Livelihood vulnerability to climatic stresses: A study of the northeastern floodplain communities of Bangladesh

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April 2018

A thesis submitted to McGill University in partial fulfilment of the requirements of the degree of Doctor of Philosophy

ABSTRACT

Climatic stress vulnerability has cross-scaler influences on development interventions, particularly in developing countries. While most of climate adaptation plans and interventions are developed at national or international scales, relatively little attention has been paid to incorporate the contextual properties of climate vulnerability in adaptation-related decision making. Focusing on the wetland ecosystem dominated northeastern floodplain communities of Bangladesh, this exploratory research seeks to better understand how locally-specific socio-economic and biophysical properties serve to compound vulnerability to climatic stresses; how community members use their resources and assets in order to reduce their sensitivity to climatic stresses; and the extent to which government adaptation programmes reflect context-specific adaptation demands.

Recognizing that Bangladesh is widely acknowledged to be one of the most climate-vulnerable countries in the world, this dissertation begins with a systematic literature review of the state of knowledge related to climate change impacts in Bangladesh. Results indicate a shortage of context-specific scientific studies and identify that northeastern floodplain region is the most understudied area in the country. Issues related to multidisciplinary research approaches and geographic connectedness of research efforts point to potential limitations in the evidence base used to support public policy initiatives on climate change adaptation.

A participatory climate stress exposure assessment reveals that local biophysical changes and resource use behaviors significantly contribute to compounding the impacts of climatic stresses. However, these observations are generally poorly represented in local-level climate model-based stress assessments. Results reveal that community stress perceptions are largely determined by the

temporal occurrence of a climatic event, with a climatic event considered a stress if it occurs in their production period and causes losses to their productivity. Stress perceptions are also influenced by household resource ownership, local innovation and technological uses.

Using the sustainable rural livelihood approach, a mixed method study is then used to better understand the actions taken by households to reduce their livelihood sensitivity to climatic stresses. Households were found to organize, transform and combine their capital assets for generating different livelihood portfolios. Using diverse combinations of assets, two strategies were observed: 1) extending external networks in order to create non-natural resource dependent livelihood opportunities; and 2) extending uses of available natural resources. Both of these strategies required external supports from government programmes or market mechanisms.

Finally, a climate change policy analysis of Bangladesh, supported with key informant interviews, is presented to assess how different government policy interventions have supported local adaptation initiatives. The results reveal that despite recent advancements in climate change-related policy making and institutional changes for supporting local adaptation actions in Bangladesh, plans and policies often fail to respond to local demands. More specifically, the existing climate change adaptation planning and policy processes tend to lack wider public participation and have inadequate coordination with natural resource management policies. This dissertation considers the diverse socio-economic and social-ecological contexts of climate vulnerability in rural Bangladesh. The results offer important research and policy insights to developing more a systematic understanding of climate vulnerability, and how local knowledge might be better integrated into national and international policy processes.

RÉSUMÉ

La vulnérabilité au stress climatique a des implications sur les initiatives de développement à de multiples niveaux particulièrement dans les pays en développement. Alors la plupart des interventions et des plans d'adaptation aux changements climatiques sont développés à l'échelle nationale ou internationale, peu d'attention a été allouée à l'intégration des propriétés contextuelles locales dans la prise de décision relative aux efforts d'adaptation aux changement climatiques. Cette recherche exploratoire étudie les communautés vivant dans les plaines inondables du nord-est du Bangladesh au sein d'un écosystème dominé par les milieux humides. Elle a pour but de mieux comprendre 1) comment les caractéristiques du système socioécologique local aggravent leur vulnérabilité au stress climatique, 2) comment les habitants des communautés locales utilisent leur ressources et leurs actifs afin de réduire la probabilité qu'ils subissent un stress climatique et 3) à quel degré les programmes gouvernementaux d'adaptation répondent aux demandes locales liées au contexte.

Partant du fait que le Bangladesh est parmi les pays les plus vulnérables aux changements climatiques, cette thèse présente d'abord une revue de littérature systématique sur les impacts des changements climatiques au Bangladesh. Les résultats indiquent qu'il a trop peu d'études scientifiques sensibles au contexte et que la région des plaines inondables du nord-est du Bengladesh est la régi la moins étudiée du pays. Des problèmes liés aux approches multidisciplinaires et à l'absence de lien géographique dans les efforts de recherche indiquent certaines limites potentielles dans les données probantes utilisées dans les initiatives de politique publiques liées à l'adaptation aux changements climatiques.

Une évaluation participative de la probabilité de subir un stress climatique révèle que les changements biophysiques et les comportements liés à l'utilisation des ressources aggravent de façon significative les impacts du stress climatique. Ces constatations ne sont toutefois que bien peu prises en compte dans les modèles qui servent de fondement aux évaluations du stress climatique au niveau local. Les résultats révèlent que la perception du stress climatique par la communauté est principalement déterminée par l'occurrence temporelle des évènements climatiques, évènements qui sont considérés comme un stress s'ils ont lieu durant les périodes de production et causent une perte de productivité. La perception du stress est aussi influencée par d'autres facteurs comme la propriété de son domicile, l'innovation locale et l'utilisation des technologies.

Dans le cadre de l'approche centrée sur les sources de revenus durables (sustainable rural livelihood approach), une étude de méthode mixte est déployée pour mieux comprendre les gestes posés par les ménages afin de réduire leur probabilité de vivre un stress climatique. Les ménages organisent, transforment et combinent leurs actifs afin de générer des portfolios de subsistance (livelihood portfolios). Deux stratégies particulières de combinaison des actifs sont observées: 1) étendre son réseau externe afin de générer des opportunités de subsistances qui ne dépendent pas des ressources naturelles et 2) étendre l'utilisation des ressources naturelles disponibles vers d'autres usages. Ces deux stratégies nécessitent le soutien de programmes gouvernementaux ou de mécanismes du marché.

La thèse conclue avec une analyse des politiques climatiques du Bengladesh. Nourrie parn des entretiens avec des informateurs clés, cette analyse évalue comment les différentes interventions gouvernementales ont soutenu les initiatives locales d'adaptation. Les résultats démontrent que malgré des avancées récentes en matière de développement des politiques climatiques et des

changements institutionnels visant à soutenir les initiatives locales d'adaptation au Bengladesh, les plans et les politiques gouvernementales répondent encore trop peu aux revendications locales. En particulier, les processus actuels de planification et de développement de politique d'adaptation peinent souvent à inclure la participation d'un plus large public et présentent des lacunes de coordination avec les politiques de gestion des ressources naturelles.

Cette thèse examine les différents contextes socio-économiques et socio-écologiques de la vulnérabilité climatique des régions rurales du Bengladesh. Les résultats permettent d'offrir des pistes de solutions importantes pour la recherche et pour les politiques publiques afin de développer une compréhension plus systématique de la vulnérabilité climatique et de mieux intégrer la connaissance locale dans le développement des politiques nationales et internationales.

CONTRIBUTIONS TO KNOWLEDGE

This dissertation provides novel empirical insights in support of developing better contextualized climate change adaption planning and policy processes in the northeastern floodplains of Bangladesh.

Chapter 2

- Using a systematic review approach, I assess the historical evolution of climate change research, existing research gaps and their implications for public policy in Bangladesh. Most research has been undertaken at a national scale, although the need for local-level studies is well acknowledged. Multidisciplinary studies were concentrated in six main groups: socio-economic, environmental conservation, technological innovation and environmental risks, health impacts and impacts on fish resources. The northeastern floodplain is the most understudied area in Bangladesh.

Chapter 3

- Using empirical evidence, I identify that local changes can alter a climatic event to a stress, which would not be represented in local-level climate models. While both socioeconomic and climatic factors are considered in explaining multiple exposures, very little is known about how the local bio-physical changes intensify a climatic event to a stress. I identify land use practices, resource types and their uses can serve to constrain the adaptation measures available to affected communities. I also find that climatic stress perceptions among community members vary with local innovations and practices.

Chapter 4

- I present and test a methodological approach designed to better explain the adaptation measures taken by community members to sustain their livelihoods in response to climatic stresses. I find that community members organize, transform, and combine their livelihood assets to reduce climate sensitivity through generating non-natural resource dependent activities and intensifying natural resource uses. I also identify a strong role for external supports provided either by government, non-government organizations or market mechanisms.

Chapter 5

- Assessing climate change-focused policy making and institutional adaptation in Bangladesh, I find that the government has made significant advancement in establishing institutional structures that can support adaptation actions. Evaluating local communities' responses to government interventions, I find that discrepancies still remain between national adaptation plans and local demands, which results from insufficient knowledge on climatic impacts in local level.

CONTRIBUTIONS OF CO-AUTHORS AND REMARKS ON STYLE

This thesis follows a manuscript-based format. As a result, there is some repetition in the text.

I am the primary author of all the chapters of the thesis. Chapter 2 is co-authored with Dr. Gordon M. Hickey, Dr. James D. Ford and Malcolm A. Egan. Chapter 3 is co-authored with Dr. Gordon M. Hickey, Dr. James D. Ford, Dr. Brian E. Robinson and Ekhlas Mia. Chapter 4 is coauthored with Dr. Gordon M. Hickey, Dr. James D. Ford and Dr. Brian E. Robinson. Chapter 5 is co-authored with Dr. Gordon M. Hickey. Chapter 2 and Chapter 4 have been published in the journals Regional Environmental Change and Ecological Economics respectively, and Chapter 3 and Chapter 5 are under review in the journals Land Use Policy and Environmental Management respectively.

I designed the study, including the conceptual and methodological frameworks, and undertook the systematic review of academic literature. I obtained research funding and travelled to the field to collect the primary data and undertook all quatitative and qualitative data analysis presented in this thesis. Dr. Gordon M. Hickey provided academic supervision, intellectual input, methodological and theoretical development, research funding and writing support for all chapters. Dr. James D. Ford and Dr. Brian E. Robinson provided academic input, critical feedback and writing support. Malcolm A. Egan and Ekhlas Mia aided with data collection and analysis for Chapter 2 and Chapter 3 respectively.

ACKNOWLEDGEMENTS

To begin with, I thank my PhD supervisor Dr. Gordon M. Hickey not only for his academic supervision and advice but also for giving me moral support throughout this journey. His conscious surveillance of my work has rescued me from many dead ends that I have experienced at different stages of my study. I undoubtedly acknowledge that his restless effort to harness my understanding on scientific process has brought me to this stage. I feel that his advice and inspiration has had far more effect on my life than only this research.

I thank the members of my PhD advisory committee: Dr. Jim Fyles, Dr. James D. Ford and Dr. Brian E. Robinson, who helped me to conceptualize, develop and refine the concepts of this thesis. Their wise support and enthusiastic involvement have inspired me to keep going.

I acknowledge Dr. Ford and Dr. Robinson for helping me to conceptualize and analyze specific chapters. I thank Ekhlas Mia, who is an elderly villager, for his outstanding support in the field and also for enlightening me with many local issues without which this study would remain unfulfilled.

I convey my deepest gratitude to Shah Abu Sayeed Choudhury, MD. Mozammel Haque and Shiplu Chanda for their unconditional support in collecting field data and managing the process. In particular, my heartiest appreciation is for Kazi Newaz Mustafa, without whom the fieldwork would have been impossible.

This thesis is funded and supported by the Inter-Governmental Panel on Climate Change (IPCC), Prince Albert II of Monaco Foundation, the William Dawson Scholar Award McGill University, the South Asian Network for Development and Environmental Economics (SANDEE) and the

Asian Centre for Development (ACD). I would also like to thank Dr. MD. Salehuddin, Dr. A.K. Enamul Haque and Dr. MD. Qumruzzaman Chowdhury for providing me with institutional support during data collection in Bangladesh. Dr. Muntaha Raquib, Dr. Belal Uddin, Dr. Munim Zoardar and Dr. Swapan K. Sarker of Shahjalal University of Science and Technology, Sylhet, Bangladesh supported me with conceptualizing many theoretical and local issues. I am in debt to Metropolitan University, Sylhet, Bangladesh for hosting me.

I must thank all of the people I interviewed: villagers, local leaders, government officials, guides and many more. Without hesitation, they extended their help to me either by providing me with data or with technical supports, and made the challenging data collection process a pleasant memory.

My sincere acknowledgement is to my lab mates. Dr. Archi Rastogi, Dr. Kristen Lowit, Dr. Andrew Song, Dr. Elsa Berthet, Dr. Nicolas Brunet, Dr. Arlette St Ville, Dr. Matthieu Mondou, Dr. June Po, Colleen Edit, Stephanie Shumsky, Lingaraj Jayaprakash, Graeme Reed, Ashlee-Ann Pigford, Samantha Darling and Stephen Clare your every word makes me worthy and costs me nothing. Without your intellectual and mental support, motivation and criticism, this journey would be completely different. My dear friends: Dr. J.C. Deb, Mohasinul Haque, MD. Mahmudul Haque and A. Halim thank you very much for listening to my research ideas and sharing your views with me.

Shrabanti R. Shil and Atia Hamida Ipshita thank you very much for inspiring me every time I needed. And of course Mahfuza Akter, who never left me alone in this long journey, deserves my heartiest acknowledgement.

Finally, none would have been possible without the unconditional support and affection of my family members: Anjuman Ara Parvin, Dr. Khandoker kashfia sultana, Major MD. Mostafizur Rahman psc, H.M. Shahriar, MD. Akhteruzzaman and Rayan Yusuf Zaman. This work is dedicated to my parents Fazila Begum and MD. Abdul Aziz.

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LIST OF ABBREVIATIONS

WOK	Web of Knowledge
IPCC	Intergovernmental Panel on Climate Change
UNFCCC	United Nation Conference on Climate Change
COP	Conference on Parties
GBM	Ganges-Meghna-Brahmaputra
DoE	Department of Environment
FGI	Focus Group Interviews
SRL	Sustainable Rural Livelihoods
FGD	Focus Group Discussions
FAP	Flood Action Plan
NAPA	National Adaptation Program of Action
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
NPDM	National Plan for Disaster Management
MPHA	Master Plan for *Haor* Areas

CHAPTER 1: GENERAL INTRODUCTION

1.1 Literature review

Climate vulnerability is defined as *'…. the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with, adverse impacts of climate change'* (Intergovernmental Panel on Climate Change (IPCC), 2007). Climate vulnerability is a complex and dynamic policy challenge, interacting with social, political, economic and ecological factors at global, regional, national and local scales (Adger et al., 2005; Adger, 2006). The interpretation of climate vulnerability therefore differs across sectors and contexts (Jurgilevich et al., 2017). Despite the complex nature of climate vulnerability, governments and communities internationally are taking actions to help support climate adaptation, defined by the IPCC (2014) as *'the process of adjustment to actual or expected climate and its effects'.* The IPCC Working Group II Fifth Assessment Report (2014) noted that different regions are responding to the impacts of climate change through climate-sensitive decision making in diverse ways. This reflects the growing understanding of climatic uncertainties, the types of resources available for different actions and the socio-political dynamics in different contexts (Adger et al., 2005; Thomas and Twyman, 2005).

Bangladesh is considered one of the most climate-affected countries on Earth (Ayres et al., 2014), experiencing diverse climatic stresses (e.g., floods, droughts, storms) with significant implications for its natural resource dependent communities and households (Ahmed et al., 1999). The nature and impact of these climatic stresses vary across the country because of diverse geographic properties, resource abundances and resource management practices. For example, soil salinity and massive oceanic storms are common in the southern and southeastern regions of Bangladesh (Pouliotte et al., 2009), while drought and seasonal flooding are frequent in the northern and central regions of the country (Barua and van Ast, 2011; Jabeen et al., 2010; Etzold et al., 2014) with the northeastern region particularly affected by flash-flooding, seasonal flooding and drought (Masood and Takeuchi, 2016).

Beyond the local geographic and resource use characteristics of climatic impacts, resource management policies, strategies and institutional approaches also influence local levels of vulnerability and adaptation (Cash et al., 2006; Adger et al., 2005). Despite generally high levels of livelihood vulnerability to climate-related stresses in Bangladesh (Alam et al., 2011), locally-based knowledge and systematic, in-depth research that can inform policy options and approaches remain relatively scarce. Consequently, much of the existing adaptation-related policy tends to be 'top down', centralized and generalized, with potential biases and omissions limiting their effectiveness in rural regions (Cash et al., 2006; Larson and Soto, 2008; Alam et al., 2013). In particular, knowledge gaps concerning the complex relationships between climatic stress and livelihood vulnerability in rural communities has created many policy challenges (Kelly and Adger, 2000). This PhD research seeks to help address these gaps by better identifying the nature and intensity of the existing challenges posed by climatic stresses and the resources that might be available to offset vulnerability in northeastern Bangladesh.

1.1.1 Rural livelihoods and climate change policy challenges

IPCC (2012, p. 798) defined livelihoods as *'……. the ensemble or opportunity set of capabilities, assets, and activities that are required to make a living'*. Livelihoods in the rural areas of developing countries are often characterized by extreme poverty, social discrimination and over-dependence on natural resources (Barnett et al., 2008). In the presence of climate change-related stresses, natural resource dependent and climate-sensitive livelihood activities become particularly threatened (Hahn et al., 2009). This points to two key research and policy challenges: first, local resource use and distribution politics (Adger et al., 2006); and, second, the degree of livelihood uncertainty due to climatic variability (Ellis, 2000a). Both these challenges can be better understood when climatic influences on locally-specific socio-economic and social-ecological properties are studied (Ford and Pierce, 2010). However, knowledge of the diverse contexts within a particular country may not be available. For example, certain areas may get more priority in policy than others due to political interests, highly visible climatic impacts (e.g., extreme loss of life and property) and media coverage (Weichselgartner and Kasperson, 2010; Miah et al., 2011; Schäfer and Schlichting, 2014). It has been argued that climate change and its stresses will likely reduce a state's capacity to provide opportunities and services for affected people (Barnett, 2003), and curtail rural communities' capability to respond to climatic impacts (Tompkins and Adger, 2004; Smit and Wandel, 2006; Morton, 2007). Moreover, imbalanced information and knowledge may lead to inequitable distribution of scarce resources leading to a potential rise of conflict and social insecurity (Barnett and Adger, 2007). This issue is particularly relevant to developing countries where knowledge and research infrastructures have not been sufficiently developed (Holmes and Clark, 2008).

1.1.2 Rural livelihood vulnerability in Bangladesh

Bangladesh is located just below the Himalayan mountain range distributed across India, Nepal, China and Bhutan; and a number of trans-boundary rivers that originat in the Himalayas travel through the country before discharging in the Bay of Bangla bordering the southern part of the country (Mirza, 2002). Because of its low topographic features, riverain land forms and its location in the monsoon climatic region, Bangladesh experiences diverse climatic stresses that include flood, cyclone, oceanic surges, saline water intrusion, sea-level rise, drought and ground water depletion (Karim and Mimura, 2008; Shahid and Behrawan, 2008; Alauddin and Sarker, 2014). Recent studies reveal that the frequency, extent and duration of all these climatic phenomena have intensified in the last three decades (Ali, 1999; Mirza, 2002; Ahmed and Ahmed, 2003; Karim and Mimura, 2008; Islam et al., 2014; Nowreen et al., 2015; Kay et al., 2015). Faced with diverse climatic impacts, it is extremely difficult for both the government and affected rural communities to support and promote sustainable socio-economic development (Alam et al., 2011). Nevertheless, the country has instituted a number of significant adaptive responses to climatic impacts in both policy and practice, although much remains to be done (Rawlani and Sovacool, 2011; Ayres et al., 2014; Islam et al., 2014).

To characterize the nature of climatic events and their influences on rural livelihoods, a number of studies related to climate vulnerability have been conducted in Bangladesh (McDowell et al., 2016), resulting in diverse perceptions and policy interpretations (McDowell et al. 2016; Jurgilevich et al., 2017; Singh et al., 2017). Most previous research on climate vulnerability in Bangladesh have broadly sought to answer questions related to: i) the present and future natures (e.g., duration, extent, frequency) and impacts of different climatic stresses; ii) the socio-economic factors that limit the capacity of affected populations to adapt to the stresses; and iii) the policy interventions and their limitations for facilitating future interventions. Drawing on meteorological perspectives (Füssel, 2007; O'Brien et al., 2007), many studies have characterized the nature of climatic stresses and estimated their impacts on different livelihood-related production sectors, including agriculture and fisheries in Bangladesh (Karim et al., 2012; Rahman et al., 2012; Rajib and Rahman, 2012; Hossain and da Silva, 2013; Rabbani et al., 2013; Hasan et al., 2014). At the same time, these studies have forecast future climatic stress potentials at national and sub-national scales contributing significantly to national policy processes (Kay et al., 2015; Nowreen et al., 2015). For example, Begum and Fleming (1997) and Mirza (2002) predicted that sea level rise and increasing river water discharge due to global warming will change and alter the natural flood properties in Bangladesh, and that this will influence agriculture and other rural economic activities. Later, it became clear that climatic events have been changing, with impacts shifting from one region to another (Shahid and Khairulmaini, 2009). As a consequence, many natural resource dependent communities in rural Bangladesh have been experiencing new types of stress. Such studies have been primarily based on a 'scientific framing' (O'Brien et al., 2007), particularly focused on how greenhouse gas emissions and the subsequent global warming will drive climatic vulnerability. However, as noted by Burton et al. (2002) and Füssel and Klein (2006), this approach generally fails to adequately detect the socio-economic dimension of vulnerability.

The socio-economic factors associated with climate vulnerability are known to be highly context specific, where a context can be defined in terms of ecological and/or political boundaries and the sector of interest along with its associated properties (Füssel, 2007; O'Brien et al., 2007). More specifically, in a single ecological or political system, diverse livelihood groups may reside along with varied levels of dependence on natural resources. Each of these groups may not be equally vulnerable (Simelton et al., 2009). It is, therefore, important to identify what type of livelihood activities and sectors need particular attention within the defined boundary (Preston et al., 2011; Jurgilevich et al., 2017). The identification of contexts can be better facilitated by exploring questions related to *who* and *what* is vulnerable to what kind of climatic stress (Schröter et al., 2005; Moser, 2010). Research into the socio-economic aspects of climate vulnerability in Bangladesh has been exploring how rural poverty, disproportionate distribution of livelihood resources and socially embedded political marginalization are jointly enhancing vulnerability (Kelly and Adger, 2000). These studies reveal that climatic impacts like water stagnancy and saline water intrusion are altering the land and resource qualities in Bangladesh, resulting in a dynamic change in rural livelihood practices (Pouliotte et al., 2009). Rural communities in Bangladesh, who historically depend on agricultural livelihoods, are diversifying their livelihood practices to reduce risks (Ahsan et al., 2011; Kartiki, 2011). As a consequence, a widespread shift in land use practice, rural-urban migration and seeking employment in non-natural resource dependent livelihood activities have been emerging (Pouliotte et al., 2009; Hassani-Mahmooei and Parries, 2012; Etzold et al., 2014). However, it has also been observed that vulnerability has intensified as a consequence of widespread poverty, limited access to natural resources and insufficient institutional development at the local level (Rahman et al., 2015; Szabo et al., 2016; Islam, 2017; Haq and Ahmed, 2017; Alam, 2017). In relation to rural livelihoods, resource distribution and access are particularly important because ownership of resources enhances the capacity of affected communities to take adaptive actions (Ribot, 2014). For example, Pouliotte et al. (2009) observed that the land use decisions of small land owners in the southern coastal region of Bangladesh depended on the decisions of larger land owners, while many such decisions do not support the adaptation actions of the poorer households. As a result, these smaller landholders move to urban areas to shift their livelihood practices, losing control over land resources, and becoming potential victims of urban climate vulnerability (Adri and Simon, 2017).

