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Inequality and adaptation to Sea Level Rise under RCP4.5 until 2100: a study of adaptation strategies for vulnerable communities in India's Ganga Delta

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Summary

This research focuses on adaptation strategies for vulnerable communities in the Indian Ganga Delta against projected sea level rise (SLR) under RCP4.5 until 2100 and how adaptation strategies can be designed to reduce SLR-related inequalities for these social groups. In general, societies can adapt to SLR-related threats in three ways: planned migration, managed retreat, accommodation, and "hold the line" through structural, non-structural or ecosystem-based adaptation approaches. Although these can be combined, sometimes choices have to be made between multiple options. Landless people, who are predominantly agricultural labourers, are likely forced to migrate due to tidal erosion of mud embarkments and land degradation by saline water intrusion. For these people, SLR poses a significant risk, and it is already happening today. Other social groups such as women and older adults also tend to have higher vulnerability to hazardous events. SLR shows how an environmental threat can have an uneven impact in terms of severity and urgency on certain groups and how it can cause certain livelihoods to become even more precarious than they already are. For this reason, it is important to see which measures have been adopted in the past, what the current situation is, what the drivers behind SLR-induced inequalities are and how adaptation strategies can be designed to prevent or reduce this. Hence, the main research question is the following: "What are the adaptation strategies for vulnerable communities in the Ganga Delta in India for projected Sea Level Rise under RCP4.5 until 2100 and how can it reduce potential SLR-induced inequalities"

By looking at a mean SLR of 0.55 meter (which is the IPCC's intermediate projection under RCP4.5) combined with storm surge sea level heights of 4,5 and 6,5 meters, this study has applied geographic information systems (GIS) to map which areas in West Bengal India will be affected by SLR. These maps show critical flood-prone areas in and around the Sandurban region, including urban hotspots near the banks of several large rivers. Furthermore, this research did a review of recent literature on SLR-induced inequalities. It identified several corridors that increase vulnerability and inequality by reproducing exposure, sensitivity and adaptive capacity of vulnerable communities. Subsequently, the LASI wave-1 survey dataset from 2018 was used for a vulnerability indicator assessment of women, older adults and landless agricultural groups. Lacking geo-codes of the respondents (which are yet to be released) limited this analysis, as it prevented an integration of geospatial vulnerability variables. At last, a literature-based analysis of recent and potential future adaptation strategies was done, which concluded that a mix of soft and hard approaches while incentivizing long-term migration will potentially protect vulnerable communities the most.

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1. Introduction

Since 1900, our global CO_2 emissions have significantly increased to a staggering annuals emission of 33.1 billion metric tons (IEA, 2020). The main contributor to this surge is the combustion of fossil fuels for energy production in combination with economic growth and population growth. As of the 1970's the scientific community has increasingly expressed its concerns about this trend and are warning for global warming due to the greenhouse effect. In short, greenhouse gases (such as CO_2) in the atmosphere trap long-wave radiation and cause the global temperature to increase. The effects of global warming were unclear for a long time, but nowadays there is a large consensus on the altering effects it has on the climate system. One of the most worrying aspects is the influence on the hydrological cycles and in particular the melting of land ice and the temperature increase of the oceans. In 1990 the First Assessment Report of the Intergovernmental Panel on Climate Change was published which showed the potential sea level rise under several emission scenarios, the so-called Representative Concentration Pathways. Nowadays, as climate science is understood more clearly, these projections have been updated and RCP4.5 (the IPCC's intermediate scenario) shows a projected SLR of 0.55 meters in 2100 (IPCC, 2019). It is important to understand that these projections are the most likely scenarios. Indeed, SLR can go up or down, and this is largely due to the uncertainties around tipping points and positive feedback loops within the climate system (such as the collapse of ice sheets or the release of methane gas in the Arctic permafrost). For decades this panel, the scientific community and environmental organizations have been calling for mitigating actions, but these efforts have successfully been worked against by for instance extensive lobby efforts of the fossil fuel industry (Laville, 2019). Moreover, the current economic system based on liberal economic theory has favoured these cheap easily available energy sources as fuel for the arguably required economic growth. Nevertheless, popular view on climate change have increasingly become more in favour of climate action and governments around the world are slowly committing to climate goals, with the Paris Agreement in 2015 as the most promising achievement. Here, world leaders decided that a global warming of less than 1.5 degrees Celsius should be strived for, but there has also been more attention devoted to the other side of climate action: adaptation. This was namely in the form of providing financial assistance to countries that are less endowed and more vulnerable, acknowledging the unequal aspects of climate change in terms of contribution, responsibility and impact (IPCC, 2019). Aside from the debate whether this support is fair and justified, environmentalists and policymakers argue whether a focus on adaptation may hamper the more urgent matter of mitigation (i.e., prevention is better than cure). However, the effects of climate change can already be experienced around the globe in the form of droughts and floods and our historic efforts to tackle climate change are far from promising. In addition, even if global warming stabilizes below 1.5 degrees Celsius, there is a change that climate change will still have detrimental effects on society and ecosystems (IPCC, 2019). And to make matters worse, SLR-induced threats will probably be unequally distributed across and within these vulnerable countries. Due to this it is necessary to look at different adaptation strategies and assess them with respect to socio-economic vulnerabilities.

In general, societies can adapt to SLR-related threats in three ways: planned migration, managed retreat, accommodation, and "hold the line" through structural, non-structural or ecosystem-based adaptation approaches. Although these can be combined, sometimes choices have to be made between multiple options. Moreover, to ensure that vulnerable communities are not left behind, supplementary strategies that prevent increasing inequalities are indispensable.

1.1 Regional background and problem definition

India, and the West Bengals in particular, is considered one of the most vulnerable regions in the world to natural disasters due to its high population density, low economic development and its geographical location in the Ganges Delta (Thattai et al., 2017). West Bengal (see figure 1) is India's fourth-most populated, and second-most densely populated, state with a population of more than 91 million (1,029 people per square kilometre) (Census of India, 2018). Geologically, the delta is a rather dynamic region, as the land continuously changes due to sedimentary deposits of the rivers and oceanic transformations due to tidal dynamics, waves and coastal streams (Harms, 2018). SLR poses a significant risk to the delta as the region frequently experiences floods caused by monsoons, tropical cyclones and storm surges. Although SLR is a gradual process, storm events and looming thresholds in the climate system may cause for more rapid future SLR. Thus, it is probably inevitable that the local physical environment and traditional livelihoods will be heavily altered, which will have disruptive consequences for local communities. Although people located far from the ocean are rather well adapted to cyclical floods caused by monsoons (which even nourish the agricultural land), the nature of the floods near the delta's estuaries will undergo significant changes with SLR due to tidal incursions. These tides will push huge swaths of water inland, causing coastal erosion and soil salinization (Harms, 2018). In the event of storms, mainly the coastal "belt" has to undergo the majority of the wind impacts as the wind velocities rapidly decrease after a storm makes landfall. Hence, the direct coastal areas have to withstand most of these hazardous forces.

Figure 1: location of the state West Bengal in India (MapsOpenSource.com, n.d.)

In general, a distinction can be made between two types of hazards related to SLR, namely floods and storm surges (i.e., extreme weather events), and normalized transformations such as erosion and permanent submergence. Thus, two distinct areas will exist, namely: areas that will avoid permanent submergence (and experience severe floods) and areas that will be seriously and frequently damaged or permanently submerged (i.e., wetlands, estuaries and mangrove forests). Although SLR will greatly affect the sustainability of coastal communities in the prior areas, it is questionable whether it would create enough pressure for outright migration. As such, these areas could potentially suffice with a mix of strategies that comprise of technological and socio-economic adaptations. The latter areas, on the other hand, will need large-scale adaptation measures or else the only option left would be migration (which is also a type of adaptation). Although these hazards are interrelated to each other (as storm surge events will also result in erosion) the impacts of these hazards will have different effects and outcomes. This also has to do with the fact that the normalized transformations are easily overseen and forgotten, whilst floods are swiftly labelled as "disasters". This is mainly due to the looming and chronic nature of normalized transformations, where coastal erosion happens over an endless series of tiny gnaws at beaches and shores. On the contrary, floods have a huge impact in a relatively small timespan, and they demand direct and simultaneous action. Thus, these SLR-related threats require very distinct adaptation strategies, however not exclusively because of this.

Although the SLR-related disasters impact almost everyone in the region, literature shows that many damages and losses that occur are unequally distributed across social groups; especially for women, older people and landless agricultural labourers (Islam & Winkel, 2017). Between 125 and 143 million people live on the delta with around two-third of them working as agricultural labourers (Taramelli et al., 2020). The livelihoods of these people are dependent on arable lands that are, aside from depleting agricultural practices, threatened by increasing events of coastal erosion and saltwater intrusion. Many people believe that the highest segment of Indian society is comprised of land-owning farmers, but latest census data have shown that rural landless agricultural labourers have become the highest segment of Indian society, with 107 million in 2011 to 144 million in 2018 (against 119 million land-owing farmers) (Census of India, 2018). Already, the livelihoods of these landless labourers are extremely precarious, and they are almost entirely absent in policies and policy-debates on farming and climate-adaptation (Dogra, 2020). The case of landless labourers illustrates how SLR can exacerbate local inequalities as especially these people will be affected by SLR, with forced migration as the only option available. If people migrate permanently, lack of education and skills can lead to low employment opportunities in the 'safe-zones'. In West-Bengal, 13.3% of the population is 60 years or older and more than half of the population are women (LASI, 2018)). As these groups are already vulnerable (and have a disadvantaged position on the societal ladder), projected SLR will have a disproportionately negative effect on them, which could lead to an exacerbation of socio-economic inequalities. As floods are rather "normal" for the region and there is hardly any help or guidance from governmental institutes, rural communities frequently fall back on their own adaptation strategies, with temporary migration in particular (McLeman, 2017). For instance, during the monsoon (flood) season, many young men leave the area in search of employment elsewhere until the harvest season in November. This means that women and older adults are left behind, which makes their position even more precarious (especially if remittances fail to be sent home or post-disaster restorations fall on the shoulders of women) (McLeman, 2017; Abebe, 2014). This makes it important to understand the degree of vulnerability of these groups and the drivers around SLR-induced inequality.

1.2 Objective and research questions

Hence, this research aims to find out how projected SLR can result into increased socio-economic inequalities for vulnerable communities, what the drivers behind this are and how adaptation strategies for coastal communities can lead to lower vulnerability and more just and resilient adaptation by vulnerable groups.

The main research question is the following:

> "What are potential adaptation strategies for vulnerable communities in West Bengal, India for projected sea level rise and how can it reduce SLR-induced inequalities"

The sub-questions are:

1. Which areas in West Bengal, India are currently and will be threatened by projected SLR?
2. What is the degree of vulnerability of women, older adults and landless agricultural labourers in West Bengal?
3. How can SLR-related threats exacerbate socio-economic inequalities for vulnerable communities and what are potential adaptation strategies against SLR-related threats?

The main research question has been answered through research based on secondary data and literature analysis in the period of September until the beginning of January. This study applied geographic information systems (GIS) to model which areas in West Bengal will be threatened by SLR. Secondary demographic data have been quantitatively analysed to indicate vulnerability of the women, older adults and landless agricultural labourers. For this a normalized vulnerability index was calculated which provides a vulnerability score for each respondent/vulnerable group. This in turn allows for assessment and comparability among (vulnerable) communities. A literature review has been done to analyse the drivers that revolve around vulnerability and SLR, and how these can result into more socio-economic inequalities for vulnerable communities. Literature study has also collected adaptation strategies that are needed to tackle this. The findings are eventually analysed in a Driver-Pressure-State-Impact-Response Framework (DPSIR), which will allow exploration of possible roads ahead and will serve as input for adaptation (policy) recommendations.

2. Literature Review

A collection of papers from different authors were regarded for the literature study. The main purpose was to construct a theoretical framework, to discover a knowledge gap and to select appropriate methodology/variables. As the thesis was planned around adaptation to SLR, the initial search for literature was focused on establishing a coherent idea of adaptation strategies to SLR and what the theoretical background could be. Subsequently, research on the local context and the sub themes of the research were done, which are vulnerable communities and inequality.

Theoretical Framework: Complex Adaptive Systems Theory and Vulnerability
The research of Nguyen et al. (2019) will be important as they used complex adaptive systems theory to analyse drivers of change and adaptation strategies of coastal systems to salinization in Vietnamese deltas. They showed how feedback dynamics affected several drivers of change which had its impact on adaptation strategies during recent decades. The theoretical framework of this research will be used for this research just as their approach to link adaptation strategies with drivers of change in order to identify the socio-economic context of SLR-induced exacerbation of inequalities. For this, the theoretical basis around Complex Adaptive Systems and Drivers of Change will be integrated with the DPSIR framework that is used by Hossain et al. (2018).

Vulnerability is an important aspect of this research as it focuses on vulnerable communities. For this it was needed to get a coherent idea of vulnerability and how this can be viewed in the context of resilience, adaptive capacity and inequality.

Interestingly, in Oliver-Smith, A. (2009) the authors stated that "the relationship between vulnerability and resilience is not linear, but rather dialectical (i.e., reducing vulnerability may or may not increase resilience, but it may also create other forms of vulnerability)". They stated: "The concept of vulnerability is fundamentally a political ecological concept, integrating not only political economic, but environmental forces in terms of both biophysical and socially constructed risk.". Throughout the paper, there has been much attention devoted to social vulnerability in the context of SLR and the human processes that undermine their integrated natural systems: "These forms of socio-ecological vulnerability can be imposed on a local environment, however, by exogenous social, political and economic forces.". For instance, coastal erosion and deforestation are results of human-made pressures and increase the exposure of land (and thus the coastal communities) to sea level rise. It is this interaction between human actions and ecological change that can cause for growing vulnerability which can have different impacts on certain social groups. How communities respond and cope with these pressures are key for designing adaptation strategies against SLR. The findings and discussion of this research will be providing excellent insights for identifying drivers of change behind increasing inequality and how vulnerability is linked to this.

In Smit & Wandel (2006), adaptation strategies were put in the context of adaptive capacity and vulnerability. They set out important concepts revolving vulnerability, such as exposure, sensitivity and adaptive capacity and look how these concepts are applied to social and ecological systems. They stated: "This conceptualization broadly indicates the ways in which vulnerabilities of communities are shaped. It does not necessarily imply that the elements of exposure, sensitivity and adaptive capacity can or should be measured in order to numerically compare the relative vulnerability of communities, regions or countries. Vulnerability, its elements of exposure, sensitivity and adaptive capacity, and their determinants are dynamic (they vary over time), they vary by type, they vary from stimulus to stimulus, and they are place- and system-specific.". This insight is important for the quantitative analysis for measuring vulnerability of the three social groups, women, older adults and landless labourers.

In Smit & Pilifosova (2003), an in-depth reflection on adaptive capacity was done, and it focused on so-called coping ranges. The coping ranges of systems show how some systems can "accommodate some deviations from "normal" conditions", which can be called a "vulnerability threshold". This insight is important for the adaptation strategies study, which looks to reduce or prevent increasing inequality and increase adaptive capacity. For this, this research needs to establish certain tipping points or thresholds, and with this in mind it could base these threshold values on the demographic characteristics that are collected and subsequently analysed. For instance, if an adaptation strategy will lead to more exposure or sensitivity of older adults to floods, of which a variable has been linked to vulnerability, it will result in more inequality. Thus, it is not a suitable strategy.

Weis et al. (2016) assessed vulnerability and came up with an integrated approach to map this. Their study focused more on regions and did not look at communities though. Nevertheless, their approach is quite useful as it put up a list of indicators and variables, and they have established a method to produce a vulnerability index. They defined vulnerability as a product of exposure, sensitivity and adaptive capacity. This research will also use these concepts.

O'Brien et al. (2004) presented a method to assess climate vulnerability combined with other global pressures. This method, which includes vulnerability maps and local case studies, is applicable to analyse different degrees of vulnerability, and can be used for policy recommendations. Although their research is more focused on regions and agriculture, and it largely ignored differences in vulnerability among social groups, their view on key concepts of vulnerability, namely adaptive capacity, sensitivity and exposure are important. Moreover, for adaptive capacity they looked at biophysical, socioeconomic and technological factors that influence agricultural production. Socio-economic factors were based on human and social capital, with indicators such as adult literacy rates and degree of gender equity in a district. I would argue that their scope is rather limited, as the indicators for vulnerability are rather narrow due their focus on agricultural production. However, they have tried to map out adaptive capacity across the entire country (India) and logically tried to narrow down their scope. This research will also look at agriculture as an important facet of adaptive capacity, but it is not looking to design adaptation strategies to realize high production. Nevertheless, the research will provide good insights into vulnerability against climate change and how this can be used as a basis for policy interventions.

In Karmorkar et al. (2019) cyclone vulnerability of women in Bangladesh was analysed. The authors have proposed a framework to quantitatively assess vulnerability with the use of indicator statuses. They stated: "The proposed scores-based vulnerability expresses the vulnerability status with an integer value easier to understand and allows spatial comparability." Their approach and especially their formulas will be used to calculate the vulnerability indices in this research.

Inequality

In Islam & Winkel (2017), the relation between socio-economic inequalities and climate change were conceptualized. They focused on the vicious cycle that revolves around inequality and SLR: vulnerable people are disproportionately sensitive to future hazardous events, which subsequently result into more inequality etcetera. Throughout the research they focused on three main drivers behind this interplay, which are increase of exposure to climate change impacts, increase in susceptibility to damage and decrease of adaptive capacity (ability to cope or recover from damage). This paper is highly appropriate for answering the second and third sub-question on SLR-induced inequalities as it has gathered a lot of evidence that back this rhetoric. For the quantitative analysis assumptions will partially be based on this article in order to link demographic characteristics to vulnerability, and subsequently to inequality.

Schlosberg, Collins & Niemeyer (2017) analysed public involvement in the development of adaptation strategies and how this attributes to more justice. They highlight the importance of public, engaging and transformative thinking of adaptation and theorize the relationship between climate justice and adaptation. They conclude: "despite a discursive disconnect between governmental focus on a risk or resilience-based approach and a community concern with the vulnerability of basic needs and capabilities of everyday life, deliberative engagement in adaptation planning can both address issues of justice and represent a transformative practice". These insights can prove to be important for designing strategies that can reduce SLR-related inequalities for vulnerable communities.

With respect to inequality and gender, Ylipaa, Gabrielsson and Jerneck (2019) did qualitative research on gender, adaptation strategies to climate changes and agricultural livelihoods in Vietnam. They identified unequal norms, social structures and duties between agricultural women and men, which lead to higher vulnerabilities to climate change for women. They argued for certain drivers behind this increase and stress the importance of gender-informed climate change adaptation.

Moreover, Abebe (2014) wrote an article about climate adaptation, gender inequality and migration in East Africa. Although the context is different, the drivers and the impacts of SLR-induced inequalities have a universal nature and can thus be used to support certain assumptions on vulnerability of women to SLR. Additionally, it can be used to identify drivers and assess adaptation strategies.

Phan et al. (2018) studied how social capital regulates and mobilises resources and approached it with a focus on gender. They concluded that "gender norms explain the division and interactions of men and women in formal and informal networks". Although my research will not use a sustainable livelihoods approach, the arguments and the findings of this research with respect to social capital of women will back assumptions on vulnerability and will be important to identify drivers of SLR-induced inequality.

