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ADAPTING AGRICULTURAL LIVELIHOODS IN DELTAIC ENVIRONMENTS: EXPLORATIONS FROM THE INDIAN BENGAL DELTA

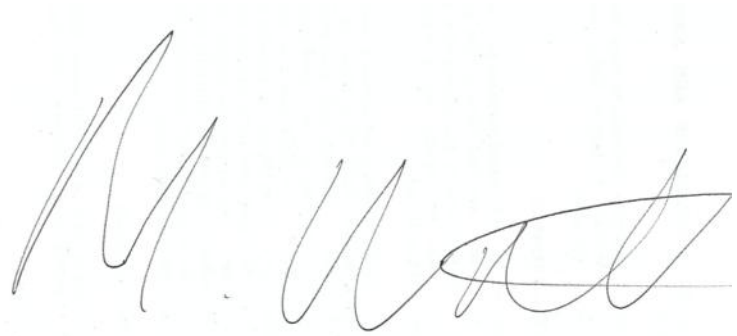
Martin Watts

A dissertation submitted in partial fulfilment of the degree of MSc Social Research Methods

Statement of originality

Except for those parts in which it is explicitly stated to the contrary, this thesis is my own work. It has not been submitted for any degree at this or any other academic or professional institution.

Signed..



Candidate’s name: MARTIN WATTS

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List of Abbreviations

BLR	Binary Logistic Regression
CTC	Climate Tolerant Crops
VIF	Variance Inflation Factor
INAPCC	India's National Action Plan on Climate Change
IBD	Indian Bengal Delta
IPCC	Intergovernmental Panel on Climate Change
NAP	Number of Adaptations Practiced
IFU	Increasing Fertilizer Usage
IOQ	Integration of Qualitative
ACIAR	Australia Centre for International Agricultural Research
GDP	Gross Domestic Product

Abstract

Environmental change is a significant threat for many vulnerable crop farmers residing in environmentally sensitive deltas. In an unfolding future, where the degree of change is expected to intensify, adaptation in South Asian deltas is becoming increasingly important. However, in the Indian Bengal Delta (IBD) the understanding of farmers' adoption of adaptation strategies is limited. This dissertation therefore aims to investigate what influences deltaic crop farmers' adaptive responses to environmental change in the IBD. An explanatory sequential mixed method design was employed. In this, binomial logistic and generalised Poisson regression models quantitatively analysed the association between on-farm adaptations, and farmers' credit access and household and farmland characteristics, using an IBD household survey. Next, semi-structured interviews with crop farmers in a case study of two villages in the IBD then provided explanation and depth to the quantitative results.

Results indicate that the effect of farmers' employment type, education, farm size and access to credit (through loans) were significantly, and generally positively, associated with adopting various on-farm adaptation strategies. Interviews implied that permanently employed farmers were more reliant on adaptation strategies, while low education levels prevented some farmers understanding and applying information disseminated by local agricultural extension services. Smaller farm sizes constrained farmers' ability to feasibly implement adaptive measures, and having access to loans enabled farmers to affordably implement irrigation and effectively apply crop diversification strategies. Farmers' employment type, land size and education was positively associated with the intensity of adaptation. Interviews also highlighted that the main barriers hindering adaptation concerned a lack of market access to organic fertilizer, farmers' normative beliefs and the unintelligible delivery of information by extension services. This dissertation concludes by recommending that market actors retail organic fertilizer in shop outlets to enable organic farming, and that extension services undertake practical approaches to comprehensibly communicate information to farmers.

Chapter 1 Introduction

This chapter sets the context for this dissertation, and highlights the research motive. It presents the research questions and objectives, and describes the study areas used. It finishes by describing the dissertation structure.

1:1 Research Background and Significance

Global environmental change is undeniable, and the remainder of the century is expected to see significant changes in climatic and environmental conditions (IPCC, 2014b). Adaptation is therefore an essential research topic, particularly regarding agriculture in South Asia where changes in environmental factors, such as rainfall and temperature, are expected to hinder crop production (Le Dang *et al.,* 2014). Subsistence rural farming provides a livelihood to millions living on or below the poverty line in South Asian deltas (Khatun and Roy, 2012), and these populations will unequally take the brunt of environmental change (Lazar *et al.,* 2015; Government of India, 2015a). Sensitive environmental habitats and natural resources that are heavily relied on are already altering under changes in temperature, rainfall and salinity, effecting the service of environmental goods such as crops (Cazcarro *et al.,* 2018). This is documented in parts of the IBD, where delicate balances in environmental conditions required for mono-cropping paddy, which supports 77% of the economy, are changing (Ghosh, 2012). Subsequently, crop farmers already struggling with poverty and food insecurity are now faced with greater challenges associated with environmental change.

Unless appropriate adaptations are undertaken, agro-climate models project that by 2030 crop production could fall by 1.23%, and by up to 51% by 2050 (Banerjee *et al.,* 2015; IPCC, 2014b). The implementation of adaptation strategies is therefore imperative to ensuring that vulnerable smallholder farmers do not fall further into poverty and food insecurity (Skoufias *et al.,* 2011). Adapting accordingly would improve the resilience of agricultural livelihoods (Gupta *et al.,* 2017), though deltaic farmers often do not have the household assets and capacity needed to adapt, owing to being geographically and economically isolated. Therefore, extreme poverty and food insecurity persist as threats.

Research is emerging on the adoption of agricultural adaptation to environmental change in deltaic environments, particularly across Asia's Mekong, Ganges-Brahmaputra-Megha and Indus deltas (Chapman *et al.,* 2016; Johnson *et al.,* 2016; Salik *et al.,* 2015). However, little is known on the uptake of adaptive strategies by farmers in the IBD. Research still cannot offer insight into the complex and context-specific characteristics that enable farmers to adopt, or act as barriers to, adaptive strategies. Not only will an empirical study address research deficits, but it is timely as the topic of adaptation in agriculture broadly relates to recent initiatives. The Government of India's (2015b) recently developed National Climate Action Plan and their sustainable development goals both consider increasing farmers' resilience to climate change, and to enable more sustainable farming. Other initiatives, such as India's National Initiative on Climate Resilient Agriculture (NICRA), encouraging the uptake of adaptive agricultural technology have been effective (Joshi *et al.,* 2015). Moving forward, focus is on scaling-up initiatives to benefit the wider agricultural population (Bager *et al.,* 2017: Pound *et al.,* 2018). Given that in 2011, 18,171,742 people, the majority farmers, lived in the IBD (Census of India, 2011), empirical results uncovering the processes influencing farmers' adoption of adaptive strategies here will in general be well received by decision-makers.

1:2 Research Questions and Objectives

This dissertation's overarching research question is: What influences deltaic crop farmers' adaptive strategies to environmental change? To allow for more specific focus, and augment the data collection, Table 1's research questions and objectives were adopted. These research questions were developed using the identified literature gaps summarised in chapter 2.

Table 1: Dissertation research questions and objectives.

Research Question	Objective
1. What adaptation strategies are crop farmers using in response to perceived environmental changes?	1. To identify the perceived and experienced environmental risks. 2. To document the adaptive responses adopted.
2. What factors and processes affect crop farmers' adoption of adaptation strategies?	3. To uncover which factors condition the uptake of on-farm adaptation strategies. 4. To explain the processes which condition the uptake of such strategies.

3. What are the main barriers preventing farmers adapting?	5. To uncover the main barriers that constrain farmers' adaptive responses.

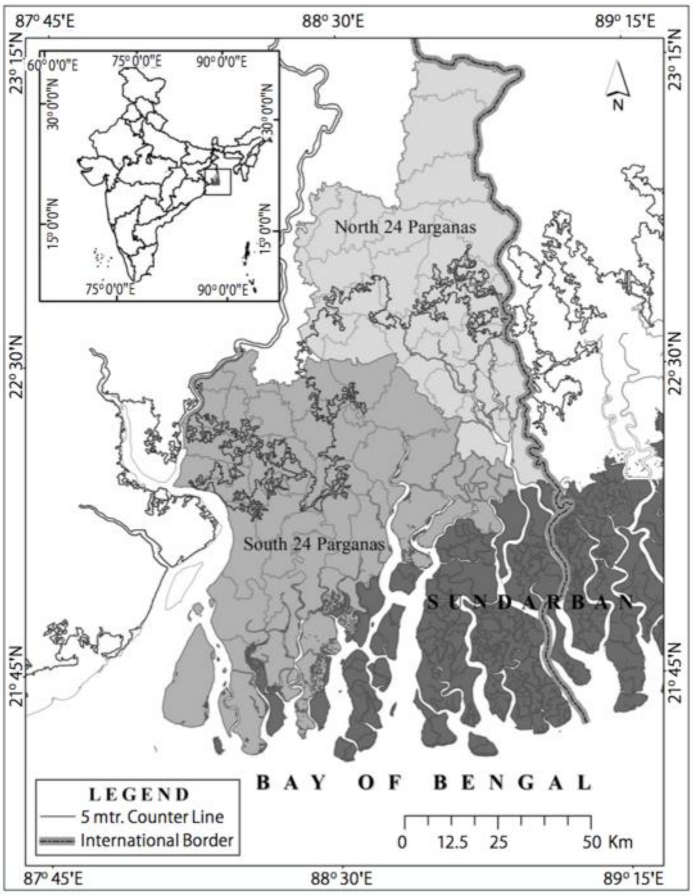
1:3 Study Areas: The IBD, and the Case Study Villages

This dissertation uses two study areas to address Table 1's research questions and objectives. The first is the IBD, in which the analysis of an IBD household survey, collected by DECCMA, will identify the context for adaptation and the relationships framing crop farmers' adaptive responses to environmental change. DECCMA is a wider project that evaluates household adaptations undertaken across four major deltas, including the IBD. The second study area comprises two IBD villages, Dulki and Sonagar, employed as case studies to gather qualitative contextual explanatory information corresponding to the initial survey findings. In doing so this holistically addresses the research objectives and questions. The details linking how each study area was assessed is presented in chapter 3.

The IBD, located in West Bengal, is comprised of 51 community blocks distributed throughout the districts of North 24 Parganas and South 24 Parganas (Ghosh *et al.,* 2018) (Figure 1). As defined by DECCMA, it spans 14,054 km^2, with 9630 km^2 in the Sundarbans region (Cazcarro *et al.,* 2018). After rapid decadal growth, the population in 2011 was 18,171,742, with the majority of people being in rural provinces (Census of India, 2011). Forests cover approximately 4264 km^2 of land, with 1810 km^2 of this wetland. Overall, 44% of the IBD's land is used for agriculture, however the delta also encompasses a large trade-transport sector (Cazcarro *et al.,* 2018). The agriculture sector is predominantly paddy cultivation, as around 833,000 hectares of land is used for rice production (Table 2). The IBD is known to experience multiple environmental stresses and shocks associated with environmental change, such as coastal flooding, sea-level rise, salinization, erosion and cyclones (Ghosh *et al.,* 2018), which has a detrimental effect on agriculture (Singh *et al.,* 2016). This underpins the IBD as an ample study area to not only fill research gaps, but to investigate the agricultural adaptive responses to environmental change.

The case study villages Sonagar and Dulki, located in the Sundarbans's Basirat Subdivision, and the Gosaba district, are surveyed at three community sites, as Figure 2 shows. Dulki is a medium sized rural village with a population of 416, whilst Sonagar is larger at 3391 (Census of India, 2015). In an assessment by DECCMA, where villages within the IBD were categorised through a vulnerability multi-hazard map, Dulki and Sonagar were identified as high-risk. This made them ideal locations to further explore the survey results.

Figure 1: The Indian Bengal Delta.



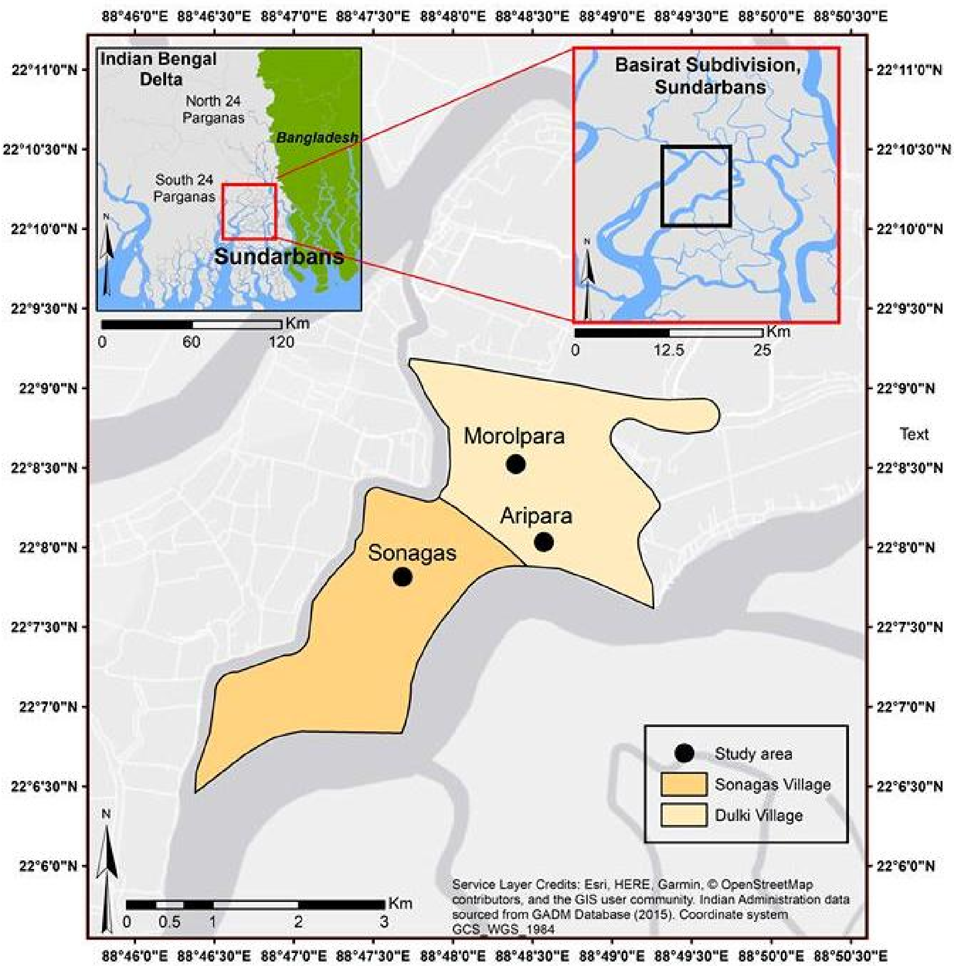
Source: Ghosh et al., (2018).

Table 2: Cropland used (1000 ha) in each delta by agricultural sector.

	Direct Land Mahanadi	Direct Land IBD	Direct Land GBM	Direct Land Volta
Paddy rice	845	833	3000	15
Wheat	0	12	108	0
Cereal grains nec.	157	0	4	31
Vegetables, fruit, nuts	60	30	655	51
Oil seeds	95	79	9	0
Sugar cane, sugar beet	2	1	71	0
Plant-based fibers	1	76	54	0
Crops nec.	19	31	93	66
Bovine cattle, sheep and goats, horses	29	21	0	25
Animal products nec.	26	76	0	142
Raw milk	76	82	0	341
Wool, silk-worm cocoons	5	5	0	0

Source: Cazcarro *et al.,* (2018).

Figure 2: Case study area and location.



Source: Author.

1:4 Dissertation Outline

This dissertation follows a general thesis structure, in which a review of the key concepts such as resilience, vulnerability, adaptive capacity and adaptation barriers, as well as the empirical findings of comparable research, is undertaken in chapter 2's literature review. Although a hoped research output is to inform relevant decision-makers, a review into India's agricultural policy and initiatives was not undertaken as literature relating to the research questions/objectives took precedence. For a review of India's and West Bengal's agricultural policy see Mohanaiah (2009), Dey *et al.,* (2016) and Ghosh *et al.,* (2016). Chapter 2 concludes with a summary of the research gaps identified. Chapter 3's methodology transparently explains the mixed-methods design, and each individual method's data collection and analysis to enhance the trustworthiness of findings (Guba, 1981). It concludes with a self-critical evaluation of the methodology. Chapter 4's findings and results is sub-divided corresponding to the research objectives. The first section details farmers' perceived risks to environmental change using descriptive statistics, and interviews to add depth to the results. The second uses identical approaches to report the observed adaptive responses is in the IBD, and the case study areas. The third sub-theme covers research objectives 3 and 4, whereby regression analysis undertaken on the determinants of farmers adaptation strategies, and the intensity of adaptation, are integrated with interview accounts to report the processes influencing adaptation. The last section employs frequency charts depicting the main adaptation barriers in the IBD to set the context for farmers' interview accounts. Chapter 5's discussion and conclusion discusses the most important findings corresponding to each research question in the wider context of the literature. It also discusses the limitations encountered in this study, policy implications and recommends areas for further research.

Chapter 2 Literature Review

2:1 Climate and Environment

Around the IBD, regional climates are characterised by relatively high humidity and temperatures, reaching 25ºC in winter, 43ºC in March and 32ºC during the monsoon (Gopal and Chauhan, 2006). The region experiences 1500-2400mm precipitation annually, with approximately 74% deriving from June-September's monsoon season (Ibid). Storms are common and between May-October these can frequently develop into cyclones (Ghosh, 2014). Regional hydrology is influenced by freshwater flows mainly from the River Ganga, and ocean tides generating varying gradients of salinity (Gopal and Chauhan, 2006). However, low-lying topography incorporated with regular embankment failure during heavy rainfall makes the region susceptible to saline water intrusion, which is exacerbated by high evaporation rates (Yadav, 1979; Hajra and Ghosh, 2018). Soils mainly originate from alluvial deposits, whilst coastal soils exhibit greater levels of sodium chloride (Gopal and Chauhan, 2006). Subsequently, regional soils vary in salinity, alkalinity and in fertility owing to changeable levels of organic matter, calcium and magnesium.

2.1.1 Trends and Environmental Changes

In the Sundarbans, decadal water temperatures have been increasing by 0.5ºC, quicker than the global average of 0.06ºC (Mahadevia and Vikas, 2012). Figure 3 represents water temperatures since 1980 (emphasis is on the Western Sundarbans), and evidently temperatures exhibit sharp rises, which Ghosh (2012) accredits to climate change. Little reliable air surface data exists, though the IPCC (2014b) report increasing mean annual temperatures in South Asia in the last 50 years, and a likely 3ºC increase by 2100.

Figure 3: Water Surface Temperature

Source: Mitra et al., (2009).

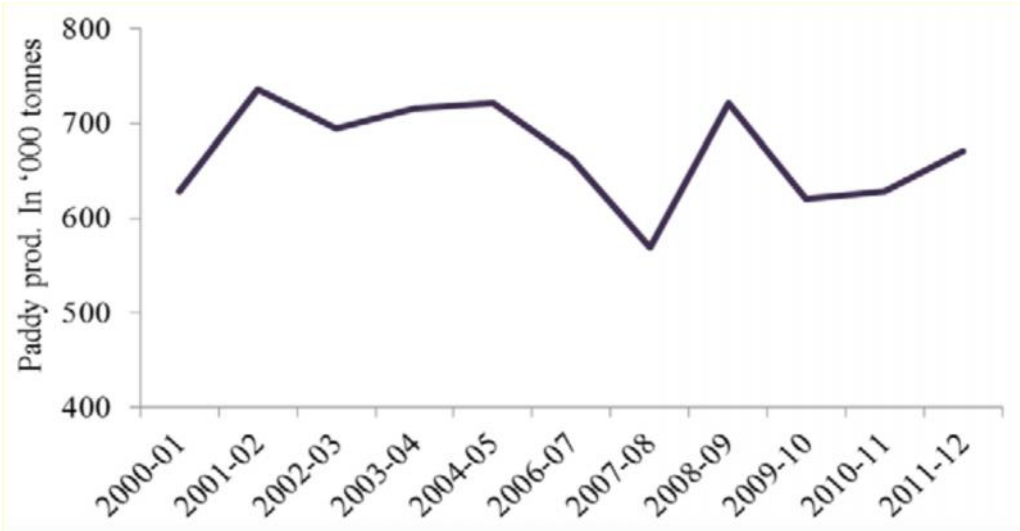
Regional sea-level rise (17.8mm/yr) is higher than the global average (3.27mm/yr) (Hazra *et al.,* 2010; NASA, 2018) over identical time frames. This is indicative of global warming and land subsidence in amalgamation (Mahadevia and Vika, 2012). In terms of erosion, rates post-2000 have nearly doubled from 1930 onwards, leading to losses of farmland (Rudra, 2011). Progressive river siltation has severed the influx of freshwater, creating shallower and more saline rivers (Gopal and Chauhan, 2006). Soil and water salinity is gradually increasing, and has been described as a "slow poison" (Ghosh, 2012 p35), as embankments can no longer protect against amplified seawater flooding. Regarding rainfall, researchers report that rainfall intensity is increasing (Hazra *et al.,* 2010), but low-pressure systems are lengthening without culminating to rainfall (Jadhav and Munot, 2007). This suggests that monsoons are gradually becoming longer and drier, with increasingly erratic and intense single rainfall occurrences (Guhathakurta *et al.,* 2011). Newer research indicates climate variability also plays a role, as El-Nino years will reduce overall rainfall, whilst La-Nina increases it (Chanda *et al.,* 2018). Similar research also forecasts that while decadal cyclone and storm incidences have decreased, intensity continues to increase (Hazra and Samanta, 2016).

2:2 Environmental Change and Agriculture

Across India's population 68% are directly or indirectly involved in agriculture (O'Brien *et al.,* 2004), which accounts for 14% of India's GDP (Kaur, 2017). India's agricultural productivity is closely tied to the timing and strength of the monsoon season, and other environmental factors such as temperature and drought (Kumar and Sharma, 2013). Increasing temperatures may benefit productivity, however studies have found that previous growing seasons 4°C warmer than normal caused a 41% deduction in rice production (Geethalakshmi *et al.,* 2011). Other studies found that previous droughts, which are expected to intensify, led to 12-33% increases in the level of poverty amongst farming households (Pandey *et al.,* 2007). According to Zhai and Zhuang (2009), by 2080 India's agricultural output could decrease by 24%, reducing overall GDP by 6.2%.

Around the IBD, subsistence mono-crop (paddy) agriculture is common, providing 77% of the area's economy directly and indirectly (Ghosh, 2012). Rapid population growth and an overreliance on natural resources have made subsistence farming livelihoods vulnerable to the effects of environmental change (Hajra *et al.,* 2016). Farmers already suffer low yields as excessive rainfall, low-lying topography and inadequate drainage generate water logging damaging crops (Singh *et al.*, 2012). Growing situations are exacerbated by insufficient groundwater irrigation systems, which have seen increases in salinity. Studies also directly relate increasing salinization and decreasing yields (Hajra *et al.,* 2016). For example, soil degradation due to increasing salinity has been associated with deductions in paddy production (Figure 4) (Chand *et al.,* 2012). Therefore, agriculture relies predominantly on monsoon rainfall (Ghosh, 2012). Paddy and other cash crops are sensitive to alterations in temperature and unseasonal rainfall. Therefore, warmer temperatures and increasingly intense rainfall events are generally declining yields (Ibid). Unsurprisingly, incidences of poverty and food insecurity are increasing, as farmers cannot sustain themselves against the effects of environmental change (Hajra *et al.,* 2017).

Figure 4: Trend in Paddy Production in IBD



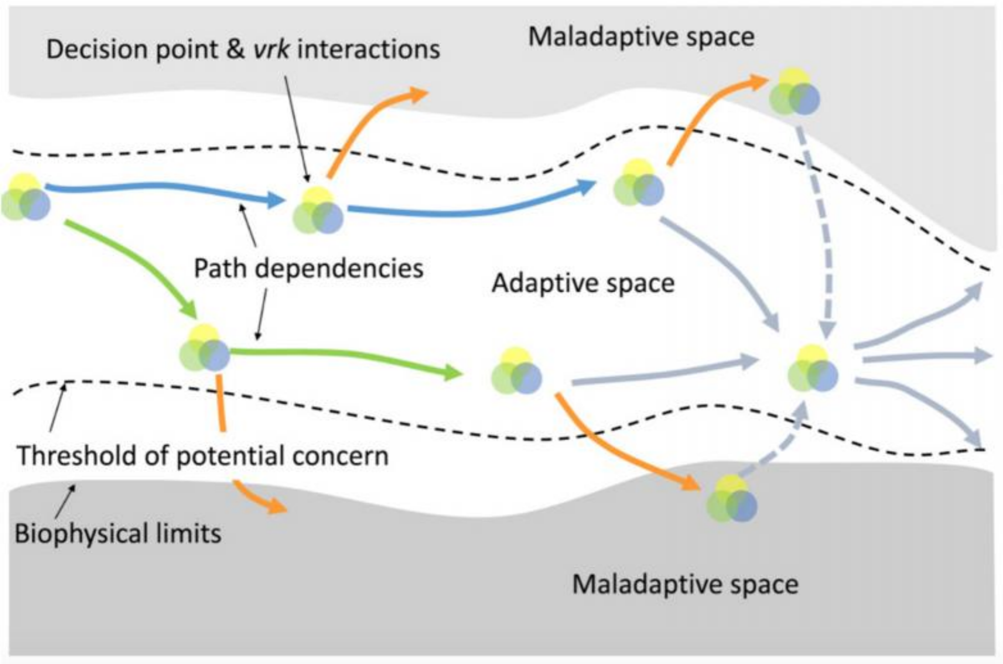
Source: Hajra and Ghosh (2018)

2:3 Adaptation to Environmental Change

In adaptation literature, the definition of 'adaptation' differs widely between authors and disciplines (Ekstrom *et al.,* 2011; Feder, 2012; Smit and Wandel, 2006). The occurrence of varying definitions means that the researcher must specify the context in which adaptation is studied (Smit *et al.,* 2000). Adaptation in this dissertation is studied in response to environmental changes in deltas. A broader definition applicable to environmental change is given by Nelson *et al.,* (2007, p 398) as "an adjustment in ecological, social, or economic systems in response to observed or expected changes in environmental stimuli and their effects and impacts in order to alleviate adverse impacts of change". This definition provides a useful starting point, as it considers adaptation in terms of the level, such as planned or autonomous, the actors involved, including private and public, and timing, such as anticipatory or reactive adaptation. Mimura *et al.,* (2010) stress the importance of the type/level/timing of adaptation, as measures taken in response to an impending impact necessitate swift short-term responses. These alleviate immediate risk, whereas forthcoming, more detrimental impacts in the long-term require more integrated, planned and anticipatory adaptive measures. It is important to recognise that adaption does not always derive from environment and climate stimuli. Tompkins *et al.,* (2009) highlight other reasons for adaptation, such as sustainable development and social responsibility.