Despite the increasing intensity of climatic stresses, Bangladesh has been gradually mainstreaming climate-sensitive adaptation actions in its national development policy and programming (Ayers et al., 2014). Bangladesh was one of the pioneering countries to develop a National Adaptation Plan of Action (2005), which was further revised and developed through the Bangladesh Climate Change Strategies and Action Plan (BCCSAP, 2009). These plans envisioned the need to identify adaptation deficits, and intended to locate potential sectors and regions where adaptation supports are necessary (Ayers and Huq, 2009; Ayers et al., 2014). The broad aim of these plans was to enhance the capacity of affected communities by ensuring poverty eradication, sustainable livelihoods, efficient governance systems, infrastructural development and knowledge generation (Ayers and Huq, 2009; Heltberg et al., 2009; BCCSAP, 2009; Rai et al., 2014). In order to ensure financial support for implementing the plans, the government established funding mechanisms supported by both the national government and international donor agencies (Huq and Rubbani, 2011). Bangladesh's intention to combat climate-related impacts has also been well reflected in the National Sustainable Development Strategies and in other more recent development plans in almost all sectors (NSDS, 2010). Despite these advances, the national development and adaptation plans have been heavily criticized because of their generalized nature, insufficient contextualization and the inadequate and inefficient incorporation of affected communities' knowledge and viewpoints in the planning processes (Parvin and Johnson, 2015; Tashmin, 2016).

Further, there has been a general lack of adequate science and policy interaction in the policy and planning process leading to incongruences and significant knowledge gaps (Haque et al., 2017). As a result, it is difficult to identify which sector and region needs priority research and data collection to inform adaptation policies (Preston et al., 2011; Jurgilevich et al., 2017). Despite the growing number of studies, it remains difficult to ascertain the extent to which usable and salient knowledge is available to decision-makers (Cash et al., 2002; Lemos et al., 2012; Ford et al., 2013; Lalor and Hickey, 2014). Nationally, the northeastern floodplain of Bangladesh has been identified as one of the areas that has received the least research priority, despite being exposed to significant climatic stresses (Miah et al., 2011).

1.1.3 Livelihood vulnerability to climatic stresses in the northeastern floodplain of Bangladesh

The northeastern floodplain is considered one of the most climate vulnerable parts of Bangladesh because of its geographic location, climatic properties and ecological nature (Miah et al., 2011; Haque et al., 2017). This area is bordered by Assam and Meghalaya mountainous territories and receives the highest rainfall in Bangladesh (Nowreen et al., 2015). The area also falls under one of the most complex trans-boundary river systems in South Asia, known as the Barak river tributary (MPHA, 2012). A total of 23 trans-boundary rivers flow through the floodplain, and serve as the main ecological driver of the wetland dominated ecosystem of the area. These wetlands are locally known as *Haor,* which are enriched with natural resources and biodiversity (MPHA, 2012). According to the Bangladesh *Haor* and Wetlands Development Board (BHWBD, 2012), *haors* are *the bowl-shaped depressions of considerable aerial extent lying between natural levees of rivers or high lands of the northeast region of Bangladesh. In most cases haors have been formed as a result of peripheral faulting leading to the depressions*. During the monsoon period, most of the wetland areas are submerged, while water remains only in some permanent depressions in winter (MPHA, 2012). These depressions serve as habitat for fish resources, while agriculture is extensively practiced in the dry areas. A large number of populations directly or indirectly depend on these *haors* for their primary livelihood activities, particularly agriculture and fisheries (Rahman et al., 2015).

The wetland resource dependent communities of this area are subjected to extreme poverty and economic marginalization (Ahmed et al., 2008). In particular, economic inequality is extremely high in the area, dividing the resident communities into two contrasting economic groups (Rahman et al., 2012). This divide influences the political power differentials and reduces the poorer group’s capacity to get access to the natural resources for livelihood activities (Khan and Haque, 2011; Rahman et al., 2012). Most of the population depends on agriculture for their primary livelihood, despite landlessness being a common feature (Rahman et al., 2015). Landless or extremely poor farmers depend on shared cropping systems (MPHA, 2012). Fisher groups are particularly marginalized in this region driven by government fisheries resource management policy that make it difficult to obtain property rights (for more details see Khan and Haque, 2011; Rahman et al., 2012; Rahman et al., 2015; Hossain et al., 2016).

Climatically, the floodplain system experiences both flash-flooding and regular seasonal flooding, with an increasing frequency, duration and extent of these stresses reducing agricultural and fisheries productivity (Nowreen et al., 2015). The consecutive and highly destructive flash-flooding events experienced in 2014, 2015 and 2017 have underlined the urgency of developing more locally-appropriate policies and actions that can better support resource dependent communities in the area.

1.2 Research need

Adaptation policies need to be pragmatic, problem oriented and participatory (Dovers and Hezri, 2010). Previous studies have suggested that policy making based on rigorous scientific evidence (e.g., climate modeling) is not sufficient for guiding vulnerability reduction strategies because of the multidimensionality of climatic impact (Laukkonen et al., 2009). Furthermore, most prior studies that attempt to predict future climatic challenges are limited in order to obtain precision (Dessai et al., 2009). As such, there is an urgent need for a more holistic understanding of vulnerability in order to address the present limitations in knowledge on this important subject (Adger, 2006). Such an understanding can be achieved by identifying which components of vulnerability remain missing within scientific, community and policy perspectives. This necessity is particularly acute in countries like Bangladesh, where diverse climatic impacts are widespread and people are largely dependent on climate-sensitive natural resources for their livelihoods (Karim and Mimura, 2008; Islam et al., 2014). Although several studies have been conducted in Bangladesh to characterize and assess vulnerability from different points of view, there is little research that compares and combines these views (O'Brien et al., 2007). Thus, research is needed to develop an approach that can more systematically identify the missing components of vulnerability, characterize and integrate them, and describe their policy implications.

1.3 Motivation for the research

Despite the global agreement and active involvement and interventions of global leadership on climate change, negligible advancements have been made to meaningfully regulate the human drivers of climate change (Füssel, 2007). Many climatic stresses are known to result in persistent poverty, socio-economic disparity and continued loss of lives and resources, particularly among the rural smallholders of developing countries (Adger and Kelly, 1999; O'Brien et al., 2004). While international efforts struggle to bring meaningful change, more locally-based adaptation measures, often emerging from the joint interventions of governments, non-government organizations and affected communities, are making significant contributions to adaptation in response to climatic stresses (Baker et al., 2012). There is a growing consensus regarding the need to further understand the potential for public policy institutions to deliver more localized approaches to enhance climate-related innovation, adaptation and implementation (Urwin and Jordan, 2008). This understanding can be facilitated by more precise identification of existing knowledge gaps and enhanced vulnerability assessment that can reduce the maladaptation risk of policy making (Ford and Pearce, 2010).

1.4 Research objective

The objective of my research was to better understand livelihood vulnerability to locally observed climatic stresses in the natural resource-dependent livelihood systems of northeastern Bangladesh with a view to informing climate-related adaptation policy, research and practice.

1.5 Research questions

Based on my research objective, I sought to answer the following broad research question:

To what extent are the livelihoods of natural resource dependent communities in the northeastern floodplain of Bangladesh vulnerable to climatic stresses (e.g., drought, over and under rainfall and floods), and how do communities and government respond to this vulnerability?

This generalized research question was broken down into four sub-questions, each of which forms the basis for a results chapter (manuscript) of the thesis:

a) *What is known, what is not known, and what has been identified as being necessary to know about climate change vulnerability and adaptation in Bangladesh?* (Chapter 2)

   Identifying scientific knowledge gaps can help with efforts to improve adaptation-related policy by suggesting areas requiring further research attention.

b) *How do exposure factors (e.g., climatic and non-climatic) influence household-level livelihood activities in our study area?* (Chapter 3)

   Understanding the climatic and non-climatic factors of stress exposure and their influence on livelihood activities is the main motivation for this research question. Answering this question involves the assessment of community perceptions, resource and land use practices, and local bio-physical changes.

c) *How do capital asset and local institutional factors affect household-level livelihood sensitivity in the natural resource dependent communities located in our study area?* (Chapter 4)

Both qualitative and quantitative assessments of livelihood sensitivity at the household-level are used to inform policy options and future research on livelihood vulnerability.

d) *How can adaptation policies better function to support adaptive capacity and sustainable rural livelihoods in the study area?* (Chapter 5)

Public policy analysis designed to offer insights of relevance to national and regional policy actors seeking to foster community capacity in the study area.

1.6 Theoretical foundation

This dissertation has been built upon two well-developed and widely used theories: 1) the human dimension of the vulnerability assessment framework (Turner et al., 2003; O'Brien et al., 2007); and 2) the Sustainable Rural Livelihoods (SRL) approach (Scoones, 1998). These theories are described in detail below.

1.6.1 Human dimension of the vulnerability assessment framework

Climate change studies have generally adopted the "human dimension" of vulnerability from Sen's (1981) work on hunger and famine in order to understand the socio-economic aspects of vulnerability (Ribot, 1995). The human dimension approach to vulnerability assessment generally views human and ecological systems as two inter-connected systems, and considers vulnerability to be the outcome of not only changing climatic properties, but also of social, economic, institutional, political and technological processes (O'Brien et al., 2007). Focusing on the capacity of a household to anticipate and cope with climatic impacts, this approach assumes that insufficient asset accumulation (in the present) limits the capacity of a household to respond to future climatic impacts (Kelly and Adger, 2000; Grasso et al., 2014; Dumenu and Obeng, 2016).

Climate change brings uncertain and transformative changes to both society and natural resource systems, and its impacts are adversely felt when it limits a household's capability to grow and develop (O'Brien et al., 2007). Sen (1981) and Devereux (2001) posited that household vulnerability depends on the availability of assets to which a household has 'full rights'. Assets buffer risk, enhance recovery and, based on the level of possession, generate disproportionate outcomes for the households in a community (Ribot, 1995). Hence, questions related to climate vulnerability are strongly connected to locally-embedded poverty, economic inequality and institutional structures (Eisenack et al., 2014). Poorer sections of a community are more prone to falling into poverty traps due to repeated climatic events that limit their capacity to sustain livelihoods, thus making them the worst victims of climate change (Heltberg et al., 2009; Paavola, 2008). Notably, access and entitlement to assets are governed by institutional processes that extend beyond those of the national government and its legal frameworks; indeed, the distribution of assets is highly connected to social norms and locally-embedded political systems (Ostrom, 1990). In a socio-economically unequal society, poorer people tend to have limited participation levels in both local and national institutional processes (O'Brien and Liechenko, 2000; Adger, 2003; Eakin, 2005) because of their insufficient social networks and political power (Gentle and Maraseni, 2012). Therefore, it is often argued that vulnerability reduction can be enhanced by securing social justice for, and the economic inclusion of, marginalized groups (Adger et al., 2006). Hence, the human dimension of vulnerability stresses the importance of deliberative policy making that values and facilitates public participation in the development of empirically-guided adaptation strategies.

Despite being widely used and accepted, the human dimension approach to vulnerability assessment has been criticized for its strong connection to socio-political systems (Miller et al., 2010). Although this approach acknowledges the interconnectivity between human and ecological systems at a conceptual level, Turner (2010) has suggested that it fails to provide an explicit schema for characterizing this interconnectivity. Moreover, the central objective of this approach is to assess a system's susceptibility to being harmed by specific climatic stresses, however it fails to adequately take into account the extent to which it can absorb the stress (Gallopín, 2006).

1.6.2 Sustainable Rural Livelihood approach

Livelihood sustainability is essential for adequate stocks and flows of food, income, shelter and other necessities (Chambers, 1997). Chambers and Conway (1991) and Ellis (2000a) have posited that rural livelihoods are environmentally sustainable when they maintain the assets on which they depend, and socially sustainable when they can cope with and recover from shocks. Livelihood sustainability can be better understood by characterizing livelihood assets, which include social, financial, human, manufactured and natural capitals. These assets are jointly known as the "asset pentagon" (Chambers, 1997; Scoones, 1998; Bebbington, 1999; Ellis, 2000a).

Putnam (1993, p. 35) defined social capital as "*the features of social organization, such as trust, norms, and networks that can improve the efficiency of society by facilitating coordinated actions*". Social capital engenders collective actions that organize people in order to provide them access to, and use of, institutional resources (Ostrom, 1995; Brondizio et al., 2009; Rahman et al., 2012).

Bebbington (1999) and Pretty (2003) posited that different forms of social capital play a supportive role in gaining access to other assets and services (e.g., property rights, credit access, development incentives). For example, bonding (connecting community members with "strong ties"), bridging (connecting neighboring community members with dissimilar situations through "weak ties"), and linking (connecting community members with power and financial resources through "vertical ties") social capitals can promote self-governance with regards to common resources, knowledge and information sharing, and cross-scaler institutional, political and economic interactions (Dale and Sparkes, 2007; Dale and Newman, 2010; Rahman et al., 2015; Saint Ville et al., 2016).

Human capital refers to the qualitative and quantitative availability of labor, skills, knowledge and experiences (Rakodi, 1999; Morse and McNamara, 2013; Rahman et al., 2012). Sen (2000) suggested that this capital widens opportunities for individuals to participate in institutional and market mechanisms and enhances their capability to choose favorable livelihood options. For example, Datta et al. (2007) found that Western European immigrants in London were employed in high earning managerial jobs, while immigrants from the Global South and East Europe tended to secure employment in low income generating sectors (e.g., daily wage earning) due to their inadequate skills, education and training. Since investing in generating human capital helps individuals diversify their livelihood opportunities in non-natural and wage-earning activities, it can also help enhance their production possibilities and their capacity to cope with risks and uncertainties (Ellis, 2000b; Rickards and Howden, 2012).

Saving and credit opportunities (or their substitutes) that can be directly invested into production activities are regarded as financial capital. This asset can also be invested for the purpose of securing other assets like natural and manufactured capitals (Babbington, 1999; Rakodi, 1999; Ellis, 2000a). For example, fishing communities in Bangladesh pay rental fees to the government in order to obtain wetland fishing rights (Rahman et al., 2012). In addition, buying water from community-based irrigation systems during the drought season is a common practice in Tanzanian indigenous peasant communities (Gillingham, 1999). Rakodi (1999) posited that, when invested in production inputs (e.g., buying improved seeds, fertilizers and pesticides for increasing agricultural productivity), financial capital can increase the productivity of other assets such as natural capital. However, climatic uncertainties can threaten these investments and intensify social inequality. For example, the rural mountain communities of Nepal generally face frequent agricultural production losses due to irregular rainfall, which is an additional burden to households that are already living in poverty (Gentle and Maraseni, 2012).

The equipment and infrastructure (e.g., roads, irrigation systems, embankments, etc.) used to maintain livelihood productivity are referred to manufactured or physical capital (Morse and McNamara, 2013). This type of asset can be owned and developed both socially and privately. The IPCC (2001) suggested that the poorest people in a society usually occupy marginal areas, which do not have adequate physical protection from climatic impacts. Hence, Rakodi (1999) suggested that investments in manufactured capital (e.g., transportation network building, irrigation channel development, etc.) should be aimed at protecting the poor from marginalization and external stresses. However, such investments need to be adjusted with local bio-physical and ecological properties (Brammer, 2010). In addition, the level of privately owned manufactured capital may significantly contribute to economic inequality and social marginalization. For example, Heltberg and Tarp (2002) observed that farming households in Mozambique possessing privately owned manufactured capital (e.g., a motorcycle, radio, television, mobile phone) enjoyed wider market participation opportunities for selling their products, which in turn afforded them an economically advantageous position in society. In addition, Heltberg et al. (2009) noted that the loss of this capital due to climatic impacts (e.g., destruction of houses from floods or cyclones) may exacerbate asset inequality and lead to a “poverty trap”, as the poorer sections of society usually lose more than the richer sections, and recovering lost assets tends to be more difficult for them due to their generally high cost of repair and replacement.

According to Rakodi (1999, p.316), natural capital is “*made up of the natural resource stocks from which resource flows useful to livelihoods are derived, including land, water and other environmental resources*”. Access to and ownership of natural resources is central to rural livelihood sustainability (Morse and McNamara, 2013). Babbington (1999) suggested that households possessing high levels of natural capital have a marked advantage in terms of obtaining support from and influencing external agents (e.g., government institutions). Poor households that do not own private natural resources may rely on common or open access resources (Rakodi, 1999; Schlager and Ostrom, 1992). However, locally-embedded political processes, conflicts over resource use, and government policy may limit the ability of poorer households to access such resources (Agrawal, 2000). Consequently, their insufficient capacity to cope with climatic stresses, and the resultant loss of natural capital, may lead to recurrent vulnerability (Carter and Barrett, 2006).

Chambers (1989) and Rakodi (1999) have suggested that capital assets are connected to each other. However, rural households tend not to invest all their capital assets towards a single activity; instead, they often opt to distribute their assets in order to diversify their livelihood strategies through agricultural intensification (obtaining more output from a unit of land by investing more in production inputs), extensification (increasing land for cultivation) and migration to seek non-farming activities (Scoones, 1998). Rakodi (1999) and Mphande (2016) suggested that the selection of strategies depends on three conditions: i) the internal structure of a household (e.g., the ratio of employed to unemployed household members, timely availability of usable workforce, inheritance of parental livelihood activities, etc.); ii) the geographic locations of the households (e.g., households located in urban areas are more privileged than those in rural areas due to a greater availability of opportunities); and iii) the household's connectivity to the wider market, as well as social and political systems (e.g., national political instability or agricultural market failures may reduce the availability of opportunities).

Although the Sustainable Rural Livelihoods approach provides some useful concepts and assessment techniques, it has been criticized for having a few notable limitations. First, the SRL framework is a static approach that analyzes livelihood sustainability at a certain temporal and spatial scale (Small, 2007) without taking into account the cross-scaler dynamics of vulnerability (e.g., global climate change, market globalization, telecoupled vulnerability) (Morse and McNamara, 2013). Second, although this approach analyzes livelihood management policies and public institutional contexts, it fails to incorporate locally-embedded politics related to resource distribution, as well as power differentials, customs and norms (Morse and McNamara, 2013). Finally, while this approach offers a useful set of variables by differentiating assets into several categories for the exploratory assessment of livelihood sustainability, it can neither quantitatively nor qualitatively measure actual poverty or livelihood sustainability because these assessments are subjective to research contexts, questions and analytical objectives (Morse and McNamara, 2013).

1.7 Conceptual framework: Combining vulnerability and Sustainable Rural Livelihoods frameworks for context-specific livelihood vulnerability assessment

The vulnerability assessment framework developed by Turner et al. (2003) (see Figure 1.1) considers vulnerability as being a function of context specific exposure (intensity of climatic stresses), sensitivity (propensity of a system to be affected by the stresses) and adaptive capacity (capacity to respond to the stresses and derive positive outcomes). This framework can be applied across sectors following contextual modifications to ensure appropriate assessment variables (see for example Ford and Smit, 2004; Ebi et al., 2006; Johnston and Williamson, 2007; Wilhelmi and Hayden 2010; Hughes et al., 2012; Prosperi et al., 2014). The SRL framework (Figure 1.2) conceptualizes vulnerability as the external stresses that can affect livelihood assets, while assets can also generate feedback responses to the stresses (Scoones, 1998). Asset responses can be aided by external institutional and policy support (e.g., government, donor, non-government organizational supports) when needed for deriving favorable livelihood outcomes (e.g., increased income, agricultural productivity, health care system, food security etc.) (Ellis, 2000a).

It is evident that both frameworks consider relationships between stresses and livelihood sustainability, with the variables included in the SRL framework (e.g., capital asset and livelihood activity variables) (Hahn et al., 2009) particularly useful for understanding livelihood dynamics under climate change (Scoones, 1998). As a result, I developed an integrated conceptual framework to guide my dissertation research (see Figure 1.3), that includes four functional components (i.e., context specification, exposure, sensitivity and policy context). The analytical variables associated with the 'context specification' component have been derived from the climate vulnerability assessment framework (e.g., spatial and temporal scales, geographic space and sectors), the analytical variables used for the remaining three components derived from SRL framework. Recognizing that the SRL framework does not adequately account for local power, politics and cultural properties, it does not address the adaptive capacity component of vulnerability, which would require wider descriptions of the local institutional, social and political structures for initiating adaptation actions (Smit and Wandel, 2006).

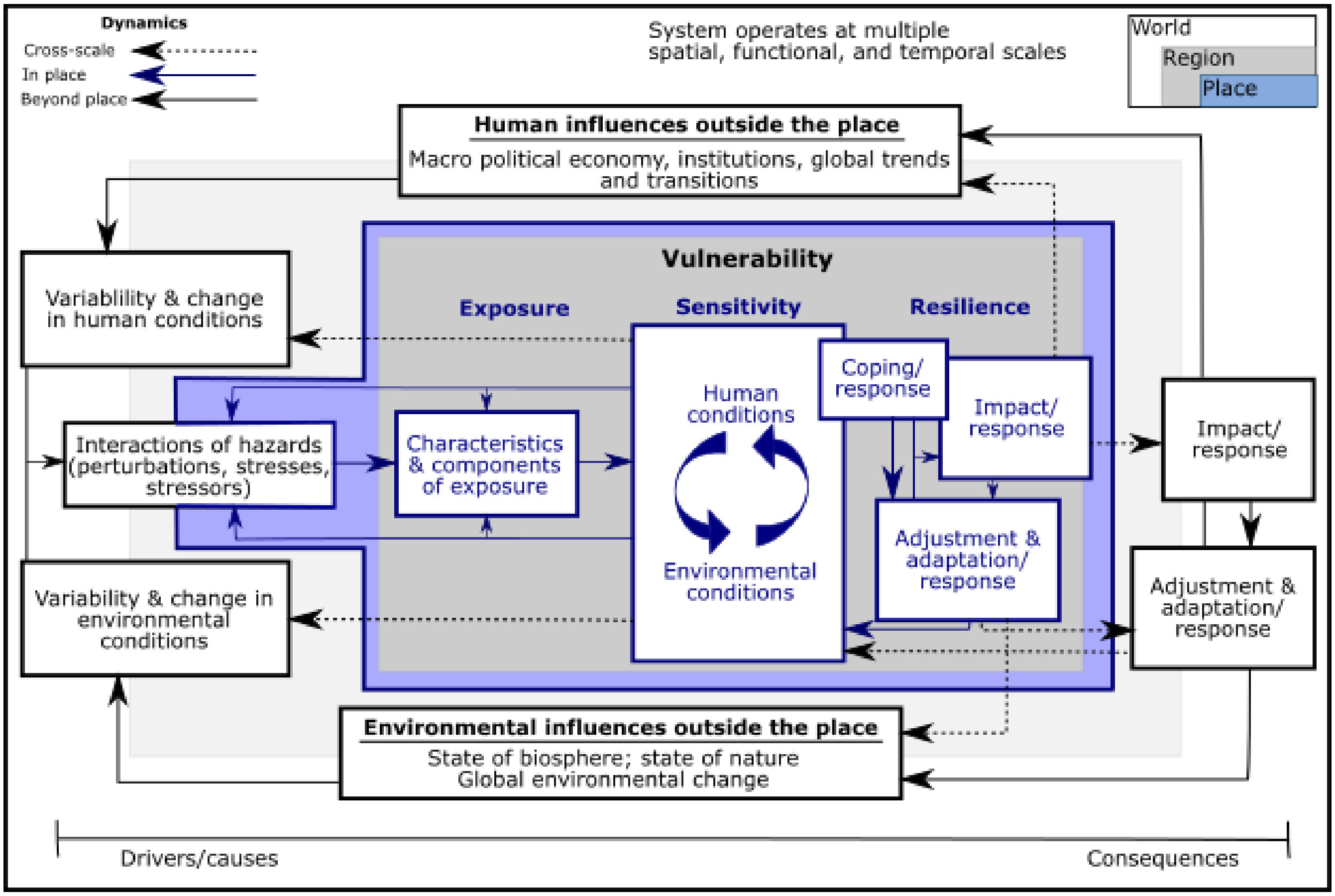

Figure 1.1. Climate vulnerability assessment framework (Source: Turner et al. 2003).