McLeman (2017) wrote a book chapter on climate-related migration and its linkages to vulnerability, adaptation, and socio- economic inequality. He has focused on Bangladesh for this analysis and argues that floods are a rather 'normal' risk that needs to be coped with by households and that only events that are outside of these normalized risks (such as droughts, but arguably also salinization and erosion) tend to result in noticeable changes in migration. He concluded: "Migration patterns in Bangladesh tend to be highly gendered in general, and women, children, and the older adults have a high potential to be trapped in difficult situations when rural men migrate in search of temporary employment during the flood season or in the aftermath of cyclones. Further, it is the rural poor who suffer most greatly from floods and other disasters and are most likely to resort to migration as a coping strategy.". The rhetoric used throughout the chapter will be important for analysing demographic characteristics for local vulnerability.

The same book has a concluding chapter from Schade, Faist & McLeman (2016) and looked at environmentally induced migration as adaptation and inequality. They summarize important aspects surrounding inequalities in the scope of migration and zoom in on remittances and household-inequalities. Moreover, they identified how social inequality is currently viewed in environmental migration-related policies. Not only will this provide useful insights for the assessment of adaptation strategies, but it will provide a review of relevant institutions and policy frameworks. Suitably, it already puts the issues of adaptation in the light of inequality and does certain policy recommendations that should integrate this issue in the climate adaptation debate.

Quite similarly, Sánchez-Triana et al. (2018) has focused on the India's Sundarbans in West Bengal and recommended an adaptation approach that would combine migration and risk management. They supported this with analysis of the risks and the economic, human and social capital requirements that people need to safely and migrate to stable zones. This research has influenced my view on adaptation strategies, and it could also result in a reconsideration of my assumptions on adaptation tipping points, as I initially had the notion that migration should be prevented at all times.

Coastal livelihoods and adaptation strategies

To get a better grasp of the pressures on coastal livelihoods and how this can be combined with adaptation strategies, the research of Smith (2013) will be taken into account. He studied adaptation strategies in the Mekong Delta and identified social, economic and physical barriers to adaptation strategies. Based on these findings, he analysed a sustainable livelihoods adaptation framework, which uses a system and futures workshop to set forth complexity, identify plausible futures, develop strategies and identify or verify adaptive capacity. Their focus on sustainable livelihoods as an overarching vision for the future is interesting for this research, as this larger frame entails higher adaptive capacity and equality. They state: "Scoones identifies three main livelihood strategies for adaptation strategies for rural communities—these include: agricultural intensification/extensification; livelihood diversification; and migration to less vulnerable areas." Concerning complexity, they concluded that "interventions should not only target the key system drivers but also relays that affect a high number of other variables in the coastal zone system. Similarly, feedback loops, which are self-reinforcing should also be targeted. However, the magnitude of impacts resulting from those drivers, relays, and feedback loops (and thus the magnitude of the success of an intervention) need to also be considered.". This view falls in line with the theoretical background of this research and their findings will contribute to the identification of drivers behind SLR-related inequalities. Moreover, the authors focus on adaptive capacity, and they based their research on the following definition: "Adaptive capacity is the ability of a system to evolve in order to accommodate climate changes or to expand the range of variability with which it can cope". They used a 'capital framework' to assess adaptive capacity, which are social, human, organizational, financial, built and natural capital. For this research, the demographic analysis for vulnerability will be based on indicators of adaptive capacity, susceptibility and exposure, but my adaptation strategies study will integrate these indices with this capital approach (lower vulnerability and inequality prevention are the objectives of these adaptation strategies).

Furthermore, Barnett et al. (2014) tested how relevant and feasible a local adaptation pathway against SLR was. They regard previous research on adaptation pathways (e.g., Thames and Rhine Delta) as less appropriate for smaller town as these town/communities have less capacity and much less assets to protect. Firstly, small areas usually do not have enough technical skills and financial resources for large-scale (infrastructural) projects. Second, risks at local level are not significant on a national level, which is why policymakers tend to lack political mandate for action. Thirdly, decisions at the local scale rely on consensus with local constituencies. Concerning consensus, they state: "Local consensus on adaptation decisions is difficult, because within communities there are differences among people with respect to their awareness of the risks of climate change, preferences for the distribution of benefits and costs of action and inaction, associations and attachments to places, and hopes for the future. The local politics of climate change is further complicated by degrees of resistance to outside and expert framings of risks, typically inadequate inclusion of local knowledge and values, failure to agree on the goals of adaptation, and processes that do not allow for the slow working through of psychological, spiritual and emotional responses.". They argue that "local governments are not adapting to sea-level rise because it is difficult to build consensus on the need for change and the best way to implement it". This rhetoric will be considered for assessing different adaptation measures, especially in light of preventing inequality for vulnerable communities as these challenges can explain why adaptation at local levels can be very slow and inadequate.

For answering the third question, revolving adaptation strategies, Roy et al. (2020) will also be used, as the authors designed adaptation pathways to improve livelihood resilience of flood-prone households in Bangladesh. For this they used three steps: "(1) assessing livelihood resilience by constructing resilience indices; (2)

determining adaptation options by employing principal component analysis (PCA) of resilience indicators; and (3) designing pathways of selected adaptation options by conducting key informant interviews (KIIs), and participatory workshops". The authors focused on livelihood resilience, which they define as "long-term capacities to sustain and improve livelihood opportunities and well-being despite climatic and non-climatic hazards". They state that the primary source for the livelihoods of coastal communities is agriculture, with mainly rice, wheat and fish production, and its resilience depends on local people's "capacities, institutions, technologies and governance". The way these authors approach resilience could be quite similar to my approach on vulnerability, as these concepts are in some manner two sides of the same coin. Low resilience means high vulnerability, and vice versa. In the research they name numerous ways how adaptation pathways could improve resilience and they acknowledge the difficulties of this approach, which are "long time horizons, long lead times (i.e., the time from first consideration to execution), time lags (i.e., a period between two interventions), and tipping points/thresholds (e.g., ecological or physical)". For assessing livelihoods resilience, this research constructed indices that corresponded to three capacities: "absorptive, adaptive and transformative, and six dimensions (i.e., social, institutional, economic, ecological, physical and political)". Subsequently, these indices are laid out with regard to measurement and logic and come with references. Although their method is quite different, as they have collected data on these indices through surveys, the index framework will be useful for the demographic analysis for vulnerability. Moreover, the acquired adaptation measures through key-informant interviews will be taken into consideration for this research.

Bonnet & Birchall (2020) further explored this local approach by focusing on vulnerable communities and assessing adaptation types and barriers in the context of climate adaptation. They base their assumption on vulnerability on a definition from IPCC where "vulnerability can be characterized as the tendency or likelihood of human and natural systems to be adversely affected by climate impacts and threats.". Factors that influence vulnerability are exposure, physical setting and sensitivity (susceptibility), and adaptive capacity. Moreover, they stress the importance of adverse climate effects on resources, social and economic context, and geographical location. Although the authors focus a lot on physical sensitivity, there is attention to the uneven distribution of climate impacts and the variability of vulnerability. For instance, they name distribution of wealth, demographics, adaptive capacity, and governance structures as factors that influence susceptibility to climate impacts. Furthermore, they set out the most relevant adaptation types to vulnerable coastal communities, namely structural-, non-structural-, and ecosystem-based approaches, in put them into the context of SLR, coastal erosion and extreme weather events. Logically, this paper will be important for backing up assumptions on vulnerability for the demographic analysis, how certain drivers can exacerbate SLR-related inequalities and to assess potential adaptation strategies.

Ahammad, Nandy & Husnain (2013) did research on ecosystem-based adaptation strategies. For this they focused on Bangladesh's CBACC-Coastal Afforestation initiative, which holds a total of 6,100 ha of new mangrove plantation and the introduction of 10 important mangrove species in existing monoculture areas. The project increased protective and carbon rich forest coverage and provided functional capacity of coastal vegetation to adapt to current and future climatic shocks. Moreover, it also developed co-benefit regime for community-based adaptation through innovating integrated land uses for livelihoods of adjacent households. The findings in this study and the arguments that are being apprehended will be integrated in the multicriteria analysis of my research for assessing adaptation measures.

In the book 'Climate Change and Ocean Governance: Politics and Policy for Threatened Seas', Harms (2019) wrote a chapter named 'Adapting to Sea-Level Rise in the Indian Ocean' that takes India and Bangladesh as the case studies. Not only does it provide a very in-depth analysis of the physical conditions that revolve around SLR in the Bengal area it also sheds light on the governance of the climate change impacts and how hazards emanating from global warming are responded to and how it can affect social vulnerabilities. Moreover, it offers a critical analysis of policy documents and ethnographic evidence gathered during long-term research on the subcontinent. Not only will this provide a lot of information of the system dynamics it will provide a local frame on which adaptation strategies can be based for improving local adaptive capacity and reducing local inequalities.

Hossain et al. (2018) analysed the drivers behind salinization, how this affects coastal communities and what the potential adaptation strategies are. A driver-pressure-state-impact-response (DPSIR) framework is used to integrate local perceptions on strategies (bottom-up and top-down). The DPSIR framework will be used in this research to identify the way SLR and other drivers lead to increased inequality for vulnerable communities and what their feedback and interactions are.

Conclusion and research gap

The literature review found rather useful articles on adaptation strategies, SLR, vulnerability and inequality. It showed the numerous aspects that are important during an adaptation strategies study. The focuses were rather different though, as some focused on livelihood resilience and vulnerable local communities, while others looked at primarily top-down and large-scale cases. Moreover, while most papers focused on SLR, many had their specific focus on groundwater salinization due to SLR, while only one research focused on SLR-related erosion of the shoreline. Furthermore, most had their case study in Bangladesh or other deltas around the world. Although there are papers that link SLR and inequality, I could not find research where the authors tried to design adaptation strategies that reduce of prevent increasing inequality due to SLR. Thus, it shows there is a research gap between other SLR-related threats (such as floods and coastal erosion), how this can lead to more inequality for vulnerable communities, and how adaptation strategies can be adopted to reduce or prevent increasing inequality.

3. Theoretical Framework

3.1 Complex Adaptive Systems Theory

Finding its origins in biology, complex adaptive system theory focuses on the interrelation between human societies and nature, future uncertainties due to changing system dynamics, and the manner in which systems adapt and evolve in these conditions (Nguyen et al., 2019). Complex adaptive systems (CAS) are applied in order to explain how systems are featured with interconnections and feedback mechanisms between its system components. Usually, the systems are influenced by several "drivers of change" in different scales and on multiple levels. The system components tend to have nonlinear relationships (i.e., small changes can have large effects) and are thus rather unpredictable. Nevertheless, due to these characteristics, complex adaptive systems can continually adapt to changes and pressures. As Nguyen et al. (2019) states: "changes and adaptations in complex adaptive systems are considered as processes of interactions and feedbacks of multiple drivers of change with internal processes of system components at different levels over time (Lambin et al., 2003). These drivers can be endogenous or exogenous factors and operate synergistically to cause a change in the system (Millennium Ecosystem Assessment, 2005). These changes in the ecosystem create feedbacks on drivers at various levels and affect the next interactions of change (Lambin et al., 2003).". However, this makes it rather difficult to identify the drivers of change as alternating pressures and drivers in (coastal agricultural) systems can be non-linear and separated through space and time.

This theory analyses systems by recognizing complexity, patterns and interrelationships rather than a mere focus on cause and effect. It challenges the assumptions that are taken for granted such as that every effect has a cause, that the most complex things can be understood by narrowing down the whole into smaller parts and that if the past is sufficiently analysed, future events can be predicted. Complex adaptive systems theory suggests that the agents/actors in a complex system are all the components of that system and interact and connect in an unpredictable manner. These interactions and relationships are usually seen as more important for the system dynamics than the agents themselves. In other words, the system-level properties for an individual agent cannot be fully understood in general, or even be defined. For this reason, systems must be studied with a holistic approach, looking at all the agents in the system and their respective interconnections.

As mentioned, important properties of CAS are thus complexity, agents, feedbacks, endogenous/exogenous drivers and emergence/self-organization (adaptation).

Complexity can be generally divided in disorganized and organized complexity, where disorganized complexity refers to many millions of system components that interact randomly and can be predicted through statistical methods and probability. Organized complexity has a sizeable number of agents having correlated interactions which can produce emergent system properties. Correlation among interaction means that the agents within the system show feedback mechanisms and are endogenous to the system itself. Thus, the agents affect each other in a correlated way. Agents in CAS apply to simple rules and attributes, are generally autonomous (using local knowledge only) and can be replaced by similar agents without altering the emergent features of a system. Feedback mechanisms means that system outputs affect the inputs of the same system, meaning that agents in CAS interact and thus influence future interactions. The system and its agent can be changed by endogenous or exogenous drivers: drivers from inside or outside of the system. To determine when it is either, it must be considered whether or not the feedback goes both ways.

Coastal (agricultural) communities can be considered as complex adaptive systems, where human systems (such as household resources, agricultural practices and social structures (e.g., strong role of community) are constantly intertwined with ecological systems. To understand how changing ecological conditions (due to climate change and sea level rise) will impact these communities, and especially vulnerable communities such as landless labourers, women, older adults, it is important to investigate drivers of SLR-induced inequality and adaptation strategies in the context of complex, dynamic social-ecological systems. Not only could this lead to a better understanding of coastal socio-ecological dynamics, but it could lead to the design of appropriate adaptation strategies that would integrate how local communities self-organize, learn and shape change through social networks, institutions and organizations.

3.2 Vulnerability

The most important reason for initiating climate action is to reduce the risks that climate change imposes on social and natural systems. Whether this is climate mitigation or climate adaptation, the goal is to reduce the chance that negative effects occur due to climate change. For instance, if the temperature rise would be halted at 1,5 degrees Celsius, it would mean that the risks that systems undergo are slimmer than if global warming would exceed that threshold. Adapting to climate change related threats, such as SLR, will lower the risk that these threats impose on societal and natural systems.

In the fourth assessment report (AR4) of IPCC (2007) an impact risk framework has been proposed which shows that risk and potential impact are caused by an interaction of exposure, sensitivity and adaptive capacity. Exposure and sensitivity have a positive functional relationship with impact, while adaptive capacity has a negative functional relationship. Higher risk and impact mean that a system is more vulnerable. According to the IPCC (2007), vulnerability (to climate change) is "the degree, to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity".

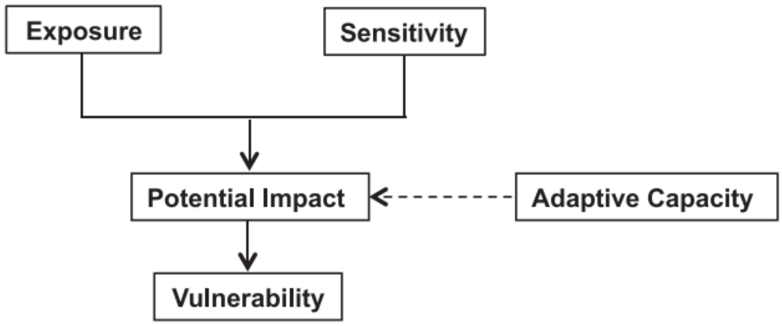


Figure 2: Schematic overview of concepts around vulnerability in IPCC (2007). Dotted arrows indicate a negative relationship and solid lines are negatively related (Sharma & Ravindranath, 2019).

So, the key aspects for assessing vulnerability are adaptive capacity, sensitivity and exposure. According to IPCC (2014), adaptive capacity is "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences". Usually, this capacity is comprised of so-called 'strength-attributes' of which a system has possession of. For instance, high biodiversity makes an ecosystem stronger and more resilient, high crop diversity and high availability of fresh water sources make an agricultural (eco)system more robust and people/societies with more financial resources are less vulnerable to threats. As such, adaptive capacity could be regarded as being the opposite of vulnerability; a perfect adaptive capacity could mean that a system is not vulnerable at all. However, this is where sensitivity and exposure come into play.

Sensitivity is "the degree to which a system or species is affected, either adversely or beneficially by climate variability or change. The effect may be direct (e.g., change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC, 2014). If for instance system A and system B have similar adaptive capacities (e.g., both have equal financial resources and equal physical assets), but system A has a higher sensitivity, (e.g., only old people live in this system) system A will be affected more severely than system B and is thus more vulnerable. This definition implies that sensitivity is operationalized through a cause-effect mechanism, where exposure is the cause (exposure to SLR), and sensitivity is the effect. The sensitivity, i.e., the effect, can subsequently be reduced by the adaptive capacity of a system. In other words, the inherent strengths of a system will raise the adaptive capacity, while the system's weaknesses will contribute to its sensitivity.

Exposure is "the degree to which people and the things they value could be exposed to climate variation or change". It refers to the "inventory of elements" in a region in which hazardous events may occur. So, if a system would not be located (i.e., exposed to) in an environment that poses any threat, there would be no risk at all. This makes exposure a key element of vulnerability, but it is not all-encompassing. If a system would be exposed, but they can easily defend/adapt themselves, they are not vulnerable. For instance, The Netherlands is highly exposed to higher sea levels, but they have strong and tall dikes and other water defence systems that protect them. Due to this, the Netherlands are, currently, not seen as a vulnerable country (in terms of flood-related threats). Nevertheless, it is necessary to be exposed to a threat in order to be labelled as vulnerable.

Until now, the term resilience has not entered this research's discourse. Although it slightly differs from definition, this research uses adaptive capacity as its umbrella concept. The UN International Strategy for Disaster Reduction (UN/ISDR) defines resilience as: "The capacity of a system, community or society to resist or to change in order that it may obtain an acceptable level in functioning and structure. This is determined by the degree to which the social system is capable of organising itself and the ability to increase its capacity for learning and adaptation, including the capacity to recover from a disaster." (Klein et al., 2003). Adaptive capacity can thus be seen as an umbrella concept, which integrates the manner in which people can plan and prepare for natural hazards, as well as to install technical adaptation measures prior to or after the wake of a hazard. As Oliver-Smith (2009) states: "the relationship between vulnerability and resilience (i.e., adaptive capacity) is not linear, but rather dialectical". This means that lower vulnerability does not necessary mean that a system has higher resilience (adaptive capacity). This can be attributed to the other two factors, namely sensitivity and exposure. These in turn (just as adaptive capacity) are dependent on various factors, such as infrastructural patterns, level of societal development or the awareness of hazards. It shows that the relationship of vulnerability and risk to hazards is rather a relationship of humans and the environment within the existing local socio-political structures. "The concept of vulnerability is fundamentally a political ecological concept, integrating not only political economic, but environmental forces in terms of both biophysical and socially constructed risk." (Oliver-Smith, 2009). As vulnerability is produced in the context of socio-political structures, risk is therefore unequally distributed across the different layers of society, which raises the question whether vulnerable communities will be equally threatened by SLR.

