons: lack of available full articles, a focus on the adaptation of mangroves and plant communities rather than human adaptation, or not including Bangladesh (focusing solely on the Indian Sundarbans).

Eligibility Phase: The full papers were read and evaluated for relevance. Some papers were eliminated because they were systematic reviews or did not include any specific discussion of adaptation. Papers were also excluded if they did not involve fieldwork, or if the fieldwork did not take place in southwestern coastal Bangladesh.

Inclusion Phase: The papers that met the inclusion criteria were selected. To increase the sample size, snowballing was employed to identify other possible sources cited in the included texts.
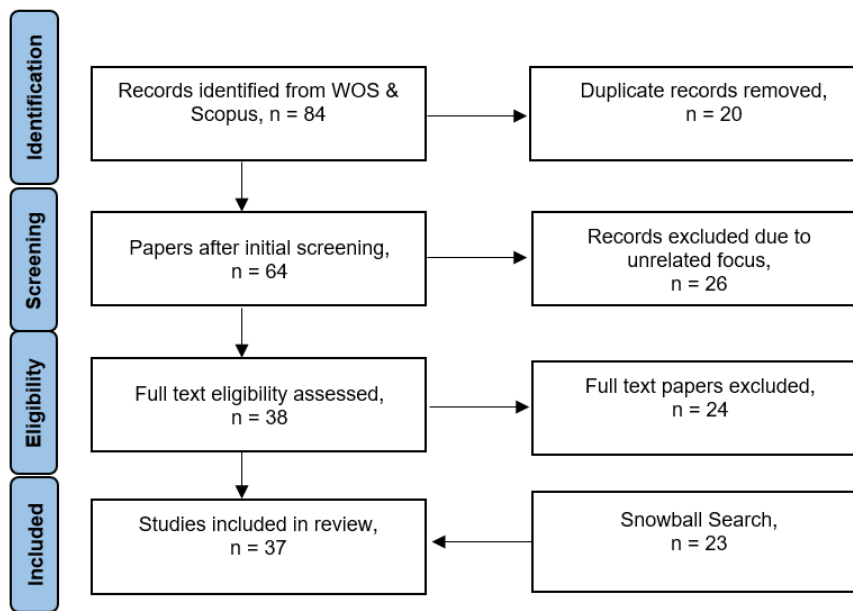

Figure 2: Summary of the four stages in the review protocol following PRISMA.

There are inevitable limitations to the review that can be minimized, but not completely eliminated, through the use of systematic methods with clearly defined criteria for inclusion and exclusion (Rahman et al., 2018; Pickering & Byrne, 2014). For this study, research published in other languages and grey literature was not included, nor were studies conducted using Google Scholar, which could have yielded additional literature.

4.0 Results

4.1 Summary of the Selected Articles

Figure 3 shows the years of publication from 2014 to 2022 included in the systematic review. As illustrated, there has not been an upward trend in the number of studies; even though maladaptation has become increasingly recognized (Pörtner et al., 2022), this awareness has not translated into more research focusing on southwestern coastal Bangladesh. Surprisingly, maladaptation was discussed in only 11 of the articles, considering how prevalent it is in climate change adaptation measures in Bangladesh (Sovacool & Linnér, 2015). Additionally, there is little discussion on how to overcome maladaptation, with only one article offering specific suggestions for addressing the barriers to adaptation.
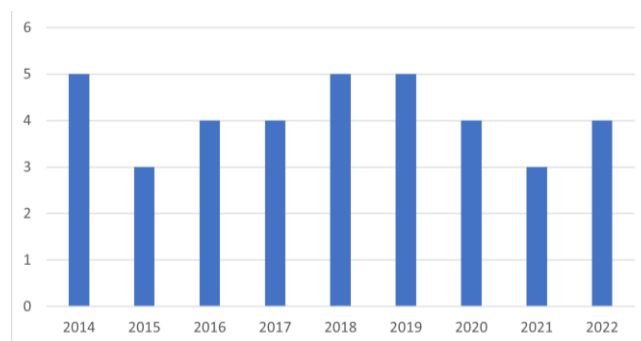

Figure 3: Publication by year.