Previously, the adaptation community had focused on predict then act approaches by studying barriers and opportunities for adaptation and providing broad and general principles for adaptation (Burch, 2010; Hallegatte, 2009). However, a requirement for more decision-orientated research, that allows decision-makers to make pressing choices in intertwined and dynamic natural and social systems, has engendered a recent reconceptualization of adaptation as an 'adaptation pathway' (Wise *et al.,* 2014). Adaptation pathways integrates two core concepts. It first draws from Smith *et al's* (2011) notion of adaptive decision-making. This frames adaptation as a pathway of timely decisions, not a one-off decision, under the assumption that one adaptive decision may not suffice in an unfolding future. Gorddard *et al's* (2016) notion of decision context is also integrated. This considers the prevailing societal values, rules and knowledge (VRK), and their interaction, that determines the context for decisions. This context then fashions and restricts what adaptive decisions are practical and permissible, which will alternate with progressively changing VRKs. Adaptation pathways accentuates decision timing and context to represent adaptation as evolutionary, in which changing decision contexts and normative behaviours may facilitate or limit future adaptive decisions (Figure 5). This importantly highlights the factors of uncertainty and learning in the process of adaptation.

Figure 5: Adaptation pathway through an adaptive landscape.



Source: CSIRO (2017)

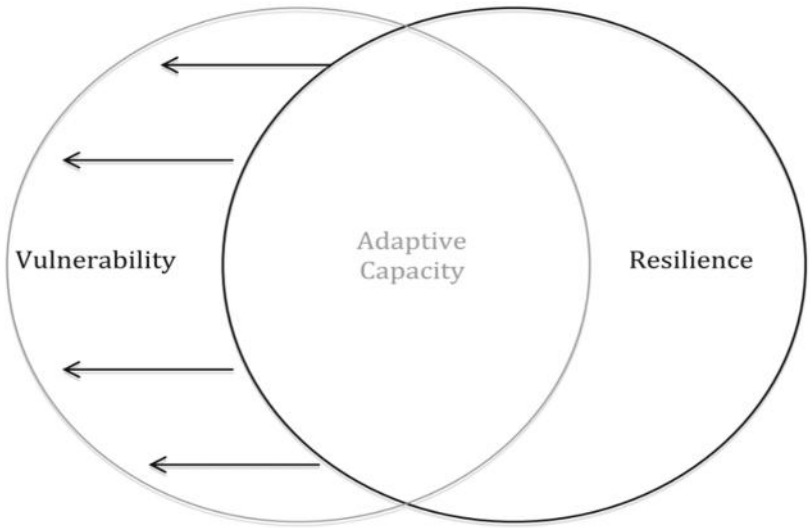
2:3:1 The Concepts of Vulnerability, Resilience and Adaptive Capacity

From an adaptation to climate change perspective, human geographers such as Pelling (2010) frame resilience as adaptive actions undertaken that seek to maintain the identity and the primary functions of a socio-ecological system. Others present resilience as an assortment of system characteristics comprising self-organisation, capacity for learning and capacity to absorb change, that facilitate the transformation and incremental adjustment of a system into a state of greater 'adaptedness' (Nelson *et al.,* 2007). When applied to Indian deltaic rice farmers, Duncan *et al.,* (2017) defined their resilience to environmental hazards as their capacity to uphold or enhance their standard of living against risk. Their findings indicated that farmers' resilience can be adversely influenced by institutional, economic and cultural contextual drivers.

In the context of climate and environmental change, vulnerability is the degree to which a system is predisposed to, and unable to manage the harmful effects deriving from climate and environmental stress (Macchi *et al.,* 2011). It is a function of a system's sensitivity, exposure and adaptive capacity (Adger, 2006). Zahran *et al* (2008) highlight two forms of vulnerability, physical and social. Physical vulnerability refers to the physical or structural properties of an environmental hazard (Ibid), whilst social vulnerability regards "the socially differentiated nature of people's capacity to cope with change" (Brown, 2016 p101). Any existing social vulnerabilities will likely be amplified by climate and environment change for the most marginalised and poorest groups (Brown, 2016). However, evidence suggests that social vulnerability is not simply linked to poverty, instead it is complex, variable and particular to time, space and social context (Brouwer and Nhassengo, 2006). The Indian Sundarbans region is physically and socially vulnerable. Physical hazards, such as cyclones and flooding, amplified by climate change and sea-level rise are frequent (Hajra *et al.,* 2017). Additionally, poor and isolated dense populations working in climate-sensitive and natural resource dependent agriculture characterise the area's high exposure, sensitivity and low adaptive capacity (Hajra and Ghosh, 2018; Danda, 2007).

There are varying perspectives on how vulnerability, resilience and adaptation are applied and understood (Janssen, 2007; Folke et al., 2002). Kaul and Thorton (2014) link vulnerability and resilience to provide attention to adaptive capacity (Figure 6). In this respect, by increasing the resilience of a system the adaptive capacity improves, which consequentially reduces vulnerability.

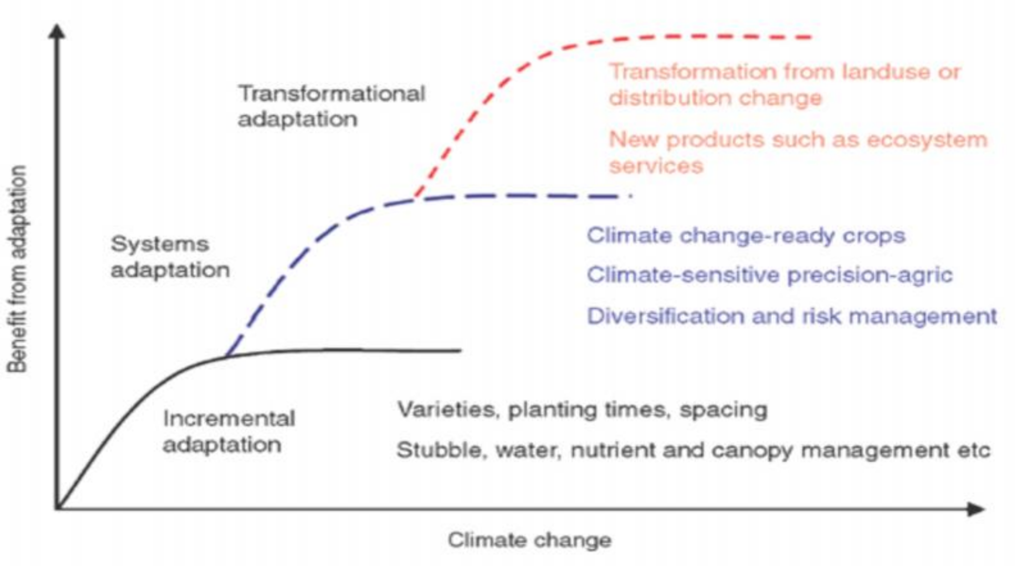
Figure 6: Resilience-Adaptive Capacity-Vulnerability Model



Source: Kaul and Thornton (2014).

Adaptive capacity is multidimensional (Vincent, 2007), and is defined as "the ability of systems, institutions, humans and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC, 2014a p118). Therefore, it is contingent upon one's flexibility, perception of change/risk, values and livelihood resources (Kolikow *et al.,* 2012). Livelihood resources are normally deemed the most influential when determining adaptive capacity in farmers' adaptive decision-making (Wall and Marzall, 2006; Bryan *et al.,* 2009). Research by Gbetibouo (2009) signified that farmers' adaptations to climate change were mostly hindered by insufficient knowledge of adaptive strategies and a lack of credit sources, water resources and market accessibility. However, a farmer's motivation is equally essential (Mertz *et al.,* 2009), and has been empirically linked to risk perception (Osberghaus *et al.,* 2010). Thus, a farmer's capacity to adapt will be influenced by their risk perception, which may vary depending on individual characteristics, and their access to livelihood resources (Kolikow *et al.,* 2012). The level of adaptive capacity largely determines the extent that a farmer can adapt, for example, transformative adaptation requires substantially more resources and willingness than systems adaptation or incremental adjustments (Richards and Howden, 2012). Figure 7 provides examples of the extent that farmers can adapt, which according to Richards and Howden (2012) depend on their adaptive capacity.

Figure 7: Levels of adaptation in agriculture



Source: Howden et al., (2010)

As poorer farmers often lack livelihood resources they generally reflect meagre adaptive capacities (Abdul-Razak and Kruse, 2017). Many farmers in the Indian and Sundarbans deltas have low adaptive capacity, owing to a multitude of interacting factors, namely: monocrop farming; declining income from agriculture; being geographically and economically marginalised; reliance on rain-fed agriculture and natural resources; a lack of access to land and technology, and illiteracy (Jain *et al.,* 2016; Singh *et al.,* 2012; Hajra and Ghosh, 2018). Further, institutions largely influence adaptive capacities through dispersions in resources (Adger *et al.,* 2007). Around the IBD, many farmers rely on government welfare, however the top-down governance often leaves gaps in supply and demand in agriculture (Jain *et al.,* 2016). No literature to the researcher's knowledge has investigated the impact of this on farmers' adaptive capacity in the IBD. As a result, this is framed as a constraint on farmers' adaptation, instead of an urgent issue that can be addressed using empirical data backing.

2:3:2 Agricultural Adaptation in Deltas

Due to deltas being sensitive and changeable from the effects of environmental change, farmers adapt to uncertainty using hard (physical) and soft (social) action approaches. According to Ngo (2016), agricultural adaptation encompasses two forms of modification, increased diversification and crop management practices. The former refers to engaging in cultivation practices that are climate tolerant and water efficient, and the latter entails activities which ensure that harsh environmental conditions do not overlap with critical growth periods by elongating growth seasons. Evidence of these modifications in deltas are apparent. Mainuddin *et al.,* (2010) reported farmers adjusting planting times and crop types to conform to changing climate routines, whilst others recorded the usages of temperature and salinity resistant crops and enhanced water efficiency methods, such as irrigation (Douven and Buurman, 2013; Uddin *et al.*, 2014). Harder adaptation approaches appeared generally less common, but were recorded in Vietnam's Mekong Delta and in Spain's Ebro Delta in the form of flood-defence barriers (Schipper *et al.,* 2010; Fatoric and Chelleri, 2012). Other common forms of adaption concerned migration and livelihood diversification, such as integrated agriculture-aquaculture (Udo, 2008). Mixing practices enables deltaic farmers to capitalise on available natural resources to align themselves with alternations in environmental, social and economic contexts (Erenstein, 2006), and to diversify their income pathways to spread risk.

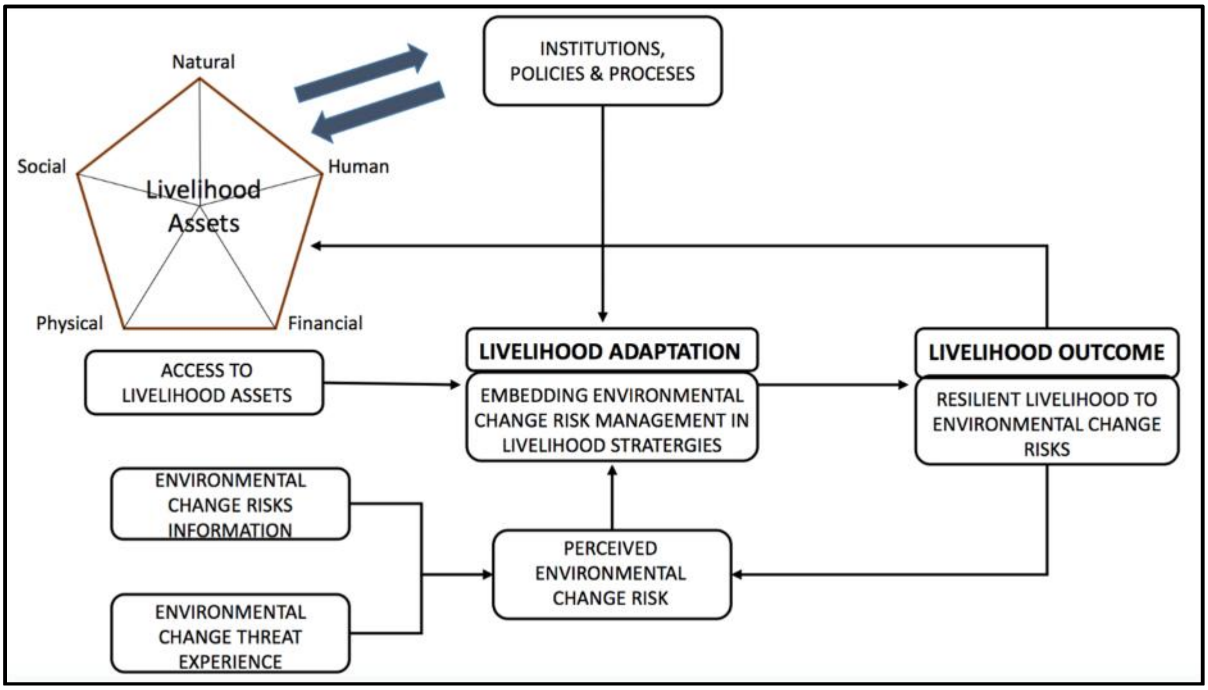
Around the IBD there is evidence of these adaptations. Hajra and Ghosh (2018) recognised an association between declining agricultural productivity and outward migration in the IBD. Jain *et al.,* (2016) mentioned that farmers in the Sundarbans would reduce investment in monocrops (paddy) and invest in inland fishing in dugout ponds as a secondary livelihood to alleviate risk from increasing soil salinity. Jain *et al.,* (2016) also reported farmers balancing agriculture with labour work, such as rebuilding infrastructure including roads, embankments, and pond reconstruction. Farmers have been found to engage in land shaping and rainwater harvesting activities (Singh *et al.,* 2012). Here ponds are excavated to a depth of 8-9 feet to harvest rainwater to enable irrigation and fish cultivation, and the excavated earth is used to elevate the farmland (Ibid). This enhances resilience to increasing salinity, flooding and drought, and allows the cultivation of different crop types. Mandal and Mandel (2012) however warns that irrigation water eventually becomes saline. Both Jain *et al.,* (2016) and Singh *et al.,* (2012) reported the intensification of chemical fertilizer as an adaptation which sustained paddy yields against rising soil salinity, though the poorer farmers were unable to afford this. The concept of organic farming was introduced for its inexpensive, sustainable and high yielding traits by NGOs (Jain *et al.,* 2016), though little research follows up the success of this in practice. Additionally, whilst the above authors simply report on adaptive practices adopted, none report on the conditions, factors or processes that enabled the adoption. This perspective is in line with Wang *et al's* (2017) critique of current adaptation research in South Asia, who state that knowledge is derived from studies that have not undertaken an empirical and systematic approach, especially regarding larger assessments of farmers' adaptations. Consequently, little is still known on the adoption of adaptive agricultural strategies in deltas (Ibid). As mentioned in chapter 1, to facilitate the up-scaling of agricultural initiatives knowledge concerning farmers' adoption of technologies is importantly required. The research gap outlined above implies that this will be challenging to operationalise, especially for the IBD, which has not been a primary focus in assessments of adaptation.

2:3:2:1 Conceptual Framework

Drawing on the above literature and those in section 2:3:1, Momtaz and Shameem's (2016) conceptual framework for livelihood adaptation to climate risk provides a useful lens to view this dissertation given the aim and research problem (Figure 8). Momtaz and Shaeem (2016) innovatively merged insights from the sustainable livelihoods approach with the cognitive factors recognised to determine adaptation behaviour (the Model of Private Proactive Adaptation to Climate Change (MPPACC)) (see Grothmann and Patt, 2005). The resulting framework can then explore how farmers, who are reliant on natural resources, insert climate risk into their livelihood routine to increase resiliency to climate stresses and shocks. Figure 8 has been adapted to incorporate the risks posed by environmental change.

The framework integrates four keys components: access to assets, perceived environment change risk, the institutional environment, and embedding risk management into livelihoods. Figure 8 recognises that a household's capability to manage environmental change risk is determined from a succession of livelihood decisions. These decisions are conditioned by the household assets and the provision of these assets in an institutional context. This translates into a household's adaptation capacity, which governs their livelihood adaptation measures to lower vulnerability to environmental changes. Momtaz and Shameem's (2016) framework recognise that livelihood adaptations are rarely isolated actions, and that adaptation is an ongoing process where households use their assets in the current institutional framework. Therefore, any environmental or non-environmental policies or institutional frameworks will have a decisive role in enabling or hampering adaptation strategies. The framework importantly addresses the cognitive factors which initiate the intention to adapt, as adaptive capacity cannot immediately convert into adaptive action (Dang *et al.,* 2012). Figure 8 represents this in both reactive adaptation, where action is adopted after experiencing environmental stress, and proactive adaptation, where measures are undertaken to avert future stress. Observably, households then begin adapting by embedding the appropriate management into livelihood activities, transforming their livelihood system. This is to endure and recuperate from environmental shocks and stresses and avoid stresses in the long-term. The framework highlights the feedback mechanisms amongst these four components, as adaptations producing advantageous outcomes can increase access to assets improving adaptive capacity (Adger *et al.,* 2007). The reduced vulnerability then adjusts people's environmental change risk perception.

Figure 8: Conceptual framework for adapting farming livelihoods to environmental change.



Source: Adapted from Momtaz and Shameem (2016).

2:3:3 Factors Influencing Farmers' Adaptation Strategies

Numerous factors, such as farm and household characteristics and access to credit, are postulated by scholars to influence the adaptive strategies adopted by farmers. Of course, there are various other influences, such as institutional, economic and social factors. Due to word limit constraints, a review into the influence on farmers' adoption of adaptations from household and farmland characteristics and access to credit will be undertaken here, as they were found to be heavily influential in comparable research conducted close to, or in a context similar to, the IBD (Sahu and Mishra, 2013; Aryal *et al.,* 2018; Uddin *et al.,* 2014). Where possible, insight from South Asian deltas and India is reviewed.

Household Characteristics

Older farmers, within a productive age range, are hypothesised to adapt more, given their farming experience and ability to assess the utility of strategies (Ibid). Works by Tekleworld *et al.,* (2006) and Khatun and Roy (2012) in Ethiopia and West Bengal, India, respectively support this.

Increasing household size typically corresponds to a greater ability to implement labour intensive adaptations inexpensively and more intensely, owing to greater labour endowment (Deressa, 2008; Denkyirah *et al.,* 2017). However, increasing household size can negatively influence on-farm adaptations, as members may seek off-farm labour to reduce consumption pressures inflicted by a large household size (Yirga, 2007). Studies in South Asian deltas mostly present evidence for the latter (Mishra and Pede, 2017; Uddin *et al.,* 2014; Nguyen-Van *et al.,* 2017). It is not uncommon for age and household size variables to be theoretical control variables in research, as they can influence adaptation, but are rarely the factors of interest.

Generally, farming households headed by men are more likely to risk change and have easier access to information regarding adaptive practices and technologies, than households headed by women (Asfaw and Admassie, 2004). Women are also hindered by social barriers making them less able to implement adaptive measures (Tenge *et al.,* 2004).

A farmer's occupation status also determines adaptive decisions. Whether farming comprises most of a farmer's employment can indicate the degree of time invested in agriculture, and in off-farm employment/activities (Addisu *et al.,* 2016). This can be mediated by household size since larger households could still provide sufficient labour (Ibid). In their study, Holden and Shiferaw (2002) found that income from off-farm employment increased on-farm adaptation, as the money was invested into farming. Others have argued that farmers earning off-farm feel more secure, and thus deem on-farm adaptations unnecessary (Oluwatusin, 2014). Works by Parganiha (2016) and Ngo (2016) in rural North India and the Mekong Delta support this, finding that farmers also in off-farm employment were negatively associated with on-farm adaptations.

Aryal *et al.,* (2018) state that a member from a farming household working elsewhere from the village enables the up-take of less labour-intensive agriculture technology, due to less labour endowment but increased access to diverse income sources. Deshingkar and Start's (2003) research suggests this, as household members undertaking farming and non-farming activities outside of Indian deltaic villages were found to return five times that normally earnt inside the village. Working outside the village also increases exposure to other farmers, which can provide additional agricultural information (Parganiha, 2016). Research in India's Gangetic Plains has indicated that farmer-to-farmer communication increases the adoption of new technology, as strategies such as stress tolerant crops were implemented more intensely (Aryal *et al.,* 2018).

A farmer's education level can largely determine the adoption of adaptive strategies (Addisu *et al.,* 2016). More educated farmers are able to receive, interpret and understand information concerning improved agricultural technologies and possible yield outputs (Deressa, 2008). Research by Meghwal *et al.,* (2017), Arumugam *et al.,* (2014) and Chen *et al.,* (2018) found that the adoption of multiple adaptation strategies, such as crop diversification, climate tolerant crops, and the intensification of adaptation was positively influenced by increasing education levels in Indian and deltaic farmers.

Farm Characteristics

Farmland size generally has two main influences on adaptation. First, increasing farmland size is normally associated with an increased adoption of adaptation strategies, as lack of land can be a barrier (Bryan *et al.,* 2009). Secondly, larger farmland sizes are often indicative of higher wealth and increased financial capacity, allowing farmers to adopt a range of agricultural technology (Knowler and Bradshaw, 2007). The resulting more mechanized farms are hypothesised to increase the adoption of alternating crop types, climate tolerant crops and irrigation (Boansi *et al.,* 2017; Nhemachena *et al.,* 2014). However, Deressa (2008) points out that the influence of increasing farmland size on adaptation is inconclusive, as associations are not always consistently positive, suggesting that contextual explanations are likely needed. Further, evidence shows that ownership type influences how farmers perceive risk (Maddison, 2007). Copious studies have reported that farmers owning land had a higher tendency to invest more in adaptation, and adapt more intensely than non-owners (Nhemachena and Hassan, 2007; Deressa *et al.,* 2009; Yameogo *et al.,* 2018).

Literature states that the availability of farm implements/equipment, such as power tillas, pumps and ploughs amongst others are a prime necessity to operationalise timely adaptive practices in response to climatic and environmental change (Parganiha, 2016). Without accessible implements at the farm-level, a farmer's capability to adapt to climate and environment change is considerably constrained (Abid *et al.,* 2015). Recent works by Sarah *et al.,* (2017) reinforce this theory, as having access to farming equipment was found to increase the likelihood of a farmer adapting to climate change by over 700%.

Access to Credit

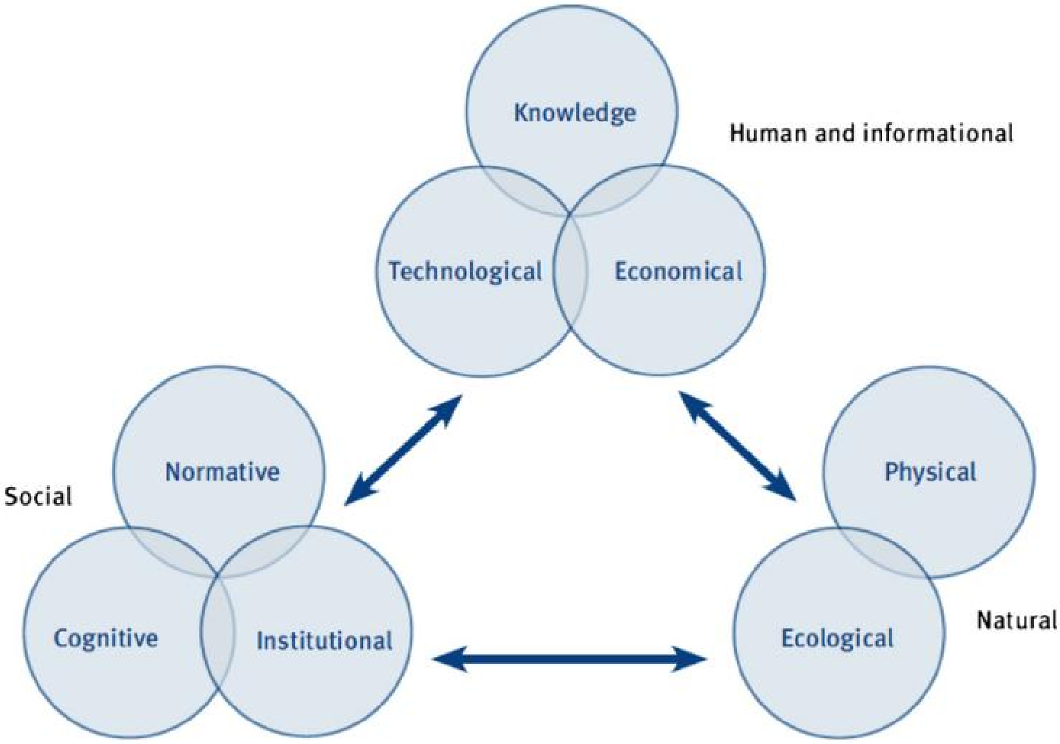
Theoretically, inaccessibility to credit can be a constraint to adaptation (Maddison, 2007). Credit access permits farmers to gain new technologies and purchase inputs, such as irrigation facilities and new crop varieties, as financial constraints are eased (Deressa, 2008; Fosu-Mensah *et al.,* 2012). Yameogo *et al.,* (2018) state that smallholder farmers receive credit access which enables affordable adaptation in two ways; 1) informally through loans from neighbours and friends, 2) formally through farmer associations or bank loans. In West Bengal, India and other South Asian deltas, having access to credit generally positively influences the adoption of adaptive agricultural technology (see Khatun and Roy, 2012; Ngo, 2016; Sahu and Mishra, 2013; Aryal *et al.,* 2018), supporting the overarching hypothesis.