3.3 Conceptual Framework

Below is the research's conceptual framework consisting of complex adaptive system theory and how this is linked through drivers of change with adaptation strategies. At the core of Complex Adaptive Systems Theory stands the integration of humans and its environment who are being confronted with future uncertainties due to an emergence of new system properties and regime shifts (which in this research are SLR-related threats and Climate Change). In light of these uncertainties and threats, systems (in this case coastal communities) can adapt and co-evolve with the environment, which depends on their degree of vulnerability. These are also influenced by processes of interactions and feedbacks of multiple drivers of change which reproduce and worsen vulnerabilities and socio-economic inequalities. The systems can however be choosing a set of adaptation strategies that reduce vulnerability to SLR-related threats and aim to prevent increasing socio-economic inequalities.

In the light blue boxes, you can find the used methods to analyse the variables that can be found in the yellow boxes. On the right in the darker blue boxes, you can find the underlying concepts that will be identified throughout this research.

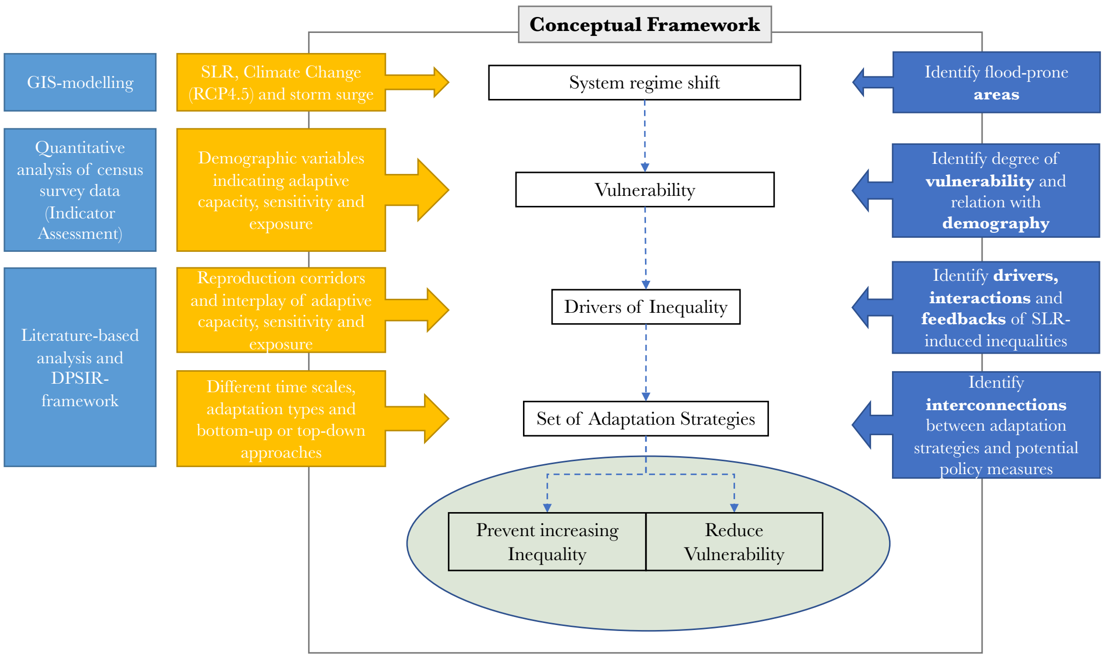


Figure 3: Conceptual Framework.

4. Research Design and Methodology

4.1 Research Framework

The research framework is presented in Figure 4. In the first step, the theoretical context in which the research takes place has been set. Based on this, the second step involved three research methods to answer the three research questions. First, the areas that are threatened by SLR have been geospatially modelled, which can potentially be linked to demographic data obtained from local surveys and census data. After this, a quantitative vulnerability assessment has been done of women, older adults and landless agricultural labourers, based on 11 indicators for adaptive capacity, susceptibility and exposure. Subsequently, drivers around SLR-induced inequality have been analysed through literature review. These insights have been used to analyse potential adaptation strategies, also through literature review, and are synthesised in a DPSIR framework. In step 3 the main research question is answered, and adaptation (policy) recommendations will be provided.

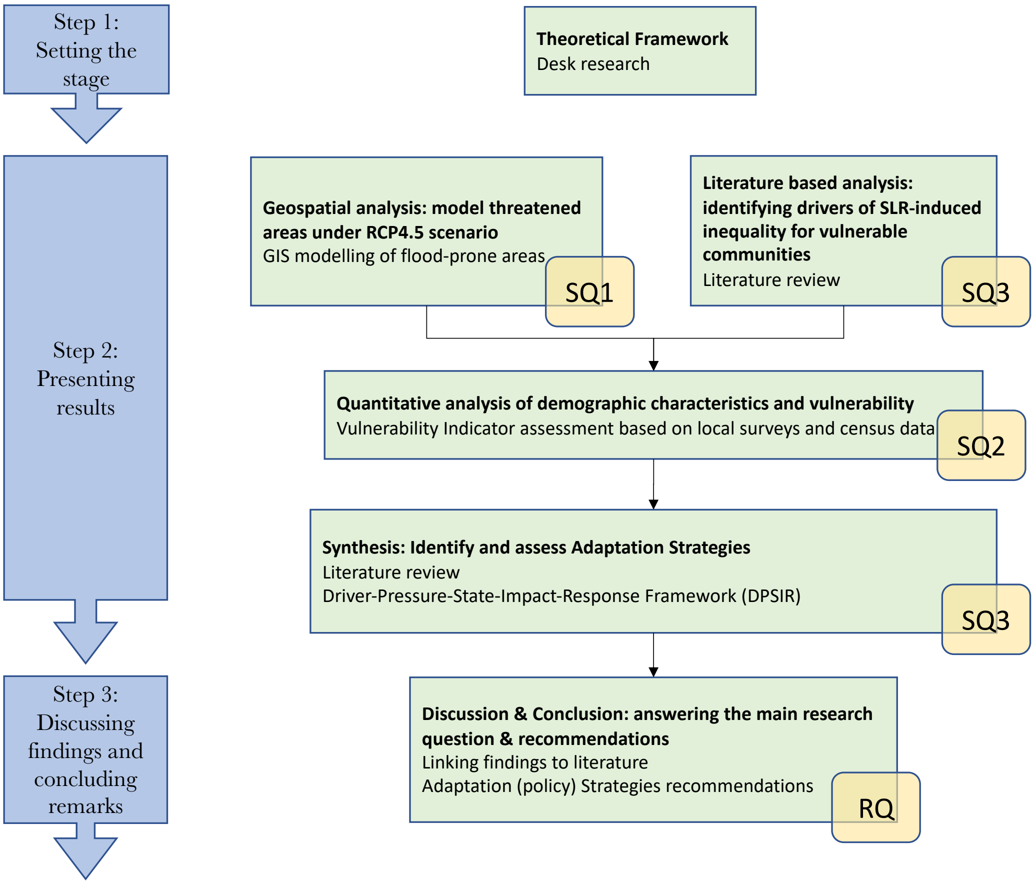


Figure 4: The Research Framework.

4.2 Research methods

4.2.1 Data Collection

For the geospatial analysis and the demographic analysis, data from GIS databases, local surveys of Indian (research) institutes and census and survey data from the Indian Government has been collected. The Digital Elevation Models were retrieved from NASA (2019) and spatial data on population and settlement type were obtained from Balk et al. (2019) and Balk et al. (2020).

Demographic data has been acquired from the LASI wave-1 survey, which is GIS-linked (but the geo-codes have not been released yet). An overview of the collected variables can be viewed in Table 2 on page 21. The Longitudinal Ageing Study wave-1 survey is an extensive multidisciplinary panel study of more than 70.000 adults of >45 years and their household members that are less than 45 years old. It is the world's largest, and India's first longitudinal ageing study and it is designed to provide data on important economic, social and health characteristics of India's (older) population. The survey comprises of a household and individual schedule and the household surveys were conducted with a selected key informant in the household, who could be any knowledgeable adult aged 18 or older. It was administered per household and information about the household finances and living conditions for all persons in the household were collected. The survey was conducted across India from April 2017 to December 2018 with a household response rate of 96%. This research only looks at the survey data in West Bengal, which count a total of 2,279 households and have a response rate of 98,4%.

4.2.2 Geospatial analysis

By looking at Representative Concentration Pathway 4.5, which is the IPCC's intermediate climate change scenario with a projected mean SLR of 0.55 meter, this study has applied geographic information systems (GIS) to model which areas in West Bengal India, will be affected by SLR. However, the threat of SLR does not only lie within gradual SLR, but mainly in the occurrence of storm surges that are combined with high tides, high rainfall and/or cyclones. In a simulation study by Sahoo & Bhaskaran (2017) total water level elevation (storm surge + tide + wave setup) in India's Cyclone region could reach up to 6–7 m at the end of the century. Hence, these sea level heights are included in the geospatial analysis. In total, two inundation maps have been produced: one with 5 meters and one with 7 meters (due to integer resolutions of the used geospatial data, it was impossible to model fractions of SLR). The maps were modelled and created with the use of QGIS 3.20.3.

In order to make these maps, a Digital Elevation Model (DEM) of the region was required. A collection of 9 GeoTiff raster files was downloaded from NASA (2019) that show the elevation of the region with a spatial resolution of 30x30 meter. Each pixel has an integer value that indicates elevation, with the highest point in the region being 260 meters. Logically, the lowest point is 0, which is the sea level.

Subsequently, these 9 raster files were mosaiced (i.e., merged together) and clipped to the administrational boundaries of West Bengals. After this a raster file with a binominal land-sea distinction was created with the raster calculator tool, by assigning a binominal value to land (>=0) and sea (<0) for present time, and the two sea levels mentioned before (sea levels in combination with storm surge heights).

The modelled inundated areas were then converted to polygons, by using a raster to polygon function. As the precision of these areas is 30xm30 per pixel, and the intersection/distinction of pixels is not smooth, it is impossible to merge the inundated polygon areas (in order to identify flood inundation regions). For this, a small buffer area around each polygon was created, which resulted in minor overlaps of the individual polygons (which allows for merging). This does lead to minor inaccuracies though, as some pixels suddenly become partially flooded. However, due to the resolution of the elevation models and the use of integers, it is reasonable to assume that many pixels are artificially "flattened" and thus contain small parts that have lower elevation than indicated.

After the flood regions were modelled, spatial data were collected from Balk et al. (2019) and Balk et al. (2020). These data contain raster files with a spatial resolution of 1x1 kilometre with integer values. Two files were selected with data on population count and census classification of settlement types with built-up areas. Population pixels were then clipped to the flood regions, which produced a raster layer with population count per square kilometre of the pixels that lie within the modelled flooded regions. In other words, these are disaster-prone areas where many people are potentially threatened by future SLR. The process of clipping did produce minor inaccuracies as the layers have different spatial resolutions. Because of this, some pixels were not included as there were insufficient flood region polygons imbedded in them (usually at the edge of a larger flood region). On the other hand, some pixels were included even though their surroundings were rather low in flood region density, or they were located far from the sea.

To create the inundation maps, shapefiles of roads and places were added, and the different layers were combined with a legend, scalebar and north arrow.

Originally, this research intended to combine the inundation maps with the demographic data from the LASI Wave-1 survey data. The database stated to have the geocodes of all the interviewed household, which enable the research to locate the respondents within or outside the inundated regions. This information could be used for the quantitative analysis as it could be added to the vulnerability indices. For instance, distance to the sea and distance to the nearest healthcare facility are important indicators for exposure to SLR. Unfortunately, it turned out that the International Institute for Population Sciences (IIPS) decided to currently conceal these codes, and they are still deciding when or whether to release them.

4.2.3 Quantitative analysis of demographics and vulnerability

For the quantitative analysis demographic information of the local communities has been collected through census surveys and information data. Mainly, data from the Longitudinal Ageing Study of India (LASI) wave-1 survey has been used. It is India's first and the world's largest survey that provides a longitudinal database for designing policies and programmes for the older population in the domains of social, health, and economic well-being. For this research, variables such as gender, age, income, source of income (e.g., salaried work, day labour or remittances), financial/physical resources, household size (and head of family), education level, marital status, house/land possession and more have been selected (see table 2). These demographic data have been quantitatively analysed in IBM SPSS Statistics 28.0 to indicate degree and patterns of vulnerability of local communities (with a focus on women, older adults and landless labourers). These data were divided in three datasets. The first contained household roster data with 65,584 eligible households across India. The eligible respondents were the head of the household, or any household member aged 18 and above and having some basic knowledge about the household members. The second dataset was household data, which contained much more variables, although there were less cases (42,949 households). The third dataset contained individual data of 72,250 individuals, and these are all persons aged 45 and above and his/her spouse irrespective of age.

Data processing

First, all cases were filtered for State ID=19, which are the respondents from West Bengals. As some variables of the household members were only found in the household roster data, and others in the household data, the datasets had to be restructured. These roster data contain cases where a single household ID would have multiple sub-variables per variable, as these were collected for each household member. The sub-variables would be indicated with ascending integers, with "_1" indicating the first respondent, "2_" for the second, "3_" for the third and so on. This would continue until the last household member (there is a household with 19 household members, so this case would have 19 separate sub-variables for a single variable). For individual assessment these cases had to be taken apart, whilst selecting the associated variables per household member, and placing the cases underneath each other. This led to duplicates of household ID's, as the individual people were singled out while some are living together in the same household. For analysis, only people of 18 year or older were selected. Table 1 shows some socio-demographic features of the selected individuals.

Age	18 years or older
Number of people	7361 individuals (with overlapping
Households	2277
Male	49,90%
Women	50,10%
Mean Age	44,5 years
Mean HH size	4,9 people
Mean HH Income	225.302 INR
Median HH Income	154.000 INR
Overall Literacy rate	75,20%
Female Literacy rate	66,90%

Table 1: Socio-demographic features of the respondents in Wave-1 Survey Data.

Selecting Indicators and Normalization of Indicators

The selection of variables was done manually, and they were subsequently filtered on completeness and whether they would be suitable as an indicator for vulnerability. The assumptions for indicating vulnerability were based on the literature study for analysing drivers of SLR-induced inequalities. Eventually, 11 indicators made the cut. Most indicate adaptive capacity, while only a few indicate sensitivity and exposure. Ideally, there would be more indicators on these two components as well, but as this research uses secondary data, this was not possible. In table 2 an overview of these vulnerability indicators is shown, including an explanation and the used indicator statuses and values.

Component	Indicator Variable	Description	Indicator status	Value
Adaptive Capacity	Household income (INR/year)	People with higher income will likely be less vulnerable as they can cope more easily with natural hazards, or they can even avoid the detrimental effects of them. Moreover, they can more easily recover as they can pay for reparations of damages to their houses/assets.	>250.000 180.000-250.000 90.000-180.000 45.000-90.000 <45.000	1 2 3 4 5
	Education	Higher education results in lower vulnerability due to better/extensive job opportunities. It could also result in people to have a better understanding of weather forecasts and have more adequate preparation tactics.	College and above High school Primary school No schooling Illiterate	1 2 3 4 5
	Household size	If a household is larger it tend to be less flexible and responsive to natural hazards, due to the difficulty of evacuation and the higher chance of damages. Moreover, larger families usually have lower incomes and lower education levels.	<5 5-8 >8	1 2 3
	Asset ownership	The amount of assets (financially or physically) that are owned tells a lot about the chances and capabilities to adapt to or recover from damages from SLR-induced damaged.	>750.000 300.000-750.000 150.000-300.000 <150.000	1 2 3 4
	Marital Status	Divorced, widowed or single people are more vulnerable than people that have a partner.	Married or live-in relationship Divorced/separated/deserted Widow Never married	1 2 3 4
	Spouse living in HH	Although being married increases your capability to respond to natural hazards, it does matter whether your spouse lives with you as well. People are better suited if they live together, and this is especially true for women.	Yes No	1 2
Sensitivity	Age	Being young (and physically fit) has a positive effect on someone's chances and capacity to adapt/respond, and are thus less sensitivity.	<25 25-40 40-55 >55	1 2 3 4
	Sources of household income	Secure sources of income are less vulnerable to natural hazards. This is especially true for full-time salaried workers (i.e. in the service sector) or remittances income. Agricultural labourers are especially vulnerable due to the flood damages to the land. Non-agricultural contract workers are moderately vulnerable as the demand for such workers will rise after flood events.	Full-time salaried worker/Remittance Part-time, contract worker / Govt employed Non-agricultural labourer / Own-account worker Agricultural labourer + other source of income Agricultural labourer	1 2 3 4 5
	House Type	Houses made from permanent material (i.e. stronger material) are less sensitive as they are stronger and more stable.	Pucca (permanent material) Semi pucca (combination of temporary and permanent material) Kutcha (temporary material)	1 2 3
Exposure	Water source	Accessibility to safe drinking water is very important during and after flood events. Most public/open water sources will be affected by salt water or are inaccessible.	Piped water / bottled water Public tap / Tube well / Dug well / Tanker / Cart with small tank Spring water / rain water / surface water	1 2 3
	Communication	Owning more telecommunication devices will allow easier access to weather forecasts and evacuation warnings.	Radio + phone + tv Phone + radio / phone + tv / radio + tv Phone / radio / tv	1 2 3

Table 2: Vulnerability indicators, indicator status and status values.

These statuses do vary in terms of scale and units. Hence, it was necessary to normalize these indicators, which was done through the following formula:

$$X_{ij}= x_{ij}-Min_i (x_{ij}) / Max_i (x_{ij}) - Min_i (x_{ij})$$

X_{ij} = normalized indicator value of i^{th} respondent for j^{th} indicator
x_{ij} = indicator value of i^{th} respondent for j^{th} indicator
$Min_i (x_{ij})$ = Minimum indicator value for all respondents for j^{th} indicator
$Max_i (x_{ij})$ = Maximum indicator value for all respondents for j^{th} indicator

For the 11 indicators, the normalized indicator value would then be between 0 and 1, with 1 indicating the highest vulnerability and 0 indicating the lowest vulnerability.

Calculating Vulnerability Scores
For all respondents a Vulnerability Score was calculated by using the formula:

$$VS = \Sigma x_{ij} / K$$

VS = Vulnerability Scores
x_{ij} = normalized indicator value of i^{th} respondent for j^{th} indicator
K = number of indicators (k = 11)

This score would also range in-between 0 and 1, with 1 indicating highest possible vulnerability and 0 lowest possible vulnerability. For analysis, these scores have been classified in four vulnerability classes (see table 3).

Vulnerability Class	Vulnerability Score Range
Minimally vulnerable	<0.30
Moderately vulnerable	0.30-0.50
Vulnerable	0.50-0.70
Extremely vulnerable	>0.70

Table 3: Vulnerability Classes.

4.2.4 Literature-based analysis of SLR-induced Inequality and Adaptation Strategies

In order to analyse SLR-induced inequalities, a literature study has been done to analyse the drivers around SLR-induced socio-economic inequalities for vulnerable communities and how actual adaptation strategies need to incorporate and tackle this. For this, literature was collected that studied adaptation to SLR, but also literature on vulnerability and inequality. Some of these papers have been reflected on in the literature review. Vulnerability has been approached similar to the quantitative analysis: by looking at adaptive capacity, sensitivity and exposure. In other words, how can these components of vulnerability combined with impacts from SLR-related threats result into more inequality for vulnerable communities? As this research follows the rationale of "higher vulnerability + SLR-related threats = higher inequality", adaptation strategies need to tackle vulnerability and/or protect against SLR.