Figure 4 shows the frequency of fieldwork conducted in the different districts of southwestern coastal Bangladesh. By far, the most studied district was Satkhira, which is immediately adjacent to West Bengal in India, followed by Khulna and Bagerhat. Only one study was found for Pirojpur, which is not part of the Sundarbans but borders it and thus interacts with the Sundarbans ecosystem. Since the impacts and vulnerabilities of climate change are highly geographically specific, it is important that all the various geographical areas of the broader Sundarbans region are studied.
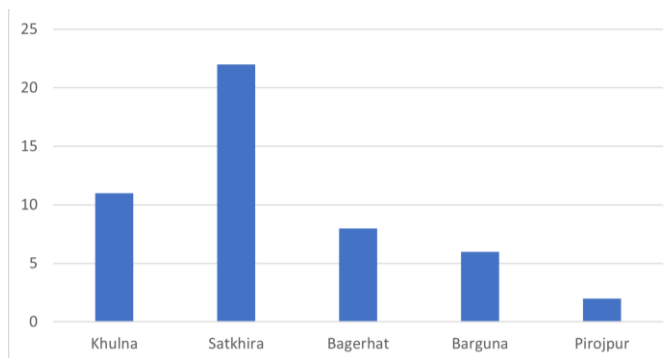

Figure 4: Number of studies by districts.

Figure 5 illustrates the various climate-related impacts discussed in the systematic review. As shown, the two most significant climate stresses are the increased frequency of cyclones (Rakib et al., 2018) and rising salinization levels. Cyclones not only result in the loss of many human lives but also cause damage to agricultural land and a loss of income (Roy, 2017). Salinization is increasing due to sea level rise, potentially reaching up to 160 km inland during the dry season (Khanom, 2016). As rice fields become infertile, an increasing number of livelihoods are threatened (Roy, 2016). Other climate change effects, such as changes in rainfall and temperature, are not generally reported as impacts necessitating adaptation measures in the Sundarbans.
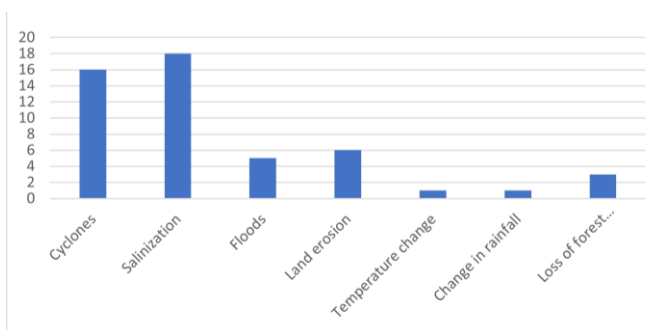

Figure 5: Climate change-related impacts.

Finally, Figure 6 presents the various adaptation measures discussed. The most common measures include modifications to farming practices, such as the use of pesticides and fertilizers, crop intensification, and crop rotation (Khan et al., 2022). An alternative is switching to aquaculture. However, the rise in aquaculture is problematic due to its impact on ecosystem services, which will be discussed in a later section. Migration to urban areas in search of paid work is also a common strategy due to the lack of local livelihood alternatives. This trend impacts gender inequities, as it is predominantly men who move away. There were few mentions of community-based adaptation measures, but in the instances where they were noted, they related to ecosystem-based adaptation (EBA).
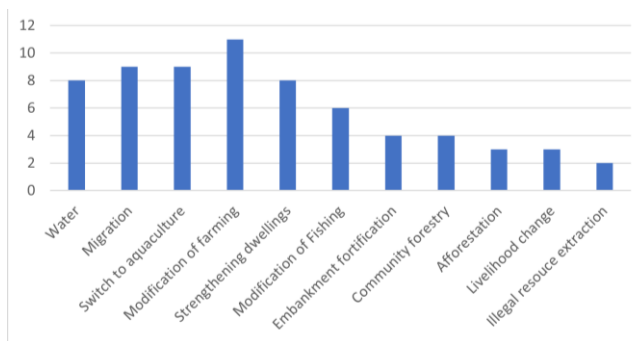

Figure 6: Number of studies by districts.

The analysis revealed significant research gaps regarding how climate change adaptation in the Sundarbans of Bangladesh can lead to maladaptation. It also highlighted the need for examining existing barriers to adaptation, incorporating gender concerns, and utilizing an ecosystem-based approach that involves local communities, rather than imposing a top-down approach on the affected parties.

5.0 Discussion

5.1. Maladaptation

According to Juhola et al. (2016), maladaptation is defined as "a result of an intentional adaptation policy or measure leading to negative outcome(s) for the targeted or other actors." Maladaptation can result in three different outcomes: 1) Rebounding vulnerability, where adaptation measures increase the vulnerability of a party by increasing exposure or sensitivity, or by reducing adaptive capacity; 2) Shifting vulnerability, where vulnerability spills over to external parties; and 3) Eroding sustainable development, which increases greenhouse gas emissions and has negative impacts on environmental conditions and/or social and economic values.

Sovacool and Linnér (2015) identified four different types of maladaptation outcomes. Enclosure refers to the process of transferring either assets or responsibilities from public to private entities, which can involve the capture of public management functions or privatization. Exclusion is understood as the prevention or hindrance of stakeholders from participating in decision-making and influencing the political agenda. The third type of maladaptation outcome is encroachment, whereby an adaptation measure aimed at strengthening human resilience negatively impacts natural areas, species, and ecosystems. Finally, entrenchment leads to greater social and economic inequality by diminishing the power of already disadvantaged groups, such as women and minorities, for instance, by destroying livelihoods or entrenching wealth.