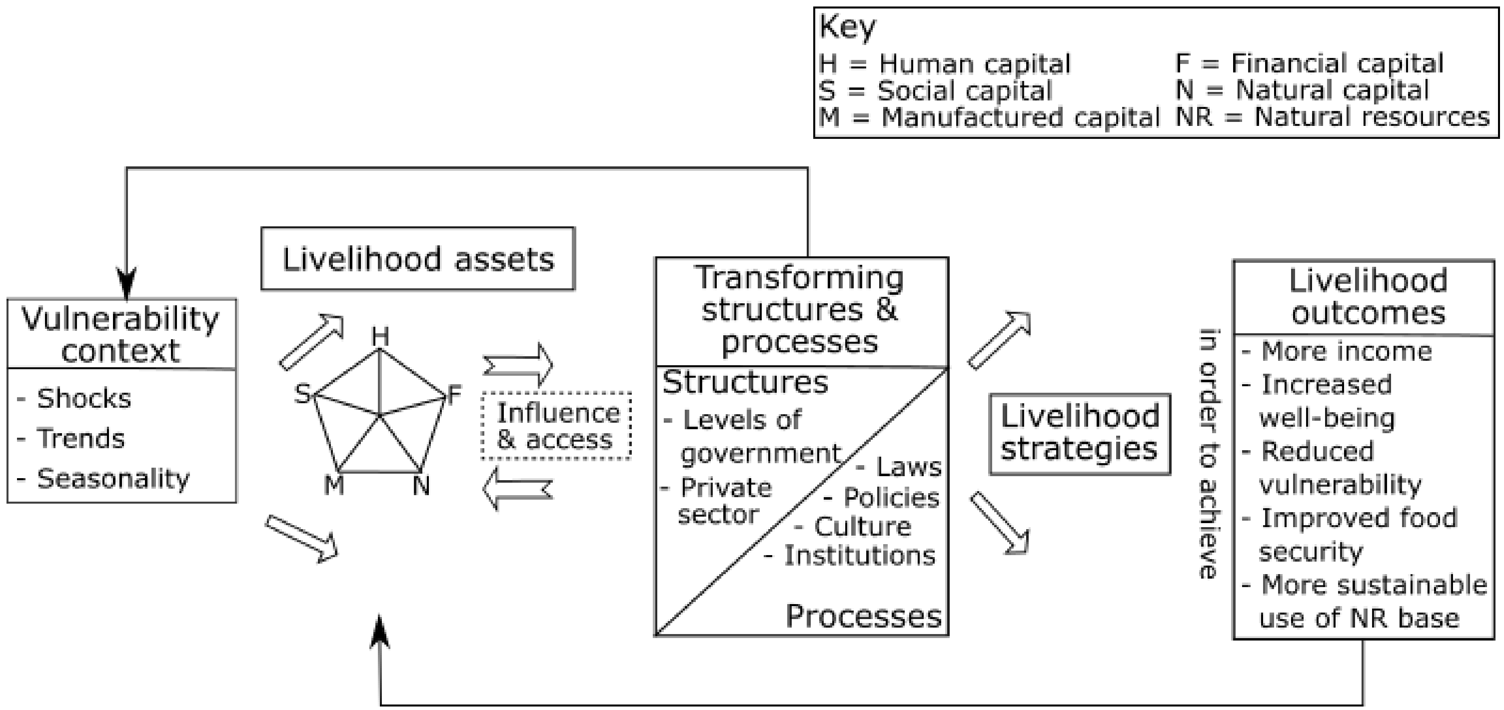

Figure 1.2. Sustainable Rural Livelihoods (SRL) framework (Source: DFID, 1999).

Context determination: The conceptual framework begins with careful identification of what scientific knowledge is available and necessary for fostering future climate-related policy revision in Bangladesh. Since both vulnerability and livelihood sustainability are context-specific, there is a need to assess and synthesize the temporal, spatial and sectoral dimensions of formal scientific knowledge. In so doing, I have adopted a systematic approach developed by Ford and Pearce (2010) and Berrang-Ford et al. (2015), in order to identify what is known, what is not known and what is necessary to know in order to inform and adjust the following functional components of the framework.

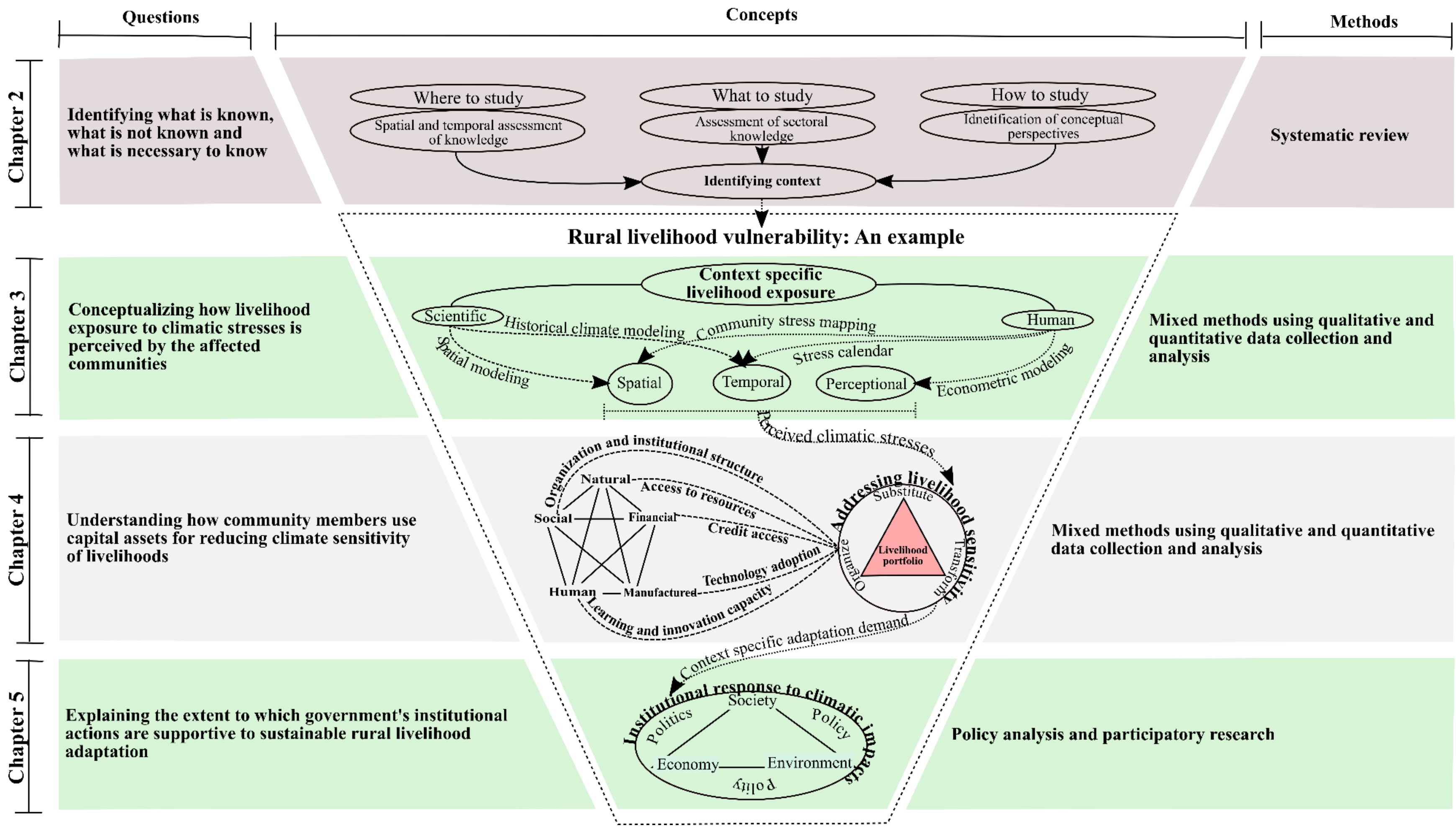

Figure 1.3. Conceptual framework and organization of the thesis.

Exposure: IPCC (2012) defines exposure as the frequency, extent and nature of climatic extremes in a local setting. Ribot (2014) and Ford et al. (2006; 2013) posited that social phenomena along with climatic variability are responsible for exposure, which indicates that both social and ecological components are important. However, exposure is most frequently studied using climatic variables that are used to observe potential present and future risks (Ford et al., 2010; Antwi-Agyei et al., 2012). Engaging community perception-based assessment of stresses is also important (DFID, 1999) with experiential interpretation being key to context-specific rural livelihood vulnerability assessment (Byg and Salick, 2009; Bele et al., 2013). Such assessments can be influenced by local ecological properties, nature and use patterns of resources, and the availability and seasonality of resources (Marino and Ribot, 2012; McCubbin et al., 2015). Further, many regional climatic models based on long-term climatic data fail to adequately account for local climatic properties, and thus, insufficiently inform understandings of more locally-observed impacts (Campbell et al., 2011; Shameem et al., 2015). Importantly, exposure does not sufficiently indicate a system's vulnerability to climatic stresses. More specifically, a system, community, household or individual may be exposed but not vulnerable. A system can be said to be vulnerable only when it is exposed to stresses and reacts to it (IPCC, 2012).

Sensitivity: Sensitivity is defined as the degree to which a system is affected, either positively or negatively, by climatic stresses (IPCC, 2014), and along with exposure, determines the extent of vulnerability. Thus, Smit and Wandel (2006) and Ford et al. (2006) identify exposure and sensitivity as two inextricably associated components of vulnerability; with this association explained as having "dose-response" interactions (Turner et al., 2003; Adger et al., 2005; Füssel and Klein, 2006; Ribot, 2011). Smit and Wandel (2006) characterized this dose-response association stating that it depends on interactions between system characteristics and climatic stimuli. Further, Füssel and Klein (2006) distributed climatic stimuli and system characteristics (i.e., non-climatic factors) between exposure and sensitivity respectively. Characterizing access to, and use of, capital assets is considered key to understanding livelihood interactions with climatic sensitivity (Fang et al., 2014). The underlying notion of such analysis is that the assets generate livelihood opportunities and diversities (Chambers, 1989; Amekawa, 2011; Cinner et al., 2012). However, the SRL framework suggests that capital assets are organized, transformed and substituted for strategizing livelihood portfolios (Scoones, 1998; Rakodi, 1999), although this remains understudied in the livelihood vulnerability literature. Better understanding this property of capital assets could be particularly important because asset organization determines feedback relationships with vulnerability, and may help with reducing livelihood sensitivity (Morse and McNamara, 2013).

Policy context: Knowledge that is generated through vulnerability analysis should ultimately contribute to facilitating communities' adaptation to climate change and the sustainability of adaptation practices (Eriksen et al., 2011). It has been argued in a number of studies that both communities' and governments' responses to climatic stresses may lead to 'maladaptation' – the unintended consequences of adaptation actions (Barnett and O'Neill, 2010), and may fail to appropriately serve the adaptation demands of the affected community. Such situations may occur as a consequence of weak adaptation options and insufficient foresight resulting from knowledge gaps (Juhola et al., 2016). Adaptation actions in a knowledge vacuum may serve to redistribute vulnerability from one sector to another or from one community to another (Adger et al., 2006). For example, flood compartmentalization for protecting agriculture from flood increased the vulnerability of the fisheries sector in Bangladesh (Sultana and Thompson, 1997). Since large scale adaptation decisions are most often made at national levels, it is important to assess how local understandings of vulnerability are translated into policy and what changes result from decision-making processes seeking to facilitate adaptation actions at local-levels. Notably, government decision-making processes are an assembly of three institutional levels including: policy (decisions that are taken), polity (bureaucracy that bridge national decision making and local demand) and politics (dynamics of decision making) (Fischer et al., 2007). Hence, analysis of change should occur at each of these decision-making levels in order to help inform government adaptation strategies (Ribot, 2014; Kelly and Adger, 2000).

1.8 Methodological approach

The case study method (Yin, 1994) was used to conduct contextual analyses of livelihood vulnerability to climate stresses in the northeastern floodplain of Bangladesh. More specifically, multiple case study analysis was applied in order to explore the socio-economic characteristics of locally-embedded climate sensitivity (Mjoset, 2009). A limitation of this approach is that the results are not appropriate for generalization to broader populations (Gerring, 2004); rather, they are restricted to a theoretical understanding of this issue (Yin, 1994). However, the strength of the case study approach is that it enables intensive observation within "real life" settings involving a large number of variables and their co-variation (Yin, 1994; Gerring, 2004). Ford et al. (2010) have provided a detailed description of the appropriateness of case study research for explaining in-depth, locally-based climate vulnerability, and it is based on their arguments that my work began. However, Adger et al. (2009) noted that case-based studies also have the potential to distort understandings of the cross-scalar causes and consequences of climatic stresses; and this is something that I have taken into consideration throughout my research. Despite criticism, the case study method is recognized as being particularly important for locally-oriented adaptation planning

(Ford et al., 2010), particularly in developing area contexts where research investment is often scarce (Engle et al., 2014).

Climatic impacts generate a multiplicity of "realities" for different groups of affected people (Creswell and Plano Clark, 2007). The research questions asked in this study aim to describe how these impacts are experienced and how this experiential knowledge can be better utilized for future policy formation across scale (Morgan, 2014). Hence, this "pragmatic" research design seeks to involve multiple stakeholders who have either been affected by climatic impacts, or who facilitate adaptation processes (Creswell and Plano Clark, 2007; Denzin, 2012). However, stakeholder involvement in this study faces two key challenges. First, each group of stakeholders may have subjective bias stemming from their personal experience with, and interpretation of, climatic impacts (Creswell and Plano Clark, 2007; Morgan, 2014). Second, when used alone, neither qualitative nor quantitative data collection techniques can fully capture the stakeholders' descriptions (Creswell and Plano Clark, 2007). Therefore, I also adopted a mixed-method research design that combined qualitative and quantitative methods to help enable more systematic observation and analysis of empirical phenomena (Johnson et al., 2007; Feilzer, 2009). Both qualitative and quantitative variables can help to explain livelihood vulnerability, and each involves different research methods and considerations that ensure data reliability and validity (Lorenzoni et al., 2007; Ford et al., 2011). An advantage of taking a mixed-methods approach is methodological overlap, which enables a degree of validation and observational triangulation that helps to enhance research reliability (Harwell, 2011; Bergman, 2011). For this dissertation, I adopted a convergent parallel mixed-method approach in order to produce a more comprehensive analysis (Creswell, 2013), which in turn will provide more integrative insights into climate vulnerability issues in Bangladesh. The specific research methods that were used to answer the research questions are described in detail in each results chapter. All research involving human subjects was conducted in accordance with the requirements of McGill's Research Ethics Board.

1.9 Research setting and participants

This study was undertaken in the two most important wetland systems of the northeastern floodplain of Bangladesh: the Hakaluki and Tanguar *haors*. These wetlands are the only two government-designated Ecologically Critical Areas in the floodplain due to their high levels of local environmental degradation arising from climatic and human-induced stresses, and also for the intensive socio-economic dependency of the local communities on the wetland systems (Anik and Khan, 2012). Hakaluki *hoar* is the largest freshwater wetland in Bangladesh, while Tanguar *haor* has been designated as one of two Ramsar sites in Bangladesh. Both of these areas are home to diverse natural resource dependent livelihood groups including peasants, fishers, herders and rural small businesses. Like other wetland systems of the floodplain, poverty is extensive among the wetland communities making the area one of the most marginalized in Bangladesh (Figure 1.4).

1.10 Organization of thesis

This research has been carried out through a series of connected research steps, designed to progressively inform the research questions (Table 1.1 and Figure 1.3). This thesis follows a manuscript-based format and is written as a series of papers, all of which are at varies stages of submission and publication in international peer-reviewed journals.

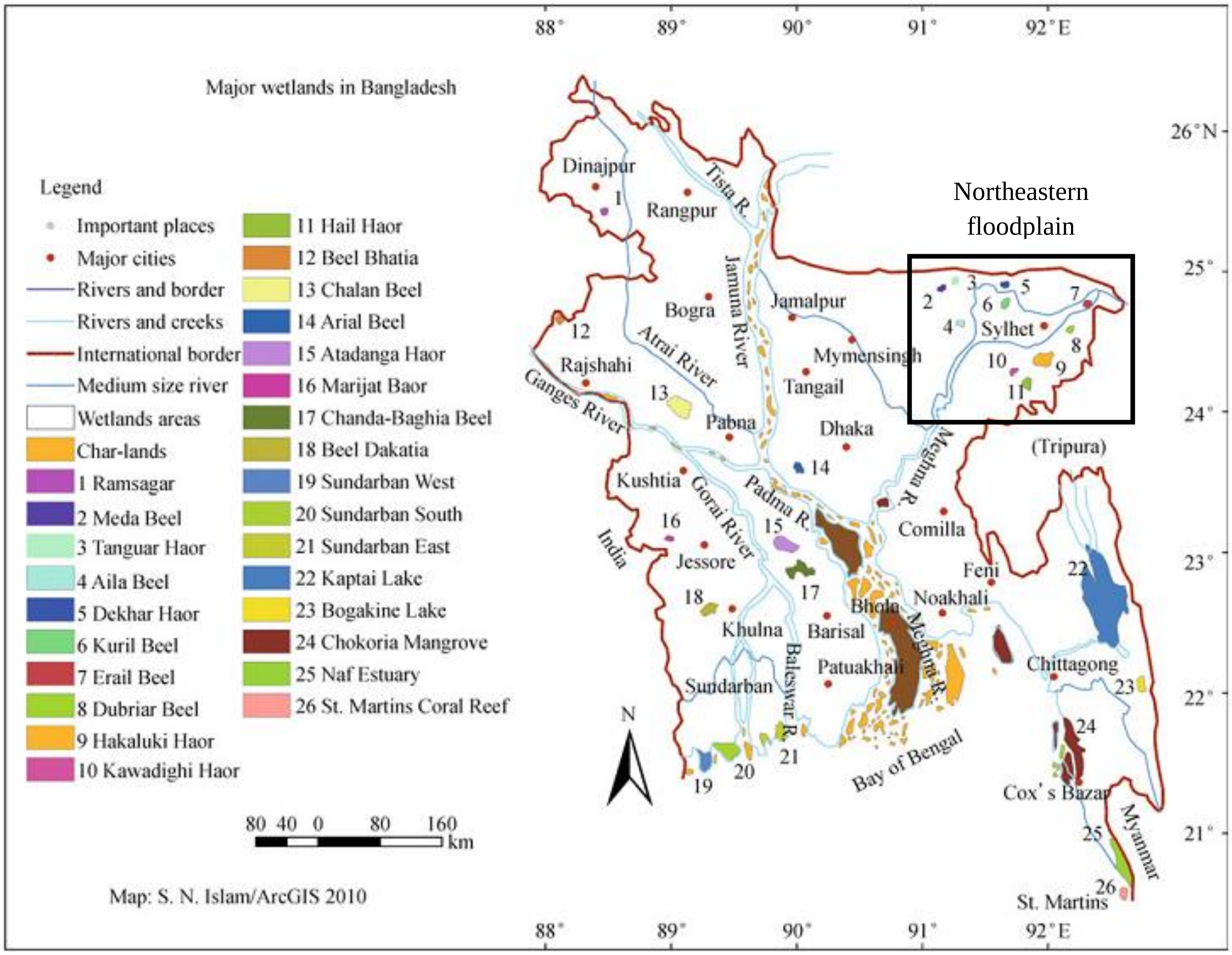

Figure 1.4. Major wetlands in Bangladesh (Source: Islam, 2010).

In Chapter 2, I assess the gaps in climate change research in Bangladesh and the potential policy implications from spatial, temporal and socio-economic sectoral perspectives. Using a systematic literature review approach, this chapter evaluates the climate change-related studies on Bangladesh published in international peer-reviewed journals between 1994 and 2017 (April). It analyzes the distribution of these studies at local, sub-national and national scales, and identifies their geographic connectedness, trends and relevance to policy processes to identify research gaps, concluding that the northeastern floodplain is the most understudied area in Bangladesh in terms of climate change.

Building upon the findings presented in Chapter 2, I then consider the climate change exposure of the northeastern floodplains of Bangladesh from the perspective of affected communities. Collecting data from 12 villages bordering the two most important wetland systems (e.g., Hakaluki and Tanguar) of the area, Chapter 3 identifies how human-induced environmental degradation, bio-physical change and land use practices expose wetland resource-dependent communities to different climatic stresses. Results reveal that the community members are all too familiar with the stresses that they encounter at different times of year (e.g., flash-flood, regular seasonal flood, over rainfall and drought), although they also identified changes in their frequency. In particular, community members identified the occurrence of a climatic extreme event during their production period as a stress rather than depending on the duration and extent of the event.

Table 1.1. Organization of the thesis.

Chapter	**Scope of analysis**	**Dominant methodological disciplines**				**Major analytical methods**	**Qualitative/ Quantitative**	**Targeted journals**
		Interdisciplinary review	Participatory research	Economics	Political science			
2	Literature	■				Systematic review	Qualitative & quantitative	*Regional Environmental Change**
3	Community		■			Mixed methods	Qualitative & quantitative	*Land Use Policy*±
4	Community			■		Mixed methods	Qualitative & quantitative	*Ecological Economics**
5	National & community				■	Policy analysis	Qualitative	*Environmental Management*±

* Published

± Under review

Chapter 4 details how community members in the same study areas adapt in response to their livelihood sensitivity to the climatic stresses that are identified in Chapter 3. In doing so, this chapter offers a methodological approach to estimating sensitivity, and describes the relationship between different household-level capital assets and estimated livelihood sensitivity. Results suggest that external support, either from government, non-government organizations, or from market mechanisms, is generally necessary for successful community-level interventions to reduce livelihood sensitivity to climatic stresses.

In Chapter 5, I assess the level of changes and reforms by the Bangladesh government focusing on the climate change-related policies and plans designed in response to the adaptation demands and needs of affected communities. Findings from the policy analysis are then triangulated using primary qualitative data collected from community, government and non-government actors. Findings reveal that government interventions have significantly contributed to facilitating community-level adaptation initiatives, however challenges related to insufficient public participation and inadequate contextualization remain.

In Chapter 6, I conclude the thesis, discussing the main findings of each chapter to address my overall research question highlighting its contributions to theory and practice and identify future research directions.

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CHAPTER 2: CLIMATE CHANGE RESEARCH IN BANGLADESH: RESEARCH GAPS AND IMPLICATIONS FOR ADAPTATION-RELATED DECISION MAKING

Abstract

In this paper, we present the results of a systematic literature review of climate change vulnerability related research conducted in Bangladesh between 1994 and 2017 in order to identify trends and knowledge gaps. Our results identify interesting evolutions in the temporal and spatial scales of study and the nature of spatial and thematic associations, suggesting important knowledge gaps in the existing literature that likely limit understandings of scale-sensitive climate change impacts. We also observed a temporal mismatch between the published studies and policy making processes focused on adaptation and mitigation and a bias towards the economic aspects of climate change, with less focus on social and environmental issues. Thematically, the climate change-related scholarship on Bangladesh would benefit from more integrative, cross-theme and transdisciplinary studies, potentially drawing on the different theoretical constructs of vulnerability and adaptation. Such studies will be needed to better support evidence-based public policy and also to more accurately reflect the diversity of knowledge gaps and challenges concerning climatic stresses in Bangladesh at different scales and in different contexts.

Keywords: Bangladesh, Climate change, Adaptation, Vulnerability, Systematic review, Knowledge synthesis

2.1 Introduction

The success of national climate change adaptation strategies largely depends on the capacity to generate appropriately contextualized information on climatic risks and adaptation opportunities at different scales through scientific research (Dilling and Lemos, 2011; Ayres et al., 2014). Since adaptation-related decisions are closely related to a country's economic, social, environmental and climatic characteristics, science can help to explain relationships likely to affect outcomes (Füssel, 2007; Lemos et al., 2012). As a result, systematically analyzed and summarized knowledge from existing, often cross-scaler, scientific literature has been identified as being useful in assessing what is known, and what may need further research attention (Ford et al., 2012). According to Ford et al. (2010; 2015), only a small number of studies have been conducted to better understand the overall effectiveness of adaptation actions taken at both local and national levels. This situation has the potential to result in policy bias, where particular geographic areas and specific sectors (e.g., livelihoods, health, natural resource management) may be emphasized due to greater research effort while other, equally important, areas and sectors may remain under-represented. Adger et al. (2003) acknowledged that some societies are more vulnerable to climate change than others, and therefore may demand policy privilege. However, when government and researchers are unaware of the vulnerability of certain communities and/or societies due to historical, cultural or geographical issues, determining where best to direct limited resources becomes problematic.