In order to make social-ecological-economic connections and to integrate information from literature review, a Driver-Pressure-State-Impact-Response Framework has been created (DPSIR) (See figure 5). The DPSIR framework allows analysis of the drivers of change, how these result in certain pressures on the system's state and what the impact of this will be. These impacts demand appropriate responses (adaptation strategies), which will have certain positive of negative feedbacks on the drivers, pressures, system state and impacts. This in turn allows for assessment and recommendations, while reaching for strategies that reduce SLR-induced inequalities.

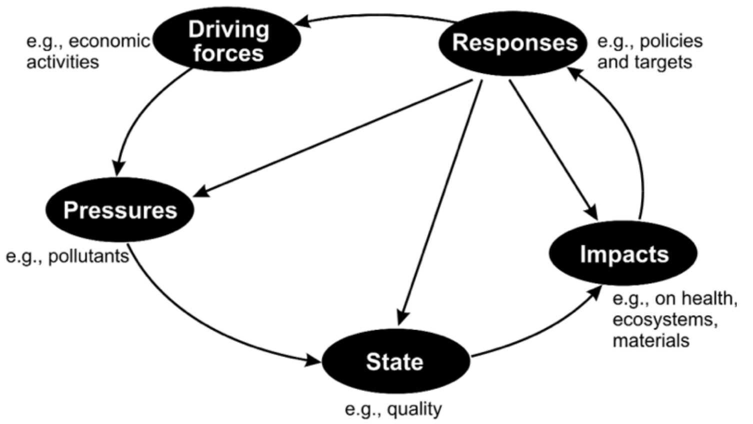


Figure 5: Conceptual image of the DPSIR framework (Stanners et al., 2007).

5. Results and Discussion

The following four sections show the modelled inundation maps, the identified drivers of SLR-induced inequalities, the vulnerability assessment and the potential adaptation strategies. Firstly, the inundation maps provide a geographical context of the most flood-prone regions in West Bengal, which support a focus on certain adaptation strategies and target areas/communities. Subsequently, an analysis of drivers of SLR-induced inequalities has provided insights in feedbacks and relationships between the components of vulnerability: exposure, sensitivity and adaptive capacity. This in turn has supported assumptions that were made for the vulnerability indicators assessment, which used demographic variables to identify the degree of vulnerability of women, older adults and landless agricultural labourers. Lastly, the previous sections are synthesized in the literature-based analysis of adaptation strategies, where recent adaptation efforts and potential new measures are discussed.

5.1 Flood Inundation Maps

Below the produced maps can be observed. The prior three maps represent a flood scenario where sea levels are 5 meters and the latter three show a sea level of 7 meters. As such, these maps show 0,55 meters of SLR (which is the average SLR projected in the RCP4.5 scenario of the IPCC) combined with respectively 4,5 meters and 6,5 meters storm surge. This range can be regarded as flood events during heavy storms and extreme storms such as cyclones (Sahoo & Bhaskaran, 2017). Note that the eastern boundary of the target area is attached to Bangladesh, and not the sea.

5 Meter Sea level
Image 1 shows a combined inundation map of the flood-prone regions (red) and the population grid of flooded areas (colour wave). Because of this combination the indicated flood-prone areas are almost entirely covered with the population grid (except for the Sundarban National Park, as there are barely people living there). A distinction has been made between urban and rural areas (urban is lightly purple). Roads and places have been added (and filtered to relevancy) to indicate the threatened cities and towns. To clarify these parts, the other two maps have pulled population and flood-prone regions apart.

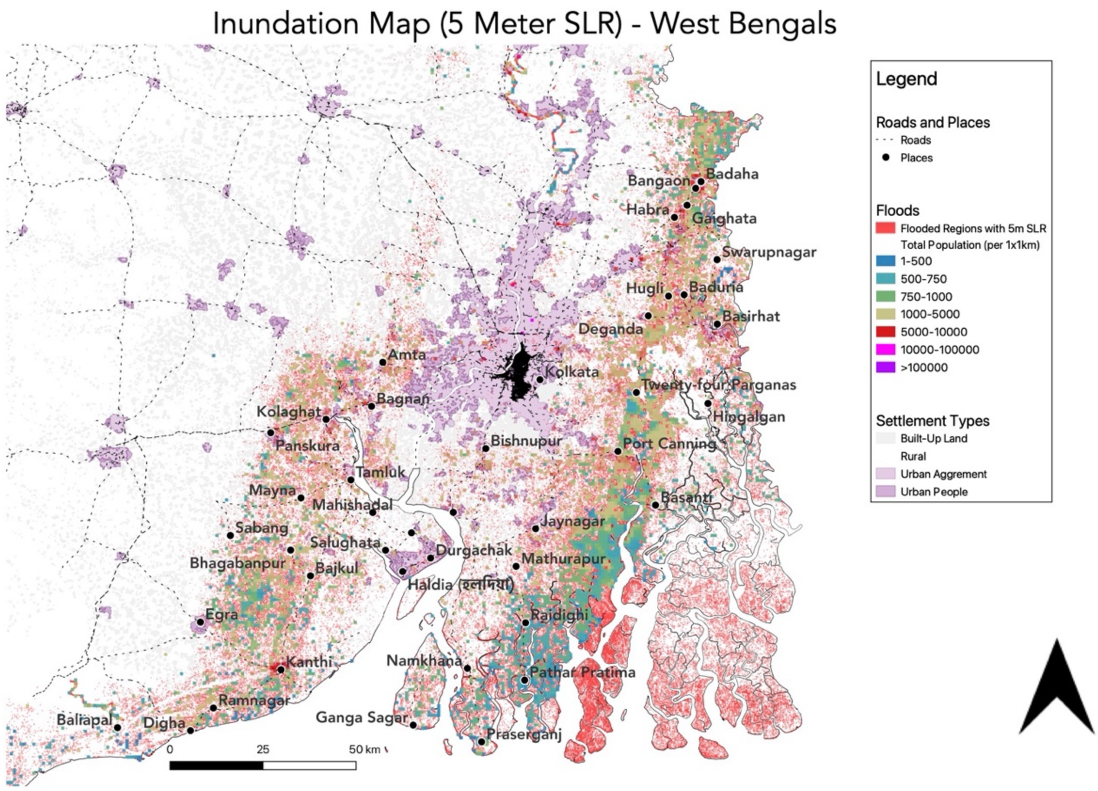


Image 1: Combined map of flooded regions and threatened populations with 5-meter sea level.

The inundation map in image 2 shows the flood-prone areas with a 5-meter sea level. Most critical areas are located in the south-west between Kolkata and the Sundarbans and the area north from it near to the border of Bangladesh. Urban areas that are threatened are the north-eastern places Bangaon, Badaha and Habra; the eastern places Basirhat and Port Canning; the western places Kolaghat and Panskura; and the southwestern place Kanthi.

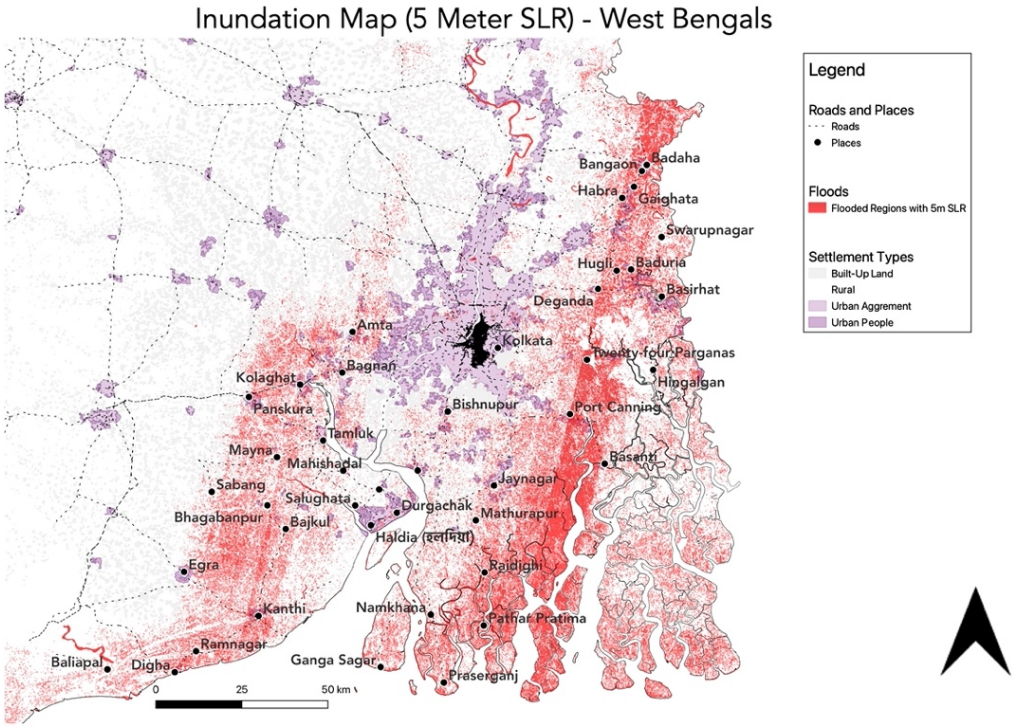


Image 2: Flooded areas with 5-meter sea level.

Image 3 shows the population density grid of the flood-prone areas in image 2. The threatened areas that show the highest density correspond with the urban places mentioned above. However, it can be seen that there are also large rural areas with densities of 500-1000 people per square km that are threatened by SLR, especially in the region between the Sandurbans and Kolkata.

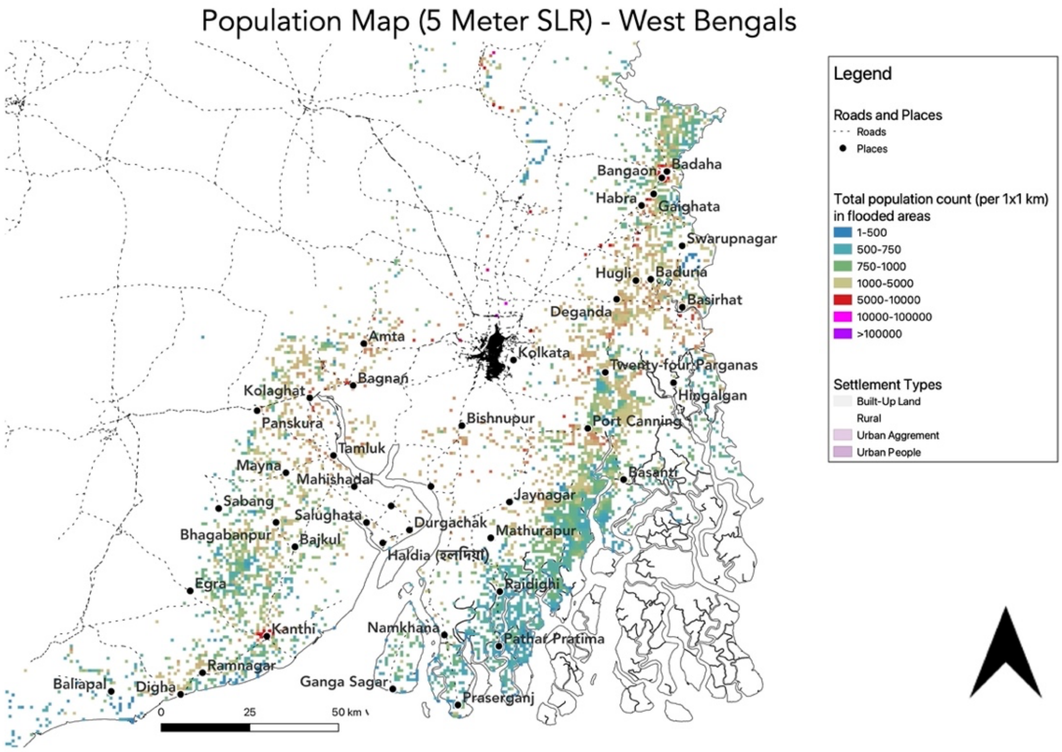


Image 3: Threatened population with 5-meter sea level.

7 Meter Sea level

Image 4 shows the combined inundation map of the flood-prone regions (orange red) and the population grid of flood-prone areas (colour wave) for a SLR of 7 meters. As can be seen, two-meter extra elevation greatly increases the threatened areas in West Bengal. Even parts of Kolkata can become inundated during a 7-meter flood.

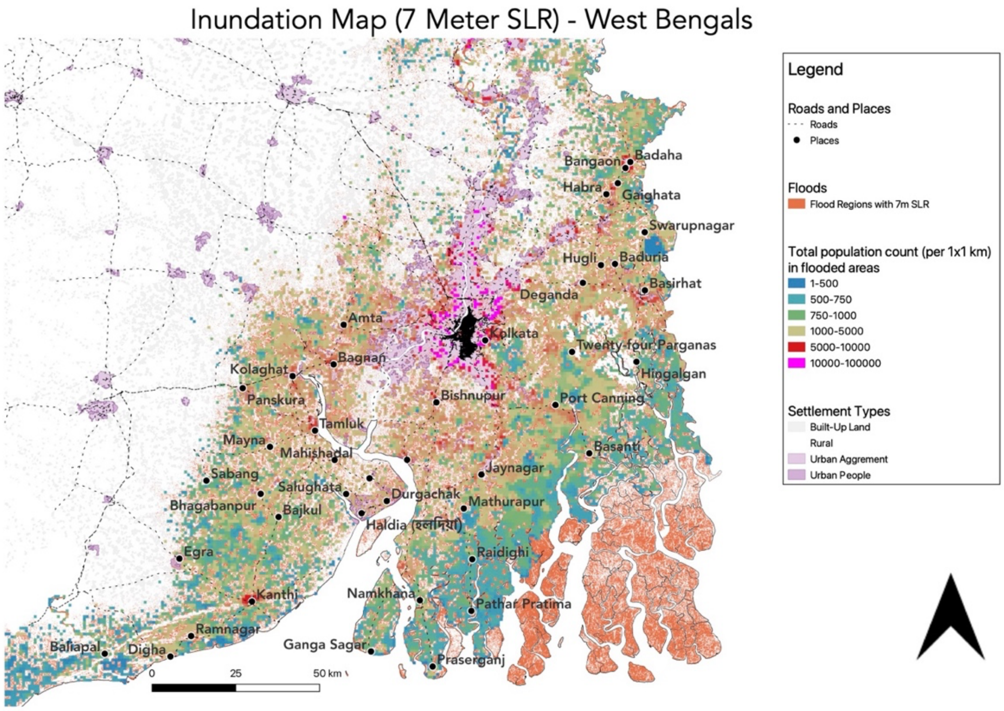


Image 4: Combined map of flooded regions and threatened populations with 7-meter sea level.

The inundation map in image 5 shows the flood-prone areas with a 7-meter sea level. Almost the entire perimeter of Kolkata is flooded, including the east and west of the Bengali capital. Additional threatened urban areas (with respect to the 5-meter flood) are the southern places (in relation to Kolkata) Bishnupur, Jaynagar, Durgachak, Haldia; the western places Bagnan and Tamluk; and the southwestern place Egra.

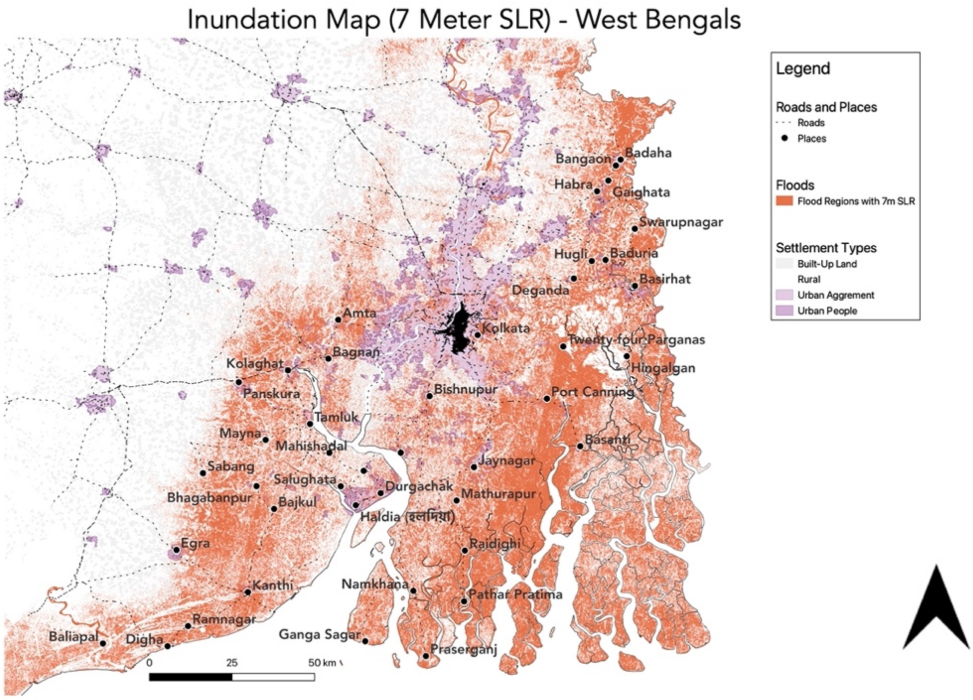


Image 5: Flooded areas with 7-meter sea level.

Image 6 shows the threatened populations with 7 meters sea level. More high-density areas are being threatened, with the outskirts of Kolkata being the most critical example (densities of more than 10.000 people per square kilometre). The rural areas that are located nearby the city are also increasingly threatened and they have population densities ranging between 1.000 to 10.000.

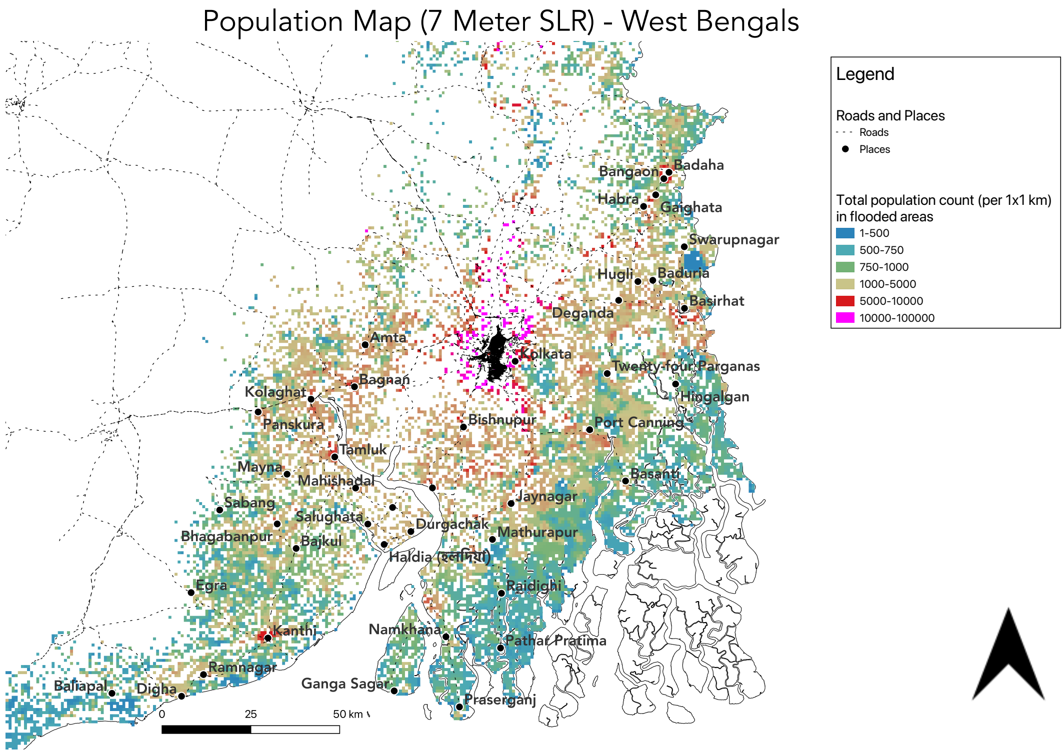


Image 6: Threatened population with 7-meter sea level.