2:4 Adaptation Barriers

Adaptation limits and constraints are commonly used interchangeably, but each are defined differently. Limits are "the point at which an actor's objective or a system's needs cannot be secured from intolerable risks through adaptive actions" (IPCC, 2014c p907), whereas constraints are "factors that make it harder to plan and implement adaptation actions" (Ibid). Constraints are normally referred to as barriers, and can be overcome with concentrated effort and management (Moser and Ekstrom, 2010). In their systematic literature review Biesbroek *et al.,* (2013) noted that studies of adaptation barriers were more geared towards coastal zones and water sectors, with minimal reference to agriculture. Further, farmers' understanding of barriers is restricted, and since barriers will hinder farmer's' adaptive capacity an improved comprehension of barriers is needed to enable effective adaptation (Masud *et al.,* 2017), especially for vulnerable deltaic farmers. In reference to the above research gap, and that barriers can be addressed given sufficient attention and management, this dissertation chooses to focus on adaptation barriers (research objective 5). Therefore, emphasis will be placed here rather than on limits.

As adaptation barriers are context-dependent due to different communities, regions and actors, there are various frameworks offered in literature (Moser and Ekstrom, 2010; Lorenzoni *et al.,* 2009). The general consensus suggests that barriers stretch across natural, economic and social factors, as depicted in Masud *et al's* (2017) agricultural adaptation study. Jones and Boyd (2011) provide a broad model that involves categorising the adaptation barriers into three discrete groups, and their relationships (Figure 9). This is useful as barriers rarely act in isolation, and the interaction between multiple barriers can considerably hinder the variety of adaptive options, and in cases create maladaptation (IPCC, 2014c).

Figure 9: Barriers to Adaptation and their connections



Source: Jones and Boyd (2011).

Natural barriers integrate ecological and physical constraints. These are extensive in scope and practice, and restrict what adaptations are contextually feasible. For example, temperature increases in the physical environment will likely necessitate greater effort for adaptation than some have the capacity to generate (IPCC, 2014c). Also, dispersions of water resources and physical soil conditions will influence the range of viable agricultural activities, such as irrigation (Hanjra and Qureshi, 2010), and subsequently the capacity of the system to adapt (Kato *et al.,* 2011). Ecosystem thresholds are closely tied to natural barriers, and relative sea-level rise in deltas may create critical thresholds from which ecosystems can no longer support agricultural systems to facilitate adaptation (Jones and Boyd, 2011). Other relevant ecological barriers concern pests and diseases. These interrelate with the physical environment because temperature rise increases incidences of crop pests and disease outbreaks, reducing the effectiveness of control mechanisms (Hellman *et al.,* 2008), including pesticides.

Social barriers, regarding the "social and cultural processes that govern how individuals respond" (Jones and Boyd, 2011 p1263), have more recent scholarly focus (Kolikow *et al.,* 2012). Social barriers usually indicate how society is structured, implying that they change gradually, and mainly function at the individual decision-making level (Hulme *et al.,* 2007). They are associated with pre-existing societal values, cultural norms, views and behaviours that influence risk perception and rational adaptive decision-making (O'Brien, 2009). Therefore, specific barriers may entail cultural or normative beliefs preventing the implementation of sustainable adaptive action.

Nielsen and Reenberg (2013) found that pastoral farmers in Burkina Faso would not adopt livelihood diversification due to their tribe identity and personal integrity. Institutional capacity can also hinder the adaptation process, as it relates to the degree of prioritisation of adaptation in policy against other values (Berkhout, 2012). This is fundamental for building capacity for farmers to adapt, however corruption within institutions can constrain adaptation as Schilling *et al.,* (2012) indicates. Also, the IPCC (2014c) stress that the actors of NGOs, market actors, community agriculture organisations and governments within governance networks must be well coordinated to operationalise common adaptation objectives. Without doing so, collective action and therefore adaptation implementation is inhibited.

Constraints in human and informational resources can have connotations for monitoring, forecasting and the tailoring of suitable adaptation measures (Jones and Boyd, 2011). This barrier typology is more frequent in agricultural literature, due to adaptations normally requiring financial resources, agricultural technology and knowledge for implementation. Emphasis in studies is commonly on the former (Hassan and Nhemachena, 2008). According to Shardul and Samuel (2008), farmers will only actively implement the adaptation if the perceived benefits exceed the resources, costs and efforts required. Actively adapting may be further constrained by competing values and trade-offs with other pressing needs, such as healthcare (IPCC, 2014c), and when financial resources are scarce other needs may take precedence. Literature indicating how knowledge is acquired, distributed and used determines whether the information constrains or enables adaptation (Moser, 2010a,b). This is an important consideration for educating farmers who may usually opt for using familiar but unsuitable traditional knowledge to inform active measures (Jones and Boyd, 2011). Without sufficient education on climate and environment change, and how to adapt pertinently, farmers may not be capable of managing the environment's negative impacts effectively (Masud *et al.,* 2017). Regarding agricultural technology, the IPCC (2014c) emphasises that technology must be accessible for farmers to operate, fund and maintain. Studies have suggested that adequate market access, finance and the exchange of information is required in order to sufficiently employ agricultural technology for effective use and benefits (Deressa, 2009; Isham, 2002; Hassan and Nhemachena, 2008).

In contrast to the above conceptualisations of barriers, Biesbroek *et al.,* (2015) presents an alternate stance. They critique barrier thinking by contending that categorizing processes and factors into barriers prevents the explanation of the causes responsible for an effect, as dynamic and complex decision-making processes are heavily simplified. Biesbroek *et al.,* (2015) blames incongruities between academic frameworks and practical reality, on current barrier thinking. Alternatively, they advocate adopting more policy and various top-down and bottom-up based thinking to enable more tailored interventions as something to consider. This is an argument to reflect on during the analysis of the barriers found in this study.

2:5 Summary/Gap

This chapter has illustrated that copious amounts of literature exists on adaptation by farmers to climate and environment change. However, research gaps still exist regarding empirical assessments of a systematic nature of farmers' adaptations undertaken to environment change in South Asian Deltas (Wang *et al.,* 2017). This was apparent, as the literature did not sufficiently uncover the complex and context-specific features facilitating the uptake and process of adaptation for farmers in the IBD delta targeted (Hinkel, 2011). For instance, it was not known the extent of the impacts on farmers' adaptability from gaps in supply and demand, which stemmed from improper governance approaches. This reinforces Masud *et al's* (2017) perspective and Biesbroek *et al's* (2013) works, which suggests that barriers influencing farmers' adaptations is an understudied topic. These are important gaps to address if the up-scaling of tailored interventions are to be efficaciously implemented.

Chapter 3 Research Methodology

3:1 Overview of Mixed-methods Approach

3:1:1 Rationale

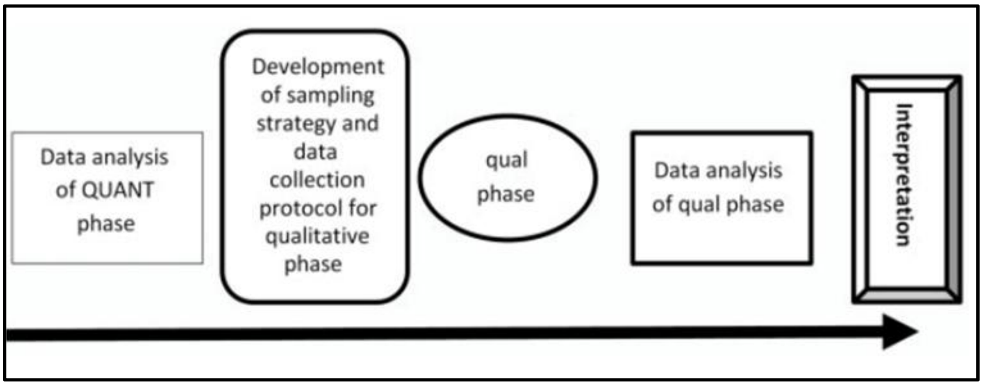
A mixed-methods approach was used to address the research objectives and identified knowledge gaps. The justifications for this are threefold: First, understanding the complex phenomena that are farmers' adaptive decisions is not straightforward (Le Dang, 2014). Mixed-methods allow the researcher to achieve comprehensive findings and understanding from complex research issues (O'Cathain *et al.,* 2007), such as the process of adapting. Quantitative methods can outline the social structures and associations between environmental change and adaptation, then the qualitative methods can explain the embedded processes (Bryman, 2017). Second, the 'completeness' and 'enhancement' of findings (Bryman, 2006) that mixed-methods provide will support addressing the identified absence of empirical and systematic studies of adaptation in South Asia's deltas (Wang *et al.,* 2017). The conclusive assertions made will be well received by decision-makers, such as those in INAPCC, as the objective quantitative findings integrated with the contextual findings from farmers are reported. Third, the appropriate application of quantitative and qualitative methods in amalgamation can minimise each method's weaknesses. Quantitative methods permit greater generalisation of findings (McKim, 2017), which is more constrained in qualitative research, and is useful for assessing adaptation across the IBD. Alternatively, qualitative research allows the contextualised documentation of how a process occurs, and enables the researcher to understand why respondents make certain decisions (Denzin and Lincoln, 2008). Therefore, including qualitative methods is pertinent for comprehending how crop farmers think in the process of adaptation.

3:1:2 Design

This dissertation used an explanatory sequential mixed-methods design where the qualitative phase succeeded the quantitative phase (see figure 10). This design provides contextual explanation and elaboration of the quantitative findings by subsequently using qualitative methods (Creswell *et al.,* 2003), and in turn providing dependable results (Shenton, 2004). Specifically, the quantitative analysis generates an understanding of the research problem, before the qualitative methods refine and explain the quantitative findings by exploring participant's perceptions in greater depth (Ivankova *et al.,* 2006). This dissertation applied this by analysing a quantitative-based household survey using descriptive statistics and regressions to outline the context of the research topic, and the factors influencing adaptation. In-depth interviews conducted in Dulki and Sonagar then explored these results further to understand the processes behind the factors influencing farmers' adoption of adaptive strategies.

The mixing of methods can transpire through merging and connecting (Creswell and Plano Clark, 2011). This dissertation connected the methods using the sampling frame as interviewee characteristics - IBD household head crop farmers - resembled those analysed in the survey. Integration through building occurred by 'development' reasoning (see Bryman, 2006 p105), as the quantitative associations under scrutiny grounded parts of the interview agenda. Development reasoning "uses the results from one method to help develop or inform the other method" (Greene *et al.,* 1989 p259). Findings regarding research objectives 3 and 4 will be reported through a 'weaving approach' identical to Classen *et al.,* (2007), where the quantitative and qualitative results are presented theme-by-theme. The rest of the findings are reported separately, which is more common in mixed-methods research (Doyle *et al.,* 2016). In this study, the qualitative methods take precedence, due to the depth required to understand decision-making processes.

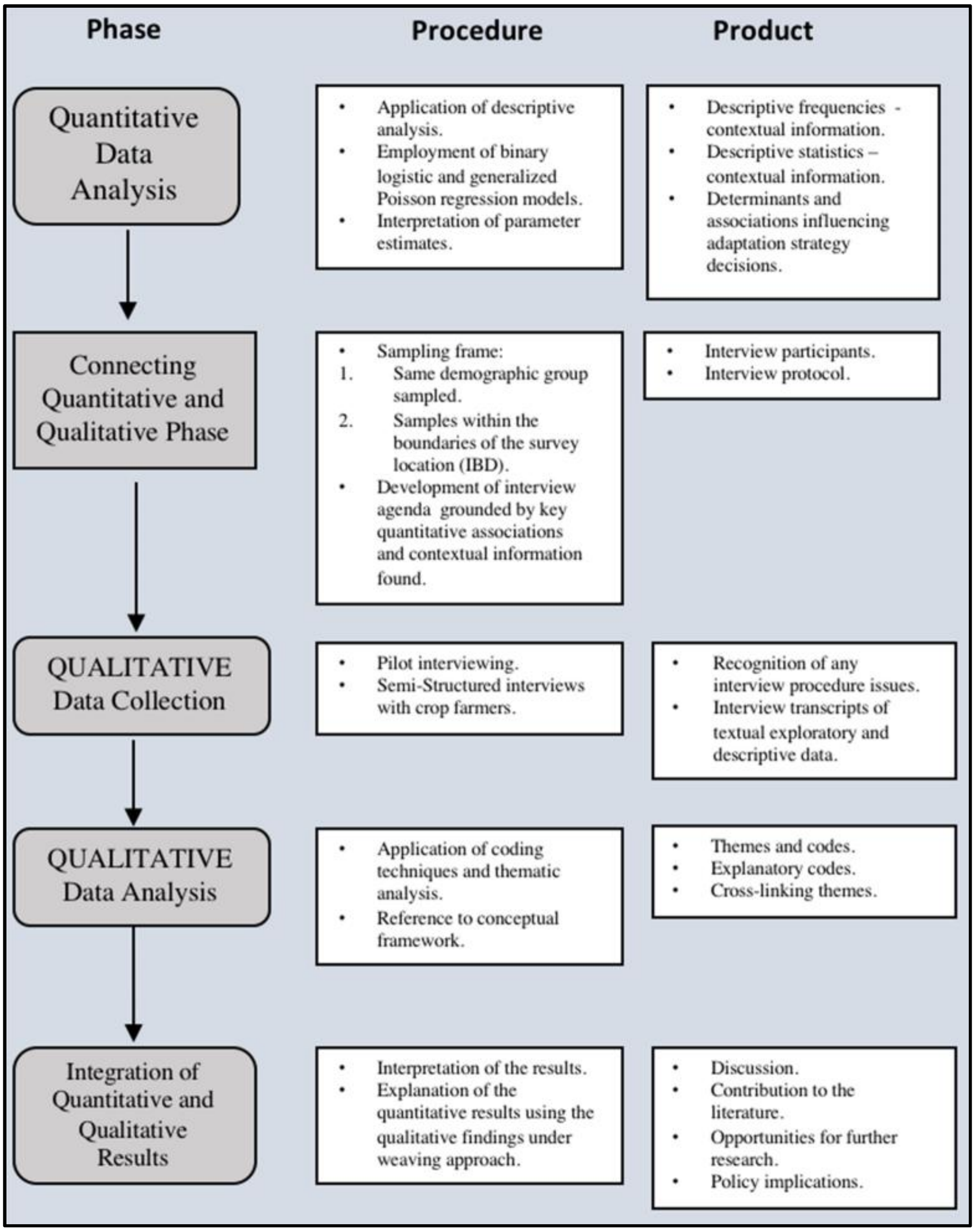
Figure 10: Explanatory sequential design.



Source: Adapted from Doyle et al., (2016) to omit quantitative data collection as was not applicable.

A graphical illustration helps the researcher envision the order of data collection, the connection of different methodologies and the precedence of either method when using multi-staged mixed-methods (Ivankova *et al.,* 2006). Figure 11 represents the visual model employed using the ten rules for developing visual mixed-methods models (see Ivankova *et al.,* 2006 p15 for rule description).

Figure 11: Visual model for explanatory sequential design procedures.



Source: Author

3:2 Quantitative Analysis

The Statistical Package for Social Sciences (SPSS) was employed for analysing the quantitative data. The IBD household survey, yet to be published, was collected by DECCMA from December 2016 to February 2017. The survey undertook a two-stage cluster sampling design, where 5 multi-hazard zones were developed in order to select 1500 households across 30 locations using proportional cluster sampling. The sampling was informed by demographic and migration characteristics, and gave a relatively representative sample of the IBD. The main survey themes were migration, environment change, and household adaptation strategies. This dissertation used the responses from 177 households' due to the applied focus on households headed by crop farmers, as household-heads normally make the livelihood decisions in rural West Bengal (Khatun and Roy, 2012). Using the survey, this dissertation employed regression analysis (detailed below) and descriptive statistics charts. These charts depicted contextual information relating to the perceived environmental changes, the adaptation strategies adopted and the main barriers to adaptation.

3:2:1 Analytical Framework

This dissertation uses two types of empirical models, binary logit and generalised Poisson, to analyse what determines the specific adaptation strategies farmers' use and the intensity of adaptation. This was tested using a set of independent variables as explanatory predictors (shown below).

- X_1 =Age
- X_2 =Employment Status
- X_3 =Household Size
- X_4 =Household Head Education
- X_5 =Land Size
- X_6 =Work Outside Village
- X_7 =Loan
- X_8 =Equipment

Variable selection was informed by section 2:3:3's literature, however gender was omitted as females were underrepresented in the sample used. The adaptations representing the dependent variables are; increased fertilizer usage, irrigation, climate tolerant crops, crop diversification and number of adaptations practiced. These adaptations in the survey were deemed the most relevant to crop farmers and the research topic. Table 3 presents the descriptive statistics for these dependent and independent variables.

As the Poisson model was not developed until after the fieldwork, only variables X_1- X_5 were used to try and allow for sufficient explanation for the intensity of adaptation from the data already collected.

Table 3: Descriptive frequencies of independent and dependent variables.

	Frequency (N) Valid Percent		Mean (2 d.p)	S.D. (2 d.p)	Variable Descriptions	Expected Sign
Dependent Variables						
Fertilizer Usage	(131) 74%		0.74	0.44	1 If Fertilizer usage has been increased, 0 if not	
Irrigation	(96) 54.2%		0.54	0.5	1 If irrigation has been implemented, 0 if not	
Climate Tolerant Crops	(49) 27.7%		0.28	0.49	1 If climate tolerant crops have been planted, 0 if not	
Crop Diversification	(56) 31.6%		0.32	0.47	1 If crop diversification has been used, 0 if not	
N of Adaptations	0 (24) 13.66% 1 (45) 25.42% 2 (56) 36.64% 3 (33) 18.64% 4 (19) 10.73%		1.88	1.18	Count Variable, Number of adaptations between 0-4 from the adaptations above.	
Employment Status – Categorical Response (Dummy)						
Permanent	(66) 37.3%		1.88	0.78	0 – Household head is a crop farmer year-round.	Ref
Seasonal	(68) 38.4%				1 – Household head only farms during the growing season.	-
Short-Term	(43) 24.3%				2 – Household head works as an agricultural labourer on another person's land for wages in money or produce share.	-
Education – Categorical Response (Dummy)						
No Schooling	(39) 22%		1.12	0.77	0 - Household head has received no school education.	Ref
Primary	(70) 39.5%				1 - Household head has received between 1 – 6 years of primary school education.	+
Secondary and above	(68) 38.4%				2 - Household head has received 1 year of secondary school education or higher such as university.	+
Land Size – Categorical Ordinal Variable (Dummy)						
Small	(38) 21.5%		0.96	0.66	0 - Size of the land cultivated is between 0 - 0.1 hectares.	Ref
Moderate	(105) 59.3%				1 - Size of the land cultivated is between 0.101 - 0.5 hectares.	+
Large	(34) 19.2%				2 - Size of the land cultivated is above 0.5 hectares.	+
Working Outside Village – Binary Categorical Response (Dummy)						
No	(143) 80.8%		0.18	0.39	0 - Have not sent a household member to work outside the village in the last 5 years.	Ref
Yes	(34) 19.2%				1 - Have sent a household member to work outside the village in the last 5 years.	+
Loan – Binary Categorical Response (Dummy)						
No	(70) 39.5%		0.58	0.49	0 - Have not taken out a loan in the last 5 years.	Ref
Yes	(107) 60.5%				1 - Have taken a loan out in the last 5 years.	+
Farming/Fishing Equipment – Binary Categorical Response (Dummy)						
No	(137) 77.4%		0.23	0.42	0 - Have not purchased farming or fishing equipment in the last 5 years.	Ref
Yes	(40) 22.6%				1 - Have purchased farming or fishing equipment in the last 5 years.	+
	Min	**Max**	**Mean**	**S.D.**	**Variable description**	
Age	21	90	47.75	1.66	Continuous - Age of the household head in years.	+
Household Size	1	14	4.12	12.32	Continuous - The number of members living in the household at the time of surveying.	+/-

3:2:1:2 Empirical Models

Binary Logistic Regression

Logit models are frequently used in the analysis of agricultural practice adoption research (Deressa, 2008). For example, Abah *et al.,* (2016) and Tun Oo *et al.,* (2017) both employed logit models to analyse which factors determined the adaptive decisions by farmers in Nigeria and Burma respectively. This indicates that logit models are suitable for understanding what influences deltaic farmers adoption of adaptation strategies (Research Objective 3). Logit models use a general logit transformation that is the logarithm of the odds of an outcome comparative to a reference category (Koch *et al.,* 2000). As this dissertation is investigating what determines the adoption of an adaptation strategy, a binary logistic regression (BLR) model is apt. BLR analyses the association between a binary dependent variable, when the outcome is 0 or 1, and one or more independent variables. Equation 1, from Gadédjisso-Tossou (2015 p1443), shows a BLR where P_i represents the likelihood of performing the adaptation, and X_i represents the independent variable. Therefore, the parameter ${}_i$ represents the log odds of the binary dependent variable and ${}_0$ is the constant.

$$log(P_i/(1-P_i)) = log(P_i)= {}_0+ {}_1X_i \quad (1)$$

The independent variables were entered into the models simultaneously, because the stepwise method can remove important theoretical control variables (Antonakis and Dietz, 2011). The models use control variables in age and household size. However, elements of the stepwise method were used to remove predictors that constrained the model fit. This was not to gain the most parsimonious model, but to ensure that model fits were sufficient to give reliable results. Model fits were assessed using the Nagelkerke R^2 value, which shows the variation in the dependent variable explained, and the Hosmer and Lemeshow and Likelihood Ratio test p-values. The Likelihood Ratio test indicates if the independent variables improved the model fit over the constant model, where the H_0 is that there is no difference between the models, and the H_a is that there is. Therefore, model Likelihood ratio (Wald Chi-square) p-values denoted as significant will indicate a significantly improved model fit. The Hosmer and Lemeshow test assesses the model's goodness-of-fit to the data (Hosmer *et al.,* 2013), where the H_0 is that the model fits well, and the H_a is that the model does not. Thus, any model Hosmer and Lemeshow p-values above the level of significance indicate a good model fit, suggesting the results are reliable. To maintain consistency with comparable studies (Boansi *et al.,* 2017), the level of significance adopted throughout this dissertation is denoted by p-values under 0.1. After considering the above points, the final BLR models are:

Model 1

The probability of a farmer increasing fertilizer usage where P_i = increased fertilizer usage (0= Not Increased, 1= Increased):

$$log(P_i)= {}_0 + {}_1X_1 + {}_2X_2 + {}_3X_3 + {}_4X_4 + {}_5X_5 + {}_6X_6 + U \tag{2}$$

Model 2

The probability of a farmer implementing irrigation where P_i = inputted irrigation (0= Not inputted, 1= inputted):

$$log(P_i)= {}_0 + {}_1X_1 + {}_2X_2 + {}_3X_3 + {}_4X_4 + {}_5X_5 + {}_7X_7 + {}_8X_8 + U \tag{3}$$

Model 3

The probability of a farmer planting CTC where P_i = planted CTC (0= Not planted, 1= planted):

$$log(P_i)= {}_0 + {}_1X_1 + {}_2X_2 + {}_3X_3 + {}_4X_4 + {}_5X_5 + {}_6X_6 + U \tag{4}$$

Model 4

The probability of a farmer diversifying their crops where P_i = diversified crops (0= Not diversified, 1= diversified):

$$log(P_i)= {}_0 + {}_1X_1 + {}_2X_2 + {}_3X_3 + {}_4X_4 + {}_5X_5 + {}_7X_7 + U \tag{5}$$

**Note U=Error Term*

The categorical dummy variables of X_2, X_4 and X_5 comprise two different regression parameters. These will be interpreted individually against the reference category in the models. For example, X_5 (land size) is made of two different parameters, moderate and large. Their parameters will be interpreted against small land size (reference category). This interpretation applies to all regression models used in this dissertation.

Assumptions

Sufficient data from all categorical combinations (cells) between the independent and dependent variables is needed in BLR. The expected frequencies in each cell must exceed 1, and no more than 20% can be less than 5 (Field, 2009). This was tested using cross tabulations, and it indicated that the boundaries of the categorical land size variable required reworking. The Box and Tidwell (1962) test checked for the assumption of linearity, multicollinearity was tested using variance inflation factor (VIF) values (Myers, 1990) and Cook's distance and residual plots tested for outliers. From these tests 2 outliers were removed from models 1 and 4.

A small sample may engender model problems (see Peduzzi *et al.,* 1996), and so Vittinghoff and McCulloch (2007) recommend that at least 5 events per variable (EPV) is prerequisite for logistic regression. The EPV only corresponds to events, for example there are 96 events of inputting irrigation, and 81 of not inputting irrigation. Since 81 is the fewest, this permits for 16 predictors (81/5 = 16.2). Given that the sample used is relatively small (N=177), the 5 EPV rule was applied.