Specifically, these maladaptation outcomes result from three broad factors: infrastructure, institutional, and behavioral (Schipper 2020). Infrastructure maladaptation often occurs in coastal regions when embankments and similar types of infrastructure are built to protect against sea-level rise, storm surges, and salinization. This can lead to changes in ecosystem functions, water availability, and the shifting of risks to other points along the coast. Institutional maladaptation can manifest in how economic agents interact with one another. For instance, it has been found that farmers who have climate insurance worry less about drought-resistant crops and agricultural techniques, as the insurance makes them less aware of risk, a case of moral hazard. Behavioral maladaptation occurs when the decisions people make to adapt to climate change over time have a detrimental effect on resilience and adaptive capacity. An example is when the out-migration of family members results in a lack of labor available for harvesting (Antwi-Agyei et al. 2018).

Maladaptation outcomes in coastal Bangladesh can be categorized into two types: maladaptation caused by the actions of authorities (infrastructure and institutional) in response to specific climate stresses (such as cyclones and flooding), and maladaptation arising from actions taken by the local population (behavioral). The latter may be a response to how their livelihoods are directly affected by climate change or indirectly impacted by government measures in response to climate change.

The construction of embankments has long been employed by the Bangladeshi government to protect against storm surges and salinization associated with climate change. However, this practice exemplifies maladaptation, as it has resulted in sediments being trapped while floodplains are starved of necessary sediments (Roy 2016). Extensive areas have become waterlogged due to the construction of polders and evaporation, leading to increased salinization that damages livelihoods. While both embankment construction and afforestation could be beneficial, their implementation is often not based on scientific understanding, causing them to work against natural forces and become inefficient (Rahman 2015). Many exotic species have been planted along the coast instead of indigenous ones, and they were not introduced in a manner that ensures their resilience. These measures serve as seawalls that mitigate climate change impacts in the short term but increase climate risks in the future (Pörtner et al. 2022).

For the local population, modifications to livelihoods can be considered maladaptation to the extent that they result in outcomes that reduce future adaptive capacity. Switching to aquaculture has emerged as one of the most common adaptation strategies in response to increased salinization caused by sea level rise (SLR) (Islam 2021; Shameem et al. 2014; Chakma et al. 2022; Alston & Akhter 2016; Hoque et al. 2019; Islam et al. 2015; Mallick 2017; Khan 2022) and has indeed been the most significant source of land use change (Shameem 2014). While the shift from agriculture to brackish water shrimp farming along the coast of Bangladesh is partly driven by exogenous factors such as increased international demand and external and national government funding and incentives, salinization has also adversely affected crop production (Shameem et al. 2014). Approximately 50,000 hectares of mangrove forest in the Sundarbans were lost between 2000 and 2010 due to the conversion of forests to aquaculture. As mangrove forests serve as a buffer against cyclones and associated storm surges, this conversion has heightened the vulnerability of the local population (Rahman & Rahman 2015).

Fieldwork in a coastal district bordering the Sundarbans revealed that the local population identified the destruction of mangroves, harm to capture and open water fisheries, and increased salinization resulting from a switch to aquaculture as factors contributing to the loss of ecosystem services (Shameem et al. 2014). Additionally, the health impacts on the ecosystem stemming from the use of antibiotics and the spread of infectious diseases due to the introduction of exotic species should be considered. Beyond the biological impacts, aquaculture employs significantly fewer people than rice paddy farming, and there is evidence of increased inequality in land ownership, along with reduced income diversification.

Many farmers in southern Bangladesh who have not switched to aquaculture have started using fertilizers and pesticides to address how changes in rainfall have hampered crop production (Khan et al. 2022). The biological impacts of fertilizers and pesticides on flora and fauna are well-documented; the reduction of ecosystem resilience and the services derived from them will especially affect the groups most dependent on these services, which tend to be marginalized, thereby reducing their adaptive capacity. The use of fertilizers may partly stem from farmers' lack of knowledge about effective adaptation measures to secure their livelihoods. Traditionally, they have relied on practices and knowledge accumulated over time, adapting to a more gradually changing climate, but this is no longer sufficient (Khan 2022) as they tend to rely on reactive and autonomous practices. Traditional adaptation measures now need to be combined with modern technologies to ensure successful adaptation.