In summary, the geospatial models map several key flood-prone areas, with the region in-between the Sundarbans and Kolkata being the most critical one. In research by Sanchez-Triana, Ortolano & Paul (2018) this region was also identified as being highly risk-prone, and was labelled as the "transition zone", lying between the "stable zone" close-by Kolkata and the Sandurban "core zone" which includes the Sundarbans National Park and Tiger Reserve and the Sundarbans Reserve Forest.

The maps indicate several threatened urban areas which show high population densities. For instance, the town and block Port Canning (I & II) in South 24 Paraganas, situated along the western bank of the Matla River and being the gateway to the Sundarbans, has ±550.000 inhabitants and is a major market for fish supply to Kolkata (Census of India, 2011). More northwards, the city Basirhat located on the banks of the trans-boundary river Ichamati counts ±150.000 people (Census of India, 2011). Apart from Kolkata itself, other major threatened urban areas which do not lie in the so-called transition zone but are located near or at the banks of the Hooghly River or Rupnarayan River are Kakdwip (±280.000), Kanthi (±320.000 people) and Tamluk (±220.000) (Census of India, 2011).

Unfortunately, it was currently not possible to gather the geographical location of the respondents in the used dataset. This would have allowed to create more relevant vulnerability indicators and the produced index values could have been combined with the maps in order to create vulnerability index maps. It is recommended that these geo-codes will be integrated with future vulnerability assessments as soon as they will be released in order to improve the quality of such analysis.

5.2 SLR-induced Inequality

As vulnerability is a biophysical and social product, we expect that risk will be unequally distributed across the layers of society. Thus, it raises the question how these vulnerable groups will be more prone to the risks of SLR. After all, high vulnerability is associated with low adaptive capacity, high sensitivity and high exposure. Through vulnerability, climate change and SLR are thus intertwined with social and organizational structures, and namely the issue of inequality. To look at how SLR can result into higher inequality, this paragraph has collected and reviewed literature on SLR, vulnerability and inequality.

The Complexity of SLR-induced inequality

To understand and fully grasp the future impacts of SLR on certain regions and communities, it is important to understand the complexity of this issue. The interactions between humans and the environment, within socio-political structures, are not easy to define, due to its non-linear relationship and the existence of many variables. As such it is needed to look at present-day events of SLR-related hazards and how these have affected local coastal communities. This will allow to identify important drivers of change and it will create an opportunity to frame certain adaptation strategies. However, the issues of climate change and SLR are not only a projection of physical exposure to natural hazards, but also what the trajectories of communities will be. These could be of social, infrastructural or physical nature and they deal with things like economic development, demographic changes, GHG emissions or technological advances. Almost needless to say, for each community or individual these trajectories will be different, and they will depend on an interplay of socio-political, cultural and economic structures (Oliver-Smith, 2009).

Inequality as a concept on itself is also less straightforward. It can appear in multiple forms, ranging from demography-based traits, such as age, gender and religion, to inequality regarding ownership of (financial) resources or access to public assets and political power. While these are different forms of inequality, they generally overlap and are reciprocally connected to each other. Although historic research has confirmed the exacerbation of inequality by climate change, the examples generally do not zoom in on inequality, directly, and the proofs are often disconnected from each other (Islam & Winkel, 2017). In order to avoid this, it is important to look at a key aspect of SLR-induced inequality, which is the vicious cycle that vulnerable communities end up in after the event of a SLR-related hazard. This cycle reinforces the negative effects of SLR, as vulnerable communities are prone to higher risks and will experience greater losses, which in turn leads to higher inequality (Dilshad et al., 2018). Figure 6 provides a schematic representation of this cycle. It starts with initial unequal vulnerabilities that result in higher exposure, higher sensitivity and lower adaptive capacity. If a SLR-related threat actually happens, this will lead to unequal losses in terms of resources and capital, which is turn increases vulnerability and inequality. As such, the cycle is repeated. Although this rhetoric seems rather straightforward, the underlying drivers need to be understood in order to design effective adaptation measures to break the vicious cycle.

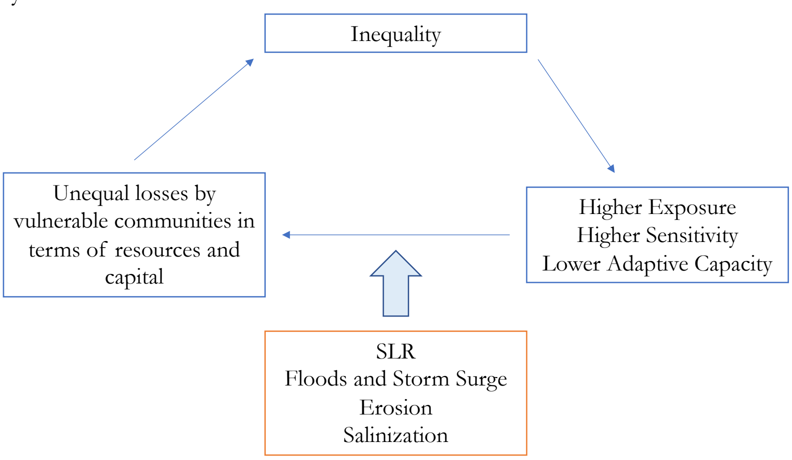


Figure 6: The vicious cycle of inequality and SLR.

Drivers of SLR-induced inequality

As vulnerability is made up from adaptive capacity, sensitivity and exposure the interrelationship of inequality and these three components needs to be studied. To clarify this relation, the issue of flooding is a good example. In general, vulnerable, impoverished, groups tend to reside in regions that are more exposed to flood risks (i.e., low-lying areas or in deltas) as these places are more affordable to live, or simply put: they are left vacant (Luo et al. 2015). Moreover, their belongings, such as their dwellings, are more sensitive to floods as they are often constructed with temporary material (i.e., they will easily wash away compared to a house made of permanent material) (Rufat et al., 2015). At last, vulnerable people will have lower adaptive capacity as they usually cannot pay for restorations or flood-damage insurances (De Silva & Kawasaki, 2018). This will cause vulnerable people to experience much higher losses in terms of resources than non-vulnerable people will. In figure 7, a schematic overview can be seen of this process.

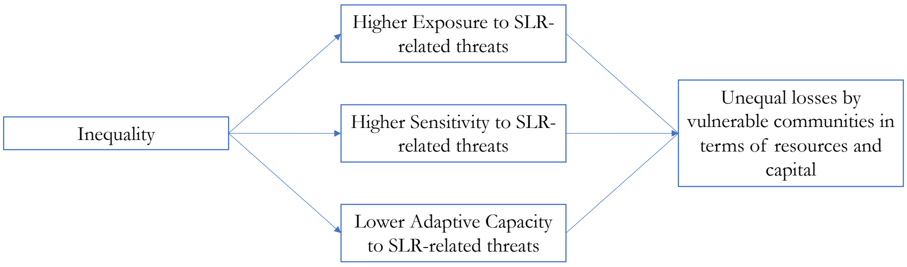


Figure 7: Three components of vulnerability and inequality.

Islam & Winkel (2017) have identified two corridors through which these three components of inequality can be reproduced, which are of economic and political origin. Economically, inequality is exacerbated through a degradation of private resources, such as income and assets, of vulnerable people. Politically, vulnerable people tend to be more absent from public debates and are unable to have a meaningful say during policymaking. In contrast, non-vulnerable people have less degradation of private resources, and they are able to put significant pressure on political discourse, which results into favouring of their socio-economic positions. It could even mean that the limited available resources to adapt to natural hazards are allocated to their protection instead of vulnerable people. Additionally, harmful practices and activities that increase the threat of SLR (such as greenhouse gas intensive activities, deforestation or excessive groundwater extraction) tend to have a net favourable outcome for non-vulnerable people, resulting in political decisions that increase the sensitivity and exposure of vulnerable people (Thomas, et al., 2019). Figure 8 shows a conceptual image of this process. Interestingly, recent West Bengal elections in May 2021 saw Trinamool Congress (TMC) party to have a historic win, which is led by India's only female head of a state government: Mamata Banerjee. The party has proposed several economic policies that advance women's interests and has ensured that more women are represented in party seats (Brulé & Gaikwad, 2021).

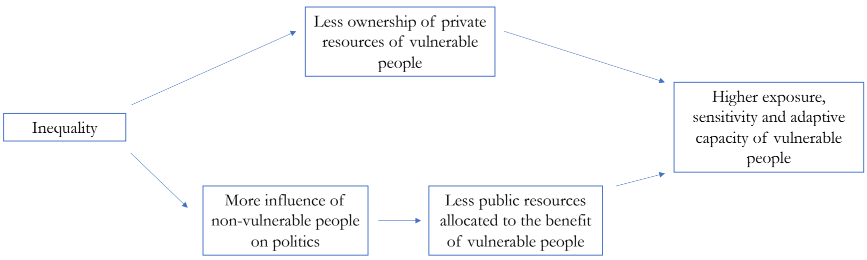


Figure 8: Economic and political corridors through which inequality is worsened for vulnerable people.

Another factor that leads to disproportionate impacts of SLR are market-based effects, which can be regarded as indirect effects. For instance, if a flood destroys agricultural land including its crops it will have a direct negative effect on people (with vulnerable people experiencing the highest relative losses). However, the destruction of local cropland will lead to an increase of food prices, which generally affect vulnerable people more strongly as food consumption takes up a relatively large proportion of their total consumption expenditures (Avalos, 2016). Another example is a rise in flood insurance fees, which will make it even more difficult for vulnerable people to acquire an insurance (Sheehan, 2018). Figure 9 shows a conceptual image of this process.

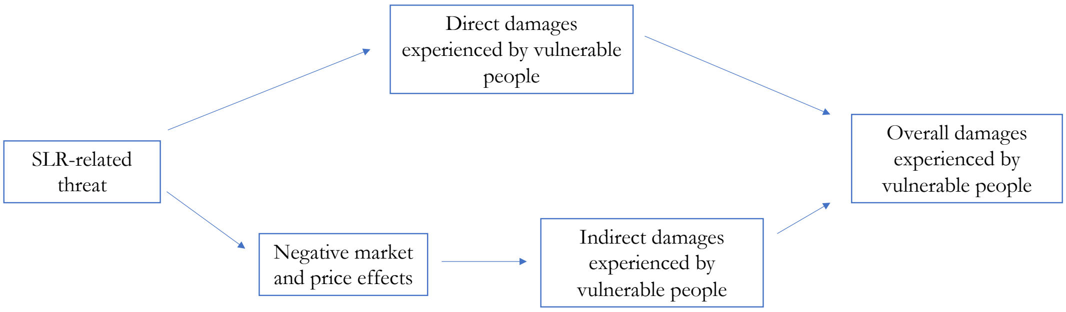


Figure 9: Direct and indirect effects through which inequality is worsened for vulnerable people.

Exposure, Sea Level Rise and Inequality

Exposure to the risks of SLR are predominantly driven by the location of someone's livelihood and their source of income, which in turn are partially driven by the political-economic corridors through which inequality runs.

In general, the most vulnerable people tend to live in low-lying areas (Luo et al. 2015). It must be noted however that this is not only the case for vulnerable people in rural areas. Vulnerable people in urban places are also frequently located in more flood-prone areas, as many slums are built in low elevated areas (Braun & Aßheuer, 2011). In terms of source of income, it is important whether someone's work is dependent on climatic conditions (such as agriculture) and to what extend the location of work is threatened by SLR. Inequality causes vulnerable people to have less options available and they are usually required to settle for less. For instance, unequal social norms and land tenure agreements can withhold women from acquiring certain assets (such as farmland or insurance) and it could even result in more direct exposure as many women are burdened with tasks like water collection. If women are able to obtain agricultural land, this is often located on marginal land (Perez et al., 2015). Usually, the limited options that vulnerable people have in terms of livelihoods, and especially its location, find their origin in political structures. Osipian (2016) did research on a cyclone in Myanmar and concluded that political and administrative constraints resulted in many vulnerable and impoverished people to end up living in a region that was eventually severely struck by a cyclonic hazard.

Sensitivity, Sea Level Rise and Inequality

Although vulnerable people and non-vulnerable people may experience a similar degree of exposure, vulnerable people in India are more sensitive to flood-related damages as their houses are usually made from temporary material (i.e., corrugated iron or straw roofs and walls of mud, wood or bamboo), called a Kutcha. Vulnerable people are also less able to perform essential reparations in order to prevent further flood damages as the costs of these repairs are too high with respect to their income (Patankar, 2015). These constrained choices for livelihoods of vulnerable people can result in higher sensitivities to flood risks and vulnerable people can even experience higher losses whilst their exposure is of lesser degree (Carter et al., 2007). Brouwer et al. (2007) reported that the cyclone Alia in 2009 mainly damaged the structures of houses of below poverty line households.

Other important drivers for high flood sensitivity of vulnerable people are a less diverse built-up of assets/resources and health-related problems. Rural people tend to hold a majority of their savings in livestock or cropland, while vulnerable people in cities hold most in form of their houses (Nkedianye et al., 2011). This is rather different compared to non-vulnerable, wealthier, people who are able to spread their possessions (and thus their risks). In terms of health, many vulnerable people, and especially poor people, are very sensitive to flood-related diseases such as malaria or water borne infections (Hallegatte et al, 2016). One of the main reasons for this is the absence of clean drinking water facilities. Such diseases greatly affect vulnerable people as their income [from work] or (agricultural) productivity falls sharply, while they also experience long-term issues such as educational disadvantages/delays or lasting illnesses (Graff Zivin et al., 2016).

Adaptive Capacity, Sea Level Rise and Inequality

At last, inequality leads to initial weak adaptive capacities of vulnerable people, which can be worsened through SLR. A study by Hill and Mejia-Mantilla (2015) coupled low adaptive capacities of poor farmers in Uganda to their inability to change cropping patterns, inaccessibility of clean water or adoption of new agricultural techniques. Furthermore, Gallopín (2006) showed that poor households in Papua New Guinea have lower adaptive capacities due to high income inequality. Mainly, it is a matter of limited available resources for vulnerable people in order to cope with the aftermaths of a natural hazard (Adger, 1999). These resources usually comprise of the following things:

1. Private resources of the household
2. Resources owned and utilized by the local community
3. Resources managed and regulated by NGOs
4. Public resources

In order to better understand how these initial inequalities can be worsened through SLR, Islam & Winkel (2017) conceptualized this through so-called 'recovery trajectories', which revolves around the rate of recovery after a disaster. If one would assume that two social groups are unequal (e.g., in monetary terms) and there would be similar degrees of exposure and sensitivity, adaptive capacity will determine whether inequality will increase or not after a disaster. Lower adaptive capacity of the vulnerable, disadvantaged, social groups will lead to slower rates of recovery after a disaster, which will mean that inequality will rise. If the adaptive capacity is similar, the level of inequality will stay the same. However, if the adaptive capacity of vulnerable groups becomes higher, the level of inequality could be reduced.

Aside from private resources, which are rather obvious in terms of how they contribute to adaptive capacity, insurances are key to ensure adequate recovery. Insurances, whether it is health insurance or insurance of material possessions, tend to be unaffordable for many vulnerable people and especially for women. During floods, only male family members receive post-disaster insurance benefits as women usually do not have legal ownership of farmland or other assets, which prevent them from gaining flood insurance (Roy & Modak, 2020). While this will result in high losses after a disaster, it can also mean that people without insurances are limited in their entrepreneurship (Clarke & Dercon, 2015). For instance, certain agricultural practices (such as the use of certain crop varieties, inputs or machinery) are rather expensive to implement, but they could create extra value over time. If a person or household does not own an insurance, such an undertaking could prove to be too risky, which means that they will stick with older methods. Eventually, this could result into an exacerbation of inequality. If vulnerable people do not have an insurance, there are only limited options available to pay for mandatory reparations. Usually, a decision has to be made between selling material possessions or cutting in daily expenses such as consumption or investments in human capital (i.e., education). This could undermine the possibilities for economic growth, and it could have an adverse impact on health (Clarke & Dercon, 2015).

In terms of common goods, vulnerable and marginalized people tend to make more use of the commons (i.e., ecosystem services such as fishery or woodlands), and especially after climatic hazards such as floods or droughts (Barbier, 2010). Research on coastal communities in Bangladesh revealed that people living near mangrove forests have higher adaptive capacities after a cyclonic event (Akter & Mallick, 2013). However, these common goods are becoming more vulnerable due to three processes. Firstly, the effects of climate change are threatening the state and productivity of the commons, which affects vulnerable people more than non-vulnerable people (due their higher usage). Secondly, common goods are becoming depleted due to over usage. Lastly, the common goods are increasingly being privatized, which restricts access or control of commonly owned resources by vulnerable people. Such access restrictions have discriminating features, as certain ethnic groups or women tend to experience more difficulties in terms of access (Abebe, 2014).

Concerning public resources, the matter in which these determine adaptive capacity have a rather socio-political nature as it depends on how vulnerable or non-vulnerable people are able to steer public resources to their benefit. For instance, if public money is spent on flood protection (i.e., dikes) of a certain area where less vulnerable people live (such as a city, or a part of it) it could mean that the area and the people living around these flood barriers become more exposed to flooding. The Flood Forecasting and Early Warning System (FFEWS) in Kolkata (introduced in 2018) is an interesting example how public resources are allocated to the protection of areas that have more economic and political leverage.

5.3 Vulnerability Indicators and Indicator Status

In the following sections the correlation between de selected vulnerability indicators are reviewed after which the vulnerability scores of women, older adults and landless agricultural labourers are presented and discussed. To be clear, index values indicate vulnerability per variable. This means that a person with a high income vulnerability index has a low HH income (as a low HH income is associated with higher vulnerability).

Vulnerability Indicator Correlations

The correlations between the vulnerability indicators are reviewed below in an order that goes along the x-axis (progressing the half-triangle downwards). As correlations work both ways, the correlations are obviously not reviewed vice versa. An overview of the significant correlations can be viewed in table 5.