Interpretation

The determinants of whether the adaptation strategy was adopted were analysed using the Wald test p-values and the predictor regression coefficients. Logit models also report the odds ratios, which are the exponential of the regression parameter. When used with adaptation as the dependent variable, odds ratios are defined as "the expected change in the probability of a particular adaptation strategy or method due to a unit change in an independent variable" (Tun Oo *et al.,* 2017 p47). Therefore, the odds ratios are also interpreted as an intuitive analysis of the explanatory effects.

Generalized Poisson Regression

As a result of experiencing environmental stresses and shocks, farmers often adopt combinations of diverse adaptation strategies to maintain high yields and income. For instance, a farmer may be exposed to drought and increasing soil salinity simultaneously, and this may require diverse adaptation strategies. In the survey, the number of adaptations undertaken can be measured as counts with positive integers. This means a Poisson model can be employed. In studies the Poisson regression model has been applied to analyse the factors which condition the intensity of which farmers adapt (Ramirez and Shultz, 2000; Yameogo *et al.,* 2018). This suggests that using Poisson regression is a useful analytical method for addressing research objective 3 (see table 1).

Poisson models assume equi-dispersion, which means that the data mean and variance are equal, although this is often unrealistic (Cameron and Trivedi, 2005). Furthermore, when the number of outcomes is relatively small, like with the survey data, this can incorrectly lead to a negative number of events predicted (Gagnon *et al.,* 2008). To address the above issues, it is suggested to generalize the Poisson model using a generalized linear model (GLM) (McCullagh and Nelder, 1989; Harris *et al.,* 2012). A GLM relaxes the equi-dispersion assumption, and is capable of adjusting regression models to non-normal distributions, including the Poisson distribution (Gagnon *et al.,* 2008). Therefore, a generalized Poisson regression (GPR) model was used to analyse the number of adaptation strategies practiced.

Rodriguez (2007 p450) states that the GPR model can be given as:

$$\text{Log}(«_i) = \chi_i' \tag{6}$$

Where $«_i$ is the predicted number/count, χ_I are the explanatory variables and is the regression coefficient which indicates the expected change in the log of the mean for each unit change in the predictor (Ibid). By applying the exponential function (exp) to the parameter estimates the expected level of adaptation strategies practiced can be predicted (Pedzisa *et al.,* 2015).

The independent variables were inserted into the model concurrently rather than using the stepwise method to ensure that control variables were not omitted. Given equation 6, the GPR analysis applied is:

Model 5

The predicted number of adaptive strategies, where $«_i$ represents number of adaptations (N 0-4):

$$\text{Log}(«_i) = \ _0 + \chi_{1i}' \ _1 + \chi_{2i}' \ _2 + \chi_{3i}' \ _3 + \chi_{4i}' \ _4 + \chi_{5i}' \ _5 \tag{8}$$

Model Fit and Assumptions

The Pearson Chi-square and Deviance mean divided by the degrees of freedom values (Value/df) indicate the model fit. A good fit is depicted by values close to 1. Excessively low values indicate under-dispersion, and overly high values indicate over-dispersion (Gagnon *et al.,* 2008). After acquiring these value/df values it was necessary to check the model estimates, as slight under-dispersion was detected, implying that the mean exceeded the variance. Model checks were carried out by sequentially removing 2 farmers at random from the sample in the count with the highest frequency. By doing this the sample variance increases. The parameter estimates were constantly checked to detect any notable change. This procedure continued until the df/value values became closer to 1. There were no major parameter estimates changes, suggesting that the original model can be used.

Interpretation

In analysing the determinants, the same approach undertaken with BLR was employed. However, in the case of GPR the level of the predictor significance corresponds to the Wald Chi-square p-value.

3:3 Qualitative Data Collection and Analysis

3:3:1 Case Study Design

As aforementioned, this dissertation employed a case study design for the qualitative methodology using two IBD villages. A case study approach is justified as it encapsulates environmental change phenomena in its real-world context (Bennet and Elma, 2007), and allows empirical investigation into research areas where present knowledge is lacking (Eisenhardt, 1989), which the literature gaps implied.

When using case study research, the 'case' studied must be defined (Yin, 2012). A case is "a bounded entity (a person, behavioural condition, event or other social phenomenon)" (Ibid p6), which act as the unit of analysis. Therefore, the 'case' studied regards crop farmer's adaptive behaviours. The case study type adopted was a holistic multiple-case design (see Yin, 2012 p8), which in this dissertation entailed surveying farmers' adaptations in different village contexts. This draws more comprehensive conclusions from the villages as a whole, enhancing the transferability of findings (Shenton, 2004), and finding confidence through replication (Bengtsson, 1999).

3:3:2 Interview Sampling

A village survey, gathered by Jadapvur University, provided the household characteristics information informing this design. Due to time constraints, a combination of non-probability purposive and convenience sampling was employed. Purposive sampling is purposely selecting participants who are representative of characteristics relevant in the study (Etikan *et al.,* 2016). A drawback is the bias element, however this technique certified that the farmers interviewed covered varying characteristics, such as employment type and age. This enabled the research to acquire explanation for the influence of characteristic factors initially found to influence adaptive decisions. This also allowed the documentation of a diversity of views, which complements Dervin's (1983) theory of 'circling reality' that suggests a variance of perspectives is required for a holistic understanding of reality. However, no female household-head farmers were sampled as they were rare. Convenience sampling, which samples more accessible people within a geographic context (Etikan *et al.,* 2016), was used as supplementary. This entailed interviewing farmers still relevant to this study, who were more immediately accessibility. Overall, 16 participants across 3 communities in 2 villages were interviewed (see table 4). This is adequate as the case study did not seek to achieve representativeness, but intended to gather in-depth responses from a diversity of farmers. The participants IDs in table 4 were used when using direct interviewee accounts. A more detailed participant profile is in appendix 1.

Table 4: List of Participants

Participant I.D.	Gender	Age	Location	Employment
1 (pilot)	Male	40	Aripara	Permanent
2 (pilot)	Male	51	Aripara	Short-Term
3	Male	60	Morolpara	Permanent
4	Male	45	Morolpara	Permanent
5	Male	60	Morolpara	Seasonal
6	Male	80	Aripara	Seasonal
7	Male	50	Aripara	Short-Term
8	Male	45	Aripara	Seasonal
9	Male	60	Aripara	Permanent
10	Male	34	Aripara	Seasonal
11	Male	50	Aripara	Permanent
12	Male	53	Sonagar	Permanent
13	Male	50	Sonagar	Short-Term
14	Male	42	Sonagar	Permanent
15	Male	30	Sonagar	Permanent
16	Male	65	Sonagar	Seasonal

3:3:3 Data Collection

Semi-structured interviews were employed for data collection for their utility in gathering insightful data on perceptions and experiences (Blanford, 2013). They allow some structure based on the pre-determined agenda, but work flexibly to collect unexpected narratives and descriptions (Brinkmann, 2014). Semi-structured interviews enable respondents to convey responses in their own terms, which is useful for providing insight into how phenomenon is perceived and eliciting aspects of human behaviour (Qu and Dumay, 2011). This is advantageous to understanding farmers risk perceptions and adaptive behaviours.

Semi-structured interviewing recorded data on the pre-determined themes of farmers' own perceived and experienced risk from environmental change, adaptive responses adopted in response to risk and factors that prevented them adapting. The interview's structured element permitted the tailoring of questions towards the quantitative findings, which was useful for assessing responses between different characteristic groups. Simultaneously, the flexibility allowed for follow-up questions to probe for explanation when it became relevant during the interview, so that applicable contextual information was supplied. Access to the participants was gained using a village gatekeeper to appear less like an outsider, and enable an establishment of trust (Aktinson and Flunt, 2001). This helped develop researcher-participant rapport (Shenton, 2004), increasing participants willingness to share their experiences and perceptions. The interviews were conducted informally using a translator, and took place in the respondent's homes to ease the participant and help equalise the researcher-participant power dynamic (Willis, 2006). Interviews normally lasted 45 minutes, and were audio recorded with the participant's permission. Additionally, the participant's body languages could be noted to capture the nuances of their response expressions, adding to finding depth (Qu and Dummy, 2011). Observations of material assets were also noted to indicate the farmers' relative wealth. Sometimes education could not be accurately recalled, and therefore proxy indicators were used, for example owning books in English.

The translator was trained beforehand by practising interview scenarios, which acquainted him with the interview structure and research objectives. The training focused on prompt use, fully translating responses, follow-up questions and behaviour e.g. body language and tones. The latter is important, as in a cross-cultural context any researcher positionality influences can be exacerbated by the translator (Twyman *et al.,* 1999). The training also ensured that questions were translatable and intelligible for farmers. Two pilot interviews were conducted, which evaluates whether the data collection process was realistic and viable (Van Teijlingen and Hundley, 2001), and to assess the translator's qualitative skills. The resulting amendments regarded re-phrasing some leading questions, and requesting more immediate translation to facilitate follow-up questions. Once all the interviews were transcribed, the pilot interview content was deemed sufficient for inclusion in the analysis.

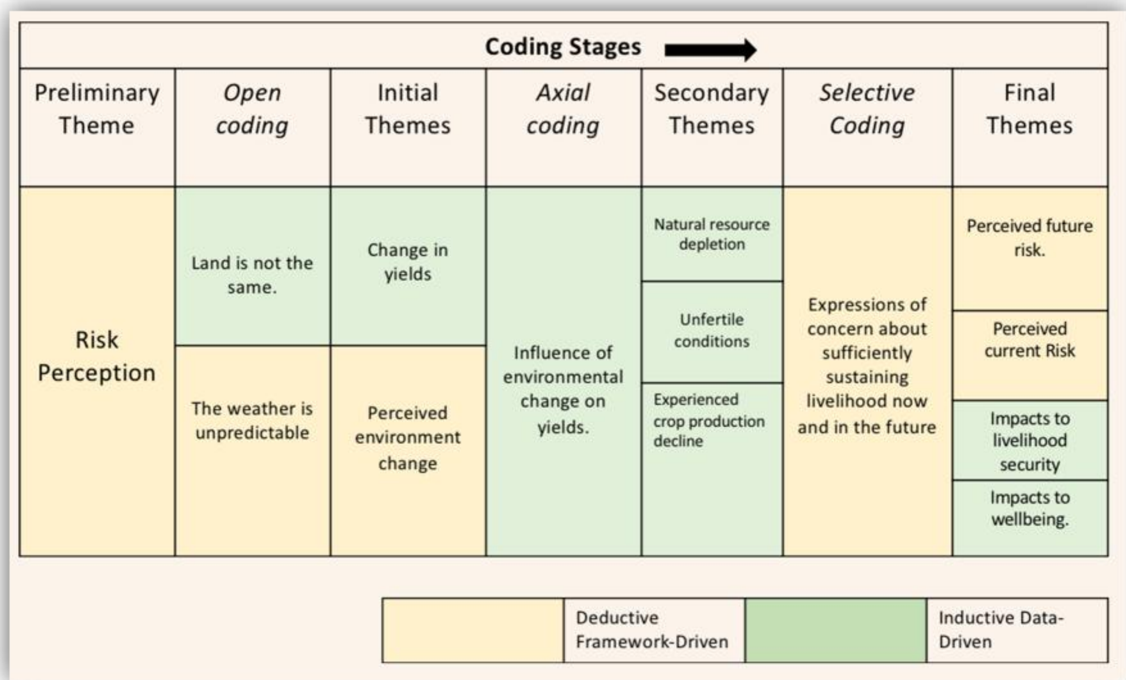
3:3:4 Data Analysis

A hybrid approach of deductive and inductive coding and theme development, similarly used by Fereday and Muir-Cochrane (2006), was employed to provide rigor in the analysis.

Preliminary codes are driven by the conceptual framework, whilst others can be inductively data-driven. The approach accords with the research questions by allowing figure 8's conceptual framework principles to guide the deductive thematic analyses, whilst permitting for relatable themes to develop.

In a top-down approach the broad categorical themes were developed from the conceptual framework and research questions, these were: livelihood assets, institutional context, livelihood/adaptation strategy and environmental change risk perception. Data was thematically coded using open coding that was guided, but not limited by the conceptual framework. Axial coding, which highlights how processes occur (Gilgun, 2005), then linked the themes across transcripts generating secondary themes. Selective coding, which tentatively forms themes corresponding to the research interests, thematically coded findings according to the research questions and quantitative findings. Figure 12 presents an example of the analytical stages undertaken corresponding to research objective 1.

Figure 12: Example of coding stages undertaken



Source: Author

3:4 Ethical Considerations

According to Gullemin and Giliam (2004) there are two sorts of ethics: 1) procedural ethics, and 2) ethics in practice. For the procedural ethics, the University of Southampton's ethics and research governance procedure was completed and approved before the fieldwork commenced – ERGO ID 40872. This entailed an outline of informed consent, participant confidentiality and anonymity (see appendices 2-6). For ethics in practice, the procedures detailed were strictly followed, and no ethical issues arose to report. However, on reflection the research felt somewhat 'exploitative' (Fieldwork Diary, 10/06/18), given that any direct benefits to respondents could not be guaranteed.

3:5 Critical Evaluation of Methods

To critically evaluate the approach taken, O'Cathain's (2010) framework for mixed-methods quality will be drawn on in this paragraph. The approach taken permits for strong interpretative rigor, as the breadth and balanced perspective gained using both farmer's individual accounts and statistical analysis gives this adaptation research value (Coyle and Williams, 2000). Under O'Cathain's (2010) framework, this suggests that the conclusions made are more credible than conclusions drawn by single method studies, such as Khatun and Roy's (2012). The interpretation of the determinants of adaptation are more expressive when explanation from personal accounts, as well as the survey variables, is produced (Mckim, 2017). This increases the utility for government and decision-makers. Additionally, by presenting findings in a weaving approach makes them more accessible for decision-makers, as shown by Classen *et al.,* (2007). This is key, as often conclusions drawn from adaptation research are too intricate to effectively inform policy (Swart *et al.,* 2014). Usefulness for policy-makers is a recognised domain of mixed-methods study quality (O'Cathain, 2010). However, the design may reflect interpretative bias (Ibid), due to the statistically significant associations mainly pre-determining the interview agenda. Consequentially, other factors effecting adaptation may have been missed, although the flexibility of semi-structured interviews helped mitigate this. Farmers' accounts may not always correspond with the survey findings, which would weaken the integration rigor during analysis (Ibid). However, discrepancies in the findings could reveal important contextual circumstances that current literature has not recognised.

A drawback of explanatory sequential designs is that the qualitative phase cannot be finalised until the quantitative phase is complete (Doyle *et al.,* 2016). Due to fieldwork time constraints, interviews were collected before model 5's Poisson results were acquired. Consequently, little data was gathered that directly explained the processes behind the intensity of farmers' adaptations. When using mixed-methods, Hughes (2016) states that a good researcher must be flexible in their approach. Therefore, contrary to the logit models, the approach will be adapted so that the qualitative data will serve as supplementary to the quantitative Poisson regression results.

As mentioned in the sections above, the qualitative method's design enables good credibility, transferability and dependability of findings. Nonetheless, the researcher's positionality warrants reflection in order to facilitate confirmability. Confirmability is the degree to which reported responses are respondent narratives and not the researchers (Shenton, 2004), whereas positionality entails the researcher delineating their own position relative to the research, with the repercussion that this position could affect how data was collected and interpreted (Qin, 2016). A discussion of the implications of the researcher's positionality will be discussed in chapter 5. Steps undertaken to minimise positionality were: interviewing in the respondents' homes to relax them, sitting closely and eye level to generate intimacy and reflectively recording perceptions and thoughts in a fieldwork diary to reflexively draw when interpreting findings (Karnielie-Miller *et al.,* 2009; Haynes, 2012).

Chapter 4 Findings and Results

4:1:1 Perceived Changes in Environment

Descriptive frequency charts were employed to depict farmers perceived environmental changes in the IBD. The majority of farmers (85.3%) perceived an increase in temperatures, whereas rainfall change was less unanimous with relatively even numbers stating increases (46.4%) and decreases (44.5%) in amounts (Figure 13). Regarding river flooding, similar proportions of farmers agreed it was increasing (32.7%), decreasing (24.2%) or were uncertain (29.9%). The vast majority of farmers were unsure of any changes in drought, salinization, coastal/river erosion and coastal flooding. The majority of farmers also agreed that the monsoon period was arriving later over the last 5 years (55.5%) (Figure 14).

Figure 13: The perceived environmental changes by crop farmers in the last 5 years

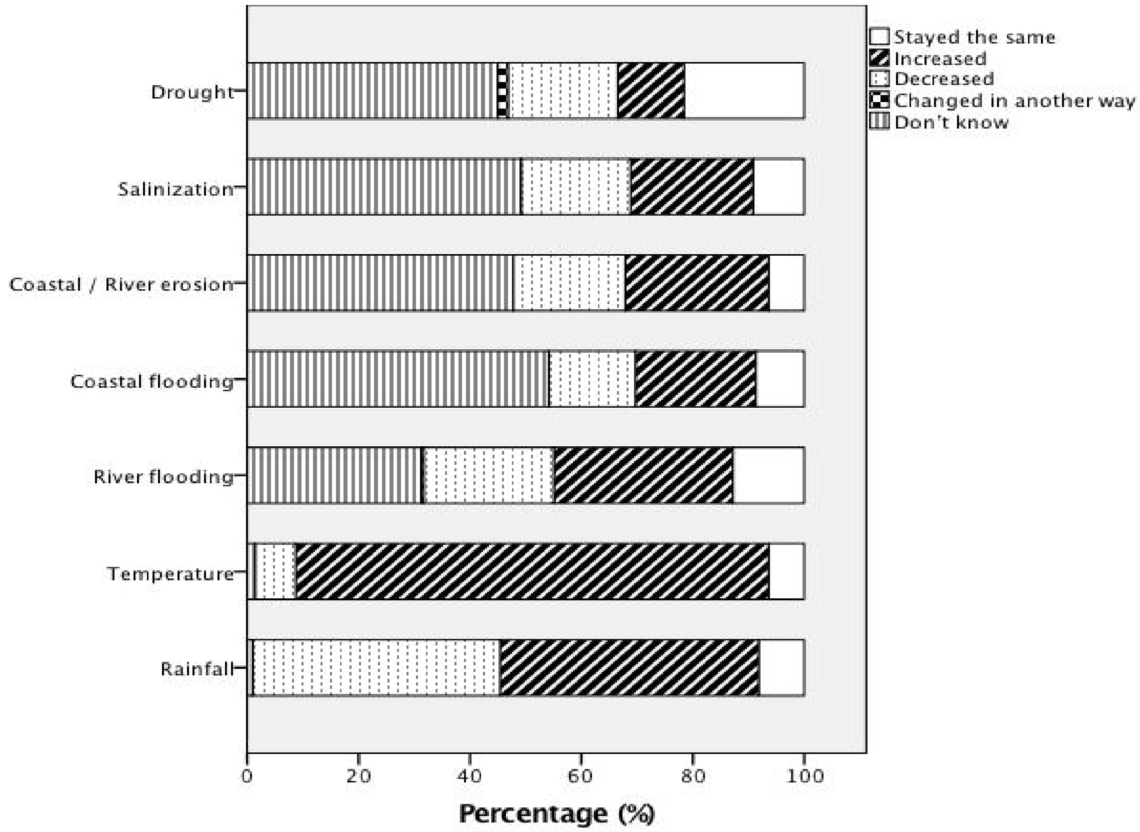
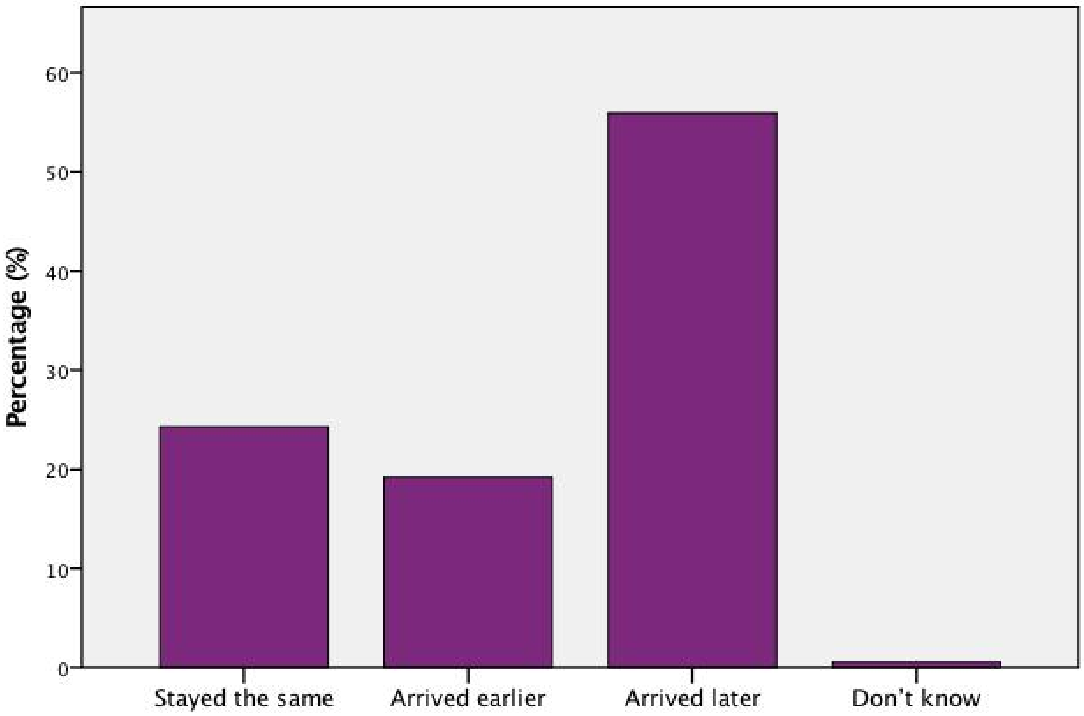


Figure 14: The perceived changes in the onset of the monsoon/rain season in the last 5 years



"10 years ago, the highest temperature 35 or 36 degrees, but now it is 42 degrees"

(Participant 8)

The majority of farmers' accounts resonated with figures 13 and 14, as the elements used to describe environmental change comprised gradual increasing temperatures and salinity and untimely monsoon rainfall. Salinity increase was more commonly noted in the coastal community of Aripara. Significant alterations recognised in rainfall were: 1) unpredictable and delayed timing of the monsoon, and 2) more erratic rainfall events. Contrary to figure 13, salinity was widely perceived to have increased, though respondents expressed that a factor for this was storm surges and flooding from cyclone Aila in 2009. Occurrences of drought and erosion were not mentioned, and farmers noted no changes in river flooding events. Respondents did not perceive the frequency of extreme events, mainly cyclones, to be increasing. Although, damages to crops, equipment and livestock had exacerbated, which suggested an increased cyclone intensity. This could be because farmers' memories of cyclone Aila were still fresh.

4:1:2 Farmer-Perceived Effects of Environment Change on Agriculture

Temperature increase was a perceived risk to farming livelihoods amid its indirect impacts on crop yields and income. Soils were still saline from cyclone Aila, and higher temperatures were amplifying salinity and infertility by increasing evaporation rates, reducing soil moisture. This hindered crop seed germination and deterred overall crop development, as a farmer conveyed:

"10 years ago, the growth of our chilli plant was 3 foot, now with salinity high it grows no more than 1 foot"

(Participant 4)

Further, warmer soils and temperatures were increasing incidences of more developed pests and diseases, which adversely effected crop performance, despite farmers frequent application of pesticides (Figure 15). Farmers were most at risk following events of short erratic rainfall during the early monsoon season, as recently planted under-developed crops were more susceptible to pests. Resulting yield shortages had connotations on farmers' income, food security and mental wellbeing, due to added stress to secure food for the year. These risks were more prominent for poorer farmers relying predominantly on paddy, who expected these impacts to worsen with temperature increasing. A high risk to livelihood security from unpredictable and changing rainfall during the monsoon season was widely perceived. Unpredictable rains did not coincide with usual seed sowing periods, requiring the untimely re-planting of crops. This reduced the growing season length, depleted resources and lowered overall yields. Furthermore, increasingly irregular rainfall intervals would deter crop growth, because growth would cease during drier intervals stunting crops. Consequently, many respondents expressed the high uncertainties associated with agricultural livelihoods:

"Every year it I am uncertain what I will get so livelihood is risky right now, in the future I fear there won't be a livelihood for farmers"

(Participant 3).

The perceived continuous decline in rainfall and increase in temperature and salinity concerned most farmers about future freshwater resources that were essential for cultivating rice paddy, since most other sources, such as groundwater and rivers, were already too saline.

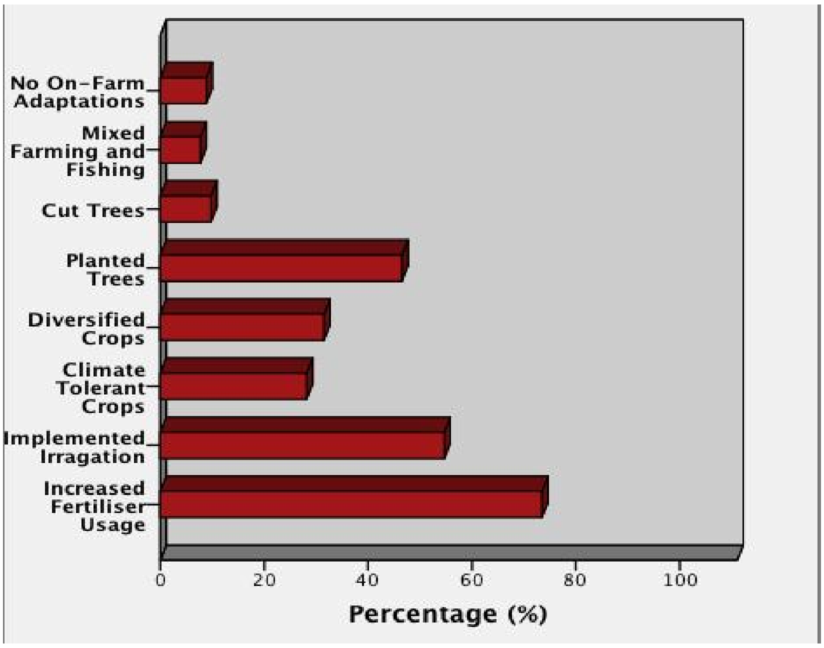
Figure 15: Incidence of pest in Morolpara.