This situation is often observed in developing countries, where available resources for adaptation actions are inadequate, and long-term investments are susceptible to uncertainties associated with the effectiveness of these investments (Fankhauser and Burton, 2011). Efforts to synthesize existing knowledge are becoming increasingly common in developed nations (Arnell, 2010; Tompkins et al., 2010; Ford et al., 2011; Ford and Pearce, 2012). However, very little equivalent research has been done in the context of developing nations, particularly at national levels. For example, Bangladesh is both highly exposed to different climatic stresses (e.g., flood, storms, drought, over and under rainfall) and experiences high rates of poverty, social exclusion, marginalization and powerlessness in both urban and rural communities (Islam, 2011; Rahman et al., 2015). While the national government has undertaken a number of important initiatives to foster local-level adaptation through different national-level policies and development plans, a high level of uncertainty surrounds the extent to which these initiatives are effective, equitable and efficient (Huq and Khan, 2006; Ayres, 2011). In order to better bridge the information gaps facing policy-makers, there is a need to credibly summarize the climate change-related research advances made in Bangladesh with a view to informing future research and policy needs (Lemos et al., 2012). Focusing on the case of climate change vulnerability and adaptation research and policy in Bangladesh, one of the most climate-vulnerable countries in the world (Ayers and Forsyth, 2009; IPCC, 2012), this paper presents the results of a systematic literature review designed to answer the following questions: what is already known, what is not known, and what has been identified as being necessary to know about climate change vulnerability and adaptation in Bangladesh?

2.2 Methods

2.2.1 Research approach

We conducted a systematic literature review following a mixed method research approach. The application of systematic literature review is common in health science (Salmond and Holly, 2012), and it has been adapted to climate change adaptation research fairly recently (Berrang-Ford et al., 2011). Systematic literature reviews aim to comprehensively synthesize, evaluate and track down scientific literature on a certain topic of interest (Petticrew, 2003; Lorenz et al., 2014;

Berrang-Ford et al., 2015). As a literature review method, it has certain advantages over the more conventional narrative review technique where the literature search process is usually unreported (Ford and Pearce, 2010). Further, the absence of a systematic management approach to literature may incur selection biases (Green et al., 2011). In contrast, systematic literature review has been designed to handle the growing amount of information available, considered to be the quality control standard of the review (Mulrow, 1994) by following strictly defined inclusion and exclusion criteria, resulting in higher accuracy and consistency (McDowell et al., 2014; Ford et al., 2014; Berrang-Ford et al., 2015; McDowell et al., 2016).

The inclusion and exclusion criteria of a systematic review needs to be based on research objectives, along with a well-defined search protocol to locate primary studies. It also requires a clearly defined mechanism for assessing the risk and biases of primary studies, and finally it needs to be presented following a systematic approach (Green et al., 2011). In addition, all research protocols need to be clearly stated in the synthesis to maximize research clarity and transparency (Green and Higgins, 2011). However, the application of systematic review in climate change adaptation research is complex because of the adoption of both qualitative and quantitative research methods in primary studies. To overcome this problem, Ford et al. (2010) have suggested applying a mixed method approach to data retrieval and analysis which involves placing equal emphasis on qualitative and quantitative approaches (Denscombe, 2008; Bergman, 2011).

2.2.2 Search protocol for primary studies

To conduct the review, we considered only peer reviewed research papers published between 1994 and April 2017. A keyword search using "Climate change" and "Bangladesh" was conducted using the ISI Web of Knowledge (ISI) and Scopus electronic database to maximize our coverage of literature. A total of 535 published articles were subsequently identified using a set of inclusion and exclusion criteria, as follows: articles had to be peer-reviewed and written in English; published in ISI and/or Scopus indexed journals; and focused on climate change vulnerability as their main research question (Table 2.1). IPCC (2012) defines vulnerability as the propensity of system elements (e.g., humans, livelihoods, assets) to be exposed to climatic stresses. More specifically, vulnerability is observed as the function of exposure, sensitivity and adaptive capacity (IPCC, 2014). We followed this definition when selecting the primary studies, which discussed at least one of the three elements of vulnerability in the context of a specific theme (e.g., livelihoods, biodiversity, natural resource management). In addition, cross-national comparative studies were excluded as they were likely to depend on relative comparison criteria which may not be directly relevant to the Bangladesh context. Following an initial review of title and abstract, a total of 363 papers were retained for full-text review and analysis (see Appendix 2.1 for full list of papers included). The inclusion and exclusion criteria and the description of analytical categories are presented in Table 2.1and Table 2.2 respectively.

Table 2.1. Inclusion and exclusion criteria of the studies.

Inclusion	Exclusion
Research papers published in English	Paper published in languages other than English
Only peer reviewed articles	Non-peer reviewed research works such as books, non-peer reviewed book chapters, technical reports and working papers.
Climate change is the primary focus of research	Climate change issues appear as secondary or supporting elements
Studies that are fully devoted to exemplify the climate change issues of Bangladesh	Studies that have considered Bangladesh as one of two or more cases for the purpose of comparison

Table 2.2. Analytical categories.

Category	Description	Measurement scale
Research scale	*National* studies, which have been conducted at a national level, are considered under this category. In addition, studies that have taken samples from all geographic locations are also taken under this category. *Sub-national* studies have samples from more than one geographic location but not from all locations, are considered. Again, for case study research, if a study takes more than one case from one or more geographic location it is also considered under this category. *Local* studies are single case study research from a single geographic location.	Binary
Temporal consideration	We examine the evolution of climate change research in Bangladesh over the time period between 1994 and 2014 under this analytical category.	Interval
Spatial consideration	*Northern part* falls under the Ganges-Brahmaputra river basin. This area is highly drought and flood prone; and particularly susceptible to seasonal hunger during the dry season. However, the establishment of embankment in the upper stream of the Ganges river under Indian territory is often responsible for drought. On the other hand, the overflow of river water during rainy season is responsible for flood. *Central part* falls under the Brahmaputra river basin, and is dominated by urban areas (e.g., Dhaka the capital of Bangladesh along with some other large cities are located in this part). This area is highly susceptible to flooding. Expanding urbanization and the destruction of wetlands and low laying areas has augmented flood risk in the area. *Northeastern part* falls under the upper Meghna river basin (also known as Surma-Kushiara river basin) and is highly dominated with wetlands ecosystem, and small hills. This part of the county receives the highest rainfall, and there are more than 22 trans-boundary rivers flowing across it. Along with rainfall, huge amounts of water flow from the upper stream territory of India. Consequently, most of this area remains under water for half of the year. However, over and under rainfall due to climatic variability significantly alter the livelihood activities and ecological structure. *Southern part* is dominated by coastal and estuarine ecosystems. Sea level rise, oceanic serge and tropical cyclone are the major climate change risks in the area. Recent cyclones have resulted in considerable loss	Binary

	of life and destruction of resources. Moreover, water stagnancy and saline water intrusion are responsible for land quality loss. Labor migration from this area is also higher than any other part of the country. *Southeastern part* is characterized by coastal and mountainous ecosystems. This area is highly exposed to tropical cyclones and saline water intrusion. Mountainous regions possess the lowest population density in the country, and several ethnic communities live in this region, practicing traditional agriculture with relatively low production. Consequently, poverty is a general scenario for these communities, which limits their capacity to adapt to a changing climate. On the other hand, plain land coastal communities are mostly farmers and fishers who encounter property loss due to cyclone events every year. In addition, saline water intrusion and stagnancy usually results in land and water quality loss.	
Thematic consideration	The selected studies have been classified under 14 themes, which include: climatology, livelihood, health, policy and governance, food security, conservation, gender, agriculture, fisheries, livestock, forest, infrastructure, non-natural resource dependent economic activities and environmental quality. These studies have been conducted to understand the theme's exposure, sensitivity, adaptive capacity and adaptive change	Binary

2.2.3 Data retrieval

Data retrieval for this research involved both quantitative and qualitative methods. For quantitative data retrieval, we coded each paper according to the categories and sub-categories described in Table 2.2 using binary (paper falls under a category =1 and does not = 0) and interval scales. The analytical categories included: research scale, based on the sample selection and the geographic focus; temporal considerations, using the temporal distribution of published research; spatial considerations, based on the geographical connectedness of the research; and thematic considerations based on the issue-focus of the research.

For systematic qualitative data retrieval, we developed a short questionnaire. Through a full-text review of each paper, we sought to answer five broad questions: 1) what is the main research question of a paper?; 2) what are the outcomes?; 3) what are the limitations of the paper identified by the authors?; 4) what are the further research needs identified by the authors?; and 5) what are the research gaps in each paper in terms of related current scholarship? Answers to each of these questions were then coded for further analysis.

2.2.4 Data analysis

All quantitative data from each paper were stored in an Excel spreadsheet for quantitative analysis. Basic descriptive statistics were used to identify the frequency and proportion of the existing studies covering each of the categories and sub-categories. After in-depth review of the articles, we distributed them among a total of 14 different climate change-related thematic areas, and coded each paper using a binary scale (presence of a theme = 1, absence of the theme = 0). A detailed description of the themes has been given in Table 2.3. Importantly, one study may have had multiple themes due to the multidisciplinary approaches used in the study. To better understand the pattern of multidisciplinary approaches we conducted factor analysis. Notably, factor analysis is used to reduce a large number of interrelated variables to a smaller number of latent or hidden dimensions (Tinsley and Tinsley 1987), which are then used to determine the 'basic constructs making up the domains of interests' (Fabrigar and Wegener 2011). It therefore helps with determining which variables are influenced by a specific common factor. Factor analysis enabled us to identify the latent dimensions in order to help explain the pattern of maximum amount of common variance in the correlation matrix among the measured variables (i.e., research themes) (Fabrigar and Wegener, 2011). Since we did not have any theoretical presumptions or constructs regarding the approaches of the reviewed studies, we conducted an exploratory factor analysis (Fabrigar and Wegener, 2011) using the minimum residual method and applying the varimax rotation technique (Comrey and Ahumada, 1964; Comrey, 1962), considered to be suitable for binary multivariate data (Kamata and Bauer, 2008). Before conducting the analysis, we determined the appropriate number of common factors using parallel analysis, an eigen value based technique, retaining the common factors which had an eigen value greater than 1 (Fabrigar and Wegener, 2011). We tested the reliability of the analysis by calculating the Tucker Lewis Index of factoring reliability and the Root Mean Square Error of Approximation values, which satisfy the standards of the tests (Taasoobshirazi and Wang, 2016). We have also reported Cronbach's α values for each variable to show the internal consistency of our data, which are close to the standard value of 0.7.

Table 2.3. Definitions of research themes used in this study.

Themes	Description of the themes
Health	Studies that discussed about climate induced health concerns including diseases exposure, diseases susceptibility due to climatic change and climate induced natural hazards, increasing health costs, adaptive responses from both community, non-government and government organizations.
Livelihood	According to IPCC (2012) livelihoods are the resources and activities undertaken by a community for their subsistence. We used this to identify the studies that focused on this issue. Therefore, the studies that discussed different types of livelihoods and their exposure to climatic change and stresses, loss of livelihood and resources, adaptation practices (e.g., technological and institutional innovations, migration for securing livelihood opportunities etc.) facelifted by the innovation of affected community members and external supports from government and non-government organizations were considered under this theme. Socio-economic discriminations based on ethnicity and marginalized social groups which have livelihood implications were also taken under this theme.
Climatology	The studies, which took at least one climatic variable for answering research questions that are related to long or short term climatic variability, future climate projection, studying climate stress patterns, and forecasting future climatic extremes like floods, storms and droughts, were listed under this theme. The studies, which used climatic variables for understanding the impact of that variable on another theme (e.g., agricultural, fisheries, infrastructure etc.) were also taken under this theme.
Policy and governance	Papers under this theme discussed about government policy making, institutional development at both international, national government and community level for supporting climate change adaptation and mitigation. Besides, studies covering issues that may influence policy and governance like climate awareness were also considered under this theme.
Food and food security	Studies that discuss the impacts of climate change on food availability, distribution and quality, and the adaptation of these issues to the climatic impacts were taken under this theme.
Wildlife and ecosystem conservation	Climate change impacts on and adaptation of wildlife, biodiversity, aquatic ecosystems including freshwater and marine, terrestrial ecosystems including agro-ecosystems, forest ecosystems, habitat conservation.
Gender	Climate impetus on gender discrimination including socio-economic marginalization, health facilities, gender sensitivity of adaptation actions (e.g., policy making, infrastructural development)

Agriculture	Climate impacts studies on agriculture as a production sector have been considered under this theme. Besides, studies that discussed agricultural production loss and its impacts on rural livelihoods, production and marketing processes, agricultural land loss due to climatic influences were also considered under this theme. Agricultural adaptation studies were also taken under this theme.
Fisheries	Fish production loss studies that identified climate change as one of main reasons of the loss were codified under this theme. Natural and non-natural fish habitat loss, fisheries as an adaptation practice and climatic challenges of shrimp cultivation are the studies under this theme.
Livestock	Climatic impacts on livestock production and the potential of livestock as an option for diversifying livelihood practices were considered under this theme.
Forest	Forest conservation, stock, growth, changing pattern of forest composition, forest expansion as an adaptation measure, carbon stock estimation and contribution of forest in trapping greenhouse gases related studies are considered under this theme.
Technology and infrastructure	Technological innovation for adaptation practices in both agricultural and non-agricultural production activities, carbon emission from industries, infrastructural development for stress impact reduction like water resource management infrastructures (e.g., embankment building, water compartmentalization, irrigation system management etc.), climate sensitive building development, energy consumption and technological innovation for renewable energy sources related studies were listed under this theme.
Non-natural resource economic activities	Impact of climate change on industrial sectors, urban migration and livelihood activities related studies were considered under this theme.
Environmental quality	Environmental pollution, quality loss as a consequence of greenhouse gas emission, sea level rise and saline water intrusion were listed under this theme.

2.3 Results and Discussion

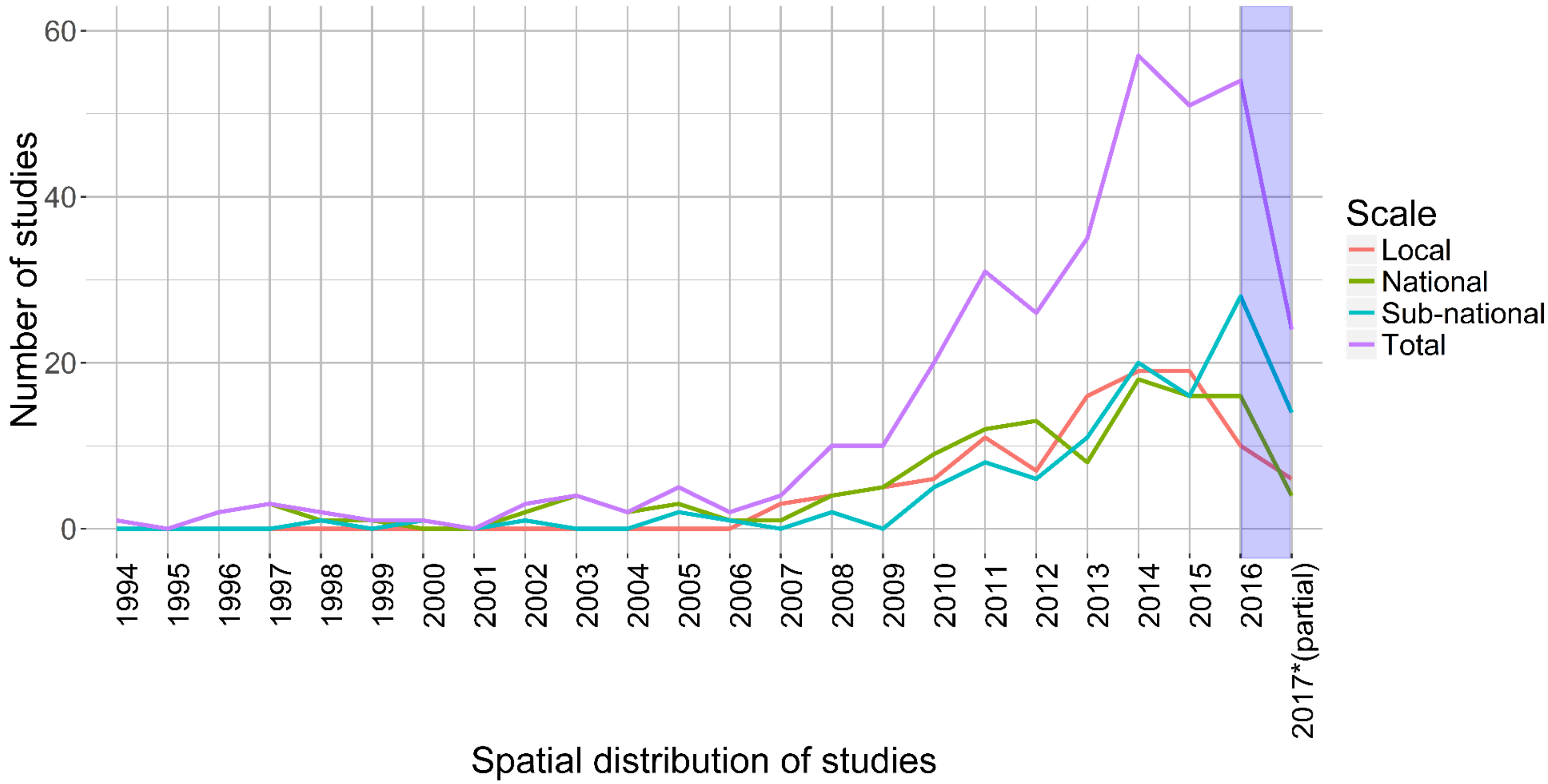
In what follows, we describe the results of the study in three sections: 1) the scale of research (e.g., local, sub-national and local); 2) the trend and applicability of the studies; and 3) the spatial connectedness of different thematic studies. Each section begins with a brief description of related scholarship and ends with a discussion of the key research gaps.

2.3.1 Research scale

The scale at which research is conducted is important because environmental changes are cross-scale phenomena and, therefore, require diverse knowledge to inform decision-making (Cash and Moser, 2000). Gibson et al. (2000) suggested that scale-related thinking influences four aspects of scientific exploration. First, the pattern that exists at one level may not be found at higher or lower levels (Adger, 2001). O'Brien et al. (2004) suggested that climate impact assessments are scale-specific and should not be generalized, although Adger et al. (2009) noted that scale-specific impacts are often connected and nested. Second, causal explanations are highly sensitive to scale because the variables in use are generally scale specific, potentially resulting in an explanatory fallacy if not adequately recognized (Adger et al., 2005). Third, theoretical generalization is both difficult and costly because one set of variables used to explain a phenomenon at a particular spatial scale may not be found sufficient or even relevant at another scale (Wilbanks and Kates, 1999). Therefore, Osbahr et al. (2008) have suggested that it may be more useful to observe cross-scale practices rather than focusing on a specific scale. According to Urwin and Jordan (2008) and Mastrandrea et al. (2010), two dominant approaches, including bottom-up and top-down scaling of scientific studies, may help to bridge the knowledge divides between scale-specific research through communication, collaboration and co-learning.

2.3.1.1 Scale issues in the existing climate change scholarship on Bangladesh

We reviewed the scale-related aspects of the published papers from local, sub-national, and national perspectives (see Table 2.2 for definitions), which comprised 30.46 (total 111), 33.33 (total 121) and 36.21 (total 131) % of the sample, respectively. Based on our results, national-scale studies were mostly focused on two major areas: climatic risk and public policy. A number of studies also described the sensitivity of national agricultural production under a changing climate. Notably, almost all of the national-level studies had a specific thematic preference, where vulnerability or adaptation issues were the focus of discussion, with issues related to agriculture and health the most prominent. Exposure studies projected national climate change patterns using time series data, and identified that Bangladesh is one of the most climate-vulnerable countries in the world. However, these studies also conclude that the vulnerability is heterogeneously distributed across different geographic locations, with specific impacts characterized by local social-ecological characteristics. Hence, despite having the ability to describe the country's status under different climate change scenarios, these national-level exposure studies are insufficient to meaningfully inform policy makers concerning specific adaptation and transformation strategies. The national public policy-related studies primarily examined how climate change vulnerability and adaptation have been institutionalized and mainstreamed in Bangladesh through national development plans and policies, noting generally good progress.



*Four months only. Data reflects publications to 30 April 2017.

Note: The number of studies depicted exceeds the total number of studies reviewed because of inter sub-national and national level studies.

Figure 2.1. Temporal trends in the published papers focusing on climate change in Bangladesh as indexed in ISI and Scopus (1994 to May 2017) (n=363)

We also identified five sub-national spaces based on their ecological distinctiveness and political boundaries, with existing studies reflecting this distinction. For example, coastal communities are dependent on both agriculture and fisheries which will be affected by changing salinity, sea level rise and oceanic storms. Consequently, the studies conducted in this sub-national area investigate how communities have generated adaptive responses. While the wetland resource-using communities in a different sub-national area have similar resource-use behaviors (i.e., agriculture and fisheries), the adaptive learning insights derived from the coastal communities have very limited implications for wetland residents due to their identified climatic risks (e.g., flood, over and under rainfall), resource type (e.g., fresh water fisheries, rain-fed rice cultivation) and cultural practices. Since the government policies of Bangladesh are generally designed at the national scale, adaptation policy-related analyses were scarce in the sub-national studies, which instead focused heavily on ecosystem exposure to climatic risks; the sensitivity of agricultural productivity (e.g., rice); the applicability of adaptive technologies; and the adaptive changes that have been undertaken at community levels.

Local studies were mostly case study-based with a relatively small sample size of communities and/ or actors involved. Adger et al. (2009) suggested that such case-based studies do not provide in-depth understanding of cross-scalar causes and consequences of climate change, and thus do not sufficiently contribute towards larger-scale generalization. As a result, some confusion remains regarding the contribution of these local-level studies to national-level policy. Ford et al. (2010) argued that local-level studies are important for gaining the in-depth understanding of climate change impacts at local levels with a large number of variables which interact and co-vary (Gerring, 2004). Consistent with these characteristics of case study research, the local level studies conducted on climate change in Bangladesh provided more contextualized information and understandings. Such studies were particularly focused on household-level climate sensitivity and adaptive capacities, incorporating a wide number of variables and offering detailed descriptions. More specifically, these studies identified a range of ecosystem and society-specific climatic risks and resident community responses to explore community-level adaptation behaviours drawing on local knowledge and experiences (for further discussion see Section 2.3.3.1). However, this research was generally not well-integrated with the existing government interventions in support of adaptation, formal decision-making processes, multi-scalar knowledge sharing initiatives and larger-scale scientific research programs.

2.3.1.2 Research gaps

Our results revealed the presence of both top-down and bottom-up approaches to climate change research in Bangladesh. However, it remains unclear how national government actions are contributing to sub-national and local scales of operation, and to what extent the local and sub-national understandings of issues are reflected in national policy. This suggests that climate change research in Bangladesh tends towards being authoritative and technocratic (Ayres et al., 2014), with local-level information generally insufficient to help understand local climate change patterns, impacts and responses. Another research gap that appears through our analysis relates to the consideration of scale in the multi-level decision-making processes affecting adaptation (Gibson et al., 2000). We observed little-to-no research that identified the appropriate scale of decision-making for different climate change-related issues and a scarcity of cross-scaler studies on Bangladesh. As a result, there is likely a mismatch between local and sub-national conditions and national-level policy responses (Juhola and Weterhoff, 2011; Osbahr et al., 2008). Moreover, questions related to fairness and equity in the adaptation-related decision-making processes occurring through multi-scaler network governance remain under-researched in the context of Bangladesh (Adger et al., 2005).