Many local people respond to a loss of livelihood options by resorting to activities in the Sundarbans, such as catching wild shrimp fry and logging, both of which violate the law. This should be viewed as a coping strategy after other livelihood options have disappeared due to climate change disruption (Ahmed 2019). For many participants in one of the cited studies, this was the case following the powerful cyclone Sidr, as well as due to increasing riverbank and coastal erosion, which has been reported in several studies (Islam et al. 2021; Chowdhury et al. 2020; Rahman & Mori 2020). The government's response to the illegal activities in the Sundarbans has been to burn the nets of illegal fishers or to imprison violators, actions that will only increase the vulnerability of the local population and further reduce their adaptive capacity.

5.2 Barriers to Adaptation

It is important to distinguish between limits and barriers to adaptation. Limits to adaptation have been defined by the IPCC as "conditions or factors that render adaptation ineffective as a response to climate change and are largely insurmountable" (Adger et al. 2007). Limits are typically seen as ecological and physical, economic, or technological, but Adger et al. (2009) have pointed out that societal limits to adaptation also exist in the form of values and ethics, risk, knowledge, and culture. Limits are absolute in that they represent a threshold beyond which existing ecosystems, species, and land use cannot be continued (Moser 2010).

Barriers to adaptation refer to obstacles that can be overcome through changes in institutions, resources, land use, etc. (Moser & Ekstrom 2010). What may appear to be limits, especially social limits, are often barriers that can be overcome with the required political will and resources (Adger et al. 2009). Therefore, questioning whether an obstacle is a limit or a barrier and if it can be overcome is often necessary for advancing the adaptation process (Moser & Ekstrom 2010). In the latest assessment report, the IPCC has outlined seven different types of barriers to adaptation: governance (adverse political structure), social (risk aversion and cultural values), institutional (lack of coordination and prioritization processes), behavioral (psychological distress from attachment to loss of a place), financial (limited resources for adaptation), structural (increased exposure due to inappropriate infrastructure), and technical (lack of access to adaptation technologies) (Pörtner et al. 2022).

Governance and institutional barriers are prevalent in a country such as Bangladesh, which has weak socio-political structures (Ahmed et al. 2019). Government policies in natural resource management do not incorporate meaningful participation from groups most dependent on these resources for their livelihoods. For instance, research on possible crop varieties adapted to climate change reportedly did not include the participation or knowledge of local farmers (Rahman 2015). Governance and institutional barriers are also mentioned in several studies (Hassan et al. 2019; Hossain et al. 2018a; Islam et al. 2014; Islam et al. 2020; Ayeb-Karlsson 2016; Rahman 2018; Hossain et al. 2018b). Government policies focusing on economic development while ignoring biodiversity impacts have reduced livelihood options and forced people to rely on aquaculture (Hossain 2018b). In the fisheries sector, rules and regulations are lacking, and a two-month annual ban on fishing reduces income and creates a financial barrier to adaptation (Islam 2019). The relationship between corruption and adaptive capacity to climate change has been little investigated, but it is prevalent in Bangladeshi politics due to rent-seeking behavior among other factors (Rahman 2018). Institutional barriers can also create other barriers, as unfavorable credit frameworks create financial barriers to adaptation for both fishermen and agriculturalists (Islam 2019).

While there is little evidence of explicit behavioral barriers found in the studies, social barriers are significant. In fieldwork in the Himalayas, Jones & Boyd (2011) found that when rigid social institutions govern behavior, people have limited options for how to act, which means that social barriers can prevent or facilitate successful adaptation. Additionally, climate change can result in social arrangements that are more discriminatory and exclusionary than those that existed before, such as women being forced into early marriage (Alston et al. 2014). For many people, such as fishermen whose livelihoods are tied to a specific geographical location, their self-identification with their traditional occupation constitutes a social barrier that makes livelihood diversification harder (Hossain et al. 2018a). At the same time, religious beliefs can present a barrier to adapting to climate change impacts (Chowdhury 2020). Many people in southwestern coastal Bangladesh, especially women, lack human capital in terms of poor levels of education and health, which reduces the adaptation options available to local populations (Islam 2021; Islam 2019; Garai 2016; Mallick 2017; Khan 2022).

Financial Barriers: The poverty of the local population in the Sundarbans is reported as a barrier to climate change adaptation (Hassan et al. 2019; Jordan 2015; Chowdhury 2020; Islam 2014; Shameem et al. 2014). Most fishermen report a lack of access to loans or credit, as well as low income, constituting financial barriers. In addition to preventing livelihood diversification, these financial barriers also make it difficult to fortify houses to withstand cyclones (Islam 2019). The lack of access to financial capital can sometimes be partly mitigated through microfinance. However, research from southwestern Bangladesh found that even when households were given access to microfinance for adaptation, they were unable to adapt their agricultural practices to flooding; the flood-resistant crops that were tried did not succeed. This illustrates that financial barriers can only be overcome when biophysical limits are not present (Fenton et al. 2016).