Source: Author.

4:2 Observed Adaptive Responses.

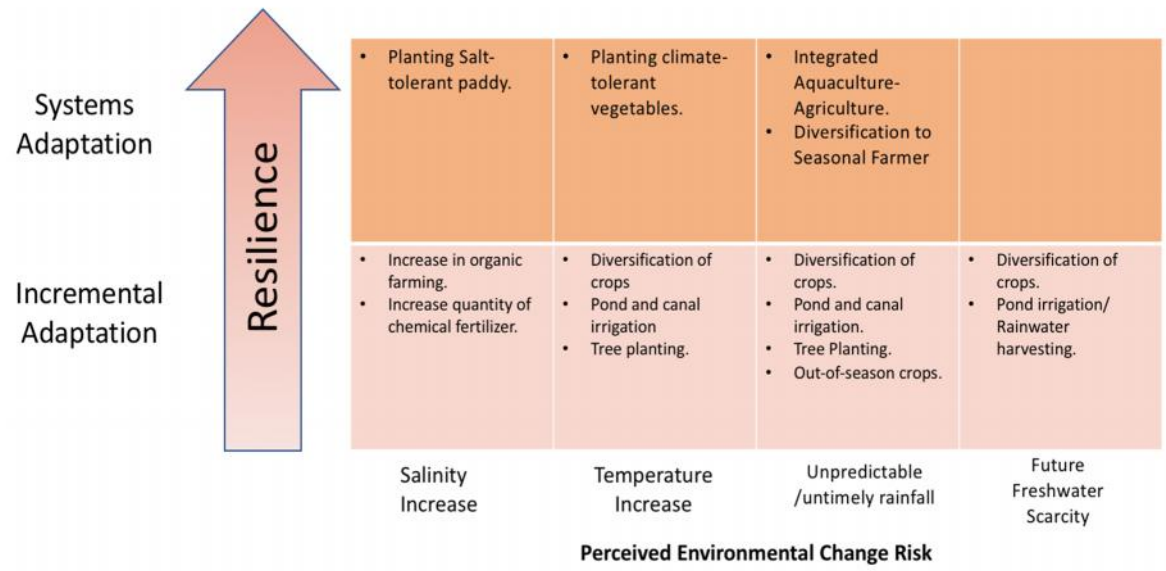
Using frequency bar charts, the occurrences of on-farm adaptation were analysed (Figure 16). Increasing fertilizer usage was the most common adaptation (74%), followed by irrigation (54.2%). Tree planting was undertaken by 46% of farmers, whereas cutting trees was more uncommon (10%). Crop diversification and planting CTC (Climate-Tolerant Crops) was undertaken by 31.6% and 27.7% of farmers respectively. Only 7.9% of farmers had adopted mixed farming and fishing, whilst 9% of farmers did not adapt using those adaptations listed.

Figure 16: On-Farm adaptations undertaken in the last 5 years



As farmers acknowledged the risk to their livelihoods from unpredictable rainfall, increasing temperatures and salinity and freshwater scarcity, further probing was conducted to observe the adaptive responses. Figure 17 summarises these adaptations using insight from Howden *et al's* (2010) framework to illustrate the resilience benefits. Evidently, most strategies comprised incremental adaptation with few systems adaptations and no transformative adaptations.

Figure 17: Adaptation strategies used in Dulki, Sonaga and Morolpara,



Source: Author

4:2:1 Farming Practices

Agreeing with Figure 16, farmers responded to increasing soil salinity by applying greater quantities of fertilizer, which was chemical, organic or a mixture. Agricultural extension services provided by the 'Ram Krishma Mission', a religious organisation, and the village agricultural development officer were advising for the intensification of organic farming. However, most respondents were increasingly using chemical fertilizer which was readily available and less labour-intensive, despite acknowledging the future environmental implications. Most respondents reported increased production, which enhanced livelihood income and food security:

"Before I was just using the crops for food, but now I am able to sell it. I am now saving up for a power tilla (farming equipment)"

(Participant 11)

Cultivating CTC such as salt-tolerant paddy (Nsanker) were encouraged by extension services and were adopted by some respondents. This importantly enabled paddy cultivation outside the monsoon season when salinities and temperatures were highest, reducing the dependency on monsoon harvests. Further, some vegetable types, including potato and chilli, were becoming increasingly farmed for their negligible freshwater requirements. Across all communities, there was evidence of shifts from mono-cropping to paddy and vegetable cropping. Employing this diversification strategy was stated to alleviate risk from unpredictable weather and pests, since not all crops required the same growing conditions or were as vulnerable to pests. Some respondents in Aripara mentioned recent tree planting, but this was not for ecological benefit. Instead, this was a form of diversification to cultivate fruits, such as jackfruit and mango, which were less sensitive to irregular rainfall and pests from soils.

4:2:2 Water Management Practices

Farmers close to canals were sharing this as an irrigation source with their neighbours. Canal water was relied on to prepare paddy fields during the pre-monsoon season, and to irrigate crops in the event of extreme temperatures or delayed monsoon rainfall. However, canals could not be entirely depended on since they were susceptible to saltwater intrusion. More innovative farmers had excavated irrigation ponds to harvest rainfall, which was predominantly undertaken for future use due to widely perceived future freshwater scarcity risks. Respondents also stressed their ponds importance for elongating the gradually shortening growing season, which enabled the cultivation of out-of-season crops and reduced the dependence on monsoon rains. Irrigation ponds however were less effective in porous soil, and were prone to siltation which required regular maintenance. Further, their utility for farmers throughout the year hinged on collecting sufficient rainwater during the monsoon.

4:2:3 Other Means

Contrary to Figure 16, numerous respondents described recently integrating aquaculture into their farm as a secondary livelihood. Aquaculture was conducted in irrigation ponds, and was undertaken to alleviate the risk to unpredictable weather by diversifying income and food sources:

"The weather does not impact this household, if paddy is effected then I will use the fishery, if that is effected I will use my vegetables. The weather does not have the capacity to impact all of these"

(Participant 8).

This also had crop productivity benefits, as nutrient enriched water would input essential nutrients of phosphate and nitrate into soils during irrigation. Other types of livelihood diversification entailed farmers also undertaking manual labour work, which primarily regarded excavating irrigation ponds for other farmers and rebuilding river embankments. However, this was contingent on the availability of employment.

4:3 Determinants and Processes Influencing Adaptation

Binary logistic and Poisson regressions were employed to assess the determinants for adapting using increased fertilizer usage, irrigation, climate-tolerant crops, crop diversification and the number of adaptations practiced. Their results are presented in Tables 5 and 6. Farmers' accounts corresponding to these are integrated in using a weaving approach.

Table 5: Parameter estimates of BLRs of Models 1-4 to analyse the factors influencing adaptation choices.

	Increased Fertilizer Use (N=175)		***Irrigation (N= 177)***		***Climate Tolerant Crops (N=177)***		***Crop Diversification (N=175)***	
	Coefficient (S.E.)	**Odds Ratio (95% CI)**	**Coefficient (S.E.)**	**Odds Ratio (95% CI)**	**Coefficient (S.E.)**	**Odds Ratio (95% CI)**	**Coefficient (S.E.)**	**Odds Ratio (95% CI)**
Age	-0.001 (0.016)	0.999 (0.969-1.030)	-0.014 (0.014)	0.986 (0.961-1.013)	-0.003 (0.015)	0.997 (0.968-1.027)	-0.011 (0.017)	0.989 (0.958-1.022)
Employment Status Permanent (ref)								
Seasonal	-1.344 (0.490) ***	0.261 (0.1-0.681)	0.299 (0.387)	1.349 (0.632-2.881)	0.240 (0.398)	1.271 (0.583-2.774)	-2.081 (0.450) ****	0.125 (0.052-0.301)
Short-Term	-1.443 (0.554) ***	0.236 (0.080-0.699)	-0.147 (0.464)	0.863 (0.347-2.144)	-0.904 (0.595)	0.405 (0.126-1.300)	-1.628 (0.531) ***	0.196 (0.069-0.556)
Household Size	0.097 (0.121)	1.101 (0.868-1.397)	--0.156 (0.107)	0.855 (0.694-1.055)	-0.290 (0.129) **	0.749 (0.581-0.965)	-0.112 (0.134)	0.894 (0.687-1.164)
Education No Schooling (ref)								
Primary	0.394 (0.492)	1.483 (0.566-3.886)	0.219 (0.447)	1.244 (0.518-2.987)	1.110 (0.634) *	3.034 (0.875-10.519)	1.094 (0.647)	2.813 (0.791-10.002)
Secondary and above	0.607 (0.513)	1.835 (0.672-5.011)	0.558 (0.465)	1.747 (0.702-4.348)	1.257 (0.632) **	3.515 (1.018-12.140)	1.356 (0.649) **	3.882 (1.087-13.864)
Land Size Small (ref)								
Moderate	1.375 (0.459) ***	3.954 (1.609-9.716)	0.745 (0.434) *	2.106 (0.899-4.932)	0.563 (0.544)	1.755 (0.604-5.101)	0.344 (0.556)	1.411 (0.474-4.197)
Large	0.031 (0.578)	1.031 (0.332-3.202)	0.685 (0.560)	1.984 (0.662-5.943)	1.495 (0.656) **	4.46 (1.233-16.138)	0.749 (0.664)	2.115 (0.576-7.767)
Work Outside Village (dummy: 1 =yes; 0 = no)	0.425 (0.534)	1.530 (0.537-4.358)	-	-	-1.383 (0.570) **	0.251 (0.082-0.766)	-	-
Loan **(**dummy: 1 =yes; 0 = no)	-	-	0.566 (0.340) *	1.761 (0.905-3.425)	-	-	0.857 (0.417) **	2.357 (1.040-5.343)
Equipment (dummy: 1 =yes; 0 = no)	-	-	0.998 (0.434) **	2.712 (1.158-6.352)	-	-	-	-
Constant	0.502 (1.118)	1.652	-0.033 (0.983)	0.968	-1.115 (1.168)	0.274	0.982 (1.427)	2.670
Log 2 Likelihood	173.945		222.088		179.709		170.439	
Wald Chi-square (Likelihood Ratio Test)	28.875 ***		22.014 **		29.130 ***		45.844 ****	
Nagelkerke R²	0.216		0.156		0.219		0.325	
Hosmer and Lemeshow (P-Value)	0.483		0.469		0.472		0.778	

*Note: * denotes significance at the 0.1 level, ** at 0.05, *** at 0.01 and **** at <0.001. – indicates that the predictor was not included in the model, and ‘ref’ indicates the reference category.*

4.3.1 Increased Fertilizer Usage

Increasing fertilizer usage (IFU) was significantly associated with employment type and land size (Table 5). Seasonal and short-term farmers were negatively associated with IFU (*P=0.01*). Seasonal and short-term farmers were 73.9% and 76.4% times respectively less likely to IFU than a permanent farmer. Having moderately sized land was positively associated with IFU (*P=0.01*). Farmers with moderately sized land were 295.4% times more likely to IFU than farmers with small sized land. Age, household size, education, large land size and working outside the village were not significant.

Employment Type

Quantitative: Compared to permanent farmers, seasonal and short-term farmers were less likely to IFU.

Integration of Qualitative (IOQ): Respondents stressed that soils would degrade each time chemical fertilizer was applied:

"I am reliant on chemical fertilizer for growing my crops and this is okay for right now, however this degrades the quality of the land and this is extremely risky for farmers in the future, even with lots of fertilizer"

(Participant 2)

Applying chemical fertilizer was the main mechanism to generate yields from saline soils. For farmers cultivating more frequently, more chemical fertilizer was applied, which enhanced soil degradation. Subsequently, more fertilizer each time was required to enable crop growth:

"*In earlier days I had to put in 5kg, but now we are having to invest more and use almost 100kg of chemical fertilizer to get production*".

(Participant 4)

Therefore, permanent farmers fell into a cycle whereby IFU was necessary to sustain crop production.

Land size

Quantitative: Compared to farmers with small land size, farmers with moderate land size were more likely to IFU.

IOQ: To enable the intensification of organic farming, manure first requires composting:

"*The agricultural development officer said that you must leave the cow dung to compost for about 6 months, otherwise it is too strong and damages the crops*"

(Participant 9)

This meant designating land for composting (Figure 18). The ability to compost also hinged on owning livestock to provide manure, since it was not marketed. Livestock keeping was commonly found in moderate and larger farms, which proved to be an accurate wealth indicator when corroborated with material assets. Chemical fertilizer costs were increasing which the poorest farmers, generally those owning smaller farms, could not afford. Affordability also impacted farmers with larger farms, as higher costs associated with hiring labour to apply fertilizer was unaffordable through on-farm income.

Figure 18: Organic fertilizer compost heaps used in farms.

Source: Author.

4.3.2 Implementing Irrigation

Implementing irrigation was significantly associated with land size, receiving a loan and equipment (Table 5). Having farming equipment was positively associated with applying irrigation (*P=0.05*). Farmers with equipment were 171.2% times more likely to implement irrigation than farmers without. Loan recipients were positively related to implementing irrigation (*P=0.1*), as recipients of loans were 76.1% times more likely to adopt irrigation than those who were not. Having moderately sized land was also positively associated with implementing irrigation (*P=0.1*), as farmers with moderate sized land were 110.6% times more likely to implement irrigation than farmers with small land. Large sized land, education, age, employment type and household size were not significant.

Equipment

Quantitative: Farmers owning farming equipment were more likely to implement irrigation than those without.

IOQ: Pumping equipment was required to transport water from the low-lying irrigation ponds and canals to crops (Figure 19). These pumps were stressed as fundamental for efficient irrigation, without having access to pumps irrigation was not possible.

Figure 19: Pump set equipment used to irrigate crops from excavated irrigation ponds.

Source: Author

Land size

Quantitative: Compared to farmers with small land, farmers with moderate sized land were more likely to implement irrigation.

IOQ: Land space was conveyed as a barrier to excavating the volume needed, since smaller ponds were vulnerable to evaporation. Deeper ponds were not preferred because it increased the waters exposure to saline groundwater and soil, therefore at least a length of 8 meters was required.

"I would like to dig a pond, but my land isn't big enough. I would have to give up part of my paddy field which I need"

(Participant 7)

Farmers would irrigate if only sufficient land space permitted it without saline water intrusion and at the detriment of arable land. This was found to be less feasible in smaller farmers.

Loan/Credit

Quantitative: Loan recipients were more likely to implement irrigation than those who were not.

IOQ: Hired labour was needed to excavate irrigation ponds, which was costly and normally not affordable:

"To dig a pond I need 50,000 rupees more than I have, I have not got this from 2 years of agriculture"

(Participant 2)

Farmers cited using loans from neighbours and banks, but bank loans were more common as a recent government scheme instructed banks to provide 2% interest loans of 50,000 rupees for farmers. As well as other agricultural inputs, most farmers described investing loans in irrigation systems. This was viewed as a good investment, since it enabled the cultivation of out-of-season crops, which were sold to repay loans.

4.3.3 Planting Climate Tolerant Crops

Household size, education, land size and working outside the village were significantly associated with CTC (Table 5). Contrary to the general hypothesis, having a household member working outside the village was negatively associated with planting CTC (*P=0.05*), as farmers who had a household member working outside the village were 74.9% times less likely to plant CTC than farmers who did not. Household size was also negatively associated with CTC (*P=0.05*), as for each additional household member the likelihood of planting CTC decreased by 25.1%. Having large sized land was positively associated with CTC (*P=0.05*). Farmers with large sized land were 346% times more likely to plant CTC than those with small farms. An increasing level of education was positively associated with planting CTC (*P=0.1 P=0.05 respectively*), as farmers with primary and secondary level education were 203.4% and 251.5% times respectively more likely to plant CTC than farmers without education. Age, moderate land size and employment status were not significant.

Household Member Working Outside the Village

Quantitative: Households with a member working outside the village were less likely to plant CTC than households who did not.

IOQ: Members working outside the village were typically young, with little interest in agriculture, and so few undertook any farm work. They brought back money under times of stress and low yields, which was generally used to purchase food. This was perceived to be less labour intensive than planting CTC, discouraging household heads to plant it.

Household Size

Quantitative: For each additional household member, the likelihood of planting CTC decreased.

IOQ: No accounts could provide sufficient insight.

Land size

Quantitative: Compared to farmers with small land, farmers with large sized land were more likely to plant CTC.

IOQ: Having an irrigation pond and cultivating traditional paddy species was ranked more important than cultivating CTC. CTCs were viewed too complex compared to traditional crops.

"I am not interested in climate tolerant crops, I am happy with my fishery and farm business so I will not plant anything else"

(Participant 8)

Respondents cultivating CTC did so because their larger farm size also allowed for other important adaptive strategies, such as irrigation ponds. One respondent, with a larger farm described how he undertook land modification to elevate sections to cultivate paddy and vegetables. This however left low-lying saline land. To avoid land waste, he planted Nsankar, which provided an additional food and income source that was not at the detriment of his other crops or adaptive strategies.

Education

Quantitative: Educated farmers were more likely to plant CTC than farmers without education.

IOQ: CTCs were introduced in village training programmes that some interviewees expressed difficulty in understanding:

(Discussed in the context of CTCs) "The agricultural training is important but I need it simpler, if someone could teach it to me using drawings then that would help, the brochures they give out do not help"

(Participant 8)

Training regarded knowing which types of CTCs to cultivate under certain environmental conditions. This also meant that farmers needed to understand their soil properties, such as levels of salinity, nitrates and phosphorus, which many did not understand. Educated farmers who adopted CTC articulated how CTCs were important, especially for coping against climate change, which indicates greater understanding and willingness to adopt them.

4:3:4 Crop Diversification

Crop diversification was significantly associated with employment type, secondary education and loans (see Table 5). Seasonal and Short-term farmers were negatively associated with crop diversification (*$P>0.01$ and $P=0.01$* respectively). Seasonal and Short-term farmers were 87.5% and 80.4% times respectively less likely to diversify crops than a permanent farmer. Secondary or higher education was positively associated (*$P=0.05$*), as farmers with this education level were 288.2% times more likely to diversify crops than uneducated farmers. Loans were positively associated with crop diversification (*P=0.05*), as recipients of loans were 135.7% times more likely to diversify crops than non-recipients. Age, household size and land size were not significant.

Employment Status

Quantitative: Seasonal and short-term farmers were less likely to diversify crops than a permanent farmer

IOQ: To generate food under fluctuating climates permanent farmers cultivated more varied paddy species and vegetables, such as potato, chilli and ginger, since these were less sensitive than traditional paddy. Farmers uncovered this by experimenting using various crop combinations and types, which necessitated time and resources.

"I'm concentrating more on vegetables as they cannot be impacted by unpredictable nature, unlike my paddy field"

(Participant 9).

Conversely, when paddy production was low, respondents not entirely dependent on agriculture relied more on their secondary livelihood, which was generally labour work. Therefore, diversifying crops was not as important.

Education

Quantitative: Educated farmers were more likely to diversify crops than uneducated farmers.

IOQ: As paddy cultivation was prevalent respondents were unfamiliar with alternative crop types, which were marketed in English, frustrating farmers. Consequentially instructions from shopkeepers were often necessary, but were not well received by all. Nevertheless, less-educated farmers understood the premise behind crop diversification in spreading risk, and described learning about different crop types from other farmers they were friendly with and replicating their cultivation techniques:

"I watch my neighbour trying out different combinations and types of crops, if he gets a good yield this season then I will try it on my land"

(Participant 11)

Therefore, contrary to the quantitative result, education was not a barrier to crop diversification due to widespread farmer-to-farmer communication within communities aiding adoption.

Loans

Quantitative: Loan recipients were more likely to diversify crops than non-receipts

IOQ: Certain crops farmers wanted to diversify, which was more accessible with enhanced financial capacity:

"To plant aubergine I would need about 10,000 rupees, so I will take this bank loan money for that and repay it over the next two years"

(Participant 14).

For respondents without loans, when given a hypothetical scenario with 50,000 rupees generally their first activity comprised purchasing more crop varieties. This appeared to be because farmers could experiment with more varieties of crops with greater financial capacity to determine the most efficient system. Furthermore, those with loans saw crop diversification as a secure practice to generate stable income under environmental variability, and so would undertake it to begin repaying back loans.

4:3:5 Intensity of Adaptation

Table 6: Parameter estimates of model 5 - Number of adaptations practiced

	Number of Adaptations (N=177)	
	Coefficient (S.E.)	**Exp Coefficient (95% CI)**
Age	-0.003 (0.005)	0.997 (0.988 - 1.006)
Employment Status Permanent (ref)		
Seasonal	-0.245 ** (0.123)	0.783 (0.615 – 0.995)
Short-term	-0.429 ***(0.167)	0.651 (0.470 – 0.904)
Household Size	-0.035 (0.036)	0.966 (0.900 - 1.037)
Education No Schooling (ref)		
Primary	0.274 (0.177)	1.316 (0.931 – 1.861)
Secondary or Above	0.399 **(0.177)	1.491 (1.054 – 2.108)
Land Size Small (ref)		
Moderate	0.383 ** (0.168)	1.467 (1.056 – 2.039)
Large	0.372 * (0.201)	1.451 (0.978 – 2.154)
Intercept	0.514 (0.351)	1.673 (0.840 – 3.330)
Likelihood Ratio (Omnibus Test)	30.490 ****	
Pearson Chi-Square Value/df (Goodness of Fit)	0.674	
Deviance Value/df (Goodness of Fit)	0.806	

*Note: * denotes significance at the 0.1 level, ** at 0.05, *** at 0.01 and **** at <0.001. 'ref' indicates the reference category.*

The number of adaptations practiced (NAP) was significantly associated with employment type, education and land size. Seasonal or short-term farmers were negatively associated with the NAP (*P=0.05 and P=0.01 respectively*). Farmers working seasonally or short-term were likely to practice 21.7% and 34.9% respectively less NAPs than a permanent farmer. This likely relates to non-permanent farmers deeming it unnecessary to implement adaptations due to alternate livelihood incomes. Secondary or above level education was positively associated with NAP (*P=0.05*), as farmers with this education level were likely to practice 49.1% more adaptation strategies than uneducated farmers. This could be due to more educated farmers being able to interpret and apply teaching from the extension services regarding organic farming and CTC cultivation. Having moderate or large land size was positively associated with NAP (*P=0.05 and P=0.1 respectively*). Farmers with moderate sized land or large sized land were likely to practice 46.7% and 45.1% respectively additional adaptation strategies than farmers with small land. An illustration of this was provided by participant 8, who had constructed long irrigation canals within his large farm which facilitated aquaculture in the low-lying area. Further, during rainfall, water levels reached a diversity of vegetables planted on the canal banks (Figure 21). Primary education, age and household size were not significant. Neither the Pearson Chi-square value/df (0.674) or Deviance value/df (0.806) were excessively lower than 1, suggesting that the model relatively fits the Poisson distribution, despite some under dispersion.

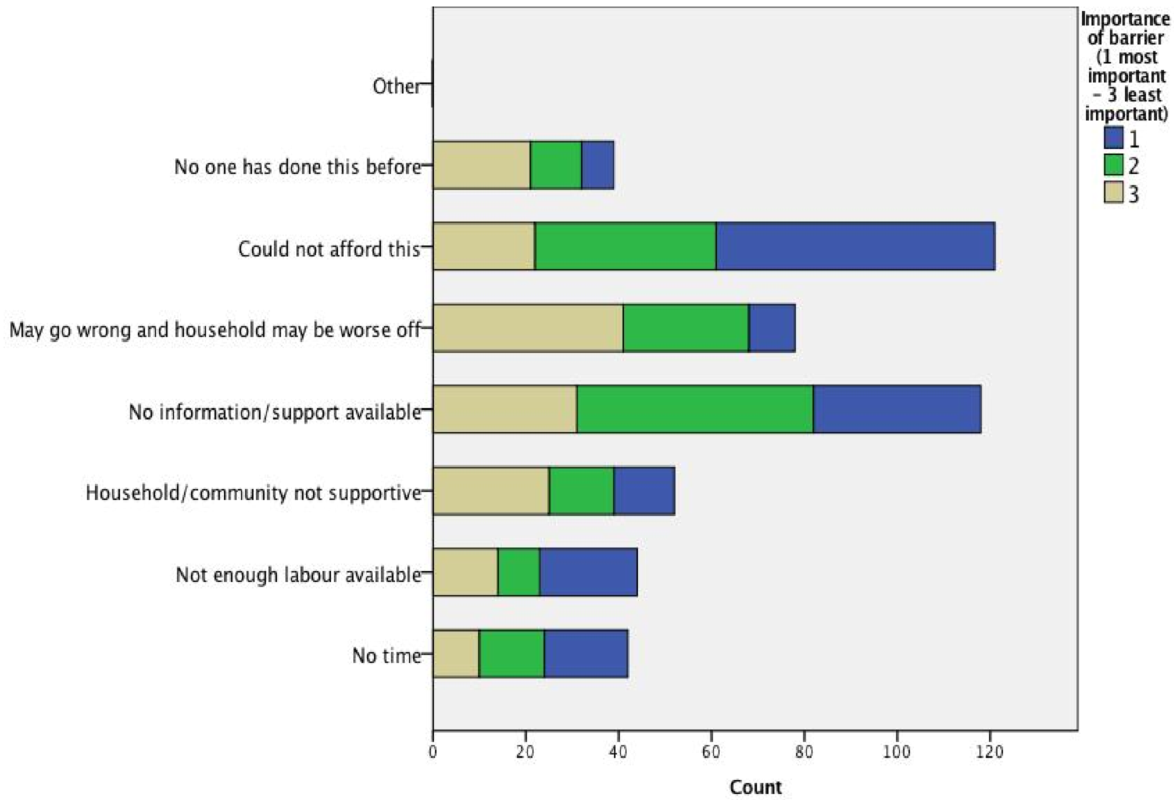
Figure 20: Excavated canals used to irrigate vegetables from aquaculture pond.