2.3.2 Temporal applicability

Equipped with theoretical grounding (e.g., Kelly and Adger 2000; O'Brien and Leichenko, 2000; Burton et al., 2002; Füssel and Klein, 2004; O'Brien et al., 2007), conceptual framing (e.g., Turner et al., 2003, Smit and Wandel, 2006; Gallopín, 2006; Füssel, 2007) and methodological specifics (e.g., Sullivan, 2011; Brooks et al., 2005; Polsky et al., 2007; Hinkel, 2011; Cinner et al., 2012), climate change vulnerability and adaptation research has been evolving, and aiming to contribute to policy process with more holistic and 'usable' scientific knowledge. However, McNie (2007) suggested that in order for scientific research to effectively inform public policy, issues related to the salience, credibility and legitimacy of the research become important, with salience related to the timeliness of findings (Cash et al., 2003; Ford et al., 2013; Lemos and Morehouse, 2005), credibility indicating reliability of knowledge and legitimacy closely related to the degree of engagement with local policy actors and affected stakeholders (Dilling, 2007; Lemos et al., 2012).Ultimately scientific research is most useful when key decisions have yet to be made and when the findings are appropriately contextualized for the relevant decision-makers (Lemos and Morehouse, 2005; Ford et al., 2013; Lemos et al., 2012; Lalor and Hickey, 2014).

2.3.2.1 Trends in climate change research in Bangladesh

Climate change research in Bangladesh has been increasing (Figure 2.1) following global trends (McDowell et al., 2016). Initially focused on understanding the national climatic risks and their influence on economic activities like agriculture (e.g., Ortiz, 1994; Mahmood, 1997; Mahmood, 1998), the scientific understanding of climate change in Bangladesh has been moving towards the exploration of socio-economic and social-ecological system-based understandings of climatic vulnerability involving stakeholders from different scales and giving more credibility and legitimacy to the scientific process (e.g., Ahammad et al., 2014; Anwar and Takewaka, 2014; Ayres et al., 2014). Initial studies mostly pointed to climate change impacts which significantly contributed to improving national political consensus on the need for action. Sea level rise and its consequential land loss in the southern coastal region, flood propensity, temperature rise and irregular rainfall along with corresponding agricultural production losses have been the main focus of these studies (e.g., Faisal and Parveen, 2004; Khan et al., 2000). Such studies have supported the government in developing climate-sensitive action plans (e.g., NAPA, 2005) and Bangladesh Climate Change Strategy and Action Plan (BCCSAP, 2009), and have provided a scientific basis from which the government could assess and communicate the country's vulnerability in different international fora.

Research into the socio-economic factors related to climate change was heterogeneously distributed in different geographic locations, with sub-national and local studies increasing through time. Along with the increasing identification of locally-embedded vulnerability, more recent studies have attempted to identify the innovativeness and gradual progress of communities in the face of climate-related shocks. Noticeably, most of these studies were conducted after the release of the latest national climate action plan (BCCSAP, 2009), meaning that both the NAPA (2005) and BCCSAP (2009) likely do not well-reflect vulnerability-based approaches to climate change impact assessment. As a result, many of these studies criticize the existing policy plans rather contributing to new policy proposals, raising questions concerning the salience of existing research to policy-making processes. In contrast, our literature review also suggests that public participation in research has been increasing over time, opening opportunities to better consider community innovations, informal adaptive actions based on indigenous and local knowledge and social networks – potentially increasing the legitimacy of research findings.

2.3.2.2 Research gaps

Although impact and vulnerability-based research approaches are common in the Bangladesh-focused climate change literature, relatively little formal attention has been paid to bridging gaps between science and policy and science and society. For example, no published study has synthesized the existing knowledge available at different scales. Other research gaps include studies on Bangladesh climate research credibility and methodological appropriateness (Lemos et al., 2012) and the longitudinal socio-economic changes occurring through adaptation actions. Based on our review, the effectiveness of adaptation has not yet been sufficiently assessed to meaningfully inform Bangladesh policy processes.

2.3.3 Spatial and thematic connectedness

Climatic impacts are not only multi-scaler but also multi-sectoral. For example, agriculture is a climate-vulnerable sector that can be studied to better understand production risks arising from potential future climatic uncertainties using agricultural productivity and climatic variables. However, as a livelihood opportunity and potential area for adaptation, agriculture also needs to be studied using socio-economic and policy variables. While each type of study on the same sector will likely produce different interpretations regarding vulnerability and adaptation, all are potentially important for adaptation decision-making at various scales. In what follows, we consider each major research theme raised in the literature (e.g., agriculture, climate, fisheries etc.) and assume that the underlying associations among these themes can generate indications of what has been studied, to what degree, and what may benefit from receiving more research focus (see Table 2.4 for summary of findings).

2.3.3.1 Cross-thematic research and spatial connectedness in Bangladesh

Figure 2.2 shows that the climate change studies were heterogeneously distributed across the national and sub-national levels (e.g., central, northeastern, northern, southeastern and southern), with variability in the thematic issue areas covered. For example, the Southern region has been most widely studied with the broadest thematic coverage likely because of the area's exposure to destructive climatic stresses and disasters such as severe storms, oceanic surge and saline water intrusion. National, southeastern and central regions each appear to have been studied to a similar degree with generally broad thematic coverage, while comparatively less research has been published on the northern region. Importantly, the northeastern region clearly stands out as the most understudied area of Bangladesh with very limited thematic coverage. This result is likely due to poor research infrastructure and the absence of a centralized scientific research administration in Bangladesh. Such large regional variation in the availability of climate change-related evidence has the potential to lead to policy biases that may perpetuate or exacerbate the knowledge gaps.

The results of our factor analysis (Table 2.5) further reveal the broad themes of the available studies to help draw a clearer picture of the scientific knowledge base. We found that six factors (Figure 2.3) describe almost 50% of the total data variability, broadly classified as: Environmental conservation; Socio-economy; Policy response; Technological innovation and environmental risk; Impacts on health; and Impacts on fish resources (Table 2.5). We now provide a more detailed description of these findings in each sub-national region.

Table 2.4. Description of synthesized knowledge and potential future research questions.

Analytical considerations	Considerations for synthesizing knowledge		
	What's needed	**What's known**	**What's not known**
Spatial scale	• Characterizing vulnerability at different scales and their interconnectivity (O'Brien et al., 2004) • Identifying appropriate scale of managing vulnerability (Haarstad, 2014) • Scale specific knowledge domains that describe socio-economic and biophysical dynamics (Füssel, 2007) • Policy implications of scale specific knowledge	• Scale specific vulnerability knowledge • Place based biophysical and socio-economic property based assessment of vulnerability • Where, why and how climate impacts interact with locally specific socio-economic properties	• Cross scaler vulnerability assessment • Scale specific actions for governing adaptation practices • Implications of local case studies to national scale policy making
Temporal usability	• What knowledge is needed and when should it be generated (Ford et al., 2013) • When and from where the knowledge should come (Ford et al., 2013) • Identifying knowledge necessities from policy makers and affected people (Moser, 2010)	• Knowledge generated from different scales in a discrete way • Initial knowledge focused on national scale and more emphasize has been given on sub-national and local scales recently • Multiple stakeholder engagement has been prioritized in contemporary studies	• Finding options for bridging science-policy and science-society divide • Identifying key areas of innovation necessities for future policy making and implementation
Cross-thematic and	• What are the future trajectories of climatic change (Burton et al., 2002)	• Future climate forecast at different scales	• Community perceptions regarding climatic stresses

geographic connectivity	• What are the potential future climatic stresses (Burton et al., 2002) • What are the geographic associations of different climatic stresses (Simelton et al., 2009) • Which sectors and societal sects are more exposed to these stresses (Adger et al., 2005) • To what extent these sectors (in terms of productivity, stability and potential) and society (in terms of life and livelihood opportunities) are either positively or negatively affected by the stresses (Patwardhan et al., 2009) • What non-climatic factors are associated with these stresses (O'Brien and Leichenko, 2000) • How do the non-climatic factors operate and intensify the stress impacts (Füssel and Klein, 2004) • How do the affected communities perceive climatic stress and their impacts for adaptation decision making (Adger, 2006; Adger et al., 2009)	• Climate impacts on local level bio-physical properties (e.g., social property, salinity level, water availability) • Future impacts on water resource and potential future demand • Future impacts of climate change in different sectors (e.g., agriculture, health, fisheries) • Socio-economic drivers of vulnerability • Climate impacts on livelihood activities • Constraints on livelihood adaptation actions • Climate impacts in large urban areas • Nature of climate change induced rural-urban migration • Community based adaptation actions, local innovation and adoption of new-technologies • Level of policy support to community based adaptation actions	• Coupled social-ecological system based vulnerability assessments • Identification of local bio-physical properties that can intensify climatic impacts • Gender aspects of climate change impacts • Vulnerability of socially, politically and economically marginalized communities like ethnic minorities • Vulnerability and adaptation of extremely natural resource dependent communities like northeastern wetland and southeastern hill forest dependent communities • Interactions of socio-economic and socio-political issues with health sector • Human vulnerability in small and peri-urban areas • Vulnerability of built environment in coastal and hilly regions • Climate induced ecosystem conservation risks

	• How do the affected community members intervene adaptation actions through technological innovations, creating livelihood opportunities and institutional and governance modifications (Adger, et al. 2009) • To what extent national and international policy making contribute to supporting local level adaptation actions (Füssel, 2007) • What is the nature of multilevel and multi-scaler interplay of adaptation governance (Adger et al., 2005) • Does the national adaptation policy making reflect local level adaptation demand (Smit and Wandel, 2006)		• Multi-level institutional linkage for governing adaptation actions • Synthesis of existing knowledge in terms of sectoral, scaler and geographic connectedness for policy incorporation

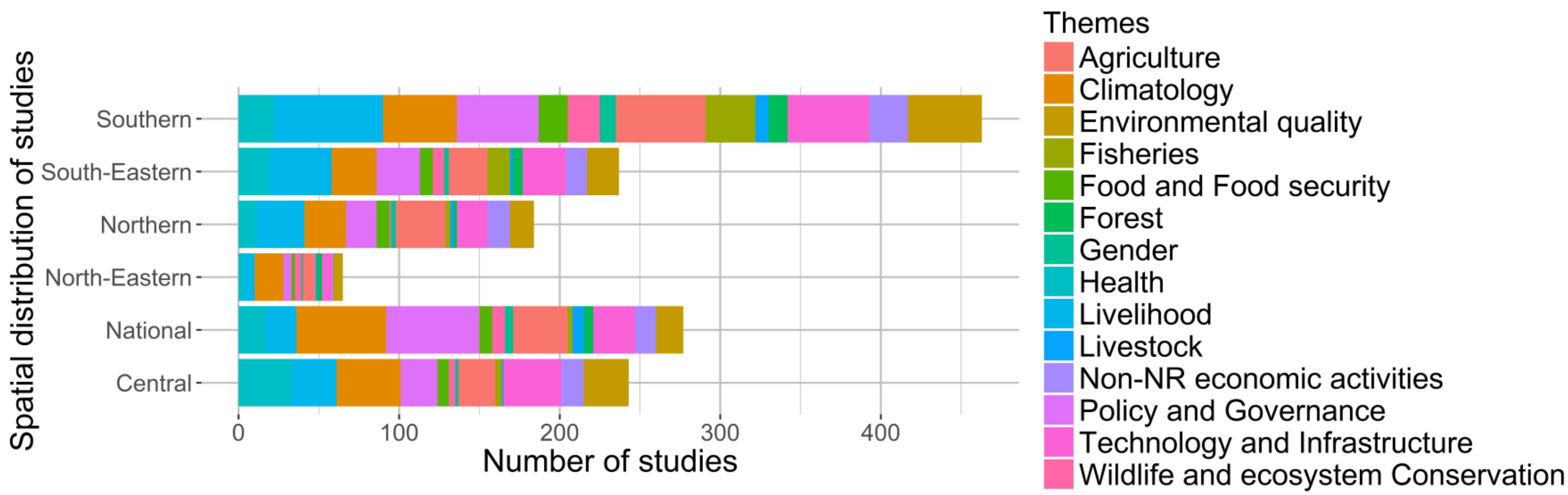


Figure 2.2. Spatial and thematic aspects of the published papers focusing on climate change in Bangladesh as indexed in ISI and Scopus (1994 to May 2017) (n=363). Note number of studies exceeds total *n* as many papers covered more than one theme.

Table 2.5. Identifying the latent dimensions of cross-thematic studies.

Themes	MR2 Environmental conservation	MR5 Socio-economy	MR3 Policy response	MR1 Technological innovation and environmental risk	MR4 Impacts on health	MR6 Impacts on fish resources	Cronbach's alpha
Health	-0.04	-0.07	-0.01	0.05	**0.76**	0	0.65
Livelihood	-0.02	**0.48**	0.27	0.04	0.03	0.21	0.59
Climatology	-0.03	-0.06	**-0.74**	0.04	-0.11	0.09	0.61
Policy and governance	-0.05	-0.11	**0.65**	0.13	-0.19	0.11	0.63
Food and food security	-0.05	**0.33**	0.12	-0.1	0.26	0.24	0.61
Wildlife and ecosystem conservation	**0.73**	-0.12	-0.02	0.04	-0.03	0.27	0.69
Gender	-0.07	0.1	**0.26**	-0.11	0.09	0.08	0.64
Agriculture	-0.04	**0.67**	-0.08	0.04	-0.14	-0.02	0.63
Fisheries	0.07	0.33	0.02	0.12	0.02	**0.43**	0.61
Livestock	0.17	**0.4**	0.05	0.12	0.14	-0.09	0.62
Forest	**0.89**	0.05	0.01	-0.04	-0.01	-0.13	0.68
Technology and infrastructure	-0.02	0.01	0	**0.89**	0.02	-0.02	0.61
Non-natural resource dependent	0.01	**0.32**	0.19	0.22	0.04	-0.08	0.61

economic activities							
Environmental quality	0.2	0.06	-0.06	**0.27**	0.17	0.13	0.64
SS loadings	1.42	1.33	1.27	1.05	0.8	0.51	
Proportion variability	0.1	0.1	0.09	0.08	0.06	0.04	
Cumulative variability	0.1	0.2	0.29	0.36	0.42	0.46	
Proportion explained	0.22	0.21	0.2	0.16	0.12	0.08	
Cumulative proportion	0.22	0.43	0.63	0.8	0.92	1	

Note: Tucker Lewis Index of factoring reliability = 0.881
RMSEA index = 0.055 and the 90 % confidence intervals are 0.03 0.077
BIC = -84.65
The degree of freedom corrected root mean square of the residuals is 0.05
Highest factor loading values are marked in bold letters.

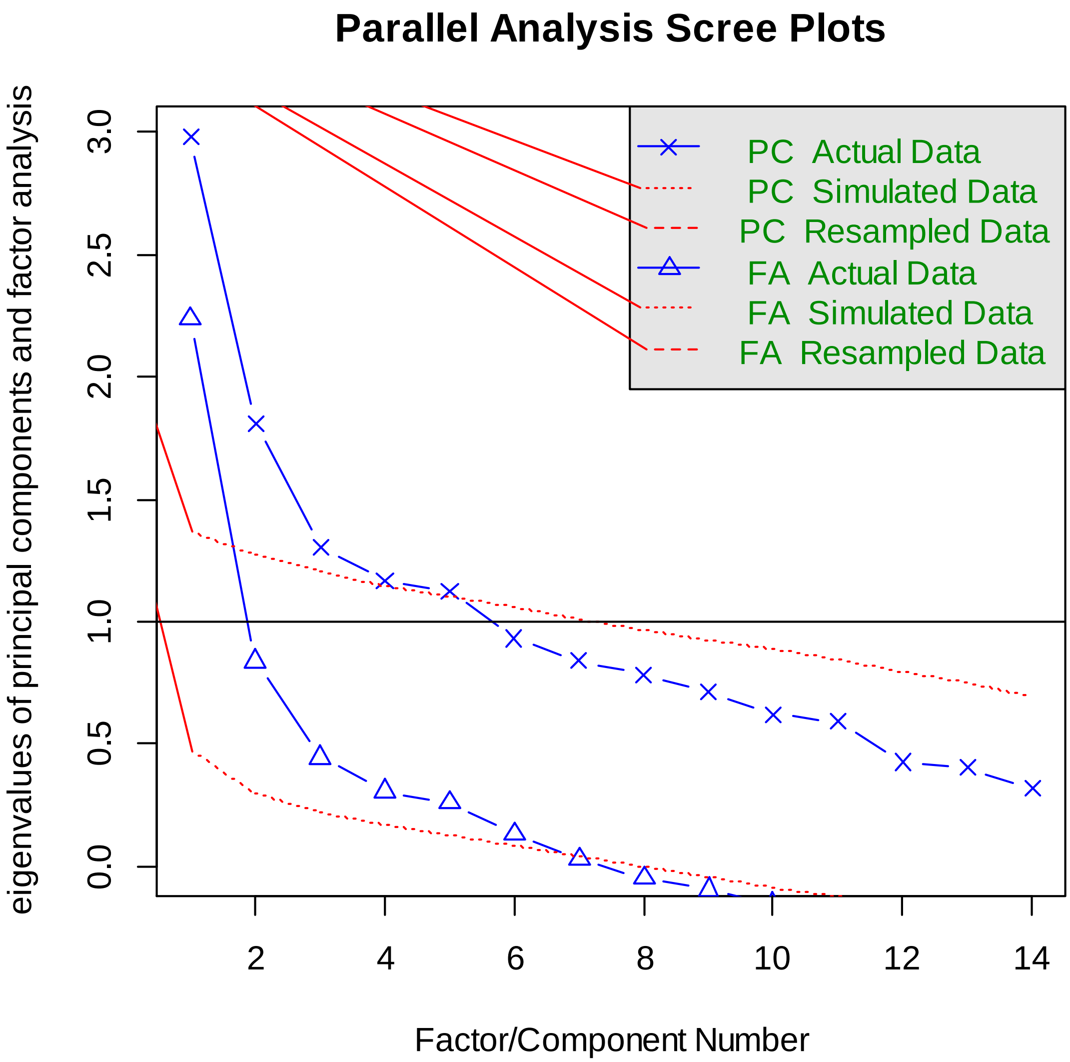


Figure 2.3. Parallel analysis for determining suitable factor numbers.

(a) Central region: 82 studies (23% of total sample) were conducted on the central region, focused primarily on understanding the vulnerability of both urban (particularly the capital city Dhaka) and rural areas to climatic impacts. Climatic exposure studies predict that annual daily maximum rainfall may become equal to, or more than, 200 mm with a return period of 12 years between 2010 and 2066, observing that rainfall trends are increasing at a rate of 4.54 mm per year (Ahammed et al., 2014). Gain and Hoque (2013) show that agricultural land use is highly vulnerable to climate change, although it is predicted that such land use will be altered in coming years through rapid urban expansion (Molla et al., 2014). Khan et al. (2014), Mynett and Vojinovic (2009) and Alam and Rabbani (2007) suggest that prolonged water stagnancy is having the largest negative impact on the poorest residents of the city who live in slums. Barua and van Ast (2011) identify that poor and inefficient infrastructural development, accompanied by inefficient institutional and planning process, are the potential causes of water stagnancy. In addition, residents of slums are generating adaptation actions to climatic impacts, particularly related to flood and water stagnancy (Jabeen et al., 2010; Jabeen and Guy, 2015), which largely depend on the level of household capital assets and social networks (Braun and Aßheuer, 2011; Rotberg, 2013). In addition, changing climatic variables including temperature, rainfall and flood frequency increment are projected to increase the risk of diseases like Dengue and Cholera, and will likely increase the health care costs, particularly for people living in slums (Banu et al., 2014; Khan et al., 2014; Burkart et al., 2011; Matsuda et al., 2008).

Water scarcity appears as an important climatic consequence in rural areas, particularly during the dry season, and water flows are predicted to increase during wet seasons resulting in flood (Gain and Wada, 2014; Gain et al., 2013). Both of these factors are expected to reduce agricultural productivity in the region, resulting in rural livelihood insecurity despite farm-level adaptation actions (Mahmood, 1998; Younus, 2015; Younus and Harvey, 2014). This is likely to lead to increasing rural-urban migration (Martin et al., 2014), which largely depends on the social networks of the affected community members. However, these migrants are also likely to encounter urban climatic exposure in their new locations suggesting that migration, as a climate change adaptation, will not be sufficient (Adri and Simon, 2017).

(b) Northeastern floodplain: The northeastern floodplain is the most understudied area in the country with only 25 (6.9%) published studies appearing in our systematic review. After studying rainfall and temperature patterns, Nowreen et al. (2014) and Nury et al. (2017) indicate that annual average temperatures will increase by almost 3°C by 2080 from the base year 1980 in the region. Using rainfall and river water discharge data, Nowreen et al. (2014) forecast that average annual rainfall will increase by 2 mm/day, while Masood and Takeuchi (2016) predict river water discharge will increase from 25% to 104% in the long run resulting in higher potential for flash-flooding, the most destructive climatic impact facing the rural economy and household livelihood practices. In contrast, Anik and Khan (2012) found that despite the increasing climatic threat, community members are generating adaptive capacities by innovating and practicing new technologies, while Pavel et al. (2014) estimated the financial efficacy of these practices. Beyond impacts on socio-economic activities, Rahman et al. (2017); Sohel et al. (2017) and Deb et al. (2016) identify climatic impacts on the growth and distribution of different forest plant species.

(c) Northern region: This area was the focus of 56 studies (15.4% of the total). This region is particularly susceptible to seasonal flooding and drought. Upstream river flow reduction and low rainfall are the main causes of drought in the area (Shahid et al., 2011a; Etzold et al., 2014). Ahamad et al. (2013) identify these factors as the cause of seasonal food insecurity, with rural poor smallholders being the worst affected, locally known as *Monga* (seasonal famine). Existing

climatologic studies indicate that annual rainfall will increase by between 1% and 5% over the next 20 years, with pre-monsoon rainfall increasing between 1% and 3% and post-monsoon rainfall increasing between 3% and 5% during the same time period (Kumar et al., 2014). Gain et al. (2013) and Gain et al. (2011) suggest that severe flooding due to higher levels of upstream river flow will occur with a 10 year return period. However, Gain and Wada (2014) identify that water scarcity during dry spells will significantly increase in the coming years, which will affect local socio-economic and ecosystem function.

To escape this situation, affected communities are adopting different techniques and practices for different sectors. For example, cropping diversity, intercropping practices and small-scale irrigation systems are some common practices identified in agricultural adaptation (Kabir et al., 2017; Hossain et al., 2016), although Habiba et al. (2014); Etzold et al. (2014) and Shahid (2011a) note that excessive ground water harvesting may lead to maladaptation. However, in a recent study, Acharjee et al. (2017) note that climate change may not always intensify agricultural water use and may instead reduce water demand in northern region. Enhancing livelihood diversity through migration is another common practice among the rural poor of the region (Martin et al., 2014). However, this practice requires some degree of social capital in order to facilitate mobilization and adequate housing. In another study Khan et al. (2014) identify that knowledge and the use of traditional medicine play a crucial role in health-related adaptation practices. Notably, Coirolo and Rahman (2014) suggest that the adoption of adaptation practices in this region may be challenged by socially embedded power differentials and disproportionate access to resources among different socio-economic groups, and thus, call for cross-level institutional linkages and greater policy support.

(d) Southern region: This is the most widely studied region with a total of 121 published studies (33.3% of the total). It is regarded as the most climate-vulnerable area of Bangladesh, exposed to tropical cyclones, oceanic surge, coastal flooding, sea-level rise, saline water intrusion and land erosion. After conducting extreme value analysis, Lee (2013) suggested that extreme sea-levels in 2050 due to oceanic surge and sea level rise, with 100-year return period, will be 2.09 m. Khan et al. (2000) note that sea surface temperature rise during the summer season is responsible for the increasing number of tropical cyclones in the area. On the other hand, Karim and Mimura (2008) identify that sea surface temperature and sea level rise are jointly responsible for oceanic surge and coastal flooding. They also predict that a 2°C sea surface temperature and 0.3 m sea level rise will increase coastal flood risk by 15.3% from the present risk, which is responsible for coastal erosion. However, Sarwar and Woodroffe (2013) observed that there is no overall significant change in landform because of dynamic and active land erosion and accretion characteristics across the coastline. Despite this shoreline feature, the resident communities, infrastructures and settlements are highly exposed to climatic influences due to these dynamics (Dasgupta et al., 2014), and thus, Hossain et al. (2017) conclude that potential climatic and socio-economic change will limit future local adaptation capacity.