Correlations

		Household Size Normalized Index Value	Education Normalized Index Value	Income Normalized Index Value	Assets Normalized Index Value	Source of Income Normalized Index Value	House Type Normalized Index Value	Marital Status Normalized Index Value	Spouse presence Normalized Index Value	Water Source Normalized Index Value	Communication Normalized Index Value
Household Size Normalized Index Value	Pearson Correlation	--									
	N	7361									
Education Normalized Index Value	Pearson Correlation	.050**	--								
	Sig. (2-tailed)	<.001									
	N	7361	7361								
Income Normalized Index Value	Pearson Correlation	-.145**	.208**	--							
	Sig. (2-tailed)	<.001	<.001								
	N	7361	7361	7361							
Assets Normalized Index Value	Pearson Correlation	-.032**	.262**	.230**	--						
	Sig. (2-tailed)	.006	<.001	<.001							
	N	7361	7361	7361	7361						
Source of Income Normalized Index Value	Pearson Correlation	.026	.367**	.176**	.261**	--					
	Sig. (2-tailed)	.163	<.001	<.001	<.001						
	N	2849	2849	2849	2849	2849					
House Type Normalized Index Value	Pearson Correlation	-.073**	.310**	.223**	.257**	.338**	--				
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001					
	N	7361	7361	7361	7361	2849	7361				
Marital Status Normalized Index Value	Pearson Correlation	-.101**	-.184**	.018	.027*	-.145**	-.022	--			
	Sig. (2-tailed)	<.001	<.001	.125	.023	<.001	.056				
	N	7361	7361	7361	7361	2849	7361	7361			
Spouse presence Normalized Index Value	Pearson Correlation	-.116**	-.100**	.046**	.031**	-.138**	-.008	.936**	--		
	Sig. (2-tailed)	<.001	<.001	<.001	.008	<.001	.488	.000			
	N	7361	7361	7361	7361	2849	7361	7361	7361		
Water Source Normalized Index Value	Pearson Correlation	.016	.246**	.132**	.218**	.324**	.413**	-.056**	-.064**	--	
	Sig. (2-tailed)	.160	<.001	<.001	<.001	<.001	<.001	<.001	<.001		
	N	7344	7344	7344	7344	2845	7344	7344	7344	7344	
Communication Normalized Index Value	Pearson Correlation	-.097**	.279**	.254**	.189**	.267**	.333**	-.001	.029*	.264**	--
	Sig. (2-tailed)	<.001	<.001	<.001	<.001	<.001	<.001	.950	.014	<.001	
	N	7361	7361	7361	7361	2849	7361	7361	7361	7344	7361

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4: Correlation Matrix of Vulnerability Indicators.

Household (HH) size and education have a significant positive correlation with each other, albeit rather low. This means that a more vulnerable household size (i.e., more household members) results in a more vulnerable education level. This can be explained by multiple causes. For instance, having larger families means that individual family members receive less health care or have lower caloric consumption. This could lead to lower success in school which leads to lower schooling years or levels. Moreover, people that are disadvantages could get more children (e.g., due to lack of contraception), which means that resources have to be distributed across more children (i.e., less education), while children also have to contribute to the household income at a lower age. A study by Ahsan & Warner (2014) also concluded that vulnerable neighbourhoods in Bangladesh have poor education facilities and high illiteracy rates. Interestingly, HH size and household income or assets have a significant negative correlation: having more household members (= more vulnerable) means a higher household income (= less vulnerable). This can however be ascribed to the fact that the household incomes are cumulative and are not corrected against household size. There is also a significant negative correlation between HH size and house type: the house type is less vulnerable if the household size becomes larger. This could be because in a larger household more people can help during construction and maintenance of the house. HH size and marital status/spouse presence have a significant negative correlation, just as ownership of communication devices. So, people with larger households tend to have less vulnerable marital statuses and spouse presence, which is rather logical as people need a spouse or need to be married (e.g., due to cultural norms) in order to have children. Ownership of communication devices status also becomes less vulnerable with higher HH size, which could be ascribed to pooling of resources to purchase the devices.

Education and income/assets/source of income/house type/water source and communication have, as expected, a significant positive correlation. This can be explained by the fact that people with higher education will find jobs in more specialized employment sectors, which will lead to higher incomes and thus will result in more robust house types, improved water access or ownership of communication devices. Marital status and spouse presence have significant negative correlations with education. This could be due to that primarily higher educated people find jobs abroad and send remittances home. On the other hand, marriage of (young) women leads to having children (earlier), which impedes educational opportunities for women (Wodon, 2017).

Income and assets are significantly positively correlated, and both are also positively correlated with source of income, house type, water source, communication and spouse presence (although the latter is relatively weak). This falls in line with the educational explanation mentioned above, which also hold true for the significant positive correlation between **source of income** and house type, water source and communication. Marital status and spouse presence have a negative correlation with source of income. So more vulnerable marital relationships lead to less vulnerable sources of income. This can be explained due to remittances being labelled a less vulnerable source of income than for instance agricultural work, and that spouse absence is associated with remittances. Moreover, if people have followed higher education, and work in more specialized sectors such as services, people generally marry at older ages. According to Census of India (2018), the mean effective marriage age for women has increased from 19.3 years in 1990 to 22.3 years in 2018.

House type has a moderately strong positive correlation with water source and communication status (which are also positively correlated to each other). This means that people with a more resilient house type have more reliable access to water and communication devices. Logically, **marital status** has a very strong positive correlation with spouse presence

.

Moderate to Strong Positive Correlation (>0,3)	Weak Positive Correlation (<0,3)	Weak Negative Correlation (<0,3)
Education + Source of Income	HH size + Education	HH size + Income
Education + House Type	HH size + Source of Income	HH size + Assets
Source of Income + House Type	Education + Income	HH size + House Type
Source of Income + Water Source	Education + Assets	HH size + Marital Status
House Type + Water Source	Education + Water Source	HH size + Spouse Presence
House Type + Communication	Education + Communication	HH size + Communication
Marital Status + Spouse Presence	Income + Assets	Education + Marital Status
	Income + Source of Income	Education + Spouse Presence
	Income + House Type	Source of Income + Marital Status
	Income + Spouse Presence	Source of Income + Spouse Presence
	Income + Water Source	Marital Status + Water Source
	Income + Communication	Spouse Presence + Water Source
	Assets + Source of Income	
	Assets + House Type	
	Assets + Spouse Presence	
	Assets + Water Source	
	Assets + Communication	
	Source of Income + Communication	
	Water Source + Communication	

Table 5: Overview of significant (a=0,01) correlations between vulnerability index variables.

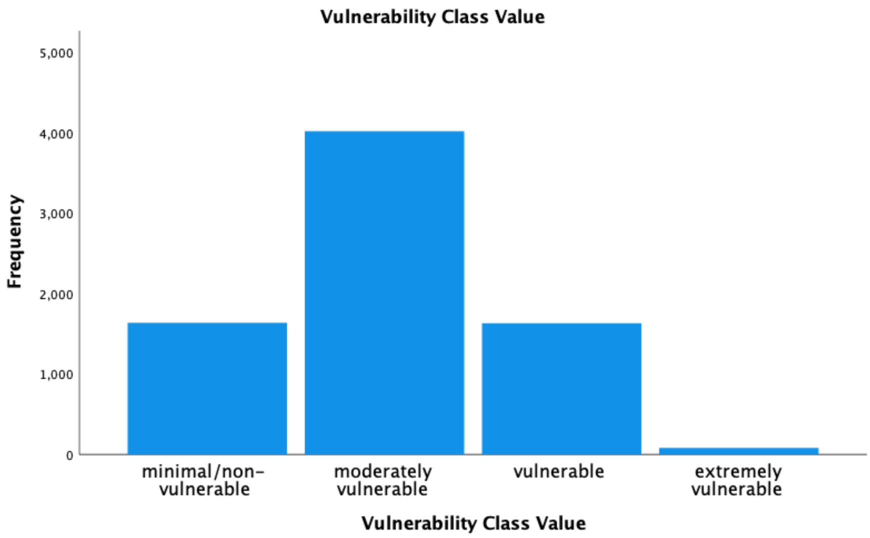
Vulnerability Classes
The frequency table of the vulnerability classes, based on the vulnerability scores, of all the respondents is shown in table 6. It must be noted though that these scores are not weighted and thus the vulnerability scores have regarded all the index values as equal. Higher vulnerability indices result in a higher vulnerability score.

54,4% of all respondents is classified as moderately vulnerable, with 22,1% classified as vulnerable. 1,1% is classified as extremely vulnerable. The average vulnerability score is 0,4015, which is classified as moderately vulnerable. The highest vulnerability score is 0,7879 and the least vulnerable person has a score of 0,0606. Table 7 provides an overview of the vulnerability classes of the studied vulnerable groups and their counterparts.

Vulnerability Class Value

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	minimal/non-vulnerable	1635	22.2	22.2	22.2
	moderately vulnerable	4015	54.5	54.5	76.8
	vulnerable	1630	22.1	22.1	98.9
	extremely vulnerable	81	1.1	1.1	100.0
	Total	7361	100.0	100.0	

Table 6: Frequency Table Vulnerability Classes.



Graph 1: Bar chart of frequencies Vulnerability classes.

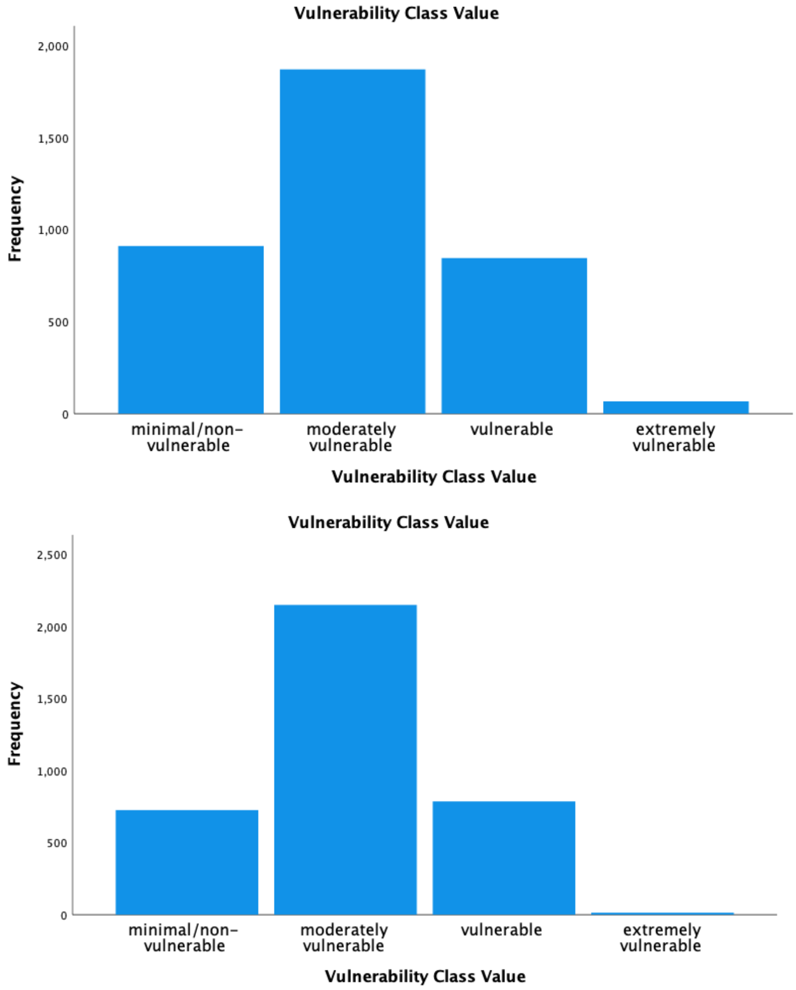
	Average vulnerability Score	Low-/non vulnerable (<0.30)	Moderately vulnerable (0.30-0.50)	Vulnerable (0.50-0.70)	Extremely Vulnerable (>0.70)
All respondents (7361)	0,4015	22,20%	54,40%	22,10%	1,10%
Women (3691)	0,401	24,70%	50,60%	22,90%	1,80%
Men (3670)	0,4012	19,80%	58,50%	21,40%	0,40%
Older Adults (above 60 years) (1628)	0,4516	15,60%	44,30%	36,80%	3,30%
Adults (below 60 years) (5733)	0,3868	24,10%	57,40%	18%	0,50%
Landless Agricultural Labourers (233)	0,5282	0,40%	38,20%	54,90%	6,40%
Land-owning Agricultural Labourers (236)	0,5089	0,80%	42,80%	54,70%	1,70%

Table 7: Overview of vulnerability class compositions of studied vulnerable groups and their counterparts

5.3.1 Women

The average vulnerability score of 3691 women is 0,4010 (moderately vulnerable). 24,7% is classified as minimal/non-vulnerable, 50,6% as moderately vulnerable and 22,9% as vulnerable. 1,8% is extremely vulnerable.

Of the 3670 men, the average vulnerability score is 0,4012 (moderately vulnerable). 19,8% is minimal/non-vulnerable, 58,5% is moderately vulnerable and 21,4% is vulnerable. Only 0,4% is marked as extremely vulnerable, which is 1,6 percentage point lower than women.



Graph 2: Bar chart of frequency Vulnerability Class Values Women (top) and Men (bottom).

Interestingly, while more women are (extremely) vulnerable (1,6 percentage point), they also show higher frequencies at minimal/non-vulnerability than men (4,9 percentage point higher). Women tend to be less represented in the moderately vulnerability class (7,9 percentage point lower than men). This means that on basis of these indicators, women are more at risk from SLR-related threats. It is however difficult to generalize women's vulnerability to flood-related threats as women are also ascribed more "coping-capacities, greater commitment to knowledge of risk, and social relations" (Rufus et al., 2015). On the other hands, Yavinsky (2012) states several reasons why women are more vulnerable to climate change, such as poverty and limited education, (early) childbearing, high fertility and lack of independence and decision-making power. Several of these reasons fall in line with the correlations found between the indicator values and gender. Gender and education level are positively correlated, which means that women tend to have higher vulnerable education index values than men. This is also true for income, albeit that this has a lower correlation. This could be explained by the role women partake in households as soon as they marry. Usually, women need to take care of children or perform other household chores, while the husband continues his education or looks for employment. This explanation could potentially be backed up by the significant negative correlation with marital status, meaning that women tend to have less vulnerable marital statuses than men (i.e., they have a spouse more often than men). This can be explained by cultural norms in India that put high pressures on women to get married (Kalpagam, 2008).

		Sex of household member
Sex of household member	Pearson Correlation	--
	N	7361
Marital Status Normalized Index Value	Pearson Correlation	-.051**
	Sig. (2-tailed)	<.001
	N	7361
Household Size Normalized Index Value	Pearson Correlation	-.006
	Sig. (2-tailed)	.637
	N	7361
Education Normalized Index Value	Pearson Correlation	.165**
	Sig. (2-tailed)	<.001
	N	7361
Income Normalized Index Value	Pearson Correlation	.037**
	Sig. (2-tailed)	.002
	N	7361
Assets Normalized Index Value	Pearson Correlation	.009
	Sig. (2-tailed)	.431
	N	7361
Source of Income Normalized Index Value	Pearson Correlation	-.006
	Sig. (2-tailed)	.758
	N	2849
House Type Normalized Index Value	Pearson Correlation	.008
	Sig. (2-tailed)	.492
	N	7361

**. Correlation is significant at the 0.01 level (2-tailed).

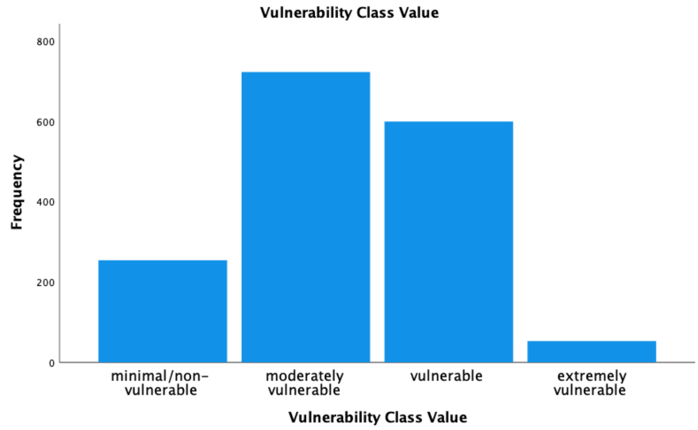
*. Correlation is significant at the 0.05 level (2-tailed).

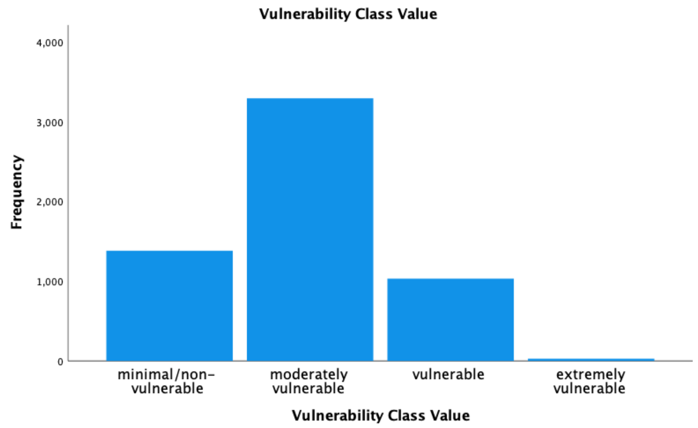
Table 8: Correlations of vulnerability indicators with gender.

5.3.2 Older Adults

The average vulnerability score of 1628 older adults (60 year or older) is 0,4516 (moderately vulnerable). 15,6% is classified as minimal/non-vulnerable, 44,3% as moderately vulnerable and 36,8% as vulnerable. 3,3% is extremely vulnerable.

The average vulnerability score of 5733 younger adults (below 60 years) is 0,3868 (moderately vulnerable), which is 0,0648 lower than the vulnerability score of older adults. 24,1% is minimal/non-vulnerable, 57,4% is classified as moderately vulnerable and 18% as vulnerable. 0,5% is extremely vulnerable.





Graph 3: Bar chart of frequency Vulnerability Class Values Older Adults (top) and Younger Adults (bottom).

Older adults have much higher vulnerability statuses than younger adults. Especially in terms of the vulnerable and extreme vulnerable classes, where older adults respectively have 18,8 and 2,8 percentage point higher frequencies than younger adults. This means that they will be less equipped against the threats of SLR. Harper (2019) states that "older adults are vulnerable to being trapped in poor environments through lack of mobility, disability and frailty. They are at increased risk of heat-related illnesses, compounded by living alone, co-morbidities, medication, and are at higher risk of dehydration than young people, due to the physiological changes that occur as part of the ageing process.". Other the other hand, Rufus et al. (2015) analysed multiple case studies of social vulnerabilities to floods and states that "the contribution of age to social vulnerability can be offset by previous disaster experience and anticipatory behaviour during the mitigation phase". The correlations between the vulnerability indicators and age are shown in table 9. It shows that the age of a person has a significant positive correlation with education level index. This means that if the age goes up, the education vulnerability index becomes higher. Poor education could have adverse consequences for older adults' awareness of SLR-related threats, and it could result into improper understanding of emergency warnings. Moreover, although the HH income vulnerability index also goes up with higher age (as older adults probably work less), the assets vulnerability index become less vulnerable. This can be explained by the longevity of life and the build-up of assets over time. It must be noted though that these correlations (income and assets) are not strong. Moreover, the source of income becomes more vulnerable if people are of higher age, meaning that older adults tend to earn their living from agricultural practices more frequently than younger adults. This could be ascribed to the poor educational opportunities older adults have experienced in past.