There is evidence that social capital, particularly informal monetary support, can play a role in coping with climate stresses in the short term (Jordan 2015; Khalil 2021b). However, difficult economic circumstances, where households spend most of their time on survival, leave little time for community engagement. In one study, 77% of the local population reported not being involved in any economic, social, or religious groups (Shameem et al. 2014); poverty exacerbated by climate change can reduce social capital and increase vulnerability.

Structural Barriers: Structural barriers exist in the form of polders and embankments, which have caused waterlogging as natural drainage is blocked, leading to polders being converted into shrimp farms (Rahman 2015). The loss of sediments has also resulted in a loss of livelihoods as the land becomes unproductive for agriculture (Roy 2016). This has meant a loss of livelihood options, thereby reducing the adaptive capacity of the population.

Technical Barriers: One study found that farmers in the Sundarbans are better informed about adaptation measures compared to farmers in a community outside it, but they still lack sufficient adaptation possibilities (Khan 2022). Another example of a technical barrier is the lack of safety equipment among fishermen, which increases their vulnerability to climate hazards. However, this technical barrier is interwoven with governance and institutional barriers, as government corruption makes inspections of fishing boats ineffective (Islam 2020).

In addition to the barriers identified by the IPCC, some researchers identify natural and informational barriers as well. Among the fishermen in the Bay of Bengal, more extreme weather resulting from climate change often prevents them from fishing, and the lost income reduces their adaptive capacity, forcing them to use poor-quality boats (Islam 2020). Many fishermen also report a lack of knowledge about upcoming storms while at sea (Ahmed et al. 2019). Additionally, many do not receive training on climate hazard management and do not know how to respond (Islam 2019). Informational barriers can also manifest as a lack of knowledge about livelihood diversification options or a lack of relevant skills or training (Chowdhury & Islam 2020; Islam 2021). For instance, a lack of access to more resilient shrimp species and stress-tolerant rice varieties and seeds has been reported (Kabir et al. 2017).

Climate change has been reducing natural capital, leading to fewer diversification options, as the loss of cultivable land has meant fewer crop varieties, loss of livestock, and a reduction of homesteads (Shameem et al. 2014). In this way, climate change can be seen as raising the natural barriers to adaptation. In some cases, several types of barriers interact. For example, rainwater harvesting (RWH) faces challenges due to salinization intruding into freshwater reservoirs as a result of climate change. While government policy encourages RWH, institutional barriers exist, as topographical and hydrological information is often confidential, interacting with behavioral barriers due to people's lack of knowledge, making it more difficult to convince them to adopt the measure (Afsari et al. 2022).

5.3 Gender

Marginalized groups, including indigenous people and poor households (often led by women), are particularly susceptible to maladaptation, which reinforces existing inequities (AR6). This vulnerability arises partly because women have fewer financial resources and because men are typically better positioned to receive information and extension services (Jost et al. 2016).

Climate disasters can have four kinds of impacts on women that reduce their resilience and increase their vulnerability. These include economic insecurity following a disaster, increased responsibilities and workload, worsening working conditions, and a significantly longer time for women to recover economically compared to men (Enarson 2000).

Gender inequality and discrimination against women are among the barriers to adaptation mentioned in the previous section. This is especially true for women in rural areas of developing countries, as they tend to rely heavily on natural resources such as water and agricultural products (Garai 2016). Additionally, men in rural areas are more likely to migrate in search of alternative income, as livelihood impacts are most acutely felt by rural populations. This often forces women to take on additional agricultural work alongside their household duties (Jost et al. 2016). The increased demands on women's time due to climate impacts leave them with little opportunity to engage in income-generating activities, such as running small businesses or pursuing off-farm employment (Kakota et al. 2011). Given that women hold much of the local and traditional knowledge (Pörtner et al. 2022), it is essential to incorporate gender aspects into adaptation programs. Women arguably play a crucial role in adaptation, as much of the traditional agricultural knowledge resides with them (Nursey-Bray 2015).

Addressing vulnerability based on social inequities requires designing measures that target existing inequities in society, including those based on gender, thereby enhancing resilience among the most vulnerable groups (Pörtner et al. 2022). Unfortunately, there is limited understanding of how women enhance their resilience to climate change, particularly for those living in coastal areas of Bangladesh (Tanjeela & Rutherford 2018).

Bangladesh is characterized by a highly patriarchal society, where women's restricted roles are reflected in climate change-related programs, which often reinforce gender divisions of labor, social norms, and customary traditions. These impose social and religious restrictions on women working outside the household, confining them to domestic responsibilities such as childcare, household management, gardening, and food processing (Asaduzzaman et al. 2015). Studies indicate that the root causes of the gender gap in employment stem from family culture and religious values (Bilkis et al. 2010).