In addition, Mallick et al. (2011) point to the inadequacy of infrastructure development for disaster protection. They note that poverty, natural resource dependent livelihood activities and poor institutional empowerment curtail the capacity of rural smallholders to adapt to disaster and post-disaster situations. Similarly, inadequate adaptive capacity significantly enhances livelihood insecurity, and consequently influences household economic structures. For instance, Mottaleb et al. (2013) found that rural agrarian households spent the least on child education during stress periods because of income loss. Disasters cause internal displacement or forced migration for the extreme poor and rural smallholders (e.g., post Aila situation). In addition, they are forced to experiment with new business approaches without having adequate capital assets (Kartiki, 2011; Martin et al., 2014).

Beyond disaster events, slow changes in environmental factors (e.g., water and soil salinity) have multi-sectoral influences. For instance, high saline concentration lowers land productivity, which is being gradually converted to shrimp ponds (Pouliotte et al., 2009). However, poorer people have limited access to these ponds because shrimp cultivation is labor and cost intensive. In addition, production losses due to oceanic surges, cyclones and any climatic factors (e.g., rainfall, drought, water temperature) may destroy partial or total investment (Kartiki, 2011; Ahmed et al., 2013). Although Ahmed and Diana (2015) and Ahmed and Glaser (2015) have identified adaptive techniques, Paprocki and Huq (2017) have criticized the expansion of shrimp cultivation since it shrinks locally-available livelihood opportunities for poorer smallholders. Additional multi-scalar governance, policy, planning, technological and socio-economic constraints are also identified as being responsible for limiting the adaptive capacity of poorer smallholders (Islam et al., 2014).

Salinity has been found to affect public health, although a limited number of studies have sought to understand this issue. Khan et al. (2011a) identify that salinity in drinking water is increasing the level of salt consumption by the rural people, leading to mental health issues. They note weak responses both from the community and government in order to adapt to this changing scenario.

(e) Southeastern region: The southeastern region was the focus of 68 published studies (18.7% of the total). The type and nature of climatic exposure in the southeastern region is similar to the southern region because this area falls under the coastal territory of the country. Consequently, oceanic storms, sea level rise, salinity increment and shoreline changes are the major threats.

Studies reveal that, like the other parts of the country, farmers and fishers are the two most vulnerable livelihood groups in the southeastern rural areas. Sea surface temperature rise combined with sea level rise are considered to be responsible for the increasing trend of cyclones and oceanic surges in the area (Karim and Mimura, 2008). Landslides resulting from high rainfall and deforestation in the upland areas of the region are increasing siltation in the estuaries, responsible for environmental quality degradation (Lara et al., 2009). To reduce the level of exposure of coastal communities to saline water intrusion, the government of Bangladesh has intervened with structural development (e.g., polders) along the coastline. However, these establishments have little effect on protecting agricultural lands from saline water intrusion because this part of the country has the highest level of inundation risk. Consequently, it has been observed that coastal polders will likely be overtopped in several areas (Dasgupta et al., 2014). Moreover, socio-economic and socio-cultural features in this area are augmenting the potential vulnerability of resident communities. Therefore, Ahmed and Cokinos (2017) suggest that institutional innovation can directly influence vulnerability, although Younus (2017) notes that corruption limits the effectiveness of institutional process.

The unique feature of this area is that migrant landless households living in small islands and estuarine isles are highly exposed to the threat of oceanic surges due to their remoteness from cyclone shelters (Alam and Collins, 2010). However, they have also noted that these people have developed their own adaptive learning mechanisms which support them in pre-disaster adaptation actions, observing that these actions help support their survival during the disaster period. These actions involve the establishment of small raised embankments around the households and migration from the islands to the mainland (Islam et al., 2014). However, both these actions are cost intensive, and are primarily available to financially secure households. Mainland communities are also vulnerable to these risks due to socio-economic structures, markets and resource managing institutions (Islam et al., 2014).

(f) National-level studies: National level studies comprised 126 (34.7%) of the total 363 studies. National-level studies can be broadly classified as focusing on exposure or policy questions. The exposure studies are mainly oriented towards assessing the sensitivity of national agricultural production. Reviewing different extreme climatic impacts in Bangladesh, Dastagir (2015) concludes that the frequency of climate-induced extreme events has been increasing in Bangladesh, while Mirza et al. (2003) earlier identify that flooding is the main climatic disturbance for the country because it occurs in all region in various forms including: flash, riverine, rain-fed and storm-surge. Other national-level climatic disturbances are sea-level rise and tropical cyclones. Mirza (2003), Shahid (2011b) and Prasanna et al. (2014) also describe that extreme rainfall in the upper tributaries of Ganges-Meghna-Brahmaputra (GMB) river basins and also water from melting glaciers from the Himalayan mountain range causes flash-flood every year. Again, inland extreme rainfall also significantly contributes to rain-fed flooding during monsoon and post-monsoon periods, observed in flooding events that took place in 1998 and 2007 (Mirza et al., 2003; Prasanna et al., 2014). In addition, after studying long-term rainfall data Shahid (2010a) and Rahman et al. (2013) identify that both pre- and during monsoon, rainfall is increasing, which may contribute to early floods, and may significantly affect rice production (Amin et al., 2015) and crop selection (Moniruzzaman, 2015). More specifically, Karim et al. (1996) predicted that temperature fluctuation and CO_2 concentration would reduce wheat and rice production, something that has been felt in almost all parts of the country for all rice crops (e.g., *Aus, Aman* and *Boro*) (for detail see Sarker et al., 2013; Sarker et al., 2012; Thurlow et al., 2012). Mahmood (1998) suggests that a 1°C reduction in air temperature will increase evapotranspiration by 5% for *Boro* rice (winter

rice), and will result in increasing irrigation demand. Another study suggests that over and under rainfall during the monsoon period significantly reduces Aman rice production (Mahmood et al., 2003; Mahmood et al., 2004). Again, production reduction has been observed for *Aus* (pre-monsoon rice) because of temperature increases in the -monsoon season (Sarker et al., 2013). Faisal and Parveen (2004) further suggest that after 2050 there will be significant freshwater deficiency for both agriculture and non-agricultural uses, although sufficient amounts of water are expected to be available until 2030. Therefore, they conclude that this situation will threaten the food security of the country in the long-run. However, they also identify that national rice production is increasing due to the planting of high yielding salt and drought tolerant varieties.

Mirza (2002) observes that climate change will have negative implications for national development. Following this observation, most of the later studies have mainly focused on the influence of climate change on agriculture, health and community displacement due to livelihood losses and disaster-related destruction (Rahman, 2008; Thurlow et al., 2012; Gray and Mueller, 2012). Contradictory findings emerged from two extensive and robust studies seeking to understand the consequences of disaster occurrence and crop loss on livelihood security at the national level. Hassani-Mahmooei and Parris (2012) developed an agent-based model for the migration pattern of disaster-affected communities and predicted that 3-10 million internal migrations will take place in the next 40 years based on the severity of disaster. In contrast, Gray and Mueller (2012) suggested that most of the internal migration is taking place as a consequence of crop loss rather than disaster occurrences because labor demand remains high during the post-disaster situation. Both of these observations have significant implications for adaptation-related decision making in government and requires further research.

Rahman (2008) observed that climate change impacts on health is generally under-explored in Bangladesh, with most of the existing research focused on the potential for changes in the incidence of diarrhea and cholera due to climate change (e.g., Cash et al., 2008; Cash et al., 2009; Ohtomo et al., 2010). Exceptions include Burkart et al. (2014) and Nahar et al. (2014), who reported that heat effects have negative impacts on human health, particularly on urban elderly residents, and post-disaster trauma will be particularly evident for rural women, who are often the worst affected by natural disasters. Here, Nelson (2003) identifies the direct disaster impact on affected communities, and observes that socio-economic status and high population density have intensified climate-induced health risks. Moreover, Shahid (2010b) and Khan et al. (2011b) describe some indirect impacts of climate change related to groundwater withdrawal, which intensifies arsenic contamination, and saline water intrusion, which pollutes freshwater and creates favorable conditions for infectious diseases.

A large number of studies have also focused on national climate change policy-making processes in support of building adaptive capacity through institutional development and innovation. For example, Ayres et al. (2014) acknowledge the advancement of climate-sensitive adaptation planning in Bangladesh, identifying the National Adaptation Plan for Action as one of the first. They also identify Bangladesh as an example of 'adaptation mainstreaming' through deliberative adaptation planning. Huq (2011) suggests that Bangladesh has achieved significant success in adaptive knowledge management and dissemination, while the country has a high potential to incorporate mitigation strategies along with its adaptation planning (Ayres and Huq, 2009). Hence, the disaster management interventions of Bangladesh offer an example for many other similarly climate-vulnerable countries (Huq, 2011), although the disaster losses, particularly in infrastructure, will cause additional cost burdens for the country (Dasgupta et al., 2011). Huq and

Rubbani (2011) have provided a detailed description of institutional development and financial mechanisms for bearing the costs of adaptation. Some other studies have identified concerns and issues which may reduce the effectiveness of national adaptation practices. For instance, Coirolo et al. (2013) identify that the objectives of the existing social protection programs designed to support affected community members has not been sufficiently realized due to information gaps between community members and government officials, and the embedded corruption within the administration. Information gaps also remain in adaption planning processes which, despite requiring participatory and inclusive approaches, often suffer from vague and inadequate community representation due to elite capture (Ayres, 2011). Moreover, institutionalized policy and political marginalization of certain community groups (e.g., urban slum dwellers; women; minority ethnic communities) also play a crucial role in excluding them from the policy process (Alam et al., 2011; Banks et al., 2011; Sultana, 2010). Ayres et al. (2014) identify this feature as an obstacle to deliberative adaptation planning in Bangladesh.

2.3.3.2 Research gaps

Reviewing the existing literature, we observe that climatic exposure at both the national and sub-national scales have been widely studied using time-series data following a scientific framing. However, most of these studies rely on the historical trends of climatic variables in order to predict the future scenario providing us with 'outcome' based vulnerability assessments. Comparatively few studies have been conducted to understand how the existing climatic changes are perceived by the affected communities in Bangladesh. Perception is an individual construct, and largely depends on the level or capacity to adapt, and thus can inform residual vulnerability, which Kelly and Adger (2000) defined as 'end-point' vulnerability. Perception-based understandings could therefore help inform questions such as what the level of adaptation is, and where to invest for short and long term preparedness at both finer and coarser scales? (Parry, 2007; Moser, 2010). Other studies aim to evaluate the influences of climatic events on production sectors (e.g., agriculture, fisheries) (Harrison et al., 2013). Patwardhan et al. (2009) called for more in-depth understanding of sector-specific vulnerability across scales through multi-sectoral and multidisciplinary research. This is particularly relevant to the case of Bangladesh due to the sometimes contrasting observations made at national and sub-national studies, for example in the case of irrigation demand for winter crops (Mahmood, 1998; Acharjee et al., 2017) (for detail see national and northern region study summaries).

Beyond identifying the nature and extent of climatic stresses, it is also important to understand the non-climatic stresses that have the potential to intensify climatic stresses. Cross-scaler institutional dynamics, market globalization, power and socio-economic differentials are some examples of non-climatic stresses (O'Brien et al., 2007; Rodima-Taylor et al., 2012; Devine-Wright, 2013; Osbher et al., 2008; Chapin et al., 2016; Adger et al., 2012). While most contemporary research in Bangladesh has characterized power and socio-economic differentials at local scales (e.g., through end-point and focal-point vulnerability studies), we did not identify any study that reveals cross-scaler vulnerability dynamics or market globalization influences on local vulnerability. Notably, issues facing ethnic minorities, women and youth have not been adequately studied with potential implications for adaptation policy. Further system-based research (Nelson et al., 2007) designed and implemented through local participation may have greater applicability to adaptation-related decision making (Smit and Wandel, 2006; Patwardhan et al., 2009; Ford et al., 2013). Here, understanding how people generate and share adaptation-related knowledge at different levels and how adaptation actions are organized through formal and informal institutions along with their horizontal and vertical interplay would be valuable (Cash et al., 2006; Devine-Wright, 2013; Temby et al., 2017; Johula and Weterhoff, 2011; Ford and King, 2015).

2.4 Conclusion

Synthesizing scientific information has multiple implications for climate change-related policy making and practice and can help to understand what we know and what we need to know. In this paper we systematically reviewed climate change research in Bangladesh over a 23-year period based on three broad aspects: spatial distribution, temporal trends, and thematic area, observing research trends and gaps. More specifically, we concentrated on the spatial connectedness, temporal evolution and thematic specifications of the studies, observing that there remains a wide range of research gaps in existing scholarship. We observed that diverse perspectives of vulnerability have been used to examine climate change related issues in Bangladesh, with significant regional variation in the number of published studies and the nature of the research conducted. Efforts to adopt more participatory and decentralized approaches to climate change-related research in Bangladesh will likely assist with better understanding how different climatic stresses are influencing the socio-economic and social-ecological conditions at different scales. Also, more locally-based studies designed to understand the capacity of affected people to respond to climatic impacts through their innovation and available resources can help inform public policy. Thematically, the climatic scholarship in Bangladesh would benefit from more multi-disciplinary studies involving cross-sectoral knowledge integration. Such studies could benefit from drawing on the large and growing climate change literature that draws on multi-level systems thinking. This paper seeks to support more evidence-based public policy and also to more accurately reflect the diversity of knowledge gaps and challenges concerning climatic stresses in Bangladesh at different scales and in different contexts.

Acknowledgement

We would like to acknowledge the Prince Albert II of Monaco Foundation and IPCC for their financial support to conduct the research. The comments of the paper are solely the responsibility of the authors and under no circumstances may be considered as a reflection of the position of the Prince Albert II of Monaco Foundation and/or the IPCC. Additional funding support was provided by the William Dawson Scholar Award, McGill University.

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Linking statement

Chapter 2 presents a systematic review of the climate change studies conducted in Bangladesh that were published between 1994 and 2017 (April) in international peer-reviewed journals. Results reveal that context-specific studies appear to be insufficient in Bangladesh, which may have negative implications for climate-sensitive policy making. Further, the northeastern floodplain of Bangladesh is one of the mostly understudied areas of the country, despite being regarded as one of the most climate-vulnerable regions in the world. Building from these findings, Chapter 3 explores the livelihood exposure of wetland-dependent communities in the northeastern floodplain region to different climatic stresses using a participatory research approach.

CHAPTER 3: LIVELIHOOD EXPOSURE TO CLIMATIC STRESSES IN THE NORTHEASTERN FLOODPLAINS OF BANGLADESH

Abstract

In this paper, we seek to better understand the temporal and spatial aspects of climatic stress on local resource production systems and resource-use behaviors by including the perspectives of resource-dependent communities. Field research was conducted over a nine-month period in the remote northeastern floodplain communities of Bangladesh, considered one of the most climate-vulnerable, least developed and under-studied regions in the country. This area is heavily dominated by wetland ecosystems, and subjected to regular seasonal flood and extreme rainfall events. Beyond these regular stresses, flash-floods and drought are the two most destructive climatic stresses on livelihood sustainability in the area. Data were collected in 12 villages bordering two significant wetlands (Hakaluki *haor* and Tanguar *haor*), involving focus groups (n=14), key informant interviews (n=35) and household surveys (n=356). Our results show that climatic stresses on rural livelihoods are catalyzed by human-induced environmental degradation and local resource use behaviors, contextual features that include both socio-economic and bio-physical properties. A climatic event appeared as a stress to livelihood sustainability when it happened in an untimely manner (e.g., flooding during resource harvesting periods) and directly affected the production process (e.g., agriculture and fisheries). We also found that human stress perceptions varied with the level of locally-driven innovation and adoption of technologies, which supports the important role of local experience and knowledge in adaptation planning. Further research is needed into how communities in different settings are already organizing to manage perceived climatic stresses, including traditional knowledge systems, local innovation networks and livelihood practices to help better contextualize adaptation policy.

Keywords: Stress assessment; Livelihood exposure; Participatory approaches; Adaptation planning; Complexity

3.1 Introduction

Livelihoods are the resources and activities undertaken by a community for their subsistence (IPCC, 2012). Rural smallholders in many developing area contexts depend heavily on natural resources for their livelihoods (Goulden et al., 2013), the availability of which is influenced by accessibility issues arising from social inequities, economic disparities and governance failures (Ferrol-Schulte et al., 2013; Rahman et al., 2015; Ribot, 2011; Swinton and Quiroz, 2003). However, resource access and uses are also challenged by external uncertainties such as climate change, which is often considered to be a global phenomenon, although felt locally.

In order to address the relationships between climatic uncertainties and sustainable rural livelihoods, the concept of exposure is widely used (Turner et al., 2003). Exposure includes '*the presence of people; livelihoods; environmental services and resources; infrastructure; or economic, social, or cultural assets in places that could be adversely affected*' (IPCC, 2012 p. 5). IPCC (2014) has posited that local-level meteorological properties like temperature and precipitation will be altered by global climatic change, resulting in climatic stresses (e.g., prolonged drought, excessive or too little rainfall and flood) that will affect the use of, and access to, different assets by household and communities (Reed et al., 2013). Such resource-use constraints due to climatic uncertainties, when compounded by non-climatic factors (e.g., the local structure of resource use, transnational and international market mechanisms), are generally identified as involving multiple or double exposure (McDowell and Hess, 2012; Leichenko and O'Brien, 2002; Leichenko and O'Brien, 2008).

There are two main approaches to analyzing livelihood exposure to climate change. First, exposure is often characterized by the nature, frequency and extent of different climatic extremes from a meteorological perspective (Antwi-Agyei et al., 2012; Hahn et al., 2009; O'Brien et al., 2004). This approach generally uses historical data for different climatic variables to predict future changes and identify potentially extreme events, in order to show how extreme events potentially affect livelihood productivity (e.g., agriculture, fisheries) as an 'outcome' of global climatic change (O'Brien et al., 2007). The second main approach centres on the socio-economic dimensions of exposure. This more 'context-specific' approach involves considering the resource access and use constraints in order to help answer how climatic uncertainties are compounded by local resource use systems (Bunce et al., 2010; Feola et al., 2015; O'Brien et al., 2007). In some studies, both approaches are combined to explore the interactions between climatic and non-climatic factors when studying the behavior of affected communities (Hall, 2011; Ford et al., 2006, Smit and Wandel, 2006).

While these different approaches have helped to improve our understanding of the influence of climatic exposure on rural livelihood sustainability, Below et al. (2012) noted that the resulting analyses have often lacked sufficient capacity to capture the complex nature of adaptation processes (see also Smit et al., 1999). Important aspects that are often missing from local exposure-related studies include social perceptions about the climatic stresses, biophysical changes in a system, the resource use behaviors and production system of a community, all of which are known to be context-specific (Campbell et al., 2011; Shameem et al., 2015; Wise et al., 2014). Such gaps have implications for the accuracy of exposure studies seeking to better understand the complex influences of climatic stresses on rural livelihoods (Smit et al., 1999). Consistent with this observation, van Aalst et al. (2008) suggested that participatory climate risk assessment research offers a useful approach to bridging this gap. Subsequently, a number of studies have adopted more participatory approaches to explain different aspects of climatic risk and stresses and help inform policy (for example Bele et al., 2013; Byg and Salick, 2009; Frazier et al., 2010; Stringer et al., 2009). Berrang-Ford et al. (2011) and Ford et al. (2010) observed that participatory research has made significant contributions to adaptation planning, policy and management. For example, Frazier et al. (2010) reported that participatory research facilitated opportunities to engage multiple resource uses and management groups to exchange their geographically-specific views and knowledge, which generated the common agenda of accelerating community resilience to climate stresses in Florida, USA. However, Birkmann and von Teichman (2010) noted scale, knowledge and norms related to climatic impacts challenges the assessment processes when adopting participatory approaches. Some of these challenges may be better addressed by incorporating the sustainable rural livelihoods (SRL) approach, which is a participatory research framework for uncovering livelihood risk and response perceptions (DFID, 1999). The SRL posits that community risk perceptions are built upon community knowledge concerning the properties, availability and use behaviors of locally available resources (DFID, 1999). As a result, this approach is necessarily a place-based, limiting its application to case studies (Morse and McNamara, 2013), which Adger et al. (2009) noted may mislead understandings of cross-scalar cause and consequences of climatic stresses. Nevertheless, as noted by Ford et al. (2010), such case studies can be particularly important for locally-oriented adaptation planning in developing area contexts where research investment is scarce.

Focusing on one of the least developed and most climate exposed regions of Bangladesh, the objective of this study was to better understand the temporal and spatial aspects of climatic stress on local production systems and resource-use behaviors by including the perspectives of communities themselves. Using a participatory research approach, we sought to explain the temporal nature of climatic events from the perspective of local livelihood, production system and resource-use practices with a view to better explaining when a climatic event appears as stress to livelihoods. We also aimed to better understand the contribution of local biophysical changes (in the form of environmental degradation) to climatic stresses on livelihoods to offer a forward looking approach that better acknowledges adaptation constraints. This approach is grounded on Amekawa's (2011) observation that the erosion of resource systems in the present will risk future livelihood adaptation actions.

This paper begins with a brief literature review on climate exposure and the SRL approach, and identifies the resulting conceptual propositions related to exposure. The background to the research setting is then described followed by the data collection and analysis methods. We then describe our results in the context of the identified propositions and discuss the implications for future research and policy.

3.2 Conceptual framework

The conceptual overview of this paper is built upon the resource use pattern, environmental degradation and human perception to the stresses. Reviewing existing exposure literature, we offer three propositions in this study, which capture the temporal, spatial and community perceptional issues of exposure. By testing these propositions in the field, we intend to better understand the context specific underlying entities of exposure, which are insufficiently discussed in historical data based exposure studies.

3.2.1 Temporal properties and climatic stresses

Recognizing the IPCC's (2014) assertion that global climate change has increased the frequency of extreme climatic events, the temporal nature of different climatic events requires that significant attention be paid to understanding their potential influences on rural livelihood and production systems. Importantly, the duration and frequency of climatic stresses may not always fully determine the intensity of the stresses (Karagiorgos et al., 2016; Santo et al., 2015). For example, flash-flooding may have a short duration but may result in the large scale destruction of both crops and property (Gautam et al., 2015; Mahmood et al., 2016). Moreover, successive stress events in the same year (for example, the occurrence of drought in one season and flood in the following season) may severely destroy rural production systems (Shah et al., 2013).

While most of the exposure assessment-based historical data informs our understanding of the slow changes occurring in climatic variables and predicts the future potential of extreme events, it is often not adequately understood how these changes are experienced by the local resource user communities (van Aalst et al. 2008; Bennett et al., 2016). Acknowledging this knowledge gap, Bele et al. (2013) observed that there is a distinction between the scientific reporting of climatic change and affected communities' perceptions regarding a stress, and that the temporal occurrence of climatic stress determines community perceptions. Drawing on the SRL approach, which emphasises the seasonal nature of livelihood practices (Morse and McNamara, 2013), we can assume that affected community members perceive a climatic extreme event as a stress to their livelihoods if it occurs in their production period (e.g., crop harvesting period in agriculture or the fishing season in freshwater wetland fisheries).

> **Proposition 1:** A climatic event is perceived as a stress on local livelihoods when it co-occurs spatially and temporally with livelihood production activities.

Climatic extremes may not be perceived as a stress unless it directly affects livelihood productivity. More generally, all extreme events may not be stresses to livelihoods, although all the stresses may appear as a consequence of extreme events, if other conditions (e.g., bio-physical properties, land use practices etc.) are constant. Confirming Proposition 1 has the potential to inform longer term adaptation actions (Birkmann and von Teichman, 2010).