Source: Author.

4:4 Uncovered Barriers to Adaptation

In the descriptive statistics undertaken, farmers' barriers to adaptation and the importance of these barriers were investigated (Figure 22). Financial resources restrictions were the most common barrier and most important. Another frequently reported barrier was the inaccessibility to information, which was mostly judged as the second most important barrier faced. An apprehension of maladaptation also prevented a significant number of farmers adapting, although this was mainly deemed one of the least important barriers. Labour shortages, lack of time, unfamiliarity and a lack of household and community support were selected by a relatively fewer farmers.

Figure 21: Barriers to adaptation.



As mentioned, farmers in these communities have employed a range of adaptive measures to environmental change. However, adaptation is not simple, as barriers can constrain farmers in the process of adapting. There were some interrelated barriers, however the main barriers uncovered in the communities concerned 1) institutional barriers, 2) physical barriers and 3) knowledge/normative barriers. In contrast to Figure 21, financial barriers were less frequently mentioned, but were still discussed by some respondents.

4:4:1 Institutional Barriers

With regard to institutional barriers, a fundamental constraint preventing organic farming for most respondents was the inaccessibility to organic fertilizer. Interviewees irately expressed how extension services would stress the economic, environmental and productivity benefits of organic farming, however no shops marketed it. Most respondents did not own livestock for a manure source due to many being lost during cyclone Aila, or were too poor to afford them financially. Therefore, farmers continued using unsustainable and environmentally degrading chemical fertilizer, despite recognising the risk:

(When asked if this was risky) "Yes, but there is no other option, there is none, you tell me the options. Earlier we had a number of cows, so we could use the cow dung, but nowadays we don't have any cows and we can't use organic fertilizer"

(Participant 13)

A lack of coordination was therefore evident between acting NGOs, government/community programmes and market actors. Respondents even reported frequently hearing businesses advertising the production benefits of chemical fertilizer over the radio, which contrasted to the training programme advice, leaving respondents confused. Subsequently, many persevered with chemical products, which most respondents eventually knew would render their land unproductive.

Other institutional barriers concerned local corruption, which was prominent in Sonagar. Farmers expressed that if they were members of the opposition party in power they would not receive support from outside aid, such as the Australian Centre for International Agricultural Research's (ACIAR), which provides important soil testing for farmers through local government. Consequently, due to political neglect this left some farmers unsure of which crops were suitable to cultivate, which restricted the efficaciousness of crop diversification and CTC strategies to increase resilience to unpredictable climate. This corresponds to Figure 21's results regarding insufficient support available.

4:4:2 Physical Barriers

Numerous physical barriers impacting adaptations such as pests and soil characteristics were reported, however the most common and fundamental regarded access to adequate water resources. Naturally, the adaptations predominantly effected concerned water management practices, specifically irrigation:

"The water storage is not sufficient enough, it does not last until the pre-monsoon season when we need to prepare our farms"

(Participant 11)

Farmers attributed inefficiencies in water storage to overall rainfall decline, higher temperatures, increasing evaporation rates and saline water intrusion, and in Aripara porous soils hindered irrigation ponds capacity to gather rainwater. These physical factors in amalgamation had wider constraints on other on-farm strategies, since irrigation ponds were relied on to cultivate some out-of-season crops, provide habitat for aquaculture and mix with fertilizer for application. Many respondents identified that irrigation would not adequately provide for their livelihoods under future environmental change, the only means to sufficiently irrigate was to extract deep groundwater. However, due the IBDs complex geology freshwater aquifers are small and sparse, and inaccessible without expensive technology.

4:4:3 Normative/Knowledge Barriers

As aforementioned, extension services were advocating CTC practices by disseminating information on salt-tolerant paddy (Nsankar). Respondents recognised its value given its capacity to grow during periods when cultivation was not generally feasible. However, interviewees compared productions of Nsankar witnessed in other farms to their own traditional paddy cultivated in the monsoon, and quoted that yields were not as high:

"I have seen the paddy that they (agricultural training programme) have told us to grow in another farmers land. It doesn't look like it grows much, not like rupusl"

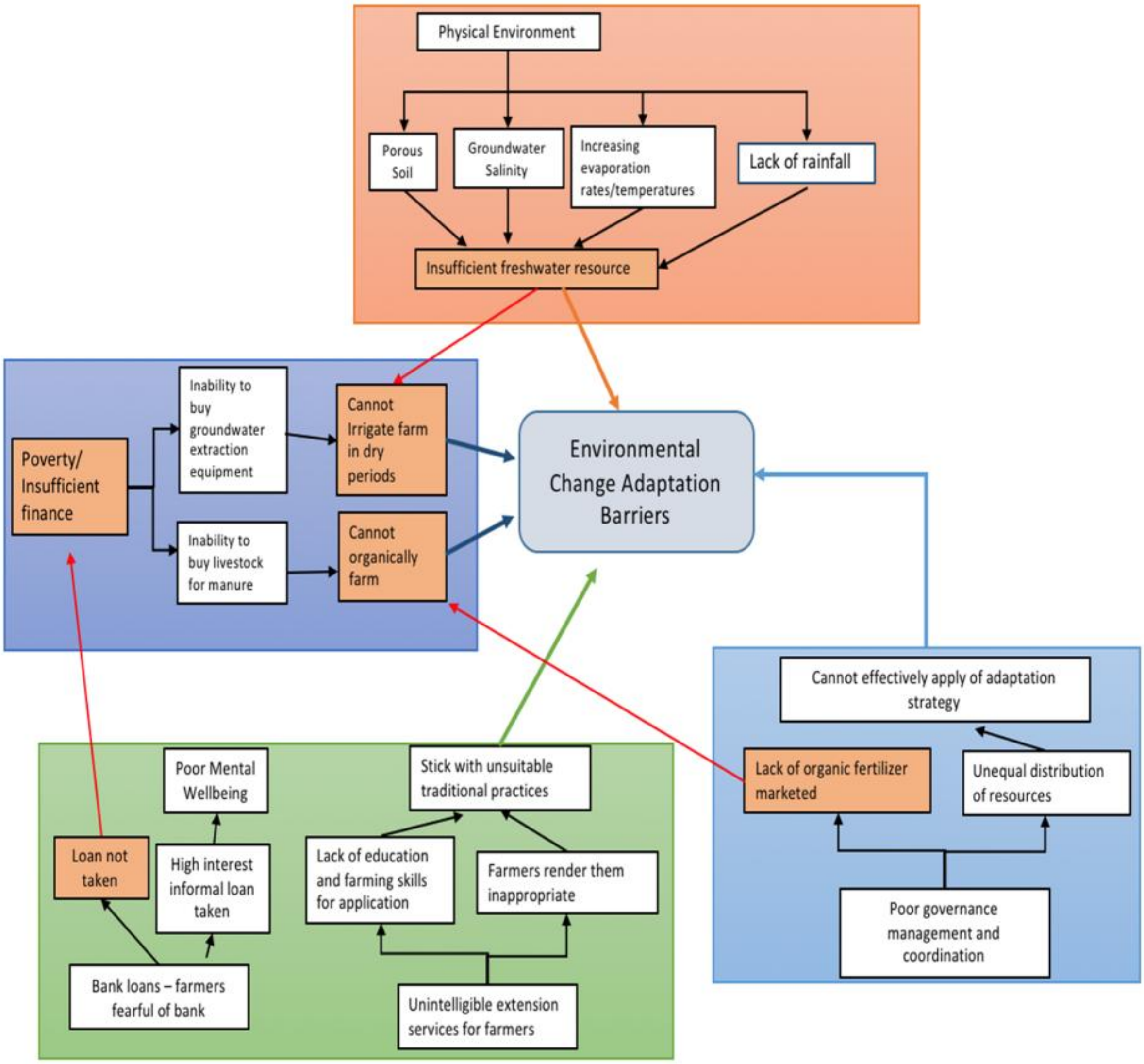
(Participant 14).

Further probing revealed that farmers seemed less willing to invest in less traditional crops which yielded lower outputs. Moreover, contact with extension services and the transfer of information regarding CTCs was undertaken in school classrooms, an unfamiliar environment for some farmers. It was commonly cited that the supplied information verbally and in brochures was too complex. This deterred farmers from re-attending and implementing CTCs, as respondents believed that time was better spent in their farm experimenting with more traditional methods. Furthermore, since agricultural officers never visited farmers' land, respondents questioned whether their advice was pertinent for their land. These two influences made respondents less willing to part with traditional methods that had previously supported their parents to undertake more 'complex' lower yielding crops. This perhaps underpins Figure 21, regarding the apprehension that the strategy may go wrong.

A further instance of normative barriers derived through respondents perceiving bank loans as risky. Many were not acquainted with the banks formal nature, which intimidated some interviewees. Respondents were worried that banks would confiscate their farms due to their 'higher power', and therefore did not adopt a loan. Instead, others went to neighbours which generally charged higher interest, putting farmers under high mental pressure.

From the analysis of farmers' accounts, it appears that the adaptation barriers documented can contribute to another barrier (see Figure 22). For instance, institutional and financial barriers interact to constrain organic farming.

Figure 22: Model of the main barriers to adaptation for the case study villages.



Note, regarding the large outer boxes and arrows (secondary-models), green denotes educational/normative barriers, light blue denotes institutional, dark blue denotes financial and orange denotes physical. The smaller white inner boxes represent the challenges faced, whilst the red arrows and boxes represent the influences from a different secondary-model to the same challenge. The black arrows illustrate the direction of effects.

Chapter 5 Discussion and Conclusion

5:1 Crop Farmers' Adaptations

Crop farmers were highly aware of current and future environmental change risks posed to agricultural livelihoods, which derived through increasing temperatures and soil salinity, and unpredictable rainfall, confirming reports by Ghosh (2012) and Guhathakurta *et al.,* (2011). The availability of freshwater is decreasing, and farmers' actions to excavate irrigation ponds were beneficial in elongating gradually shortening growing seasons, and thus reduced vulnerability by lessening the dependency on natural resources (Hajra and Ghosh, 2018), such as monsoon rains. Ensuring that harsh conditions do not coincide with critical growth periods is essential for crop farmers (Ngo, 2016). Regarding Smith *et al's* (2011) notion of adaptive decision-making, farmers will need to consider different future adaptive decisions due to potential future freshwater scarcity. Some respondents had done this by diversifying into mixed farming and fishing livelihoods, or undertaking secondary livelihoods in construction. However, this was less apparent across the IBD than in Aripara, Sonagar and Morolpara.

Increased pest outbreaks in accordance with untimely rainfall and temperature rise which decreased yields is congruent with systematic assessments (Moorhead, 2009). Furthermore, akin to Hajra *et al's* (2016) and Chand *et al's* (2012) studies, farmers recognised an association with increasing salinity and decreasing paddy yields. The subsequent adaptive responses regarding the intensification of chemical fertilizers are also reported across the Indian Sundarbans (Jain *et al.,* 2016; Singh *et al.,* 2016). However, this dissertation adds that farmers do not advocate it, and would prefer organic fertilizer, which cheaply enhances adaptive capacities, soil fertility and yields (Scialabba and Nuller-Lindenlauf, 2010). Crop diversification is advocated by scholars to spread risks of production losses and facilitate long-term adaptation (Thomas *et al.,* 2015; Meldrum *et al.,* 2018). Farmers increased their system resilience by spreading the risk of poor paddy harvests from unpredictable and delayed monsoons by also cultivating more climate-tolerant vegetables. In the case study villages, CTCs were salt-tolerant paddy, namely Nsankar. Cultivating this paddy specie allowed production in saline conditions less diluted from higher temperatures and less rainfall. This represents a more resilient systems adaptation, which required significant willingness and adaptive capacity (Richards and Howden, 2012), and was supported by extension services that added to farmers' adaptive capacity by distributing technology and increasing awareness (Ajuaye, 2010).

5:2 Factors and Processes in Adaptation in the IBD

Employment Type: Table 5's results are congruent with Ngo (2016), though the influencing mechanisms vary between adaptations. Regarding crop diversification, farmers working as construction labourers engaged less in adaptation, as their alternate income which was less vulnerable to unpredictable environments could be relied upon. Concerning NAP (Table 6), the result contrasts Chen *et al.*, (2018), but conforms to the literature hypothesising that farmers earning off-farm will feel more secure and not adapt as intensely (Oluwatusin, 2014). Considering IFU (Table 5), permanent farmers were more confined within vicious cycles whereby incessant IFU is required for production in rapidly degrading soils. This is not a common factor influencing adaptation adoption within general literature (Addisu *et al.,* 2016). This finding therefore has wider academic implication, as it indicates that decisions to adopt adaptive strategies are not consistently influenced by individual capacities or perceived benefit. Instead, some farmers adopt them because adaptive decisions have led to a higher dependence on measures.

Land size: In IFU (Table 5), farm size underpinned two general premises. 1) Land size is a constraint on the adoption of technology (Bryman *et al.,* 2009), which reported difficulties in composting demonstrated. 2) Land size is indicative of wealth (Knowler and Bradshaw, 2017), which effected farmers' capability to IFU organically using livestock, and chemically due to increasing costs. Regarding NAP (Table 6), the results echo Isgin's (2008) and Raghu *et al's* (2014). The empirical results support the theory that as farm size increases farmers are more likely to engage in additional agricultural technologies than their counterparts (Abdul-Hanan *et al.,* 2014). The association with irrigation (Table 5) accords with Pokhrel *et al.,* (2018), but conversely the uncovered explanation relates to the IBD's groundwater and soil salinity issue reported by Mandel and Mandel (2012). Consequently, farmers required wider and shallower irrigation systems to avoid saline water intrusion, which was less feasible on smaller farms. Guodarr *et al.,* (2016) asserts that physical factors of soil type and hydrology can influence farmers' decisions to irrigate. The findings build on this by showing how these contextual physical factors can interact with farm characteristics to ultimately influence adaptive decisions to irrigate. This is an important factor for decision-makers to recognise when attempting to implement water management practices in coastal deltaic environments.

Education: In line with theory (Deressa 2008), and other results (Ndam and Watanabe (2015; Boansi *et al.,* 2017; Shikuku *et al.,* 2017), the findings implied that more educated farmers could better interpret, understand and apply information disseminated on CTC. Educated farmers citing CTCs relevance in a climate change context reinforced this. However, this construes that educated farmers in the villages are more climate resilient, compared to more socially vulnerable, less-educated farmers. Contrary to the crop diversification results (Table 5), interviews suggested that education did not affect adoption due to local-scale farmer-to-farmer communication. Aryal *et al.,* (2017) reinforces this, as their results indicated that farmers' education did not influence crop diversification decisions, but partaking in farmer-to-farmer communication did (positively). The qualitative findings suggested that farmers communicated information more comprehensibly, visually and practically, which agrees with the literature (Kiptot and Franzel, 2015). This finding could have methodological implication, as it depicts how large-scale quantitative assessments of adaptations can overlook important contextual social actions, which impact how farmers process information. Since most adaptation measures must be contextual to be effective (Zizinga *et al.,* 2017), this dissertation shows that employing mixed-methods in adaptation research is pertinent to enable the development of contextual adaptation initiatives.

Other: The positive effect of credit access (loans) (Table 5) is akin to Abid *et al.,* (2014), Oluwatusin (2014), and Nhemachena *et al.,* (2014). Farmers can be deterred from irrigating due to associated costs (Guodarr *et al.*, 2016), which in the communities interviewed relates to labour expenses. Further, the findings regarding crop diversification complement Deressa (2008), who states that credit access increases the accessibility to wider crop varieties. These findings underpin the importance of loan schemes in enabling environmental resilient farming practices. Contrary to the literature (Aryal *et al.,* 2018; Parganiha, 2016), a household member working outside the village negatively affected adaptation, despite the measure thought to increase exposure to outside agricultural extension services and technology (Table 5). It was uncovered that it was often younger household members leaving, who had minimal farming interest and would subsequently engage in non-agricultural activities. This illustrates how current literature can overlook subtleties in the household member's demographic, such as age, which can affect the degree to which the member engages in agricultural related activity.

5:3 The Influence of Barriers

The research findings strongly correspond to literature which underpin the significance of societal determinants, natural resource constraints and socio-economic factors in determining adaptive capacities and responses (Bryman, *et al.,* 2009; Vincent, 2007; Francisco *et al.,* 2011). Further, the findings add to the growing scholarly attention on the notion of social barriers to adaptation (Jones and Boyd, 2011; Kolikow *et al.,* 2012), as some farmers' normative beliefs were found to prevent the adoption of climate-tolerant adaptation strategies, as traditional methods were preferred. Other key barriers, such as knowledge barriers, were identified to hinder the understanding and application of agricultural information. The findings suggested that how extension services communicated information constrained the up-take of climate-resilient practices. This resonates with Moser (2010a,b), who maintains that how knowledge is distributed, acquired and used determines whether it enables or constrains adaptation .

Recognising the role of societal institutions in influencing the contexts for what may restrict adaptive decisions (Gorddard *et al.,* 2016), numerous accounts indicating how conflicting goals between market actors and community programmes are omnipresent throughout participants' responses. This predominantly impacted those seeking organic farming, due to a deficiency of marketed organic fertilizer. This links to Grothman (2011), who states that all governance network actors must share identical objectives to facilitate apropos adaptive decision-making and implementation. Drawing on Wise *et al's* (2014) adaptation pathways concept (see section 2:3), farmers' decision pathways to sustainably increase yields are constrained by market actors. Previous adaptive decisions to increase chemical fertilizer usage are indicative of paths close to the threshold of concern, due to rapidly degrading soils from increasing salinity and overuse of fertilizer chemicals. Farmers' current adaptation pathways will persevere into maladaptive space, because soils will eventually become unusable as increasing chemical fertilizer costs coupled with greater quantities required to cultivate will become unaffordable. This builds on Jain *et al* (2016), as their identified gaps in supply and demand has been uncovered to have ramifications which reduce deltaic farmers' adaptive capacities against declining soil fertility.

Contrary to Biesbroek *et al's* (2015) critique of barrier notions (see section 2:4), adopting a barrier thinking approach provided insight into farmers' decision-making processes which constrained adaptation. It was found that decisions not to cultivate Nsanka paddy were partly influenced by extension services communicating information in an approach many farmers were unaccustomed to, coupled with traditional practices being perceived more efficient. This documentation of farmers' decision-making processes has utility for practical reality, as extension services can alter their approach, which further contests Biesbrock *et al's* (2015) argument. Indeed, categorising the barriers accordingly simplified respondents' adaptive decision-making, however it demonstrated how the recorded barriers in the villages interacted to engender adaptation challenges and barriers (see figure 22). Since the interaction between multiple barriers can significantly restrict the range of adaptive options (IPCC, 2014c), this finding has importance for how academics may approach adaptation barriers in future research, and for decision-makers seeking to increase opportunities for adaptation in farming.

5:4 Framework Reflection

Momtaz and Shameen's (2016) framework generated valuable understanding into what influenced farmers' adaptive measures. The components considering farmers' risk perception and perceived adaptive capacity permitted insight into respondents' adaptive decisions. This was demonstrated by some farmers not planting CTCs despite recognising declining yields, because they felt they lacked the knowledge. The framework also helped developed insight into how the use of farmers' assets, such as finance and knowledge, can be constrained by institutional market processes when choosing adaptive strategies. However, a criticism, that Zheng and Dallimer (2016) too noted, regards the absence of farmers' emotions. Respondents feared loaning from banks due to the apprehension that the bank could take their land, despite recognising impending environmental risks. As demonstrated, loans influenced the adoption of irrigation and crop diversification, which reduce vulnerability to current and future environmental change. This demonstrates how farmers' emotions play an important role in adaptive decisions, which the framework should consider. Future research could apply the framework to more varied natural resource dependent farmers eligible for formal loans to validate this.

5:5 Limitations and Further Research

Positionality and the order of data collection warrant reflection, since scholars often embark on fieldwork with a pre-determined knowledge that may influence interpretation (Haraway, 1999; Bruce, 2007). As models 1-4 were completed before the fieldwork, the results may have led to subconscious probing and interpretation for aligning explanations. It was found that interpretations of responses differed slightly during interview transcription, compared to in the field where emotion was higher (Fieldwork Diary 08/06/18). These emotions were recorded in a diary, and were used during the qualitative analytical coding. Further, being perceived as a powerful outside westerner could have led respondents into altering responses to align with the research agenda (Willis, 2006). The translator may have exacerbated this due to his intellect, presenting him as a different outsider (Twyman *et al.,* 1999). Consequently, any subconscious probing from the researcher could have acquired distorted responses from respondents, and should be noted. Due to the explanatory sequential data collection order, other contextual processes influencing adaptation could have been overlooked, as interview agendas focused on the quantitative findings. Bryman (2007) highlights this a structural challenge in mixed-methods research, and researchers and decision-makers should be aware of this when considering this study's findings.

Another limitation to recognise concerns variable selection. The regression predictor variables were inductively selected using insight from the literature, though it cannot be certain that the variables represent exactly what is in the literature (Vincent, 2007). This could also be impacted by the survey enumerators, who may have influenced responses in their conveyance of the questions.

At the local-scale farmer-to-farmer communication was found to support the adoption of crop diversification. However, farmer-to-farmer communication was not directly measured in the IBD, and could not be triangulated or assessed at the IBD level. Other potential proxy measures, such as cooperatives only had 17 out of 177 farmers using them, and so would not allow robust statistical regression analysis as a predictor under Field's (2009) rule adopted (see section 3:2:1:2). Further research in the IBD should observe the interactions during farmer-to-farmer communications that regard agricultural techniques to assess how information can be re-laid in extension services. This should ideally be conducted using an ethnographic approach to generate an in-depth understanding of the social action, and the nuances in different contexts (Reeves *et al.,* 2008). Regarding the incessant application of chemical fertilizer, other research could assess deltaic crop farmers' application in areas whereby organic fertilizer is marketed. This could validate whether a lack of marketed organic fertilizer due to poor governance networks is the causation.

This research primarily focused on livelihood adaptation, although it was uncovered that environmental pressures had impacted farmers' food security. Though interviews recorded data on food availability, data corresponding to food stability, accessibility and utilization required for a holistic assessment of food security is not in-depth. This was not sufficient for a robust analysis of the impacts to farmers' food security stemming from environmental change. Future research in the IBD should collect data on the stability of crop production, and how farmers access food and use it in accordance with changing environments to build on this dissertation's findings, and develop insight into farmers' risks to food insecurity.

5:6 Summary and Recommendations

In summary, current and future environmental risk to deltaic crop farming livelihoods has been documented, and farmers have responded by adopting a variety of on-farm adaptation strategies. The research questions of this study were: 1) What adaptations are crop farmers using in response to perceived environmental change? 2) What factors and processes effect the adoption of adaptation strategies? 3) What barriers prevent farmers adapting?

Crop farmers were found to employ incremental adjustments in their farming systems in response to increasing soil salinities, temperature, freshwater scarcity and unpredictable rainfall regimes. These comprised an array of changing farming practices, such as fertilizer intensification and crop diversification (shifting from mono-crop paddy to paddy and vegetables), and implementing water management measures, such as irrigation ponds. Farmers also adapted their farming system to salinity and temperature increase by cultivating climate and salt-tolerant crops, and undertook livelihood diversification in integrated aqua-agriculture in response to unpredictable climate.

Overall, the main factors determining farmers' adoption of adaptive strategies were employment type, land size, education and loans. Interestingly, a farmer's employment type could influence a cycle whereby increasing chemical fertilizer use was required to cultivate more frequently, whilst farmers also earning off-farm income were less inclined to adapt as literature suggested (Oluwatusin, 2014). Land size mainly influenced the feasibility of adaptation strategies, and was uncovered to interact with other physical factors, such as soil and hydrology, to influence water management decisions. Farmers' education level played a role in how farmers understood and applied information disseminated by extension services regarding climate-resilient crop practices. Bank loans, specific to farmers, then supported farmers with purchasing crop varieties and covering the costs of implementing irrigation, which was important for most who relied solely on low agriculture income.

Results suggest that incongruities between extension services and market actors was a fundamental barrier to organic farming, as essential organic fertilizer was not marketed. Consequently, current chemical fertilize usage may lead farmers down maladaptive adaptation pathways (Wise, *et al.,* 2014). Other barriers, such as knowledge and normative barriers, impeded adoptions of climate resilient practices and bank loans. This was predominantly due to inappropriate methods of information dissemination by extension services leaving farmers to remain with traditional crops, and the formal nature of banks discouraging the take-out of loans. This study concludes that knowledge, normative and institutional barriers, and farmers' land and household characteristics can largely influence the on-farm adaptations deltaic farmers adopt to reduce current and future environmental change risk.