This issue is particularly pronounced in rural areas, where there is a significant gender gap between males and females (Begum 2005; Tanjeela & Rutherford 2018). The poor status of women in Bangladesh is exacerbated by national policies, adaptation measures, and institutional frameworks that increase women's vulnerability.

Garai (2016) reported that cultural norms dictating that men must make decisions as heads of households diminish women's adaptive capacity, especially during disasters. This issue is compounded if the man has migrated for work. Furthermore, being confined to the home makes it challenging for women to access information about disaster risks and shelter options. This is one reason why women experienced higher fatalities during the cyclones of 1991 and 2007 in Bangladesh (Rahman 2013). In 1991, the mortality rate from the cyclone and flood was five times higher for women than for men (Rohr 2006).

Women also tend to have lower literacy rates, which can hinder their participation in training programs (Garai 2016). Additionally, they face fewer options for livelihood diversification, earning only about half of what men receive for similar labor (Hossain 2018b), and are often subject to social norms that discourage them from handling money (Tanjeela et al. 2018).

Evidence shows that climate change poses greater risks to natural resources that women depend on, such as fish, prawns, and larvae collected from rivers, which are becoming increasingly rare due to salinization (Garai 2016). Tasks traditionally associated with women, such as collecting fuel, water, and food, become more time-consuming after disasters. However, women can enhance their adaptive capacity by networking with NGOs for knowledge, and NGOs are more likely to recruit women who are receptive to new adaptive ideas (Khalil 2021b). Training from NGOs also helps women acquire additional livelihood skills (Khalil 2021a).

One observed adaptation response in rural communities in Bangladesh is an increase in early and forced marriages, as families seek to reduce the number of mouths to feed (Alston et al. 2014). Another coping strategy is for women to eat less, a detrimental intra-household coping mechanism that negatively impacts their health and capacity to generate income (Alston & Akhter 2016). This exacerbates gender-specific food insecurity and further contributes to women's heightened vulnerability to climate change. Given women's roles in food production, preparation, and as caregivers, alongside the increasing number of female-led households, special attention is needed on how food insecurity affects health and nutrition (Ivers & Cullen 2011).

While a systematic review found moderate research on women and climate change adaptation in Southwestern Bangladesh, most studies focused either on post-disaster recovery or the role of social norms in women's adaptive capacity. There is a pressing need for research that is more food-specific, examining how women leverage their localized knowledge to secure food sources. Additionally, there is a lack of in situ examples demonstrating how social mores, institutions, and legal frameworks restrict women's ability to change their livelihood strategies. Finally, while salinization was reported as a significant issue in many studies from the Sundarbans, there was little discussion of gender differences in its impact.

5.4 Ecosystem-based Adaptation

As previously mentioned, one of the causes of maladaptation is that projects or policies are often developed without adequate input from local communities and without an understanding of the local context, which can increase vulnerabilities (Eriksen et al. 2015). Conversely, incorporating biodiversity into adaptation planning reduces the risk of maladaptation, as this approach has proven to be flexible, cost-effective, and relevant for many ecosystems. Ecosystem-Based Adaptation (EBA) has advantages over other approaches due to its many co-benefits, such as its positive impact on climate change mitigation, poverty alleviation, and the protection of livelihoods (Munang et al. 2013).

EBA is defined as the use of natural resources for conservation and ecosystem resilience to mitigate the impacts of climate change (Vignola et al. 2009). Thus, the sustainable use of ecosystem services and biodiversity is key (Colls et al. 2009). Among the advantages of EBA compared to traditional infrastructural protection is its ability to maintain productive coastal land use for diversified livelihoods (Ahammad et al. 2013), while relying less on technological expertise. EBA has the potential to enhance resilience and reduce the vulnerabilities of coastal communities by focusing on ecosystem management led by local stakeholders (Colls et al. 2009). Local communities are best positioned to understand the underlying causes of vulnerability to livelihoods as well as their existing adaptive capacity (van Aalst et al. 2008).

The Sundarbans ecosystem, serving as an embankment, has weakened over several decades due to both climatic and non-climatic stressors (World Bank 2010; Saroar and Routray 2013). Mangrove forests have diminished due to a combination of shrimp farming, over-extraction of wood and non-timber forest products, population pressure, settlement expansion, and management practices not grounded in scientific principles (Alam et al. 2014). The Sundarbans provide essential ecosystem services for nearly 3.5 million people, most of whom are marginalized and face significant inequities in resource ownership and access to external assistance (Ahammad et al. 2013).