3.2.2 Local geographic and environmental properties and livelihood practices

Fazey et al. (2011) explained a linear relationship among local environmental degradation, climate change impacts and rural livelihood sustainability, stating that climatic impacts affect rural economic activities. To compensate for economic losses, resource users often intensify their activities by expending or converting agricultural land, which can negatively affect local ecological integrity (Fazey et al, 2011). Such ecological losses can limit the adaptive capacity of the community to potential future stresses (Paavola, 2008). However, this proposed relationship trajectory is, in reality, far from linear, with local environmental change resulting from non-climatic factors potentially compounding exposure to climatic stresses (Ford and Smit, 2004; Deb and Ferreira, 2015; Zhao et al., 2013). For example, Huq et al. (2004) posited that soil erosion and subsequent siltation – a natural phenomenon of Bangladeshi rivers - can be held responsible for the sediment load on river beds in Bangladesh, which may reduce the water discharge capacity of the rivers. Thus, a lower river bed gradient leads to slower water flow velocities resulting in prolonged water stagnancy, particularly in wetland areas. Similar observations have also been made in the Chilika lagoon, India, where sedimentation is occurring as a consequence of upland forest destruction and agricultural intensification (Iwasaki et al. 2009). However, such local bio-physical changes are difficult to capture in conventional climate forecast models. While much research explains how climatic changes alter the bio-physical properties of a system (Marino and Ribot, 2012; McCubbin et al., 2015), it is not well-understood how local bio-physical changes interact with livelihood impacts resulting from climatic stresses.

Proposition 2: Local bio-physical changes alter the perception of climatic stresses.

3.2.3 Determining stress from the perspectives of rural smallholders

Human perceptions are dynamic and can be influenced by learning, innovation, change in livelihood strategies and the adoption of new technologies (Reed, 2007). Previous experience with different climatic stresses may encourage community members to innovate and adapt new techniques or to change their land use practices (i.e., adaptive learning) (Berrang-Ford et al., 2011). In such cases, the community may perceive the stress within their tolerance limit (Safi et al., 2012), although historical climatic data may show considerable change. Resource use behaviors and the nature of property right regimes among rural smallholders (e.g., farmer, fisher, labor) in developing areas are known to have diverse characteristics (Rahman et al., 2015). For example, the seasonality of crop cultivation practices will determine the climatic events to which a farmer's livelihood is exposed (Ziervogel and Calder, 2003). Further, farm lands are often broadly distributed, and are therefore not equally exposed to different climatic stress. For instance, a parcel of land located near an irrigation system may have low drought stress in comparison to the lands located in an area without water infrastructure. Similarly, a fisher who has access only to degraded, open and unmanaged wild fishing grounds, may experience drought and flood stress in a very different way than a fisher who has formal property rights on well-managed fishing grounds (Adger and Luttrell, 2000). In contrast, a laborer may not encounter any of these climatic stresses if they are employed in a role that is not natural resource dependent (Dasgupta and Baschieri, 2010). Hence, as noted by Adger et al. (2009), stress perceptions are knowledge, experience and value driven.

> **Proposition 3:** Community members' perceptions regarding livelihood exposure to climatic stresses often go beyond the meteorological considerations (e.g., frequency, extent, duration) of traditional exposure studies, and are mediated by resources access and use.

3.3 Study setting: Northeastern floodplain of Bangladesh

This research was conducted in the northeastern floodplain communities of Bangladesh, an area considered one of the most climate-vulnerable and under-studied regions in the country. This area is dominated by wetland ecosystems (Deb et al., 2016; Rahaman et al., 2016), and subjected to regular seasonal flood and extreme rainfall events. Beyond these stresses, flash-floods and drought are the two most destructive climatic stresses on livelihood sustainability in the area (Nowreen et al., 2015).

The northeastern floodplain of Bangladesh falls under the upper Meghna tributary, which is one of the three major river basins in Bangladesh (Mirza, 2011). This part of the country is boarded by Indian states including Meghalaya in the north, Tripura in the south, and Assam in the east. The floodplain comprises several wetland systems locally known as *haors*, which are defined as bowl-shaped depressions, seasonally flooded by monsoon water and river flow from the Indian uplands. During dry seasons, the *haors* dry up and only a few permanent shallow lakes remain inundated, locally known as *beels*. Small rivers also pass through the *haors*, which serve as water inflow and outflow channels (MPHA, 2012). *Haors* are considered to be very important ecosystems because of their rich biodiversity and natural resources (Muzaffar and Ahmed, 2007). Local smallholders largely depend on these floodplain systems for their livelihood opportunities. Agriculture is a common practice during the dry season while fishing is practiced throughout the year (Rahman et al., 2015; Salam et al., 1994). In this area, government policies and management systems limit open water fishing practices (Rahman et al., 2012). Among the several wetland systems distributed across the northeastern floodplain, Hakaluki and Tanguar are considered to be the two most important because of their geographic location, the availability of exploitable resources, the number of dependent households and the abundance of biodiversity (Figure 3.1).

3.3.1 Hakaluki *haor*

Hakaluki *Haor* is the largest freshwater natural wetland in Bangladesh, which lies between 24º35′N to 24º44′N and 92º00′ E to 92º08′ E. It has an area of 41,614 ha (Khan and Haque, 2010) with a permanent inundation area of 4,635 ha (Choudhury and Nishat, 2005). The permanent inundation area comprises *beels* which are the natural habitats of fisheries. The Department of Environment (DoE) of the Government of Bangladesh declared this wetland to be an Ecologically Critical Area in 1999 (DoE, 2015) under the Bangladesh Environment Conservation Act (1995) for the conservation of the natural environment and sustainable use of resources. This *haor* falls under the jurisdictions of 5 sub-districts in Sylhet (Goalpganj and Fenchuganj sub-districts) and Maulavibazar (Kulaura, Juri and Borolekha sub-districts) districts. The villages are distributed in 11 unions (the lowest administrative unit of the Bangladesh Government) including: Dakshin Badepasha and Gilachara under Fenchugaj sub-district; Sharifganj under Golapgonj; Vatera, Sosharkandi under Kulaura; Poschim Juri, Jafar Nagar under Juri; Suja Nagar and Borni under Baralekha sub-districts.

Most of the villages surrounding the *haor* have access to a permanent road network that provides motor access to union councils and sub-districts throughout the year, and the villages have access to health, education and electricity services. Community members living in these villages mostly depend on agriculture and fisheries for their livelihoods. These livelihood opportunities take place in the *haor*. Most of the *haor* area has a single paddy (most widely cultivated crop) crop rotation, while some parts have multiple rotations. Although fishing is a common livelihood practice in the areas, this has been significantly reduced because of the government's wetland fisheries property right decentralization policy (Rahman et al., 2015). Consequently, many fishers rely on open access fishing grounds like rivers and canals. However, the depletion of fish in these grounds has reduced the viability of this livelihood practice.

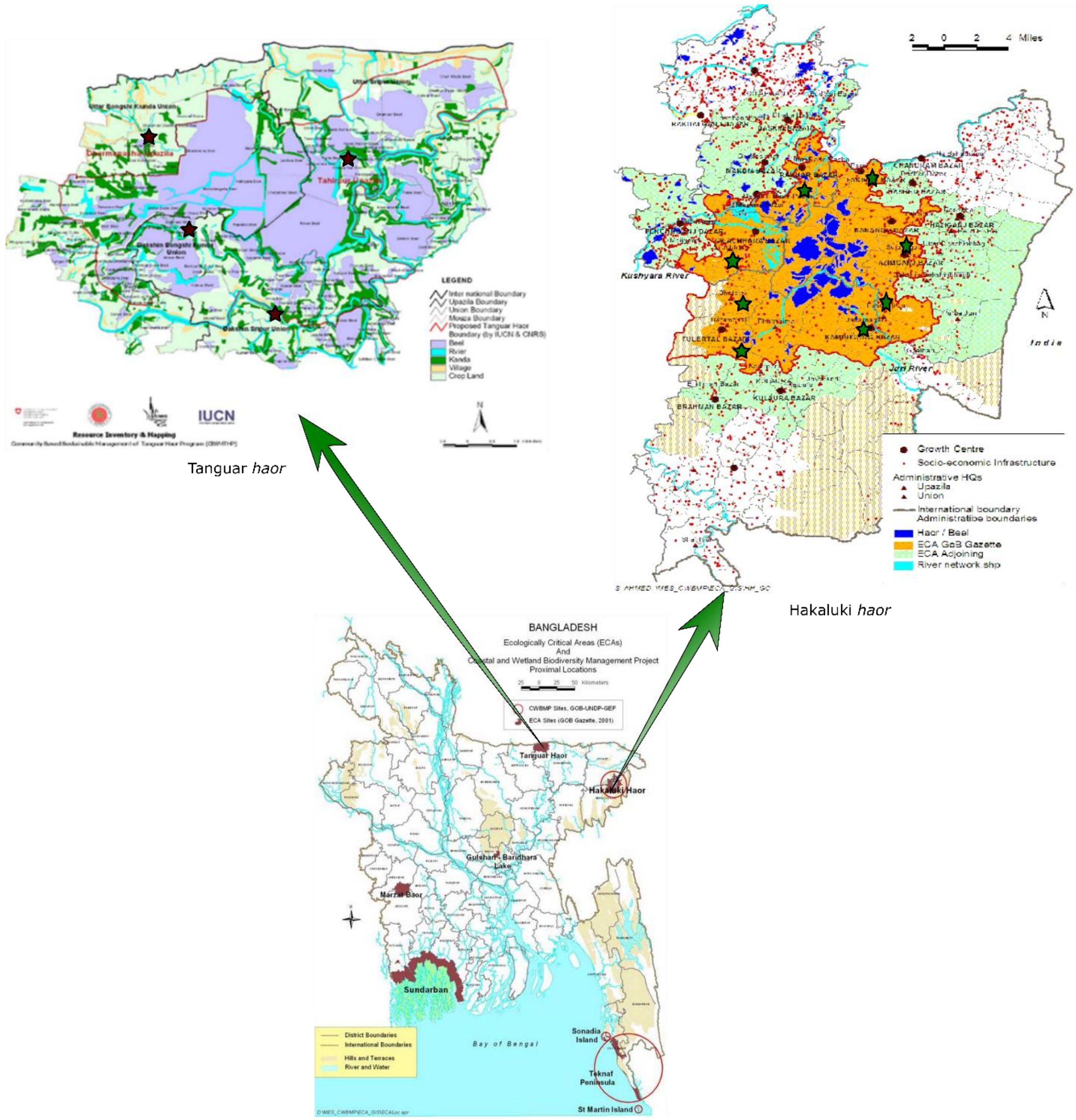

Figure 3.1. Study areas and location of data collection villages. (Source: Department of Environment, Bangladesh Government and IUCN, Bangladesh).

3.3.2 Tanguar *Haor*

Tanguar *haor* is best known for its rich biodiversity and less disturbed ecosystem. It is located at 25°05' to 25°12' north and 91°01' to 91°07' east and covers an area of around 9,527 ha. The government of Bangladesh has also declared this *haor* as an Ecologically Critical Area. Moreover, it is a Ramsar World Heritage Site. It is located near the Meghalayan foothill of India and falls under the jurisdictions of Tahirpur and Dharmapasha sub-districts in Sunamganj district. The adjacent villages are distributed under four unions including: Uttar Sripur and Dakshin Sripur under Tahirpur sub-district; and Uttar Badepasha and Dakshin Badepasha under Dharmapasha sub-district.

The villages located around the Tanguar *haor* are highly dispersed and small in size. Usually, these villages are established on small natural or artificial hillocks that protect the community from flood water. Consequently, during the rainy season, these villages are completely surrounded by water, like small islands. There is subsequently no permanent road network access to the sub-districts and other urban areas. Boats provide the only means of transport during rainy season. Most of the villages do not have adequate access to health, education and electricity services throughout the year, and the households largely depend on agriculture and fisheries for their primary livelihood activities. Unlike Hakaluki *haor,* the number of fishermen is higher because there is a formal fisheries co-management scheme in place.

3.4 Methods

We used a community-based participatory approach to data collection and analysis in order to understand the exposure experiences and perceptions of different livelihood groups (Kosmowski et al., 2016). Following a case study research design (Yin, 1994) we conducted a contextual analysis of livelihood exposure to climatic stresses in the northeastern floodplain of Bangladesh. The strength of the case study approach is its ability to enable intensive observation within 'real life' settings, involving a large number of variables and their co-variation (Yin, 1994; Gerring, 2004; Ford et al., 2010). Working within the case study design, we adopted a mixed-methods strategy that combined qualitative and quantitative methods to help generate more systematic observations and analyses of the empirical phenomena (Feilzer, 2010; Johnson et al., 2007). The advantage of this approach is methodological overlap, which enables a degree of validation and triangulation to enhance reliability (Bergman, 2011; Östlund et al., 2011).

3.4.1 Data collection

We purposively selected 12 case study villages from the two study areas using four selection criteria: i) the selected village should on the bank of the *haor*; ii) villages that are close to each other should be avoided, where 'close' was defined on the basis of relative distance between two villages. ; iii) the village should have a recent history of experiencing climate stresses; and iv) the majority of the population of the village should depend on the *haor* resources for their livelihood activities. Following these criteria, we selected eight villages from Hakaluki *haor* and four villages from Tanguar *haor* for data collection. All villages were identified in separate meetings held in the respective union offices (Figure 3.1). We involved local government representatives (e.g., union council chairmen, and members) and local leaders in the process of selection as they were highly knowledgeable on the different climatic stresses affecting the areas and villagers' livelihood activities.

Table 3.1. Kay issues discussed in focus group discussions.

Key themes of focus group discussions
Which are the major climatic stresses observed by the different livelihood groups in the area?
What are the seasonal nature of each of the stresses? (e.g., when do they occur, what is the duration of each stress, what is the chronology of stresses in a year)
When do the communities consider an extreme event as a stress?
What is the historical nature of each stress? (e.g., are they experiencing the stresses more frequent than before?)
Do they think the stresses are occurring as a consequence of changes in climatic variables (e.g., precipitation, temperature)?
Do they think the stresses are happening because of their resource use behavior?
Do they think that the stresses are felt stronger because of non-climatic factors (e.g., livelihood practices, land cover changes, changes in river morphology, agricultural intensification, unplanned infrastructural development and insufficient government support)

We used 14 focus group interviews (FGI) and 35 in-depth key informant interviews to collect qualitative data. Participants were invited to take part in an open and participatory interview session that allowed us to conduct an interactive discussion between group members (Freeman, 2006; Wong, 2008). As part of our efforts to obtain methodological sensitivity and control for FGI best practice (Krueger and Casey, 2009), we followed Freeman's (2006) four methodological considerations, which involved: i) selecting members based on a certain livelihood group (e.g., farmers); ii) the group members were roughly homogeneous in terms of socio-economic background and empowerment; iii) at least one focus group was conducted in each village and the members were derived from the villagers who interacted with each other in social and economic activities; and iv) we generalized the outcomes based on the questions we asked them during the sessions. The participants were asked to identify the different climatic stresses they commonly encounter. Discussions at each session dealt with the duration, nature, extent and timing of different stresses and other key issues (Table 3.1). Members also provided details to support the geographic description of the *haor* area adjacent to each village. Focus group interviews comprised 8-10 members and each lasted for 1-1.5 hours.

Key informants were also selected for in-depth interviews (DiCicco-Bloom and Crabtree, 2006) and included: local government representatives, local leaders and persons with in-depth knowledge of the local geography, climatic stresses and local livelihoods. In each interview, 7-8 open ended questions were asked following pre-testing. During the interview sessions, key informants were asked to identify major creeks, channels, canals and rivers that carry water to the *haor* and discharge from the *haor*. Questions were also related to the nature and history of climatic stresses in their respective villages.

Table 3.2. Variable description and descriptive statistics.

Variables	Variable description	Sample questions	Response scale	Hakaluki	Tanguar
dur_drou	Drought duration: the number of day respondents observe as water scarce period for both fishing and irrigation	How many days do you consider as drought in a season?	Number of days	52.19 (±14.21)	37.41 (±8.45)
int_drou	Interval of drought: number of occurrence of drought events in last 10 years	How many times have you experienced water scarce situations in last 10 years?	Number of times	2.53 (±0.69)	2.66 (±0.63)
loss_drou	Crop loss due to drought: degree to which a farmer or fisher lose crop due to drought	To what extent the water scarce situation does affect your production?	0 = marginal loss	19 (8.05%)	37 (31.36%)
			1 = moderate loss	208 (88.14%)	81 (68.64%)
			2 = extreme loss	9 (3.81%)	0 (0.00%)
surv_drou	Crop survival during drought: number of days a cropping practice can survive during drought days	How many days your farming or fishing practices can survive under drought?	Number of days	24.56 (±5.48)	26.80 (±3.51)
dur_ff	Drought flash-flood: the number of day respondents observe as flash-flood period for both fishing and irrigation	How many days do you consider as flash-flood in a season?	Number of days	17.74 (±6.81)	14.98 (±3.14)
int_ff	Interval of flash-flood: number of occurrence of flash-flood events in last 10 years	How many times have you experienced flash-flood situations in last 10 years?	Number of times	2.88 (±0.97)	2.84 (±0.65)

loss_ff	Crop loss due to flash-flood: degree to which a farmer or fisher lose crop due to flash-flood	To what extent the flash-flood situation does affect your production?	0 = marginal loss	27 (11.44%)	6 (5.08%)
			1 = moderate loss	30 (12.71%)	18 (15.25%)
			2 = extreme loss	179 (75.85%)	94 (79.66%)
surv_ff	Crop survival during flash-flood: number of days a cropping practice can survive during flash-flood days	How many days your farming or fishing practices can survive under flash-flood?	Number of days	10.22 (±6.04)	8.83 (±5.96)
dur_rf	Drought regular flood: the number of flood day respondents observe as negatively affecting both fishing and cultivation	How many days do you consider regular flood as destructive to your agricultural or fishing practices?	Number of days	117.62 (±26.24)	122.35 (±19.58)
int_rf	Interval of regular flood: number of occurrence of negatively affecting regular flood events in last 10 years	How many times have you experienced water destructive regular flood situations in last 10 years?	Number of times	2.83 (±0.81)	2.75 (±0.66)
loss_rf	Crop loss due to regular flood: degree to which a farmer or fisher lose crop due to regular flood	To what extent the regular flood situation does affect your production?	0 = marginal loss	127 (53.81%)	83 (70.33%)
			1 = moderate loss	84 (35.59%)	27 (22.88%)
			2 = extreme loss	25 (10.59%)	8 (6.79%)
surv_rf	Crop survival during regular flood: : number of days a cropping practice can survive during regular flood days	How many days your farming or fishing practices can survive under the flood situation?	Number of days	26.47 (±6.89)	27.40 (±6.42)

dur_er	Duration of extreme rainfall: the number of day respondents observe as extreme rainfall days	How many days do you consider as extreme rainfall in a season?	Number of days	22.27 (±5.07)	14.83 (±3.20)
int_er	Interval of extreme rainfall: number of occurrence of extreme rainfall events in last 10 years	How many times have you experienced extreme rainfall situations in last 10 years?	Number of times	2.64 (±0.83)	2.69 (±0.59)
loss_er	Crop loss due to extreme rainfall: degree to which a farmer or fisher lose crop due to extreme rainfall	To what extent the extreme rainfall situation does affect your production?	0 = marginal loss	225 (95.33%)	11 (9.32%)
			1 = moderate loss	10 (4.23%)	95 (80.50%)
			2 = extreme loss	1 (0.42%)	12 (10.17%)
surv_er	Crop survival during over rainfall: number of days a cropping practice can survive during extreme rainfall days	How many days your farming or fishing practices can survive under extreme rainfall?	Number of days	28.39 (±5.52)	12.03(±5.91)
liv_div	Livelihood diversity: number of livelihood activities, the household members are involved in	How many occupational diversities do you and your household members have?	Number of occupations	1.67 (±0.68)	1.94 (±0.68)
main_prof	Main profession: main livelihood activity that generates the largest portion of household income	Do you depend on natural resources for your livelihood activities?	0 = No	19 (8.05%)	8 (7.78%)
			1 = Yes	217 (91.95%)	110 (93.22%)
crop_div	Crop diversity: number of crops the farmers cultivate or type of fish a fisher catches each year	How many types of crops do you cultivate? Or, do you fish only small fishes or large and small fishes both?	Number of crops	1.52 (±0.5)	1.28 (±0.47)
rot_crop	Crop rotation: number of seasons for crop cultivation or fishing	How many times do you cultivate your land in a year?	Number of season	1.46 (±0.67)	1.36 (±0.72)

		Or, in how many seasons do you fish?			
lan_cul	Land type for cultivation: in the wetlands of Bangladesh, there are two types of land: 1) land remains inundated during flood season also known as low land and 2) land never remains under water except for extreme flood, also known as high land	Do you cultivate both low and high land? Or, do you fish in both open and common fishing grounds?	0 = No	170 (72.03%)	95 (80.51%)
			1 = Yes	66 (27.97%)	23 (19.49%)
Intensity of drought	Effect of drought on the livelihood activities of the respondents	To what extent drought affects your livelihood activities?	1 = marginally	72 (30.51%)	54 (45.76%)
			2 = moderately	157 (66.53%)	63 (53.39%)
			3 = extremely	7 (2.97%)	1 (0.85%)
Intensity of flash-flood	Effect of flash-flood on the livelihood activities of the respondents	To what extent flash-flood affects your livelihood activities?	1 = marginally	31 (13.14%)	7 (5.93%)
			2 = moderately	45 (19.07%)	29 (24.58%)
			3 = extremely	160 (67.8%)	82 (69.49%)
Intensity of regular flood	Effect of regular flood on the livelihood activities of the respondents	To what extent regular flood affects your livelihood activities?	1 = marginally	139 (58.90%)	88 (74.58%)
			2 = moderately	77 (32.63%)	20 (16.95%)
			3 = extremely	20 (8.47%)	10 (8.47%)
Intensity of extreme rainfall	Effect of extreme rainfall on the livelihood activities of the respondents	To what extent extreme rainfall affects your livelihood activities?	1 = marginally	229 (97.03%)	24 (20.34%)
			2 = moderately	7 (2.97%)	79 (66.95%)
			3 = extremely	0 (0.00%)	15 (12.71%)

Note: Standard deviations and percentages are in parentheses.

Quantitative data were collected though surveys with randomly selected households from the 12 villages. The size of the villages in Hakaluki *haor* varied between 100-150 households, while in Tanguar *haor* the village size varied between 70-100 households. We surveyed at least 25% of total households in each village, resulting in a sample size of 236 and 118 households from Hakaluki and Tanguar *haors* respectively. We interviewed the head of households, and in case of their absence, interviewed the most senior adult household member present. The survey began by identifying the major livelihood activities of the household head and also noted secondary and tertiary livelihood activities. The number of total employed persons and their livelihood activities per household were also discussed. Additional questions focused on the major stresses encountered by the household and how the household head perceived different stresses in terms of their livelihood activities (based on duration, frequency and loss of livelihood outcomes or by the survival of their livelihood activities in the presence of the stresses) (see Table 3.2).

3.4.2 Data analysis

We analyzed the qualitative data using dynamic coding and content analysis (Elo and Kyngäs, 2008) which allowed us to focus on the emerging context-specific phenomenon. For example, coding the data related to the seasonality and duration of different climatic stresses and the seasonality of major livelihood activities provided us with a 'stress calendar' depicting interaction between certain stresses and livelihood activities. To produce the stress calendar, we initially identified key coding terms based on the questions asked in focus group discussions, and condensed the data under key terms. Data obtained from key informant interviews were also codified and condensed to further inform the calendar and enhance reliability. This allowed us to depict the nature of climatic stresses and their impacts over time. However, van Aalst et al., (2008) warned that this information needs to be interpreted with caution because the observations can vary from group to group (e.g., different livelihood groups, age groups and social groups). Our analysis of data obtained from multiple sources helped to maximize the trustworthiness of our findings. The analysis also drew on local knowledge and extensive field visits to co-develop a 'community stress map' for each *haor*, led primarily by a field facilitator who is a local farmer in partnership with the first author, and the first author spent nine months (2015-16) living in the study areas. Notably, stress maps offer a more comprehensive and detail process of assessing locally specific stress nature and trends (Frazier et al., 2010; van Aalst et al., 2008).

Quantitative data on household-level perspectives of stress intensity were measured categorically. In order to analyze these data, we used ordered logistic regression to see how different stress and non-stress variables (e.g., duration, frequency, crop loss and survival to a stress, livelihood diversities, natural resource dependency for main livelihood activities, crop diversity, rotation of crops, and cultivated land types including high and low lands) interact with household perceptions regarding each stress events. Before performing the regression analysis, we calculated the Pearson correlation coefficients among the independent variables to understand if multicollinearity existed among the variables, and identified that the variables were not strongly correlated to each other (see Appendix 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8). The regression models helped us to identify the statistically significant variables determining respondents' perceptions regarding the effects of the individual stresses. Data were analyzed for both study areas as two different samples derived from two different populations (e.g., Hakaluki *haor* and Tanguar *haor*).