		Age of household member
Age of household member	Pearson Correlation	--
	N	7361
Household Size Normalized Index Value	Pearson Correlation	-.145**
	Sig. (2-tailed)	<.001
	N	7361
Education Normalized Index Value	Pearson Correlation	.301**
	Sig. (2-tailed)	<.001
	N	7361
Income Normalized Index Value	Pearson Correlation	.050**
	Sig. (2-tailed)	<.001
	N	7361
Assets Normalized Index Value	Pearson Correlation	-.043**
	Sig. (2-tailed)	<.001
	N	7361
Source of Income Normalized Index Value	Pearson Correlation	.112**
	Sig. (2-tailed)	<.001
	N	2849
House Type Normalized Index Value	Pearson Correlation	-.022
	Sig. (2-tailed)	.065
	N	7361

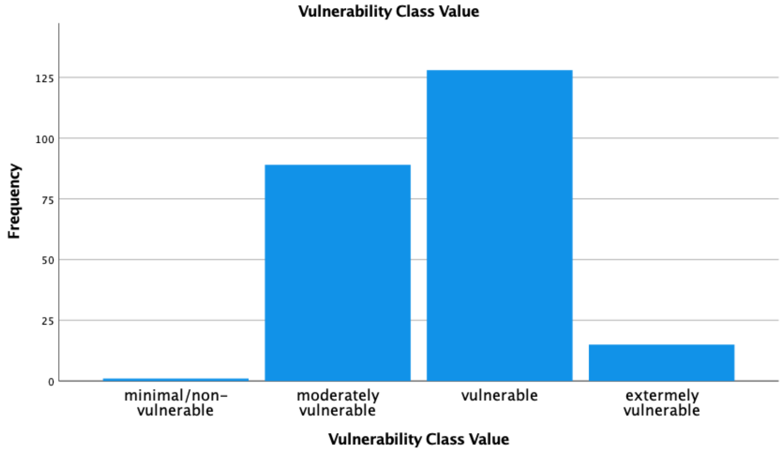
**. Correlation is significant at the 0.01 level (2-tailed).

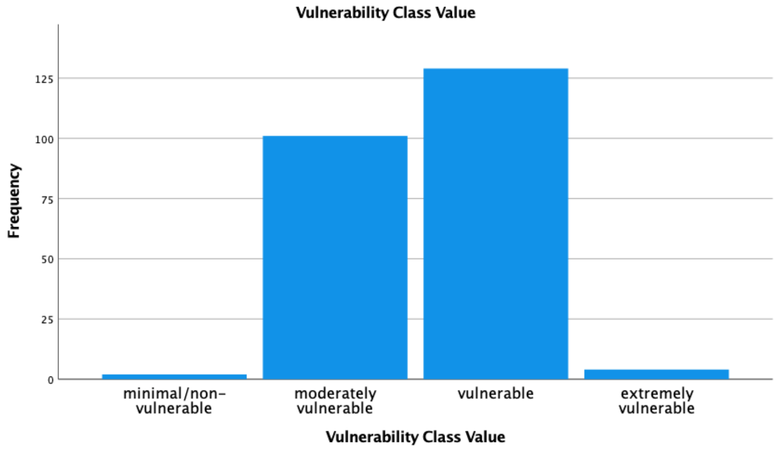
Table 9: Correlations of vulnerability indicators with age.

5.3.3 Landless Agricultural Labourers

The average vulnerability score of 233 landless agricultural labourers is 0,5282 (vulnerable). Only 0,4% is minimal/non-vulnerable, 38,2% is classified as moderately vulnerable and 54,9% as vulnerable. 6,4% is extremely vulnerable.

The average vulnerability score of 236 land-owning agricultural labourers is 0,5089 (vulnerable). 0,8% is minimal/non-vulnerable, 42,8% is classified as moderately vulnerable and 54,7% as vulnerable. 1,7% is extremely vulnerable.





Graph 4: Bar chart of frequency Vulnerability Class Values landless agricultural labourers (top) and land-owning agricultural labourers (bottom).

Vulnerability indicator status of Landless agricultural labourers

Compared to the other vulnerable groups, landless agricultural labourers show much higher vulnerability scores. The average vulnerability score of 233 landless agricultural labourers is 0,5282 with 54,9% classified as vulnerable and 6,4% as extremely vulnerable. This will mostly be due to the source of income, which has a positive correlation with education, house type and water source. Other significant (although more weakly) positive correlations with source of income are HH size and income and assets. The difference with land-owning farmers mainly lies in the extremely vulnerability class, where landless agricultural labourers have 4,7 percentage point higher frequencies than land-owning agricultural labourers. Unfortunately, there was no indicator variable for landless agricultural labourers, which is why correlations with the vulnerability indicators cannot be discussed. Nevertheless, the findings support the notion that landless agricultural labourers are one of the most vulnerable social groups in West Bengals.

Limitations to the Vulnerability Assessment

The vulnerability assessment would be much more thorough if it would have been possible to do interviews in the study area. This would allow to gather information on local people's perceptions on SLR, drivers of inequality and vulnerability, and it would result into more targeted interviews. Such a targeted interview would search for relevant variables to indicate vulnerability (which would mean that the indicator analysis would be more extensive in terms of variables), and the geographical location of the respondent could be collected. These are two of the main downsides of the LASI Wave-1 survey dataset: the variables were not collected with a focus on climate adaptation and the geo-codes of the respondent's location have not been shared (yet). If the location would have been available, more vulnerability indicators could have been created, such as distance to the sea, distance to a hospital, distance to (cyclone/flood) shelter or whether the respondent is living in an area that is threatened by future SLR-events. Moreover, it would be possible to integrate the vulnerability scores with the inundation maps; thus, creating vulnerability index maps.

Adaptive capacity and sensitivity could also be further explored if local biophysical or technological variables were included. For instance, soil conditions or groundwater availability would be good indicators whether (agricultural) communities can adequately cope with flood risks.

Another limitation to this study is that the vulnerability indicators are not weighted in terms of importance. Currently, all 11 indicators are considered as equally important, while in reality this could differ. For instance, income of a household could be of much higher importance to someone's adaptive capacity than whether they are married or not. To realize this, it would have been necessary to perform a survey among these people and ask them to rank vulnerability indicators (e.g., on a scale of 1 to 10). Although estimations could have been made, for the sake of accountability and the prevention of scientific creativity it has been decided to withhold from this.

5.4 Adaptation Strategies to Sea Level Rise

Based on existing literature on adaptation strategies by coastal communities in the Bengal delta or other deltas this chapter assesses potential adaptation strategies against SLR and its related impacts such as storm surges, subsidence and erosion and ground water salinization. Each hazard will have an adverse impact on urban and rural communities and the effects will be disproportionately distributed. Hence, the adaptation strategies need to focus on the drivers on inequality and should aim to break the vicious cycle of SLR-induced inequalities.

Types of Adaptation Strategies to SLR

In general, there are three types of adaptation strategies against SLR, namely structural, non-structural and ecosystem-based approaches (Wenger, 2015). This section will outline the most important aspects of these different adaptation approaches.

Structural approaches (i.e., hard adaptations) mostly come in the form of infrastructure and can greatly differ with respect to the target hazard. In terms of SLR there can be instalments of dams, dikes, seawalls, channels, levees or "armouring" of shorelines with breakwaters and rock armour (which is rock or other material used to protect against scour and erosion) (Bonnet & Birchall, 2020). Through structural adaptations, a close collaboration is realized between technology and engineering in order to safeguard people and assets from SLR. Traditionally, structural approaches are preferred to protect coastal areas due to their track record and the high level of protection they visually "express" (Rangel-Buitrago & Anfuso, 2018). Because of this, most coastal regions are occupied with conserving and improving these structures in order to defend against SLR (Harman, Taylor & Fletcher, 2015). Nevertheless, there is also growing critique on hard defence structures as it is argued that these structures actually lead to more negative impacts due to changing coastal dynamics (i.e., alterations of water flows and geomorphology) and that they create more intense erosion events (Harms, 2018). Moreover, while physical barriers greatly weaken storm surge, they will also trap water for extended periods, which could have detrimental consequences for agricultural land, people's health and restore/rescue operations. Structural approaches are also quite capital intensive, which is why soft approaches are increasingly becoming more favourable.

One of the two soft approaches are **non-structural adaptation strategies**, which focus on social dynamics and try to reduce the risks of SLR through land-use management, regulation and development (Bonnet & Birchall, 2020). Examples of such strategies are planned migration, increasing public awareness, building requirements, emergency protocols and insurance schemes (Harman, Taylor & Fletcher, 2015). Although these strategies are more uncommon, they have great potential as they are easily adjustable and can be designed accordingly to the local context. For instance, in the case of storm surge, coastal regions can change buildings requirements or create development rules that would take buffer zones (i.e., setback area) into account in order to reduce the impact of floods (Harman, Taylor & Fletcher, 2015). The use of setbacks and buffer zones could however increase local vulnerability over time as SLR would damage them in the long run. As such, these requirements and rules must be continuously monitored and adjusted if needed (Bonnet & Birchall, 2020). Another soft, albeit tough, adaptation strategy is planned migration (i.e., people and assets would be relocated to areas that are outside of the flood-risk region), which comes with great difficulties though. For instance, planned migration could lead to market uncertainties, diminishing land values, exacerbation of inequalities or a loss of communal relationships (Adams, 2016). Moreover, the entire venture of migration will pose issues such as public compliance, financial constraints and availability of destinations.

As an alternative, **ecosystem-based adaptation strategies** show great promise as a second type of soft approach. As its name already suggests, these strategies coexist and cooperate with ecosystems and their "ecosystem-services". Instead of fighting against it, they are working together with nature in order to defend or shield human systems from SLR (Harms, 2018). Research has indicated that this form of adaptation has many advantages such as high flexibility, affordability and "low-regret". Moreover, they integrate long-term projections and stimulate higher readiness to SLR (Jones, Hole & Zavaleta, 2012; Bonnet & Birchall, 2020). Even though it is a soft approach, it does not have to be small in scale. In the case of the West Bengals ecosystem-based approaches could mean the use of mangrove forests as natural barriers, which would protect the inland from cyclones, storm surges and coastal erosion. This does require a lot of land, which is rather difficult due to the region's high population density. On the other hand, if mangrove plantations are combined with mud embankments, or if they are placed on so-called "mudflats", it could bring about accretion of land (Harms, 2018; Borsje et al., 2011). If combined with hard approaches, such as dikes and dams (even if they are of lower engineering complexity) these coastal natural barriers can greatly reduce the impact of storm surge (Borsje, et al., 2011; Cheong et al., 2013).

Recent and current adaptation attempts

India's government published their "National Action Plan on Climate Change" (NAPCC) in 2008, which currently is the most extensive document on mitigation and adaptation to climate change. It grossly includes adaptation to normalized transformations, with measures concerning crop improvement and water management (Government of India, 2008). However, although state-wide and local governments acknowledge the increasing threat of normalized transformations, adequate adaptation measures against it are lacking and the NAPCC does not offer any precise mission statement for the Sundarbans or the coastal region in general (Dey, Ghosh & Hazra, 2016). In 2012, the state of West Bengal largely left out adaptation to normalized transformations in its climate adaptation policy plans and placed priority on adaptation strategies against flood and storm surge (Government of West Bengal, 2012). Hence, the current adaptation strategies in place are primarily built on modern disaster management policies, which mostly consist of traditional practices and can be categorized in three groups of measures (Harms, 2018).

Firstly, there are early warning systems (non-structural approach). In response to Bangladesh installing its first warning systems after a 1970 cyclone that led to 350,000 casualties, India also started with an emergency system that linked meteorological and governmental institutes to villages through radio broadcasts and sending volunteers to deliver warning signals from door to door (India Meteorological Department, 2021). However, this integration was not successful as the warnings were considered unreliable and were unfollowed. As such, West Bengali Indians tend to follow forecasts of Bangladeshi origin (Harms, 2018). The West Bengal State Action Plan on Climate Change (WBSAPCC) has recommended in 2012 to adopt an effective Early Warning System (EWS) (Dey, Ghosh & Hazra, 2016). In 2016, the Severe Weather Forecast Demonstration Project was started which disseminates warnings through social media (India Meteorological Department, 2021). In 2018, The Kolkata Municipal Corporation (KMC) introduced India's first urban Flood Forecasting and Early Warning System (FFEWS), which enables the city to manage floods more efficiently (Dhiman et al., (2019).

Secondly, storm shelters and other safe havens (structural approach) have increasingly been constructed. These elevated shelters are built with concrete and steel skeletons and are frequently equipped with water pumps (Sanchez-Triana et al., 2015). Although these shelters save many lives, and are thus of great importance, they are an example of adaptation strategies that focus solely on disasters instead of normalized transformations.

Thirdly, there is focus on defence infrastructure maintenance which deals with both types of hazards. Mainly they exist in the form of mud/earthen embankments. These are usually locally made and lack sufficient strength and height to protect against extreme storms and ongoing erosion (and especially not against future SLR). In 2009, a storm surge of around 3 meters swept through the region between the Sundarbans and Kolkata, resulting in >400 km of embankments being breached. The estimated damages were around a half billion US dollars and over 2,5 million people were affected (Sanchez-Triana et al., 2015). Nevertheless, these mud embankments are repeatedly being rebuild after flood and breach events (although the outer-ring embankments are eventually given up and "handed over" to the sea) (Bhattacharya, 2020). As a result, developments in coastal defences (such as mixing soft and hard approaches) are largely being overlooked and as the government gives priority to disaster management there have been too few investments in adaptation strategies that tackle normalized transformations (Paton & Buergelt, 2019). Although most people, including policymakers, agree that more resources have to be allocated to coastal erosion protection such as concrete dike structures, it is usually concluded that there are insufficient funds available (Harms, 2018).

DPSIR

Below the DPSIR framework of SLR-induced inequalities can be viewed. It shows that the drivers behind SLR-induced inequalities are not primarily of biophysical nature, but they are also related to socio-economic conditions. Pressures are also not merely of environmental origin but are frequently a social and political product. Due to this, West Bengal, and especially the Sandurbans wetlands and agricultural areas, are currently being affected by SLR-related threats. The ongoing damages and disasters have many negative impacts on the region, which over the last decades have spurred certain responses in terms of coastal defence, warning systems and action or policy plans. Unfortunately, these responses currently do not protect the region against SLR-related threats in an effective way and exacerbation of inequality of vulnerable people is not tackled. Hence, potential measures are reviewed below that address the drivers and pressures of SLR-induced inequalities.

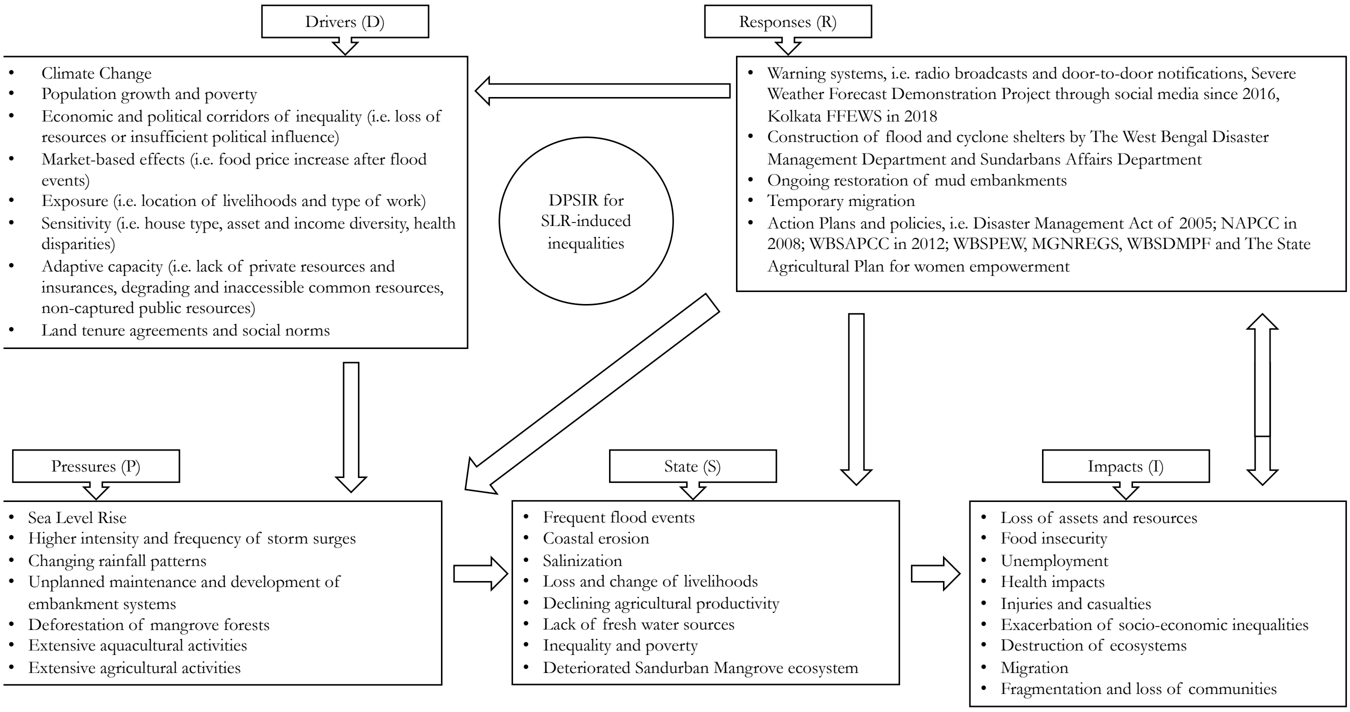


Figure 10: DPSIR (driver-pressure-state-impact-response) framework of SLR-induced inequalities (Abbreviations used in the framework: FFEWS: Flood Forecasting and Early Warning System; NAPCC: National Action Plan on Climate Change; WBSAPCC: West Bengal State Action Plan on Climate Change; MGNREGS: Mahatma Gandhi National Rural Employment Guarantee Scheme; WBSDMPF: West Bengal State Disaster Management Policy & Frame Work)

Adaptation Strategies for vulnerable communities in West Bengal

The produced inundations maps indicated that the area between the Sundarbans and Kolkata and the region south-west of Kolkata are the most exposed regions to SLR-related threats. Due to the exposure of this region, adaptation strategies are primarily concerned with the vulnerable communities that are living here. Literature points out that there are generally four adaptation pathways (i.e., set of adaptation strategies) possible, namely: continuing of current practices and strategies, increasing rural development, short to mid-term planned migration, and short-term mix of hard and soft approaches and long-term planned migration (Bonnet & Birchall, 2020; Sanchez-Triana et al., 2015; McLeman, 2017; Harms, 2018).

The first "business as usual" pathway would imply that there would be no significant changes in the adaptation strategy, which would mean that current low rates of rural development (i.e., agricultural intensification, urban sprawl, deforestation and population growth) will continue; recent adaptation strategies such as cyclone shelters, mud embankments restoration and warning systems will gradually proliferate; and the region will only receive aid after disasters have occurred. Obviously, this does not adequately tackle the issue of SLR, and it will exacerbate inequalities for vulnerable communities. Although extensive rural development may provide initial benefits for vulnerable communities such as more job/income opportunities and improved infrastructure, it will increase the number of people that will be threatened as the population will grow due to inwards migrating people that are searching for newly created jobs. Additionally, there will also be no long-term protective measures against flooding and normalized transformations and there will be more pressure on agricultural systems and local ecosystems such as mangrove forests. Short term planned migration is considered impossible due to insufficient resources and time, which will greatly exacerbate inequalities for vulnerable people (McLeman, 2017; Sanchez-Triana et al., 2015).