In Bangladesh, the conventional approach to coastal ecosystem management has primarily focused on stabilizing coastal lands and protecting mangroves. Following the adoption of its Climate Change Strategy and Action Plan in 2009, Bangladesh has begun implementing various ecosystem-based adaptations (EBA) to enhance climate resilience (Saroar et al. 2019). The most common EBAs include mangrove afforestation, establishment of a tropical green belt, integrated agriculture, aquaculture, and wetland restoration (Saroar 2018). However, there has been insufficient focus on developing alternative livelihoods that emphasize ecosystem protection and the long-term adaptation of vulnerable communities to climate risks (Ahammad et al. 2013).

Most EBA projects involve multiple sectors and policies, requiring support and cooperation from various agencies and institutions, which can be difficult to sustain (Ahammad et al. 2013). The ability to manage multiple stakeholder groups is a crucial factor determining the success of most EBA initiatives (Saroar 2018).

Coastal ecosystems are particularly complex, as they involve managing land, water, and mangrove forest resources. Consequently, their management has often been fragmented and lacking an adequate understanding of conservation and protection of ecosystem services (Shaw et al. 2013). Additionally, local traditional knowledge has often not been incorporated into EBA. The latest Working Group II Report from the IPCC found a significant correlation between a technocratic approach that lacks input from traditional knowledge and the low success rate of climate change adaptation projects in Bangladesh, which did not reflect local perceptions of risk (Pörtner et al. 2022).

A study of two coastal communities in Bangladesh found that the priority adaptation options identified by local residents closely aligned with those outlined in the National Adaptation Programme of Action (NAPA) and the Integrated Coastal Zone Management (ICZM) priorities. However, residents in both communities agreed that traditional knowledge was given little value in the decision-making process.

Community-Based Mangrove Aqua-Silvi-Culture (CMAS) has begun to be implemented on a small scale, utilizing traditional knowledge to cultivate faunal and floral species in an integrated manner. This practice has proven to be more profitable than expected while also protecting many ecosystem services (Kabir 2019a). It requires less maintenance and lower initial costs compared to conventional farming, although it remains at the subsistence level as an economic activity. However, a comparison of the sustainability of different livelihood adaptation measures in Southwestern coastal Bangladesh revealed that CMAS received a low average sustainability score of 5.50 out of 10 when social, economic, and environmental sustainability were aggregated. In contrast, the adaptation measures that received the highest scores were growing local rice varieties (8.14) and dyke cropping (7.92) (Kabir 2019b).

Much of the adaptation is occurring at the household level as individual initiatives rather than as community efforts. Fishermen have diversified their activities by engaging in different types of fisheries (especially aquaculture, including crab fattening programs) and non-fishery activities, such as farming, livestock rearing, and selling firewood. However, this diversification has been hindered by a lack of training and skills (Islam 2021).

Only a handful of articles reviewed examined EBA, and there were few criteria for evaluating the success of projects and measures, although limited time may be a contributing factor. There is a clear need for more studies based on qualitative and quantitative data to assess the success of EBA in Bangladesh and to extract lessons learned and best practices for future projects. Furthermore, there is a need to examine how barriers to adaptation can hinder EBA or lead to maladaptation. A lack of access to finance or technical knowledge may prevent communities from implementing EBA from the ground up. Additionally, government policies and institutional mechanisms, such as regulations and public management, may inhibit communities from executing effective EBA projects. Lastly, it is important to investigate whether social or behavioral norms, such as social mores and religious edicts, exist that impede local people from implementing certain EBA measures. Notably, none of the studies examined the role of women in EBA projects. It is known that much ecosystem knowledge is gendered (Pörtner et al. 2022), making it essential to understand the different roles men and women play in EBA and the extent to which social norms and traditions allow women to incorporate their traditional knowledge into EBA projects.

5.4 Ecosystem-based Adaptation

The systematic review identified several areas where government (and international) policies towards the southwestern coastal areas need improvement for climate change adaptation to reduce vulnerabilities, increase resilience, and minimize the risk of maladaptation. While migration from the Sundarbans and adjacent areas is not a new trend, it has intensified as a consequence of climate change, primarily due to a lack of alternative livelihood options. One government policy to improve these options is to provide training and access to resources for farmers whose traditional knowledge is no longer sufficient to cope with a rapidly changing climate. Given that agriculture in the region mainly depends on tidal flows, it is essential for the government to manage river water to avoid waterlogging and salinity (Khan 2022). As salinization has increased due to maladaptation from previous projects, it is crucial for government interventions to focus on ensuring the livelihood resilience of the local population. This will also require the government to invest more in creating job opportunities and enhancing human development in the region (Ahmed et al. 2019).

To make livelihoods more resilient to climate change, it is vital to provide climate-vulnerable communities with more robust livelihood options. This includes crop varieties that are more resilient to drought, salinity, and pest diseases, which are projected to be the main climate impacts on agriculture in the region. Additionally, aquaculture practices need to focus on developing less virus-prone shrimp post-larvae (Kabir et al. 2017). Research into climate-resistant agriculture and aquaculture in areas such as coastal Bangladesh must be a concerted international effort, rather than placing the entire responsibility on developing countries. However, local farmers' knowledge of crop varieties should be incorporated into crop substitution programs, which has not been the case so far (Rahman 2015).