These main findings have several key policy implications. The findings suggest that extension services approach to disseminating information to crop farmers should be adjusted to encompass more practical based teaching. This would make important knowledge more accessible for less educated farmers, and could encourage a wider adoption of climate-tolerant practices which increase farmers' resilience to dryer and warmer environments. Potentially considering identical approaches to farmer-to-farmer communications is recommended. Regarding actors, government should impose market actors to market organic fertilizer in village shops. This could aid the shift away from chemical uses to more cheap and sustainable organic farming. Having organic fertilizer readily available would enable farmers to apply it without composting, increasing its utility for smaller-scale farmers. The continuation of bank loan schemes is accentuated, though banks could distribute loans through community figures or local extension services to make crop farmers less anxious and increase uptakes. The potentially increased financial capacity would enable farmers to adopt more crop varieties and water management practices, and thus alleviate vulnerability to unpredictable environments.

References

Abah, D., Obekpa, H.O. and Enemuwe, J.O., (2016) 'Analysis of Climate Change Adaptation Strategies Among Food Crop Farmers In Oshimili North Local Government Area of Delta State'. *PAT*, *12*(1), pp.95-105.

Abid, M., Scheffran, J., Schneider, U.A., Ashfaq, M., (2015) 'Farmers' perceptions of and adaptation strategies to climate change and their determinants: the case of Punjab province, Pakistan'. *Earth System Dynamics*, *6*(1), pp.225-243.

Abdul-Hanan, A., Ayamga, M., Donkoh, S.A., (2014) Smallholder adoption of soil and water conservation techniques in Ghana*, Vol 9 (5)* pp 539-546.

Abdul-Razak, M., Kruse, S., (2017) 'The adaptive capacity of smallholder farmers to climate change in the Northern Region of Ghana'. *Climate Risk Management*, *17*, pp.104-122.

Acquah, H.D., (2011) 'Farmers perception and adaptation to climate change: A willingness to pay analysis'. *Journal of Sustainable Development in Africa*, *13*(5), pp.150-161.

Addisu, S., Fissha, G., Gediff, B., Asmelash, Y., (2016) 'Perception and adaptation models of climate change by the rural people of lake Tana Sub-Basin, Ethiopia'. *Environmental Systems Research*, *5*(1), p.7

Adger, W.N., Huq, S., Brown, K., Conway, D., Hulme, M., (2003) 'Adaptation to climate change in the developing world' *Progress in development studies*, *3*(3), pp.179-195.

Adger, W.N., (2006) 'Vulnerability'. *Global environmental change*, *16*(3), pp.268-281.

Adger, W.N., Agrawala, S., Mirza, M.M.Q., Conde, C., o'Brien, K., Pulhin, J., Pulwarty, R., Smit, B. and Takahashi, K., 2007. Assessment of adaptation practices, options, constraints and capacity. *Climate change*, pp.717-743.

Ajuaye, A., (2010). *Analysis of farmers' adaptation to climatic change in Kilimanjaro region* (Doctoral dissertation, Sokoine University of Agriculture).

Antonakis, J. and Dietz, J., (2011). 'Looking for validity or testing it? The perils of stepwise regression, extreme-scores analysis, heteroscedasticity, and measurement error'. *Personality and Individual Differences*, *50*(3), pp.409-415.

Arumugam, S., Ashok, K.R., Kulshreshtha, S.N., Vellangany, I., Govindasamy, R., (2014) 'Adapting to climate change through crop choice by small and medium farmers in Southern zone of Tamil Nadu, India'. *SAARC Journal of Agriculture*, *12*(1), pp.139-149.

Aryal, J.P., Jat, M.L., Sapkota, T.B., Khatri-Chhetri, A., Kassie, M., Rahut, D.B., Maharjan, S., (2018) 'Adoption of multiple climate-smart agricultural practices in the Gangetic plains of Bihar, India'. *International Journal of Climate Change Strategies and Management*, *10*(3), pp.407-427.

Asfaw, A., Admassie, A., (2004) 'The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia'. *Agricultural economics*, *30*(3), pp.215-228.

Atkinson, R., Flint, J., (2001) 'Accessing hidden and hard-to-reach populations: Snowball research strategies'. *Social research update*, *33*(1), pp.1-4.

Bager, S.L., Dinesh, D., Olesen, A.S., Andersen, S.P., Eriksen, S.L., Friis, A., (2017) *Scaling-Up Climate Action in Agriculture: Identifying Successes and Overcoming Challenges*. Nordic Council of Ministers

Banerjee, O., Mahzab, M., Raihan, S. and Islam, N., (2015) 'An economy-wide analysis of climate change impacts on agriculture and food security in Bangladesh'. *Climate Change Economics*, *6*(01), p.1550003.

Bengtsson, P., 1999. Multiple Case Studies–not just more data points. *Term paper in graduate course in Research Methodology. Publisher Unknown*, pp.1-9.

Bennett, A., Elman, C., (2007) 'Case study methods in the international relations subfield'. *Comparative Political Studies*, *40*(2), pp.170-195.

Berkhout, F., (2012) 'Adaptation to climate change by organizations'. *Wiley Interdisciplinary Reviews: Climate Change*, 3(1), 91-106.

Biesbroek, G.R., Klostermann, J.E., Termeer, C.J., Kabat, P., (2013) 'On the nature of barriers to climate change adaptation'. *Regional Environmental Change*, *13*(5), pp.1119-1129.

Biesbroek, R., Dupuis, J., Jordan, A., Wellstead, A., Howlett, M., Cairney, P., Rayner, J., Davidson, D., (2015) 'Opening up the black box of adaptation decision-making'. *Nature Climate Change*, *5*(6), p.493.

Bishop, F.L., (2015) 'Using mixed methods research designs in health psychology: An illustrated discussion from a pragmatist perspective'. *British journal of health psychology*, *20*(1), pp.5-20.

Blandford, A.E., (2013) 'Semi-structured qualitative studies'. Interaction Design Foundation.

Boansi, D., Tambo, J.A. and Müller, M., (2017) 'Analysis of farmers' adaptation to weather extremes in West African Sudan Savanna'. *Weather and Climate Extremes*, *16*, pp.1-13.

Box, G.E. and Tidwell, P.W., (1962) 'Transformation of the independent variables'. *Technometrics*, *4*(4), pp.531-550.

Brinkmann, S., (2014) 'Interview'. In *Encyclopedia of critical psychology* (pp. 1008-1010). Springer, New York.

Brouwer, R., Nhassengo, J., (2006) 'About bridges and bonds: community responses to the 2000 floods in Mabalane District, Mozambique'. *Disasters*, *30*(2), pp.234-255.

Brown, H.C.P., Smit, B., Somorin, O.A., Sonwa, D.J., Ngana, F., (2013) 'Institutional perceptions, adaptive capacity and climate change response in a post-conflict country: a case study from Central African Republic'. *Climate and Development*, *5*(3), pp.206-216.

Brown, K., (2014) 'Global environmental change I: A social turn for resilience?'. *Progress in Human Geography*, *38*(1), pp.107-117.

Brown, K. (2015) *Resilience, development and global change*. Abingdon: Routledge.

Bryan, E., Deressa, T.T., Gbetibouo, G.A., Ringler, C., (2009) 'Adaptation to climate change in Ethiopia and South Africa: options and constraints'. *Environmental science & policy*, *12*(4), pp.413-426.

Bryman, A., (2006) 'Integrating quantitative and qualitative research: how is it done?'. *Qualitative research*, *6*(1), pp.97-113.

Bryman, A., (2017) 'Quantitative and qualitative research: further reflections on their integration'. In *Mixing methods: Qualitative and quantitative research* (pp. 57-78). Routledge.

Bruce, C. (2007). Questions arising about emergence, data collection and its interaction with analysis in a grounded theory analysis. International Journal of Qualitative Methods, 6, 51–68.

Burch, S., (2010) 'Transforming barriers into enablers of action on climate change: insights from three municipal case studies in British Columbia, Canada'. *Global Environmental Change 20* (2) 287–297.

Cameron, A.C. and Trivedi, P.K., (2005) 'Microeconometrics: methods and applications' *Cambridge university press, Cambridge UK.*

Cazcarro, I., Arto, I., Hazra, S., Bhattacharya, R.N., Osei-Wusu Adjei, P., Ofori-Danson, P.K., Asenso, J.K., Amponsah, S.K., Khondker, B., Raihan, S. and Hossen, Z., (2018) 'Biophysical and socioeconomic state and links of deltaic areas vulnerable to climate change: Volta (Ghana), Mahanadi (India) and Ganges-Brahmaputra-Meghna (India and Bangladesh)'. *Sustainability*, 10(3), pp.893-913.

Census of India, (2011) *'Census of India'* Directorate of Census Operations, Government of India: New Delhi, India, 2011.

Census of India (2015) 'States Census 2011', https://www.census2011.co.in/states.php [accessed 02/08/18].

Chand, BK, Trivedi, RK, Biswas, A, Dubey, SK, Beg, MM (2012) 'Study on impact of saline water inundation on freshwater aquaculture in Sundarban using risk analysis tools'. *Explor. Anim. Med. Res.* 2: 170–178.

Chanda, A., Das, S., Mukhopadhyay, A., Ghosh, A., Akhand, A., Ghosh, P., Ghosh, T., Mitra, D., Hazra, S., (2018) 'Sea surface temperature and rainfall anomaly over the Bay of Bengal during the El Niño-Southern Oscillation and the extreme Indian Ocean Dipole events between 2002 and 2016'. *Remote Sensing Applications: Society and Environment*. Volume 12, pp 10-22.

Chapman, A.D., (2016) 'Evaluating an Adaptation: Rice-Sediment Trade-offs in the Vietnamese Mekong Delta' *PhD Thesis* https://eprints.soton.ac.uk/400969/1/Chapman%252C%2520Alexander%2520final%2520PhD%2520thesis.pdf [accessed 20/08/18]

Chapman, A.D., Darby, S.E., Hồng, H.M., Tompkins, E.L., Van, T.P., (2016) 'Adaptation and development trade-offs: fluvial sediment deposition and the sustainability of rice-cropping in An Giang Province, Mekong Delta'. *Climatic Change*, *137*(3-4), pp.593-608.

Chen, M., Wichmann, B., Luckert, M., Winowiecki, L., Förch, W., Läderach, P., (2018) 'Diversification and intensification of agricultural adaptation from global to local scales'. *PloS one*, *13*(5), pp 1-27.

Classen, S., E. D. Lopez, S. Winter, K. D. Awadzi, N. Ferree, C. W. Garvan. (2007) 'Population-Based Health Promotion Perspective for Older Driver Safety: Conceptual Framework to Intervention Plan.' Clinical Interventions in Aging 2 (4): 677–93.

Coyle, J., Williams, B., (2000) 'An exploration of the epistemological intricacies of using qualitative data to develop a quantitative measure of user views of health care'. *Journal of Advanced Nursing*, *31*(5), pp.1235-1243.

Creswell, J.W., Plano Clark, V.L., Gutmann, M.L. and Hanson, W.E., 2003. Advanced mixed methods research designs. *Handbook of mixed methods in social and behavioral research*, *209*, pp 209- 240.

Creswell, J. W., V. L. Plano Clark, (2011) 'Designing and Conducting Mixed Methods Research'. *Thousand Oaks, CA: Sage Publications, Inc*.

CSIRO (2017) 'Core Concepts' *Enabling Adaptation Pathways,* https://research.csiro.au/eap/core-concepts/ [accessed 19/08/2018).

Danda, A.A., (2007) 'Surviving in the Sundarbans: threats and responses'. *Unpublished PhD, University of Twente*, *203*.

Dang, L., H., Li, E., Bruwer, J., (2012) 'Understanding climate change adaptive behaviour of farmers: An integrated conceptual framework', *The International Journal of Climate Change: Impacts & Responses*, Vol 3, pp 385-401.

Denzin, N., K., Lincohn, Y., S., (2005) '*Handbook of Qualitative Research'*, 3rd edn, Sage Publication, Thousand Oaks, CA.

Denkyirah, E.K., Okoffo, E.D., Adu, D.T., Bosompem, O.A., (2017) 'What are the drivers of cocoa farmers' choice of climate change adaptation strategies in Ghana?'. *Cogent Food & Agriculture*, *3*(1), p.1-21.

Denzin, N., K., Lincohn, Y., S., (2008) '*Introduction: The Discipline and Practice of Qualitative Research*', in NK Denzin & YS Lincohn (eds), Strategies of Qualitative Inquiry, Sage, Thousand Oaks, CA, pp. 3-43.

Deressa, T., (2008) 'Analysis of perception and adaptation to climate change in the Nile Basin of Ethiopia' *Pretoria: Centre for Environmental Economics and Policy for Africa (CEEPA), University of Pretoria*. https://pdfs.semanticscholar.org/f7e1/94005dee43c8fefeac88218a9f6c2e39f927.pdf [accessed 25/06/18].

Deressa, T.T., Hassan, R.M., Ringler, C., Alemu, T., Yesuf, M., (2009) 'Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia'. *Global environmental change*, *19*(2), pp.248-255.

Dervin, B., (1983) 'An overview of sense-making research: Concepts, methods, and results to date'. The Author.

Deshingkar, P., Start, D., (2003) 'Seasonal migration for livelihoods in India: Coping, accumulation and exclusion' (Vol. 111). *London: Overseas Development Institute.*

Dey, S., Ghosh, A.K., Hazra, S., (2016) 'Review of West Bengal State Adaptation Policies, Indian Bengal Delta'. DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com, [accessed 22/08/18].

Douven, W., Buurman, J., (2013) 'Planning practice in support of economically and environmentally sustainable roads in floodplains: The case of the Mekong delta floodplains'. *Journal of environmental management*, *128*, pp.161-168.

Doyle, L., Brady, A.M., Byrne, G., (2016) 'An overview of mixed methods research–revisited'. *Journal of research in nursing*, *21*(8), pp.623-635.

Duncan, J., Tompkins, E., Dash, J., Tripathy, B., (2017) 'Resilience to hazards: rice farmers in the Mahanadi Delta, India'. *Ecology and Society*, *22*(4).

Eakin, H., Tompkins, E.L., Nelson, D.R., Anderies, J.M., (2008) 'Hidden Costs and Disparate uncertainties: trade-offs involved in approaches to climate policy'. In *Conference. Living with Climate Change: Are there limits to adaptation*.

Eisenhardt, K.M. (1989) 'Building theories from case study research'. *Academy of Management Review,* 14(4), pp.532-550.

Ekstrom, J., Susanne, A., Moser, C., Torn., M, (2011) Barriers to Climate Change Adaptation: A Diagnostic Framework' *California Energy Commission* http://www.energy.ca.gov/2011publications/CEC-500-2011-004/CEC-500-2011-004.pdf [accessed 18/08/18].

Erenstein, O. (2006) 'Intensification or Extensification? Factors Affecting Technology Use in Peri-Urban Lowlands along an Agro-ecological Gradient in West Africa'. Agricultural Systems 90 (1-3), pp 132-158.

Etikan, I., Musa, S.A., Alkassim, R.S., (2016) 'Comparison of convenience sampling and purposive sampling'. *American Journal of Theoretical and Applied Statistics*, *5*(1), pp.1-4.

Fatorić, S., Chelleri, L., (2012) 'Vulnerability to the effects of climate change and adaptation: the case of the Spanish Ebro Delta'. *Ocean & coastal management*, *60*, pp.1-10.

Feder, J.L., Egan, S.P., Forbes, A.A., (2012) 'Ecological adaptation and speciation: the evolutionary significance of habitat avoidance as a postzygotic reproductive barrier to gene flow'. *International Journal of Ecology*, *2012*, pp 1-15.

Fereday, J., Muir-Cochrane, E., (2006) 'Demonstrating rigor using thematic analysis: A hybrid approach of inductive and deductive coding and theme development'. *International journal of qualitative methods*, *5*(1), pp.80-92.

Field, A., (2009) 'Discovering statistics using SPSS'. *Sage publications, London UK*.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C.S., Walker, B., (2002) 'Resilience and sustainable development: building adaptive capacity in a world of transformations'. *AMBIO: A journal of the human environment*, *31*(5), pp.437-440.

Fosu-Mensah, B.Y., Vlek, P.L., MacCarthy, D.S., (2012) 'Farmers' perception and adaptation to climate change: a case study of Sekyedumase district in Ghana'. *Environment, Development and Sustainability*, *14*(4), pp.495-505.

Gagnon, D.R., Doron-LaMarca, S., Bell, M., O'Farrell, T.J. and Taft, C.T., (2008) 'Poisson regression for modelling count and frequency outcomes in trauma research'. *Journal of Traumatic Stress*, *21*(5), pp.448-454.

Gadédjisso-Tossou, A., (2015) 'Understanding farmers' perceptions of and adaptations to climate change and variability: The case of the Maritime, Plateau and Savannah Regions of Togo'. *Agricultural Sciences*, *6*(12), p.1441-1454.

Gbetibouo, G.A., (2009) 'Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa' (Vol. 849). *Intl Food Policy Res Inst.*

Geethalakshmi, V; Lakshmanan, A; Rajalakshmi, D; Jagannathan, R; Gummidi S; Ramaraj, AP; Bhuvaneswari, KL. Gurusamy R. Anbhazhagan, (2011) 'Climate change impact assessment and adaptation strategies to sustain rice production in Cauvery basin of Tamil Nadu', *Current Science* 101(3): pp342-347.

Ghosh, A., (2012) 'Living with changing climate–impact, vulnerability and adaptation challenges in Indian Sundarbans'. *Centre for Science and Environment,* New Delhi*,* India.

Ghosh, P., (2014) '*Subsistence and biodiversity conservation in the Sundarban Biosphere Reserve, West Bengal, India*'. Thesis and Dissertations – Geography 26, https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=1031&context=geography_etds [accessed 26/08/18].

Ghosh, A.K., Hazra, S., Dey, S., (2016) 'Review of national adaptation policies, India', DECCMA Working Paper, Deltas, Vulnerability and Climate Change: Migration and Adaptation, IDRC Project Number 107642. Available online at: www.deccma.com [accessed 22/08/18].

Ghosh, A., K., Banerjee, S., Naaz, F., (2018) 'Adapting to Climate Change – induced Migration. Women in Indian Bengal Delta' *Economic and Political Weekly 53 (*17), pp 63-69.

Gilgun, J.F., (2005) 'Qualitative research and family psychology'. *Journal of family psychology*, *19*(1), pp.40-50.

Gorddard, R., Colloff, M.J., Wise, R.M., Ware, D., Dunlop, M., (2016) 'Values, rules and knowledge: adaptation as change in the decision context'. *Environmental Science & Policy*, *57*, pp.60-69.

Gopal, B., Chauhan, M., (2006) 'Biodiversity and its conservation in the Sundarban Mangrove Ecosystem'. *Aquatic Sciences*, *68*(3), pp.338-354.

Government of India, (2015a) 'India's Intended Internationally Determined Contribution: Working Towards Climate Justice'*. Ministry of Environment and Forests,* Government of India, New Delhi.

Government of India, 2015b. *India's National Action Plan on Climate Change.* Ministry of Environment and Forests, Government of India, New Delhi. http://www.moef.nic.in/downloads/home/Pg01-52.pdf accessed 20/04/18.

Greene, J.C., Caracelli, V.J. and Graham, W.F., 1989. Toward a conceptual framework for mixed-method evaluation designs. *Educational evaluation and policy analysis*, *11*(3), pp.255-274.

Grothmann, T. and Patt, A., (2005) 'Adaptive capacity and human cognition: the process of individual adaptation to climate change'. *Global Environmental Change*, *15*(3), pp.199-213.

Grothmann, T., (2011) 'Governance recommendations for adaptation in European urban regions: Results from five case studies and a European expert survey'. In *Resilient Cities* (pp. 167-175). Springer, Dordrecht.

Guba, E.G., (1981) 'Criteria for assessing the trustworthiness of naturalistic inquiries'. *Ectj*, *29*(2), p.75-91.

Guhathakurta,P., O P Sreejith., P Menon (2011) 'Impact of climate change on extreme rainfall events and flood risk in India', India Meteorological Department, Shivajinagar, Pune, http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Impact_of_climate_change_on_extreme_rainfall_events_and_flood_risk_in_India_Journal_Earth_System_Science_2011.pdf [accessed 22/08/18].

Guillemin, M., Gillam, L., (2004) 'Ethics, reflexivity, and "ethically important moments" in research'. *Qualitative inquiry*, *10*(2), pp.261-280.

Guodaar, L., Beni, A., Benebere, P., (2017) 'Using a mixed-method approach to explore the spatiality of adaptation practices of tomato farmers to climate variability in the Offinso North District, Ghana'. *Cogent Social Sciences*, *3*(1), p.1273747.

Gupta, A., Geethalakshmi, V., Mendiratta, N., Pathak, H. and Sharma, M., 2017. Climate Change Adaptation in Agriculture in India. *Vayu Mandal*, *43*(1), pp.1-10.

Hajra, R., Ghosh, T., (2018) 'Agricultural productivity, household poverty and migration in the Indian Sundarban Delta'. *Elem Sci Anth*, *6*(1).

Hajra, R., Szabo, S., Tessler, Z., Ghosh, T., Matthews, Z., Foufoula-Georgiou, E., (2017) 'Unravelling the association between the impact of natural hazards and household poverty: evidence from the Indian Sundarban delta'. *Sustainability Science*, *12*(3), pp.453-464.

Hallegatte, S., (2009) 'Strategies to adapt to an uncertain climate change'. *Global Environmental Change 19*, 240–247

Hanjra, M.A., M.E., Qureshi, (2010) 'Global water crisis and future food security in an era of climate change'. *Food Policy*, 25(5), pp 365-377.

Hassan, R., Nhemachena, C., (2008) 'Determinants of African farmers' strategies for adapting to climate change: Multinomial choice analysis'. *African Journal of Agricultural and Resource Economics*, *2*(1), pp.83-104.

Haraway, D. (1999). Situated knowledges: The science question in feminism and the privilege of partial perspective. In M. Biagioli (Ed.), The science studies reader (pp. 172–188). London: Routledge

Harris, T., Yang, Z. and Hardin, J.W., (2012). 'Modeling underdispersed count data with generalized Poisson regression'. *Stata J*, *12*(4), pp.736-747.

Haynes, K., (2012) Reflexivity in qualitative research. *Qualitative organizational research: Core methods and current challenges*, pp.72-89.

Hazra, S. K Samanta, A Mukhopadhyay, A Akhand (2010) 'Temporal Change Detection (2001-2008) Study of Sundarban', School of Oceanographic Studies, Jadavpur University, Kolkata

Hazra, S., Samanta, K., 2016. 'Temporal Change Detection (2001-2008): Study of Sundarban' https://ideas.repec.org/p/ess/wpaper/id10526.html [accessed 20/08/18].

Hellmann, J.J., J.E. Byers, B.G. Bierwagen, J.S. Dukes, (2008) 'Five potential consequences of climate change for invasive species'. *Conservation Biology*, 22(3), pp 534-543.

Hijman, R., Kapoor, J., Wieczorek, J., Garcia, N., Maunahan, A., Rala, A., Mandel, A., (2009) 'Global Administrative Areas'. http://www.gadm.org/country [accessed 02/07/18].

Hinkel, J., (2011) '*Indicators of vulnerability and adaptive capacity: towards a clarification of the science-policy interface', Global Environment Change*, volume 21, pp 198-208.

Holden, S. T., Shiferaw, B., (2002) 'Poverty and land degradation: peasants' willingness to pay to sustain land productivity'. In C. B. Barrett, F. M. Place, & A. A. Aboud (Eds.), In the adoption of natural resource management Page 20 of 21 Denkyirah et al., Cogent Food & Agriculture (2017) 'Improving sustainable agricultural production in Sub-Saharan Africa' (pp. 91–102). New York, NY: CABI Publishing.

Hosmer Jr, D.W., Lemeshow, S. and Sturdivant, R.X., (2013) 'Applied logistic regression' *(Vol. 398). John Wiley & Sons. New Jersey.*

Howden SM, Crimp S, Nelson RN (2010) 'Australian agriculture in a climate of change'. In 'Managing Climate Change: Papers from GREENHOUSE 2009 Conference'. (Eds I Jubb, P Holper, W Cai) pp. 101–112. (CSIRO Publishing: Melbourne)

Hulme, M., W.N. Adger, S. Dessai, M. Goulden, I. Lorenzoni, D. Nelson, L.O. Naess, J. Wolf, A.Wreford, (2007) 'Limits and Barriers to Adaptation: Four Propositions. Tyndall Briefing Note No. 20, *Tyndall Centre for Climate Change Research, University of East Anglia,* Norwich, UK, 7 pp

Hughes, A.S., (2016). 'Mixed methods research'. *APS Observer*, *29*(5).

Isgin, T., Bilgic, A., Forster, D.L., Batte, M.T., (2008). Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. *Computers and electronics in agriculture*, *62*(2), pp.231-242.

Jadhav S. K., A A Munot (2007) 'Increase in SST of Bay of Bengal and its consequences on the formation of low pressure systems over the Indian region during summer monsoon season'*, Mausam*, Vol 58, pp 391-396.

Jain, S., Rawat, I., Patil, R., (2016) Livelihood Diversification by Indigenous Communities of Sundarbans, *International Journal of Humanities and Social Sciences*, volume 6, pp 135-141.

Johnson, F.A., Hutton, C.W., Hornby, D., Lázár, A.N., Mukhopadhyay, A., (2016) 'Is shrimp farming a successful adaptation to salinity intrusion? A geospatial associative analysis of poverty in the populous Ganges–Brahmaputra–Meghna Delta of Bangladesh'. *Sustainability Science*, *11*(3), pp.423-439.