As an alternative, combining adaptation types is becoming more and more favourable among policymakers and climate scientists as it is regarded as a robust adaptation pathway due to flexibilities, synergies and lower political, financial, and infrastructural constraints during planning and decision-making (Bonnet & Birchall, 2020). Based on several studies it is thus concluded that an adaptation pathway that would incorporate a **mix of hard and soft approaches, while incentivizing long-term voluntary and permanent migration** shows the most potential for SLR risk reduction and avoiding excessive exacerbation of inequalities (Bonnet & Birchall, 2020; Sanchez-Triana et al., 2015; McLeman, 2017; Harms, 2018). This approach initially tries to reduce the risk of SLR by improving structural approaches (i.e., embankments and shelters) and combining them with soft approaches such as mangrove reforestation, micro-insurance schemes, climate-smart agriculture, awareness programmes and emergency systems. Furthermore, it will encourage long term gradual (voluntary) migration of people located in the most risk-prone areas through planning strategies that will increase economic, human and social capital of vulnerable people. Although a combination of these approaches might sound like a waste of time and resources, it will buy essential time for improving and building capitals of vulnerable people and it will reduce the risk for people that will not migrate. In summary, the most important aspects of this adaptation strategy are:

- Improvement of mud embankments and combine soft approaches in order to reduce exposure to floods and normalized transformations. Risk can also be reduced through disaster risk management and better emergency systems.
- Increase adaptive capacity of vulnerable people and improve social, human and economic capital opportunities in order to incentivize migration.
- Restore and protect ecological systems such as mangrove forests. Through reforestation programmes, vulnerability of people can be reduced as ecosystem-based defence structures can be combined with hard structures and it can create opportunities for people to generate more income.
- Institutional improvements such as governmental agencies that are occupied with the execution of the adaptation strategies.

Reduce exposure and risk through embankments and disaster management
This aspect can be divided in short- and medium-term adaptation strategies, namely continuing and expanding current disaster management infrastructure, and improving embankment systems and combining them with eco-system-based approaches.

Disaster management
During the last years, a reasonable amount of cyclone and flood shelters have been built by The West Bengal Disaster Management Department and Sundarbans Affairs Department in flood-prone areas. In 2010, there were a mere 315 in the region between the Sundarbans and Kolkata (Basu, 2010). In 2013, there has been a meeting between representatives from Hindusthan Steel Works Construction Limited (HSCL) and Engineering Project India Limited (EPLL). In this meeting EPLL assured that they will complete the construction of 50 Multipurpose Cyclone shelters within March 2014 (The West Bengal Disaster Management Department and Civil Defence Department, n.d.). About 2000 people can be protected in one shelter, which would mean that around 2000 shelters are required for this area alone (the region has a population of more than 4 million) (The World Bank, 2014). As such, a great number of shelters have to be constructed, while warning systems also have to be improved and extended. In a study by Ortolano et al. (2016) it was revealed that only 3,6% of impacted households were warned of the 2006 cyclone Mala.

Embankment improvements and realignments
The current main structural defences are mud embankments, which are easily breached. Bhattacharyya et al. (2013) concluded that the main reasons for this are over-steepening of embankment slopes due to channel erosion and seepage through pores during storm surge. They modelled these erosion events and recommended to relocate and realign the mud embankments over a timespan of 20 years to areas 100 to 300 meters away from the channels and to increase the heights of these structures. Due to relocation, channel erosion would stop eroding the base of mud embankments. In order to accomplish this, it is required to maintain the current mud embankments while reforesting the areas in-between the new and old embankments with mangrove forests. These will provide a buffer and serve as an extra protective shield during storms. Moreover, the abandoned areas will then not be entirely exposed to erosion as soon as the old embankments are left unmaintained.

Increasing adaptive capacity and incentivize planned migration
Although improved embankments and warnings systems will reduce exposure and risk, it will not totally prevent it. As hard constructions like concrete seawalls are not realistic due to scale and cost, long-term voluntary migration is a rather realistic alternative (Harms, 2018). Already, there have been people migrating out of the coastal areas of the Sundarbans and the matter is increasingly entering public debate (Daigle, 2015; Harms, 2018). The Delta Vision Document 2050, which is a proposal for managed retreat made by policymakers, projects that at least one million people have to leave the most vulnerable areas of the Sundarbans from 2030 onwards (Dey, Ghosh & Hazra, 2016). However, most of the current migratory movements are temporary as people eventually return to their hometowns after the flood has retreated (Ortolano et al., 2016). While involuntary migration might be achieved within a decade, human-rights organizations stress that this will lead to great injustices and vulnerabilities (Ismangil, van der Schaaf & Troost, 2020). Hence, it is necessary to incentivize people to gradually migrate by themselves. Most of these people are poorly educated, have meagre financial resources, and many losses will occur during the process of resettlement such as "dislocation, homelessness, unemployment, the dismantling of families and communities, adaptive stresses, food insecurity, loss of privacy, marginalization, loss of access to common property, a decrease in mental and physical health status, social disarticulation and the daunting challenge of reconstituting one's livelihood, family, and community" (Oliver-Smith, 2009). Thus, it is important to create push and pulls incentives for people to start migrating in the long-term and to take these potential losses into account in order to prevent migrants to be degraded to refugees.

A push could be awareness programmes that would inform people about the increasing risk and the unsustainability of current agricultural practices and livelihoods in these flood-prone areas. Moreover, current (non-/governmental) programmes that deal with post-disaster restoration and aid could be shifting focus from rebuilding to relocating. Pull approaches could be the spread of information about opportunities in urban areas (in terms of jobs, schooling and healthcare) to rural communities. Urban areas generally offer more economic opportunities and research has shown that later generations of urban settling families tend to have higher welfare levels than if they would have continued living in the rural areas (Narayan, Sen & Hull, 2009). In order to improve people's chances for successful migration and settlement, educational and training programmes and social networks are needed to enable people to find jobs in new economic sectors (such as services and manufacturing). These programmes can be publicly set up or migrants could receive credit that can only be spend on education and training. A survey by Ortolano et al., (2016) showed that many people in the Sundarbans (86%) would be willing to send their kids off to other regions for schooling. Moreover, small "migratory-subsidies" can be provided to ease the uncertainties that come with migration (which showed rather positive results in migration-incentive programmes in Bangladesh) (Bryan et al., 2014). For instance, older adults that have physical limitations to migrate will need some financial aid to allow adequate replacement. Also pension schemes need to devote attention to migrating older adults as they will experience difficulties in terms of resettlement. State-level documents, including the major Action Plan of 2011 currently does not mention migration (Dey, Ghosh & Hazra, 2016). However, local governments have to start preparations for such mass migrations events. Firstly, urban infrastructural development is required (especially in terms of energy, transport and housing) in order to facilitate more people and coupled economic growth. Furthermore, areas have to be reserved for new residents which would mean that current urban land-uses need to be re-evaluated.

People that decide to stay in the flood-prone areas should be better protected due to improved embankment and emergency systems, and there will be more land available to improve income opportunities and livelihoods. Moreover, micro-insurance schemes for health and property risks, such as the BASIX program, could extend insurance possibilities for vulnerable people, especially for women and landless labourers. Such insurances aid low-income families by offering tailor-made insurance while having very small premiums and they do not require people to have ownership of farmland or specific assets (Islam & Winkel, 2017). Another potential adaptation would be climate-smart agriculture (such as floating agricultural systems, waterlogging-tolerant crop varieties and short duration crops) which could reduce the risks of floods as crop yields will be less affected and agricultural practices can be restarted more quickly (Roy et al. (2020). If agricultural production can be more easily picked up again, landless agricultural labourers are not instantly required to migrate in search of work elsewhere.

These adaptations can build on recent governmental plans, such as Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS), that aim to improve women's self-employment, small entrepreneurship or representation in local committees. In the context of long-term disaster mitigation, the West Bengal State Disaster Management Policy & Frame Work (WBSDMPF) 2012-2013 attempted to spur engagement and empowerment of women, while the State Agricultural Plan focussed on capacity building and self-sustenance of women (Dey, Ghosh & Hazra, 2016).

Restoring and protecting ecosystems

As many people should leave the flood-prone region on the long term, a significant amount of land could become available for mangrove reforestation. These mangrove forests could be combined with the improved and realigned embankment systems for extra protection and resilience, while the forests could also increase local biodiversity and livelihoods. Sanchez-Triana et al. (2018) identified two requirements for successful combination of mangrove forests and embankment systems:

- Simultaneous planning and implementation of embankment construction and reforestation of mangrove forests
- Authority and control over the setback areas in-between new and old embankments need to be given to the Forest Department and other land-use than mangrove reforestation has to be prohibited.

However, there is still insufficient knowledge to what extent these ecosystems could create monetary value in terms of higher resilience and improved livelihoods, which shows the difficulty of this strategy as it misses a clear economic justification (Bonnett & Birchall, 2020). For instance, income can be generated if the ecosystem services of these forests are monetized, such as flood protection, forest products harvesting or wildlife tourism. As such, the forests could create new sources of income for people that stay behind as bio-conservation programs can be initiated with vulnerable communities taking care of the forests while obtaining common ownership. Uddin et al. (2013) estimated that households whose livelihoods are dependent on products from the Sandurbans forests have an annual income of around 559 US dollars. Decision- and policymakers thus need to realize this through research and economic valuation and translate it to effective policies. Moreover, it is important that there will be more bilateral cooperation between India and Bangladesh for the Sundarbans in the form of integrated conservation policies (Sanchez-Triana et al., 2018).

Institutional improvement

In the West Bengals, most governmental programmes for regional development are executed by departments of the Government of West Bengal. The Sundarban region is currently administrated by the Forest Department and the Department of Sundarban Affairs which has incorporated the Sundarban Development Board. Sanchez-Triana et al. (2018) state that due to this subsumption and the resulted divided agencies, adaptation strategies until now have been rather ineffective in terms of incentivizing and coordinating governmental agencies. Without proper guidance and execution by local governments neither of the earlier mentioned adaptation strategies will be successful. Thus, one of the most important adaptation strategies will be a re-evaluation and strengthening of local institutions and improving collaboration between different agencies. To improve local governance, it is required there will be extra funding and training, but also to safeguard authority and accountability of the institutes (Roy et al., 2020). Furthermore, polycentric governance, which is a "governance system in which multiple governing bodies interact to make and enforce rules within a specific policy arena or location" (ApplyingResilience, n.d.), could help adapt to flood risks and improve local resilience (Roy et al., 2020). For instance, enhanced collaboration between the Irrigation and Waterways Department and the Forest Department should make it possible that mangrove reforestation in the setback areas in-between new and old mud embankments is realized (Kumar, Sivamohan & Bassi 2020). The Irrigation and Waterways Department is committed to flood protection and would oversee the construction of new mud embankments, while the Forest Department aims to conserve biodiversity in the forests and wetlands. Thus, these institutes would need further cooperation in order to improve chances for successful reforestation. Moreover, the Department of Panchayats and Rural Development, which is involved in rural development through participation in planning and execution at the village level, could increase involvement of local communities with forest management. This is currently limited due to policies that prohibit any form of extraction from the forests (i.e., harvesting non-/timber forest products) by local communities (Chaudhuri et al., 2015). At last, there have also been efforts by the Department of Fisheries and Aquaculture to increase aquacultural activities in the delta (Sanchez-Triana et al., 2018). This however counteracts investments in embankment systems by the Irrigation and Waterways Department as the increasing aquaculture activities lead to channel erosion and subsequent embankment failure (Kar et al., 2020). More collaboration between the agencies could prevent this in the future.

Policy Recommendations

To successfully mix hard and soft approaches and to incentivize long-term voluntary and permanent migration, this research recommends the following policy measures.

To reduce risk in the short and medium term, current instalments of multi-purpose shelters and early warning systems should be extended and integrated in the Disaster Management Act and aligning it to the National Action Plan on Climate Change. The Disaster Management Act had been implemented in 2005 and provides a framework for pre- and post-disaster management. Moreover, an action plan and budgetary reservations should be set up for relocation and realignment of mud embankments while reforesting the setback areas. Appropriate instalment and maintenance of mangrove forests will require collaboration between the Irrigation and Waterways Department and the Forest Department as the prior department would oversee the instalment of embankments and setback areas, after which authority over the setback areas needs to be handed over to the Forest Department for forest management. Furthermore, the Department of Panchayats and Rural Development could initiate programs to increase involvement of local communities with forest management due to the departments' close link with rural communities. Additionally, the state-government of West Bengal should start new initiatives for bilateral cooperation between India and Bangladesh in the form of integrated conservation policies for the Sandurbans. These reforestation efforts need to be combined with economic valuation and realization of ecosystem services of (new and existing) mangrove forests in order to improve livelihoods of local vulnerable communities. Designing action plans to distribute climate-smart agriculture through training and farming cooperatives could further improve the livelihoods of vulnerable communities.

Policy measures that would incentivize permanent migration are divided in push and pull measures. A push measure could be a shift in (non-) governmental post-disaster restoration and aid programmes from rebuilding disaster-struck communities to relocating the people elsewhere. This can be supported by the dissemination of awareness programmes concerning current risk, unsustainability of current agricultural practices and livelihoods, and opportunities in urban areas. Potential pull measures are implementation of educational and training programmes and creating social networks in urban/safe zones. For this, policymakers should explore whether this would require public training/schooling institutes or whether educational credit would suffice. Furthermore, "migratory-subsidies" and disaster risk integrated financial support (e.g., pension schemes or micro-insurances) for vulnerable people need to be set up in order to ease the pains of migration. These migration incentivizing-efforts need to be supported by policies regarding urban infrastructural development (especially in terms of energy, transport and housing), and re-evaluation of current urban land-use.

At last, extra funding and training for improving local governance and to safeguard authority and accountability of institutes is needed to ensure that the mentioned policies are successfully implemented. This will require a focus on polycentric governance structures to adapt to flood risks and improve local resilience.

6. Conclusion

This research aimed to identify potential adaptation strategies to protect vulnerable communities from disproportionate impacts from SLR-related threats. The main research question was "what are potential adaptation strategies for vulnerable communities in West Bengal for projected SLR and how can it reduce SLR-induced inequalities".

Prior to answering this, it geospatially modelled the threatened areas to answer the first sub-question "which areas in West Bengal, India are currently and will be threatened by projected SLR?". The threatened areas with a SLR of 5-7 meters are mainly situated along the banks of the rivers Matla, Ichamati and Hooghly or Rupnarayan. Moreover, the entire core zone of the Sandurbans will be inundated just as the zone in-between Kolkata and the Sandurbans, which is called the transition zone. Major urban hotspots in the transition zone are Port Canning (±550.000 inhabitants) and the city Basirhat (±150.000 people).

The third sub-question consisted of two parts, of which the first part was completed prior to answering the second sub-question. It stated: "how can SLR-related threats exacerbate socio-economic inequalities for vulnerable communities?". Literature analysis showed that inequality is exacerbated by SLR-related threats through economic (i.e., degradation of resources) and political corridors (i.e., insufficient political power) and market-based effects (e.g., food price increases after flood events). These corridors result into a reproduction of high levels of exposure (i.e., location of livelihoods and type of work), sensitivity (i.e., house type, asset and income diversity, health disparities), and lower adaptive capacities (i.e. lack of private resources and insurances, degradation and inaccessibility of common resources, and non-captured public resources). This in turn leads to a vicious cycle of exacerbating inequality for vulnerable communities.

The second sub-question was: "what is the degree of vulnerability of women, older adults and landless agricultural labourers in West Bengal". This was indicated through a vulnerability indicator assessment of 11 vulnerability indicators, which were based on the findings in the analysis of drivers of SLR-induced inequalities. It showed that women, older adults and landless agricultural labourers in West Bengal have high vulnerability statuses, due to their high levels of exposure and sensitivity and low adaptive capacity. Women's vulnerabilities are mainly skewed to the extremes compared to men (in either way) and older adults show much higher vulnerability statuses than younger adults (especially in terms of the vulnerable and extreme vulnerable classes). Landless agricultural labourers almost had a higher average vulnerability score of 1 integer, and they are much more present in the extremely vulnerable class (5,3 percentage point higher than all respondents).

The last sub-question, "what are potential adaptation strategies against SLR-related threats?", was answered through a literature-based analysis. Recent literature showed that current adaptation strategies are based on traditional practices and mainly consist of early warning systems, cyclone/flood shelters and mud embankment restorations. Most promising adaptation strategy that would protect against future SLR-related threats and avoid further exacerbation of socio-economic inequalities is a mix of hard and soft approaches, while incentivizing long-term voluntary and permanent migration. This would require the following:

- Improvements and realignments of embankments while combining with mangrove reforestation in setback areas. It would also need improved disaster risk management in the form of better early emergency systems and proliferation of cyclone/flood shelters.
- Adaptive capacity of vulnerable people needs to be improved through micro-insurances, climate-smart agriculture and new sources of income (such as local conservation programmes of mangrove forests).
- Creating social, human and economic capital opportunities in order to incentivize long-term migration (i.e., awareness programmes, training and education, migratory-subsidies, integration of disaster risk in pension and insurance schemes, and investments in infrastructural development in urban areas/safe zones)
- Institutional improvements in the form of polycentric governance structures and extra funding and training.

For this strategy to be successful, a handful of policy recommendation were proposed. To reduce risk, current disaster risk management policies need to be integrated with updated policies on shelter and warning systems proliferation. Furthermore, action plans and increasing budgets are needed for relocating and realigning mud embankments. The combined mangrove reforestation efforts require polycentric governance structures and initiatives concerning local involvement of (vulnerable) communities. Furthermore, several pull and push measures are recommended that would ease the pain of long-term migration for vulnerable communities, while they would increase the chance for successful relocation to safe zones.

This study provided a view on adaptation strategies against SLR-related threats through the lens of vulnerable communities and inequality. It showed how demographic variables can be linked to vulnerabilities to climate disasters. Although the individual approaches are not unique by itself, the framework to identify flood-prone areas and the indicator assessment can be used for future studies to identify key factors of vulnerability in certain areas. This also shows the limitation to this study, which was the lack of geo-locations of vulnerable communities. Having this would enable a combination of inundation maps with the vulnerability indicator assessment in order to make vulnerability index maps. This would provide insights in the spatial distribution of vulnerable communities. Moreover, on-site stakeholder interviews would enable analysis of local perceptions on indicators and indicator weights, and it would also allow to collect geospatial variables that would indicate vulnerability (such as distance to flood shelter or distance to sea). Thus, the study approach could be further extended in the future if geolocations of households are collected. Moreover, the approach could be tested on smaller target areas. For instance, a vulnerability assessment could be done between multiple neighbouring villages in order to indicate social dynamics of local SLR-related vulnerabilities. For this, on-site interviews and stakeholder meetings would have to be organized. Finally, the approach could integrate a temporal dimension, as it could gather vulnerability variables in areas that have received certain adaptation measures and variables in more neglected areas. Subsequently, these could be recollected and compared after future flood-related hazards. This would allow a quantitative assessment of the effectiveness of certain adaptation strategies.

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