One of the main barriers to livelihood adaptation is the lack of access to financial capital. It is necessary to expand microfinance schemes that target vulnerable coastal communities, possibly by establishing a national development institution to complement the microfinance provided by NGOs. Recipients of current microfinance often complain that NGOs demand repayments and are unwilling to grant temporary waivers after disasters. As the only way for loan holders to earn enough to repay their loans is by migrating to cities for paid work, this situation exacerbates out-migration (Rahman 2015). A more flexible mechanism for repaying microcredit loans is needed, potentially involving the government taking on a guarantor role. Additionally, provisions should be made for the cancellation of debts incurred by farmers if more than 50% of their crops are damaged (Kabir et al. 2017).

There is also a pressing need for a bottom-up approach to adaptation that incorporates traditional, local knowledge relevant to local conditions. One area where this knowledge can be applied is in managing exposure to hydro-meteorological hazards and other climate risks (Rahman 2015). Traditional approaches such as Tidal River Management are valuable for harvesting rainwater through natural storage systems (Rahman 2020). However, the implementation of EBA must be accompanied by an analysis of the barriers that exist in coastal Bangladesh, as these barriers are substantial (Saroar 2018).

Much of the coastal adaptation work has been hindered by a lack of integration among different sectors, which leads to barriers to adaptation. To mitigate the impact of these barriers, it would be beneficial to create a governmental coordinating agency that can ensure

adaptation policies incorporate a more holistic approach, with adequate consideration of how these measures affect the ecosystem services on which local populations depend

6.0 Conclusions

The systematic review, along with other literature discussed, has shown that Bangladesh has been implementing a number of adaptation measures; however, there is a serious risk of maladaptation due to barriers to adaptation, significant gender inequities that make women more vulnerable, and generally limited consideration of local communities, their indigenous knowledge, and their dependence on ecosystem services for their livelihoods. The sectoral approach to adaptation, as well as to environmental management in general, is arguably one of the sources of maladaptation in Bangladesh (Alam et al. 2011).

Using the frameworks of the four types of maladaptation described by Sovacool & Linnér (2015) (enclosure, exclusion, encroachment, entrenchment), we find that some types are more prevalent than others in the adaptation measures examined in the systematic review.

Enclosure, which refers to the transfer of public assets into private hands as a consequence of climate change adaptation, has a long history in Bangladesh, particularly in the char river islands. This occurs either through ex-situ displacement, where people are directly expelled, or in-situ displacement, where they are forced to move away due to indirect effects such as changes in law or land prices (Sovacool & Linnér 2015). None of the articles included in the review mentioned enclosure; however, Paprocki (2018) discusses how adaptation projects were used by local elites and donors to compel vulnerable populations to abandon their agrarian livelihoods in favor of urban wage labor (Pörtner et al. 2022).

Exclusion is highlighted in several studies, manifesting in the disregard for local communities' input and knowledge in the design and implementation of climate change measures. However, the literature lacks discussion on how decisions are made regarding local adaptation initiatives and the extent to which these decisions are shaped by elite viewpoints.

Encroachment, whereby adaptation projects impact and restrict other types of land use, is particularly problematic due to the construction of embankments and polders designed to protect against sea-level rise. These structures have caused waterlogging, rendering crop farming unviable in many areas, while shrimp farming has become more prevalent, with significant consequences for livelihoods, inequality, and local power dynamics.

Finally, entrenchment refers to how adaptation can exacerbate disempowerment or income inequality across communities. This has been particularly evident for women, whose vulnerability and lack of social equality are heightened because they have a harder time seeking shelter during disasters, fewer livelihood options, less ability to participate in adaptation activities, and are often forced to reduce food intake to manage household consumption. Their increased vulnerability is also prevalent among the most economically marginalized households, which have limited adaptive capacity and few livelihood options.

Maladaptation has been shown, in this study and others, to be a significant obstacle to successful climate change adaptation projects in Bangladesh. Much more attention must be given to the specific factors that contribute to maladaptation, and these factors should be included in the analysis of any adaptation measure, along with the specific barriers to adaptation that exist for that project. To avoid maladaptation, it is essential that projects involve local communities and consider the impacts on their livelihoods; this is best achieved through Ecosystem-Based Adaptation where possible. Additionally, adaptation must address existing inequities in the affected communities, including conducting a gender-specific analysis of the project. Only by implementing these steps can the risk of maladaptation be effectively reduced.

Conflicts of Interest: The authors declare that there is no conflict of interest.

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Supplementary Materials

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