Joshi, P.K., Aggarwal, P.K., Tyagi, N.K. and Pandey, D., (2015) 'Role of development policies in combating climate change issues in Indian Agriculture: A frist order assessment of irrigation and fertilizer policies'. In *2015 Conference, August 9-14, 2015, Milan, Italy* (No. 211817). International Association of Agricultural Economists.

IPCC (ed) (2007) Climate change 2007: impacts, adaptation and vulnerability. *Cambridge University Press*, Cambridge.

IPCC, (2014a). Annex II: Glossary [Mach, K.J., S. Planton and C. von Stechow (eds.)]. In: Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 117–130.

IPCC (2014b) Asia. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327-1370

IPCC, (2014c) 'Impacts, Adaptation, and Vulnerability'. *Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Field, C.B., V.R. Barros, D.J. Dokken, K.J.

Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L.White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 899-943

Isham, J. (2002) 'The Effect of Social on Fertiliser Adoption: Evidence from Rural Tanzania'. *Journal of African Economies*. (11), pp 39-60.

Ivankova, N.V., Creswell, J.W. and Stick, S.L., (2006) 'Using mixed-methods sequential explanatory design: From theory to practice'. *Field methods*, *18*(1), pp.3-20.

Janssen, M.A., (2007) 'An update on the scholarly networks on resilience, vulnerability, and adaptation within the human dimensions of global environmental change'. *Ecology and Society*, *12*(2).

Jones, L., Boyd, E., (2011) 'Exploring social barriers to adaptation: insights from Western Nepal' *Global Environmental Change*, *21*(4), pp.1262-1274.

Kaur, J., (2017) '*Impact of Climate Change on Agricultural Productivity and Food Security Resulting in Poverty in India'* (Bachelor's thesis, Università Ca'Foscari Venezia). http://dspace.unive.it/bitstream/handle/10579/10586/855733-1205794.pdf?sequence=2 [accessed 26/08/18].

Kaul, V., Thornton, T.F., (2014) 'Resilience and adaptation to extremes in a changing Himalayan environment'. *Regional environmental change*, *14*(2), pp.683-698.

Kaul, S., G. Ram (2009), 'Impact of global warming on production of jowar in India (special issue: sustainable agriculture in the context of climate change)', *Agricultural Situation in India* 66 (5): pp253-256.

Karnieli-Miller, O., Strier, R. and Pessach, L., 2009. Power relations in qualitative research. *Qualitative health research*, *19*(2), pp.279-289.

Kato, E., C. Ringler, M. Yesuf, E., Bryan, (2011) 'Soil and water conservation technologies: a buffer against production risk in the face of climate change? Insights from the Nile basin in Ethiopia'. *Agricultural Economics*, 42(5), pp 593- 604.

Khatun, D., Roy, B.C., (2012) 'Rural Livelihood Diversification in West Bengal: Determinants and Constraints'. *Agricultural Economics Research Review*, vol *25, pp 115-124*

Kiptot, E., Franzel, S., (2015) 'Farmer-to-farmer extension: opportunities for enhancing performance of volunteer farmer trainers in Kenya'. *Development in Practice*, *25*(4), pp.503-517.

Knowler, D., Bradshaw, B., (2007) 'Farmers' adoption of conservation agriculture: A review and synthesis of recent research'. *Food policy*, *32*(1), pp.25-48.

Kolikow, Steven & Kragt, Marit Ellen & Mugera, Amin W., (2012) "An interdisciplinary framework of limits and barriers to climate change adaptation in agriculture," Working Papers 120467, *University of Western Australia, School of Agricultural and Resource Economics.*

Koch, G., Davis, C. and Stokes, M., (2000) 'Categorical Data Analysis, Using the SAS System'. *Cary, NC*, pp.472-5.

Kumar, A., Sharma, P., (2013) 'Impact of climate variation on agricultural productivity and food security in rural India '(No. 2013-43). *Economics Discussion Papers*.

Le Dang, H., Li, E., Nuberg, I., Bruwer, J., (2014) 'Understanding farmers' adaptation intention to climate change: A structural equation modelling study in the Mekong Delta, Vietnam'. *Environmental Science & Policy*, *41*, pp.11-22.

Le Dang, H., (2014) 'Adaptation to Climate Change: The Attitude and Behaviour of Rice Farmers in the Mekong Delta, Vietnam' *(Doctoral Dissertation),* https://digital.library.adelaide.edu.au/dspace/handle/2440/91786 [accessed 22/07/18].

Lazar, A.N., Nicholls, R.J., Payo, A., Adams, H., Mortreux, C., Suckall, N., Vincent, K., Sugata, H., Amisigo, B.A., Rahman, M. and Haque, A., (2015) 'A method to assess migration and adaptation in deltas: a preliminary fast track assessment (No. 107642)'. *DECCMA working paper, deltas, vulnerability and climate change: migration and adaptation, IDRC project.*

Loë, R., Kreutzwiser, R., Moraru, L., (2001) 'Adaptation options for the near term: climate change and the Canadian water sector'. *Global Environmental Change*, *11*(3), pp.231-245.

Lorenzoni, J.W.I., Few, R., Abrahamson, V., Raine, R., (2009 'Conceptual and practical barriers to adaptation: vulnerability and responses to heat waves in the UK'. *Adapting to climate change: Thresholds, values, governance*, p.181.

NASA, (2018) 'Sea Level' *Global Climate Change*, https://climate.nasa.gov/vital-signs/sea-level/ [accessed 20/08/18].

Ndamani, F., Watanabe, T., (2016) 'Determinants of farmers' adaptation to climate change: A micro level analysis in Ghana'. *Scientia Agricola*, *73*(3), pp.201-208

Nelson, D.R., Adger, W.N., Brown, K., (2007) 'Adaptation to environmental change: contributions of a resilience framework'. *Annual review of Environment and Resources*, *32*., pp 395-419

Nhemachena, C., Hassan, R., 2007, 'Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa, file:///Users/Martin/Downloads/Micro-level_analysis_of_farmers_adaptation_to_cli.pdf [accessed 16/08/18].

Nhemachena, C., Hassan, R., Chakwizira, J., (2014) 'Analysis of determinants of farm-level adaptation measures to climate change in Southern Africa'. *Journal of Development and Agricultural Economics*, *6*(5), pp.232-241.

Ngo, Q.T., (2016) 'Farmers' adaptive measures to climate change induced natural shocks through past climate experiences in the Mekong River Delta, Vietnam'. *African Journal of Agricultural Research,* volume 11, pp 1361-1372.

Nguyen-Van, P., Poiraud, C., To-The, N., (2017) 'Modeling farmers' decisions on tea varieties in Vietnam: a multinomial logit analysis'. *Agricultural economics*, *48*(3), pp.291-299.

Nielsen, J,O., Reenberg, A., (2010) 'Cultural barriers to climate change adaptation: A case study from northern Burkino Faso'. *Global Environmental Change,* (20), pp142-152.

Macchi, M., (2011) 'Framework for community-based climate vulnerability and capacity assessment in mountain areas'. *International centre for integrated mountain development (ICIMOD).*

Maddison, D., (2007) '*The perception of and adaptation to climate change in Africa'*. The World Bank.

Mahadevia, K., Vikas, M., (2012) 'Climate change–Impact on the Sundarbans: A Case Study'. *Int Sci J Environ Sci*, *2*, pp.7-15.

Mainuddin, M., Hoanh, C.T., Jirayoot, K., Halls, A.S., Kirby, M., Lacombe, G., Srinetr, V., (2010) 'Adaptation options to reduce the vulnerability of Mekong water resources, food security and the environment to impacts of development and climate change'. *Canberra: CSIRO: Water for a Healthy Country National Research Flagship*.

Maguza-Tembo, F., Mangison, J., Edris, A.K. and Kenamu, E., (2017) 'Determinants of adoption of multiple climate change adaptation strategies in Southern Malawi: An ordered probit analysis'. *Journal of Development and Agricultural Economics*, *9*(1), pp.1-7.

Mandal, M., and Mandal, S., (2012) 'Impact of natural resource on socio-economic status of Sagar Island. West Bengal, India' *The International Journal of Engineering and Science* 2 (1), pp 76-80.

Masud, M.M., Azam, M.N., Mohiuddin, M., Banna, H., Akhtar, R., Alam, A.F., Begum, H., (2017) 'Adaptation barriers and strategies towards climate change: Challenges in the agricultural sector'. *Journal of Cleaner Production*, *156*, pp.698-706.

McCullagh, P. and Nelder, J.A., (1989) 'Generalized linear models' (Vol. 37). *CRC press. New York.*

McKim, C.A., (2017) 'The value of mixed methods research: A mixed methods study'. *Journal of Mixed Methods Research*, *11*(2), pp.202-222.

Meghwal, P.K., Singh, R.J., Singh, R., (2017) 'A Multinomial Logistic Regression on Farmers' Decision on Technology Adaptation for Nutrition-Sensitive Climate Change Vulnerable Agriculture'. *Indian Research Journal of Extension Education*, *17*(3), pp.7-9.

Meldrum, G., Mijatović, D., Rojas, W., Flores, J., Pinto, M., Mamani, G., Condori, E., Hilaquita, D., Gruberg, H., Padulosi, S., (2018) 'Climate change and crop diversity: farmers' perceptions and adaptation on the Bolivian Altiplano.' *Environment, Development and Sustainability*, *20*(2), pp.703-730.

Mertz, O., Mbow, C., Reenberg, A., Diouf, A., (2009) 'Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel'. *Environmental management*, *43*(5), pp.804-816.

Mimura, N., Hiroshi, A., Seita, E., Takahiro, O., Kuga, H., Mitsuru, T., Kaoru, N., Toshihiro, H., Yasuaki, H., Koh-ichi, F., Takao, M., (2010) "Approaches to Climate Change Adaptation", *The Committee on Approaches to Climate Change Adaption*, https://www.env.go.jp/en/earth/cc/adapt_guide/pdf/approaches_to_adaptation_en.pdf , [accessed 19/08/2018]

Mishra, A.K., Pede, V.O., (2017) 'Perception of climate change and adaptation strategies in Vietnam: Are there intra-household gender differences?'. *International Journal of Climate Change Strategies and Management*, *9*(4), pp.501-516.

A Mitra, A Gangopadhyay, A Dube, ACK Schmidt., Kakoli Banerjee (2009) '*Observed changes in water mass properties in the Indian Sundarbans (northwestern Bay of Bengal) during 1980-2007*', Current Science, Vol 97, No 10, pp. 1445-1452

Mohanaiah S. P., (2009) 'State Agricultural Plan for West Bengal' avaiolable at https://rkvy.nic.in/static/SAP/WB/WB.PDF [accessed 22/08/18].

Momtaz, S., Shameem, M., (2016) 'Adaptation in Climate Change Discourse' *in book: Experiencing Climate Change in Bangladesh*, pp 7-28.

Moorhead, A., (2009) 'Climate, agriculture and food security: a strategy for change'. International Water Management Institute.

Moser, S.C., (2010a) 'Communicating climate change: history,challenges, process and future directions'. *Wiley Interdisciplinary Reviews: Climate Change*, 1(1), pp 31-53

Moser, S.C., (2010b) 'Now more than ever: the need for more societally-relevant research on vulnerability and adaptation to climate change'. *Applied Geography,* 30(4), pp 464-474.

Moser S. C., Ekstrom J. A. (2010) 'A framework to diagnose barriers to climate change adaptation' *Proceedings of the National Academy of Sciences of the United States of America* 107, pp 22026-22031.

Myers, R.H., 1990. 'Classical and modern regression with applications' *Boston, MA: Duxby.*

O'Brien, K., (2009) 'Do values subjectively define the limits to climate change adaptation?' In: Adapting to Climate Change: Thresholds, Values, Governance [Adger, N.W., I. Lorenzoni, and K. O'Brien (eds.)]. Cambridge University Press, Cambridge, UK, pp. 164-180

O'Brien, K., R. Leichenko, U. Kelkar, H. Venema, G. Aandahl, H. Tompkins, A. Javed, S. Bhadwal, S. Barg, L. Nygaard and J. West, (2004) 'Mapping vulnerability to multiple stressors: climate change and globalization in India'. *Global Environ. Chang., 14*, pp- 303-313.

O'Cathain, A., Murphy, E. and Nicholl, J., (2007) 'Why, and how, mixed methods research is undertaken in health services research in England: a mixed methods study' *BMC health* services *research*, *7*(1), p.85-96.

O'Cathain, A., (2010) 'Assessing the quality of mixed methods research: Toward a comprehensive framework'. *Handbook of mixed methods in social and behavioral research*, pp.531-555.

Oluwatusin, F.M., (2014) 'The perception of and adaptation to climate change among cocoa farm households in Ondo State, Nigeria'. *Academic Journal of Interdisciplinary Studies*, *3*(1), p.147- 156.

Osberghaus, D., Finkel, E., Pohl, M., (2010) 'Individual adaptation to climate change: the role of information and perceived risk'. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1674840 [accessed20/08/18].

Pandey, S., Bhandari, H., Ding, S., Prapertchob, P., Sharan, R., Naik, D., Taunk, S.K., Sastri, A., (2007). 'Coping with drought in rice farming in Asia: insights from a cross-country comparative study'. *Agricultural Economics*, *37*, pp.213-224.

Parganiha, O., (2016) 'Farmers perception about climate change and its impacts on agriculture and allied activities in Chattisgrah Plains' (*Doctoral dissertation, Indira Gandhi Krishi Vishwavidyalaya, Raipur).*

Peduzzi, P., Concato, J., Kemper, E., Holford, T.R. and Feinstein, A.R., (1996) 'A simulation study of the number of events per variable in logistic regression analysis'. *Journal of clinical epidemiology*, *49*(12), pp.1373-1379.

Pedzisa, T., Rugube, L., Winter-Nelson, A., Baylis, K., Mazvimavi, K., (2015) The Intensity of adoption of Conservation agriculture by smallholder farmers in Zimbabwe. *Agrekon*, *54*(3), pp.1-22.

Pelling, M., (2010) 'Adaptation to climate change: from resilience to transformation'. *Routledge, New York.*

Pokhrel, B.K., Paudel, K.P. and Segarra, E., (2018) Factors Affecting the Choice, Intensity, and Allocation of Irrigation Technologies by US Cotton Farmers. *Water (20734441)*, *10*(6).

Pound, B., Lamboll, R., Croxton, S., Gupta, N., Bahadur, A.V., (2018) 'Climate-Resilient Agriculture in South Asia: An analytical framework and insights from practice' https://www.opml.co.uk/files/Publications/8617-action-on-climate-today-act/climate-resilient-agriculture-in-south-asia-learning-brief.pdf?noredirect=1 [accessed 27/08/18]

Qin, D., (2016) Positionality. *The Wiley Blackwell Encyclopedia of Gender and Sexuality Studies*, pp.1-2.

Qu, S.Q., Dumay, J., (2011) 'The qualitative research interview'. *Qualitative research in accounting & management*, *8*(3), pp.238-264.

Ramirez, O.A. and Shultz, S.D., (2000) 'Poisson count models to explain the adoption of agricultural and natural resource management technologies by small farmers in Central American countries'. *Journal of Agricultural and Applied Economics*, *32*(1), pp.21-33.

Raghu, P.T., Manaloor, V., (2014). Factors influencing adoption of farm management practices in agro-biodiversity hotspots of India: an analysis using Negative Binomial Count Data model. *J Nat Resour Dev*, *4*, pp.46-53.

Reeves, S., Kuper, A., Hodges, B.D., (2008) 'Qualitative research methodologies: ethnography'. *Bmj*, *337*, p.a1020.

Rickards, L., Howden, S.M., (2012) 'Transformational adaptation: agriculture and climate change'. *Crop and Pasture Science*, *63*(3), pp.240-250.

Rodriguez, G. (2007). 'Generalized Linear Models: Chapter 4 Poisson Models for Count Data' *url* http://data.princeton.edu/wws509/notes/c4.pdf [accessed 17/07/18}.

Rudra, K., (2011) 'The proposal of strengthening embankment in Sundarban: myth and reality' http://www.mcrg.ac.in/rw%20files/RW35/7.Discussion_Paper1.pdf [accessed 20/08/18]

Sahu, N.C., Mishra, D., (2013) 'Analysis of perception and adaptability strategies of the farmers to climate change in Odisha, India'. *APCBEE procedia*, *5*, pp.123-127.

Salik, K.M., Jahangir, S. and ul Hasson, S., 2015. Climate change vulnerability and adaptation options for the coastal communities of Pakistan. *Ocean & Coastal Management*, *112*, pp.61-73.

Sarah, A., Stephen, K., Boateng, A.J., (2017) 'Determinants of rural farmers' decision to adapt to climate change in Ghana'. *Russian Journal of Agricultural and Socio-Economic Sciences*, *62*(2), pp 195-204

Scialabba, N.E.H., Müller-Lindenlauf, M., (2010) 'Organic agriculture and climate change'. *Renewable Agriculture and Food Systems*, *25*(2), pp.158-169.

Schilling, J., K.P. Freier, E. Hertig,, J. Scheffran, (2012) 'Climate change, vulnerability and adaptation in North Africa with focus on Morocco'. *Agriculture, Ecosystems and Environment,* 156, pp 12-26.

Schipper L. W., Krawanchild, D., Chanthy, S. L., (2010) 'Review of Climate Change Adaptation and Tools'. *MRC Technical Paper No 34. Mekong River Comission. Vientiane.*

Shardul, A., Samuel, F., (2008) 'Economic aspects of adaptation to climate change costs, benefits and policy instruments: costs, benefits and policy instruments'. *OECD Publishing.*

Shenton, A.K., (2004) 'Strategies for ensuring trustworthiness in qualitative research projects'. *Education for information*, *22*(2), pp.63-75.

Shikuku, K.M., Winowiecki, L., Twyman, J., Eitzinger, A., Perez, J.G., Mwongera, C., Läderach, P., (2017) 'Smallholder farmers' attitudes and determinants of adaptation to climate risks in East Africa'. *Climate Risk Management*, *16*, pp.234-245.

Singh, O. P., (2007) 'Spatial variation of sea level trend along the Bangladesh coast'*, Mar Geol,* Vol 25, pg 205-212.

Singh, A.K., Maitra, N.J., Chatterjee, P., Pal, P.P., Roy, S.K., (2016) 'Enhancement of Adaptive Capacity to Climate Change in Vulnerable Regions of Sundarban (WB)'. *Indian Research Journal of Extension Education*, *12*(2), pp.31-37.

Si, S.K., (2016) 'Analysis of long term impact of cyclonic disaster 'Aila on Soil Properties and Paddy Yield of Sundarbans, West Bengal, India', *Journal of Experimental Biology*, *4*, pp.142-148.

Smit, B., Burton, I., Klein, R.J., Wandel, J., (2000) 'An anatomy of adaptation to climate change and variability'. In *Societal adaptation to climate variability and change*, volume 1 pp. 223-251

Smit, B. and Wandel, J., (2006) 'Adaptation, adaptive capacity and vulnerability'. *Global environmental change*, *16*(3), pp.282-292.

Skoufias, E., Rabassa, M. and Olivieri, S., 2011. The poverty impacts of climate change: a review of the evidence. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=1803002 [accessed 09/08/18].

Smith, M.S., Horrocks, L., Harvey, A., Hamilton, C., (2011) 'Rethinking adaptation for a 4 C world'. *Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences*, *369*(1934), pp.196-216.

Swart, R., Biesbroek, R., Lourenço, T.C., (2014) 'Science of adaptation to climate change and science for adaptation'. *Frontiers in environmental science*, *2*, p.29.

Teklewold, H., Dadi, L., Yami, A., Dana, N., (2006) 'Determinants of adoption of poultry technology: a double-hurdle approach'. *Livestock research for rural development*, *18*(3), p.2006.

Tenge, A.J., De Graaff, J., Hella, J.P., (2004) 'Social and economic factors affecting the adoption of soil and water conservation in West Usambara highlands, Tanzania'. *Land Degradation & Development*, *15*(2), pp.99-114.

Thomas, M., Thépot, S., Galic, N., Jouanne-Pin, S., Remoué, C., Goldringer, I., (2015) 'Diversifying mechanisms in the on-farm evolution of crop mixtures.' *Molecular ecology*, *24*(12), pp.2937-2954.

Tompkins, E.L., Boyd, E., Nicholson-Cole, S.A., Weatherhead, K., Arnell, N.W. , Adger, W.N., (2009) 'An Inventory of Adaptation to climate change in the UK: challenges and findings'. *Tyndall Centre for Climate Change Research Working Paper*, *135*, p.133.

Tun Oo, A., Van Huylenbroeck, G. and Speelman, S., (2017) 'Determining factors for the application of climate change adaptation strategies among farmers in Magwe District, dry zone region of Myanmar'. *International Journal of Climate Change Strategies and Management*, *9*(1), pp.36-55.

Twyman, C., Morrison, J., Sporton, D., (1999) 'The final fifth: autobiography, reflexivity and interpretation in cross-cultural research'. *Area*, *31*(4), pp.313-325.

Uddin, M.N., Bokelmann, W., Entsminger, J.S., (2014) 'Factors affecting farmers' adaptation strategies to environmental degradation and climate change effects: A farm level study in Bangladesh'. *Climate*, *2*(4), pp.223-241.

Udo, H.M., van Mensvoort, M.E., Bosma, R.H., (2008) 'Integrated agriculture-aquaculture systems in the Mekong Delta, Vietnam: an analysis of recent trends'. *Asian journal of agriculture and development*, *4*(2), pp 51-66.

Wall, E., Marzall, K., (2006) 'Adaptive capacity for climate change in Canadian rural communities'. *Local environment*, *11*(4), pp.373-397.

Wang, S.W., Lee, W.K. and Son, Y., (2017) 'An assessment of climate change impacts and adaptation in South Asian agriculture'. *International Journal of Climate Change Strategies and Management*, *9*(4), pp.517-534.

Willis, K., (2006) 'Interviewing'. In Doing development research, pp144-52.

Van Teijlingen, E.R., Hundley, V., (2001) 'The importance of pilot studies'. *Social research update*, *35*(4), pp.1-4.

Wise, R.M., Fazey, I., Smith, M.S., Park, S.E., Eakin, H.C., Van Garderen, E.A., Campbell, B., (2014) 'Reconceptualising adaptation to climate change as part of pathways of change and response'. *Global Environmental Change*, *28*, pp.325-336.

Vincent, K., (2007) 'Uncertainty in adaptive capacity and the importance of scale', *Global Environmental Change,* volume 17, pp 12-24.

Vittinghoff, E. and McCulloch, C.E., (2007) 'Relaxing the rule of ten events per variable in logistic and Cox regression'. *American journal of epidemiology*, *165*(6), pp.710-718.

Yadav, J.S.P., Bandyopadhyay, A.K., Rao, K.V.G.K., Sinha, T.S., Biswas, C.R., Bandyopadhyay, B.K., Dutt, S.K., (1979) 'Management of coastal saline soils of Sundarbans' *Central Soil Salinity Research Institute,* India. .

Yaméogo, T.B., Fonta, W.M. and Wünscher, T., (2018) 'Can Social Capital influence Smallholder Farmers' Climate-Change Adaptation Decisions? Evidence from Three Semi-Arid Communities in Burkina Faso, West Africa'. *Social Sciences, 7(3), p.33-53.*

Yin, R., (2012) 'Chapter 1: A (Very) Brief Refresher on the Case Study Methods' *in applications of case study research,* https://www.sagepub.com/sites/default/files/upm-binaries/41407_1.pdf [accessed 03/08/18].

Yirga, C.T., (2007) 'The dynamics of soil degradation and incentives for optimal management in the Central Highlands of Ethiopia' *(Doctoral dissertation, University of Pretoria).*

Zahran, S., Brody, S.D., Peacock, W.G., Vedlitz, A., Grover, H., (2008) 'Social vulnerability and the natural and built environment: a model of flood casualties in Texas'. *Disasters*, *32*(4), pp.537-560.

Zhai, F., Zhuang, J., (2009) Agricultural impact of climate change: A general equilibrium analysis with special reference to Southeast Asia'. *Climate Change in Asia and the Pacific: How can Countries Adapt*, pp.17-35.

Zheng, Y., Dallimer, M., (2016) 'What motivates rural households to adapt to climate change?'. *Climate and Development*, *8*(2), pp.110-121.

Appendix

Appendix 1: Participant Characteristics

Participant I.D.	Gender	Age	Location	Employment	Education	Household Size	Relative Land size Cat
1 (pilot)	Male	40	Aripara	Permanent	None	4	Moderate
2 (pilot)	Male	51	Aripara	Short-Term	None	5	Small
3	Male	60	Morolpara	Permanent	Secondary	4 (2 outside the home)	Moderate
4	Male	45	Morolpara	Permanent	Primary	4	Moderate
5	Male	60	Morolpara	Seasonal	None	8 (2 outside the home)	Small
6	Male	80	Aripara	Seasonal	None	3	Small
7	Male	50	Aripara	Short-Term	Primary	5	Small
8	Male	45	Aripara	Seasonal	None	3 (1 outside the home)	Large
9	Male	60	Aripara	Permanent	Secondary	4 (1 outside the home)	Large
10	Male	34	Aripara	Seasonal	None	6	Moderate
11	Male	50	Aripara	Permanent	None	9 (one outside the village)	Large
12	Male	53	Sonagar	Permanent	Primary	5 (1 outside the village)	Large
13	Male	50	Sonagar	Short-Term	None	5 (1 outside the village)	Small
14	Male	42	Sonagar	Permanent	Primary	4	Moderate
15	Male	30	Sonagar	Permanent	Primary	6	Large
16	Male	65	Sonagar	Seasonal	None	3 (1 outside the village)	Small

Note, not all of the participants characteristics were included to protect anonymity