3.5 Results

3.5.1 Livelihood activities and potential climatic stresses

The major livelihood actives in the study area involved farming, fishing and day laboring. Many households reported having more than one livelihood activity, which were described as either primary (Hakaluki *haor* = 44.07%; Tanguar *haor* = 26.27%), primary and secondary (Hakaluki *haor* = 45.34%; Tanguar *haor* = 53.39%) or primary, secondary and tertiary (Hakaluki *haor* = 10.60%; Tanguar *haor* = 20.34%) activities based on their relative contribution to household-level production. While we recognize that the effect of climatic stress may be different on each of these activities depending on their interaction with different stresses, we have focused the following analysis on the primary livelihood activity to aid interpretation.

Agriculture was the major livelihood activity documented in the survey (Hakaluki *haor* = 89.83%; Tanguar *haor* = 78.81%), reported to be affected by all three climatic stresses, including flash-flood, drought and seasonal flood, at different times of the year. These stresses were described as being felt if crop rotation and crop diversity are higher. In the northeastern wetlands of Bangladesh, rice is the main crop, which mostly has three rotations including winter (also known as *Boro* in Bengali), pre-monsoon (known as *Aus* in Bengali) and monsoon rice (known as *Aman* in Bengali). Vegetables (e.g., potato, tomato, cucumber, bean, coriander) and oil seeds (e.g., mustard) are also cultivated in specific wetland locations during the winter season when most of the land area dries. While agricultural seasonality can be classified in three classes based on the availability of land, fishing can be classified in two seasons based on access to fishing rights. For example, open access to fishing is available during the monsoon period across Hakaluki *haor*, while during winter, open access fishing prevails in rivers, canals, creeks and channels. However, common property rights to fish are distributed by the government to community organizations in the *beels* during this time (for more detail see Rahman et al., 2015; Rahman et al., 2012). Consequently, fewer fishing grounds are available for the open access fisheries. Tanguar *haor* is managed under a co-management scheme between a donor-aided project and the fishermen, who get access to fishing in the wetland throughout the year. Similarly, laborers do not have access to work in the local area during the monsoon period when there are few agricultural activities occurring in both *haors*. As a result, they seek employment outside the local area (e.g., urban areas, sand and stone quarries distributed across Sylhet division and in other districts where *Aman* cultivation is extensive). Local demand for labor increases during both the plantation (winter) and harvesting (pre-monsoon) of *Boro* rice, and decreases in the interim period.

3.5.2 Temporal nature of climatic stresses

Drought occurs during the winter and pre-monsoon period ranging from early December to early May causing river water flows to decrease substantially. Flash-flooding is not a regular phenomenon, with respondents noting that it occurs every three to four years, generally between early April and late June. However, this type of climate stress has the potential to cause total production failures, especially on farms. Although the respondents mentioned extreme rainfall as a stress, it was not reported as having a significant effect on their major livelihood activities in both study areas. Extreme rainfall usually occurs in the early monsoon and therefore contributes to both flash-flooding and regular seasonal floods. Regular seasonal flooding is a common phenomenon resulting from upstream river flow and monsoon rain, occurring between mid-June and late November, and contributes to maintaining the wetland ecosystem. However, if this rainfall is prolonged at a high intensity in late monsoon for 5 days or more (Nowreen et al., 2015), it can significantly affect both fishing and agricultural livelihood activities (see Figure 3.2).

Climatic events are perceived as being a stress on livelihoods when they take place or extend beyond the expected period. For example, drought stress prevails for approximately 6 months in the study area. However, drought as a climatic stress is only observed between February and March, when surface water (including rivers and canals and rainfall) for *Boro* rice irrigation reaches its lowest level. Although, drought was not considered a major stress for the Tanguar *haor* agricultural communities because of the presence of large water sources, it was strongly observed in the Hakaluki *haor* data, especially where there were insufficient water sources available. We discuss this spatial nature of exposure in more detail in Section 3.5.3. Although pre-monsoon or *Aush* rice is not widely cultivated in our study areas, drought was reported to affect land and seedling preparation for this crop. Drought was also reported as increasing the risk of insect infestation for both *Boro* rice and other short-rotation crops like mustard seed, cucumber, beans and coriander. Flash-flooding was perceived as a stress if it appears suddenly with a strong current during the *Boro* harvesting period in late April to early May. Under such a situation, farmers are forced to harvest pre-matured rice which reduces their expected production levels. *Aman* or monsoon rice is generally cultivated in the agricultural fields located peripherally to the villages, and not in the wetland areas themselves. This rice can thrive under flood conditions for a relatively long period, but it can also be affected if the regular flood extends beyond the harvesting period to November. Such a situation also delays land preparation for *Boro* plantation, and prolongs the cultivation period increasing its susceptibility to flash-flooding. On the other hand, fishermen perceived both flash-flooding and seasonal flooding in a different ways than farmers. They reported having inadequate physical capital (e.g., artisanal boat and other fishing equipment) for fishing in high current flash-flood conditions and highly inundated regular flood waters (see Figure 3.2).

Taken together (Section 3.5.1 and 3.5.2), we can observe that respondents determined the temporal nature of different climatic stresses based on their livelihood activities, the nature of the outputs and the seasonality of production activities and the physical appearance of different stresses, which is consistent with the first proposition (see Section 3.2.1).

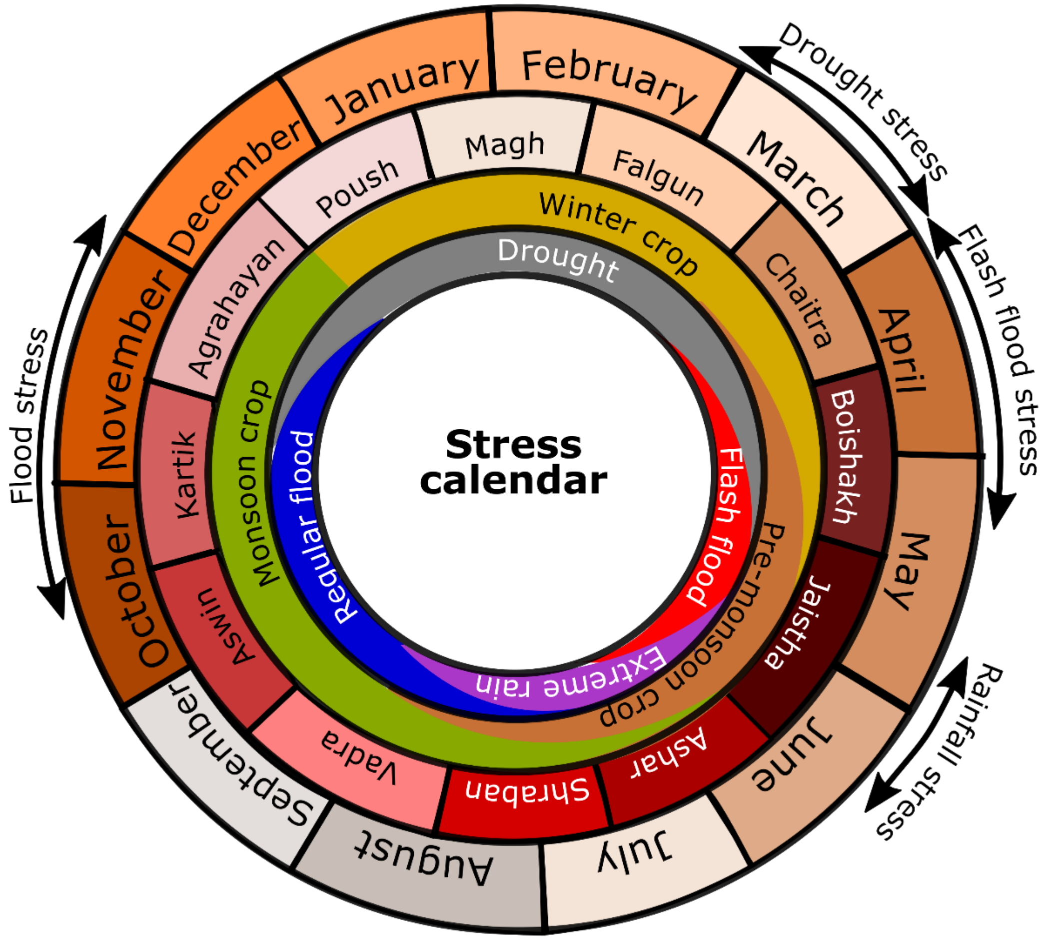

Figure 3.2. Stress calendar of the study areas.

3.5.3 Spatial nature of climatic stresses

Both Hakaluki and Tanguar *haors* function as temporary reservoirs for upstream river flow. Consequently, river water inflow and outflow governs the flooding regime of both areas. However, rainfall within the Bangladeshi territory also contributes to flooding. From the community stress map of Hakaluki (Figure 3.3), it can be observed that there are four trans-boundary rivers that carry water to the *haor*, including Juri, Panai, Borodol and Konthinala. While these four rivers play a major role in water inflow, there are a number of permanent and non-permanent hilly streams that also contribute to water flow. Importantly, all of these streams come from small hills located around the Hakaluki (inside Bangladesh), which dry up during the drought period. However, Juri river is the only outflow of flood water, which combines with Kushiara river near Fenchuganj sub-district. Notably, Baradal, Fanai, and Konthinala rivers join with the Juri river at different locations within the *haor*. Beyond serving as the main water channels inside the *haor*, these rivers and canals work as the main sources of irrigation during drought periods (see Figure 3.3). However, river bank erosion and siltation, which are both considered natural phenomena of the rivers in Bangladesh (Deb and Ferreira, 2015), has significantly reduced their water carrying and storage capacity. For example, standing on the bank of the Juri river, one key informant in Hakaluki *haor*, who is both a local farmer and a community leader involved in different environmental conservation activities initiated by government and non-government organizations, stated:

> *"Around 20 years back, this river was wider than the present. Over the years, it has gained a significant amount of silt, which has shifted its present course and made it narrower, and you can see the silt load during the drought season"*.

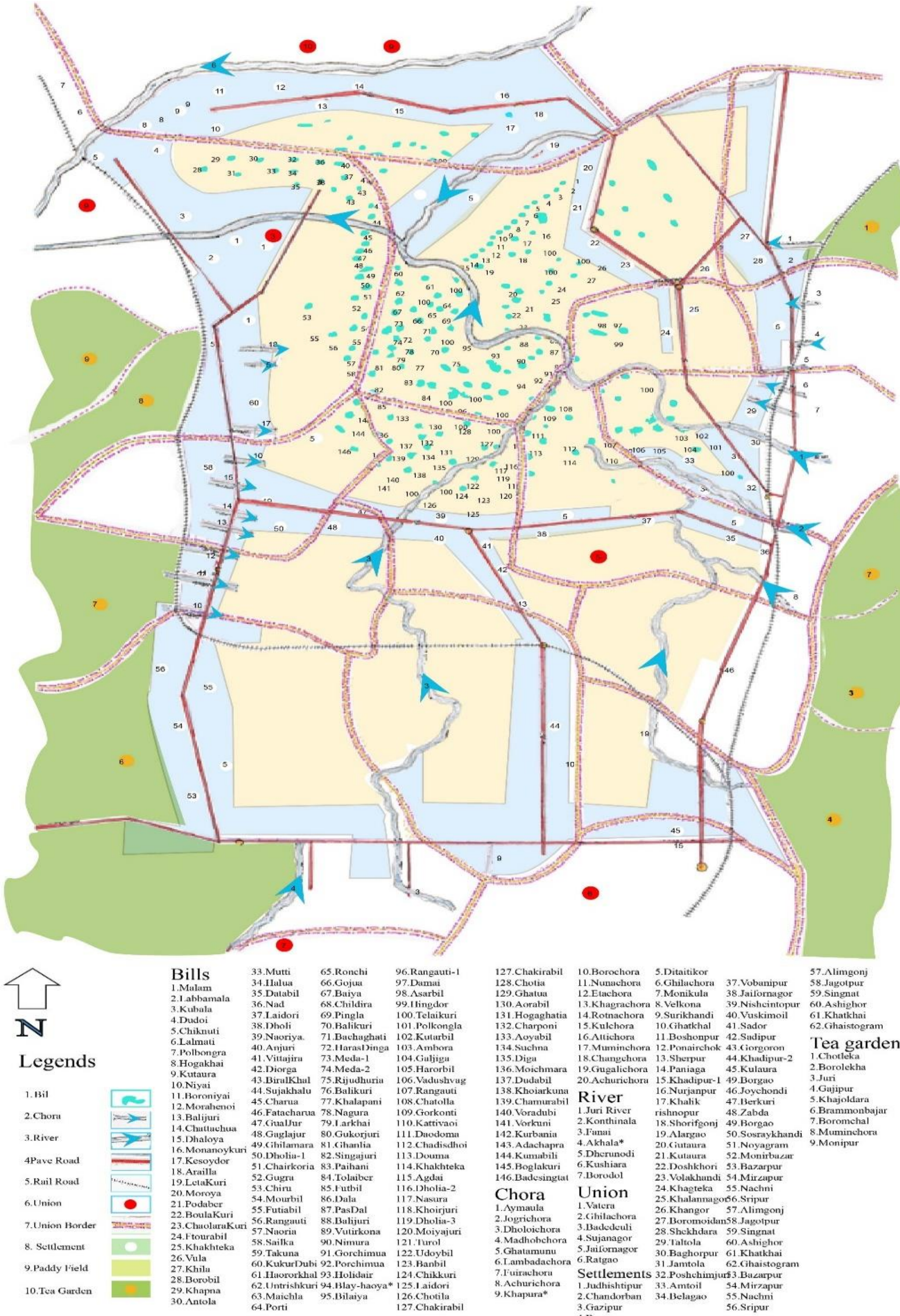

Figure 3.3. Stress map of Hakaluki *haor*.

Figure 3.4. Stress map of Tanguar *haor*.

Another key informant from Hakaluki *haor*, who is an elderly farmer, also suggested that:

> *"Canal water dries up within the first month of the drought season. So, we can irrigate our land at the beginning, however, it is impossible during the maturation period of rice. During this time, we need to depend on natural rainfall, especially in late March".*

Beyond these relationships with drought, the loss of river carrying capacity was also reported as contributing to flash-flooding. For example, the existing canals and silted Juri river were described as not being sufficient to drain flash-flood water in Kushiara river within the period of time required to maintain the desired water levels for rice harvesting (see Figure 3.3). Here, siltation was identified as causing water stagnation which reduced the time interval between flash-flooding and regular seasonal floods.

The geographic features of Tanguar *haor* are different from those of Hakaluki *haor*. Tanguar is part of a larger *haor* system, which also includes Maitan, Samnagar, Boroduma, Veramara, Shonir *haors*. A large river network flows and distributes water within this *haor* system, including Jadukata, Udalkhali, Ambarkhali, Patlai and Baulai rivers (Figure 3.4), all part of the Surma river tributary. In addition, more than 50 small permanent and non-permanent streams originating from the hills of Meghalaya contribute to water inflow. Unlike Hakaluki *haor*, the flood water passes through all of these rivers and finally flows into the Surma river through the Baulai river (Figure 3.4). The *beels* inside the Tanguar *haor* are deeper and larger than those of Hakaluki *haor*, increasing its water retention capacity. Here, respondents suggested that drought was not a major problem, instead identifying that flash-flooding was the major climatic event affecting the single rotation rice crop cultivated in the *haor*. From the field visit during the *Boro* rice harvesting period, we observed that the entire *haor* was flooded within five days, resulting in an almost total crop failure. To explain the severity of flash-flooding, one key informant from Tanguar *haor*, who is a local farmer and a leader of a community cooperative group, noted:

> *"flash-flood in this haor has two direct effects on rice plants. Either the rolling flash-flood water uproots the plants or, even after the reduction of flood water in 5-6 days, we cannot harvest the crop because most of them have rotted."*

In contrast, regular seasonal flooding was reported as not usually destroying crops because of the single rotation crop cultivation practices (e.g., *Boro*) in this *haor*.

These results support the second proposition, that the bio-physical changes of the *haors* have altered the flooding and irrigation patterns, which have potential to exacerbate the intensity of production losses, particularly for farmers (see Section 2.2).

3.5.4 Exposure determinants of the affected community members

While the spatio-temporal features of a local area significantly contribute to determining the nature of climatic stress exposure (Nowreen et al., 2015), affected community members also consider other factors. The survey of this study used nine stress and non-stress variables to help determine stress intensity. The non-climatic variables were used in these models to reveal the influence of spatio-temporal resource use practices and adaptive interventions on stress perceptions. Findings reveal that these variables were not equally considered by the affected community members when determining their exposure to different climatic events. The survey data also revealed that the selection of determinant variables showed mixed results across stress types and spaces.

Table 3.3. Exposure determinants of Hakaluki *haor* communities.

Drought		Flash-flood		Extreme rainfall		Regular flood	
Variable	**Coefficient**	**Variables**	**Coefficient**	**variables**	**Coefficient**	**variables**	**Coefficient**
dur_drou	0.033***	***dur_ff***	0.056	***dur_er***	0.114	***dur_rf***	0.003
	(0.012)		(0.036)		(0.103)		(0.008)
int_drou	0.067	***int_ff***	0.054	***int_er***	-0.235	***int_rf***	0.679***
	(0.248)		(0.195)		(1.015)		(0.247)
loss_drou	4.462***	***loss_ff***	4.214***	***loss_er***	3.641***	***loss_rf***	3.604***
	(0.830)		(0.595)		(1.347)		(0.426)
surv_drou	-0.052*	***surv_ff***	0.027	***surv_er***	-0.109	***surv_rf***	0.008
	(0.030)		(0.043)		(0.077)		(0.031)
liv_div	0.140	***liv_div***	-0.754***	***liv_div***	-1.482	***liv_div***	0.441
	(0.247)		(0.289)		(1.381)		(0.293)
main_prof	1.392**	***main_prof***	-0.664	***main_prof***	13.261	***main_prof***	0.515
	(0.646)		(0.829)		(20.432)		(0.753)
crop_div	-0.175	***crop_div***	0.172	***crop_div***	0.231	***crop_div***	0.376
	(0.291)		(0.354)		(0.692)		(0.324)
rot_crop	-0.263	***rot_crop***	-0.510	***rot_crop***	1.096	***rot_crop***	0.517
	(0.277)		(0.371)		(0.799)		(0.365)
lan_cul	-0.188	***lan_cul***	-0.195	***lan_cul***	-1.660	***lan_cul***	-0.160
	(0.430)		(0.568)		(1.611)		(0.503)
/cut1	4.808	***/cut1***	1.499	***/cut1***	16.893	***/cut1***	7.601
	(1.678)		(1.584)		(1.437)		(1.786)
/cut2	10.524	***/cut2***	5.432			***/cut2***	11.963
	(1.948)		(1.748)				(1.950)
Log likelihood	-129.517	***Log likelihood***	-92.679	***Log likelihood***	-12.845	***Log likelihood***	-103.611

Likelihood ratio χ^2	89.15***	***Likelihood ratio χ^2***	211.44***	***Likelihood ratio χ^2***	37.35***	***Likelihood ratio χ^2***	209.95***
Pseudo R^2	0.256	***Pseudo R^2***	0.533	***Pseudo R^2***	0.593	***Pseudo R^2***	0.503

Note: dur_drou = Duration of drought, int_drou = Interval of drought, loss_drou = Loss due to drought, sur_drou = Survival of crop under drought; dur_ff = Duration of flash-flood, int_ff = Interval of drought, loss_ff = Loss of crop due to flash-flood, sur_ff = Survival of crops under flash-flood; dur_rf = Duration of regular flood, int_rf = Interval of regular flood, loss_rf = Crop loss due to regular flood, sur_rf = survival of crop due to regular flood; dur_er = Duration of extreme rainfall, int_er = Interval of extreme rainfall, loss_er = Loss of crops due to extreme rainfall, sur_er = survival of crops under extreme rainfall, liv_div = livelihood diversities, main_prof = main rofession, crop_div = crop diversities, lan_cul = land cultivation. 1 = least effect on crops, 2 = moderate effect on crops, 3 = extreme effect on crops *$p < 0.1$, **$p < 0.05$, ***$p < 0.001$;* standard error is in parentheses.

Table 3.4. Odds ratios of exposure determinants of Hakaluki *haor* communities.

Drought		**Flash-flood**		**Extreme rainfall**		**Regular flood**	
Variables	**Odds ratio**	**Variables**	**Odds ratio**	**Variables**	**Odds ratio**	**Variables**	**Odds ratio**
dur_drou	1.034***	***dur_ff***	1.057	***dur_er***	1.121	***dur_rf***	1.003
	(0.012)		(0.038)		(0.116)		(0.008)
int_drou	1.069	***int_ff***	1.055	***int_er***	0.791	***int_rf***	1.971***
	(0.265)		(0.206)		(0.802)		(0.487)
loss_drou	86.621***	***loss_ff***	67.602***	***loss_er***	38.124***	***loss_rf***	36.741***
	(71.898)		(40.217)		(51.357)		(15.634)
surv_drou	0.949*	***surv_ff***	1.027	***surv_er***	0.897	***surv_rf***	1.008
	(0.029)		(0.044)		(0.069)		(0.031)
liv_div	1.150	***liv_div***	0.470***	***liv_div***	0.227	***liv_div***	1.555
	(0.284)		(0.136)		(0.314)		(0.455)
main_prof	4.023**	***main_prof***	0.515	***main_prof***	57.412	***main_prof***	1.674
	(2.598)		(0.427)		(1.19)		(1.260)
crop_div	0.839	***crop_div***	1.188	***crop_div***	1.260	***crop_div***	1.456
	(0.244)		(0.421)		(0.872)		(0.471)
rot_crop	0.769	***rot_crop***	0.600	***rot_crop***	2.992	***rot_crop***	1.677
	(0.213)		(0.223)		(2.392)		(0.613)
lan_cul	0.829	***lan_cul***	0.823	***lan_cul***	0.190	***lan_cul***	0.852
	(0.356)		(0.468)		(0.306)		(0.428)

Table 3.5. Exposure determinants of Tanguar *haor* communities.

Drought		Flash-flood		Extreme rainfall		Regular flood	
Variable	**Coefficient**	**Variables**	**Coefficient**	**variables**	**Coefficient**	**variables**	**Coefficient**
dur_drou	0.092**	***dur_ff***	-0.026	***dur_er***	0.283***	***dur_rf***	0.038
	(0.040)		(0.127)		(0.097)		(0.030)
int_drou	-0.045	***int_ff***	-0.594	***int_er***	1.369	***int_rf***	-0.451
	(0.442)		(0.520)		(0.497)		(0.811)
loss_drou	3.596***	***loss_ff***	9.780***	***loss_er***	5.617***	***loss_rf***	5.203***
	(0.911)		(0.258)		(1.058)		(1.452)
surv_drou	-0.152*	***surv_ff***	0.095	***surv_er***	-0.108	***surv_rf***	-0.180*
	(0.089)		(0.146)		(0.079)		(0.102)
liv_div	0.298	***liv_div***	0.904*	***liv_div***	0.066	***liv_div***	-0.372
	(0.403)		(0.527)		(0.423)		(0.757)
main_prof	-2.083	***main_prof***	34.855	***main_prof***	-0.397	***main_prof***	-1.394
	(1.708)		(1.344)		(1.602)		(2.682)
crop_div	0.622	***crop_div***	0.867	***crop_div***	1.866**	***crop_div***	2.174**
	(0.780)		(1.111)		(0.845)		(1.145)
rot_crop	-0.740	***rot_crop***	1.624	***rot_crop***	-1.450**	***rot_crop***	-0.347
	(0.661)		(0.172)		(0.706)		(0.772)
lan_cul	-0.436	***lan_cul***	15.938	***lan_cul***	0.490	***lan_cul***	-0.235
	(0.873)		(1.336)		(0.944)		(1.239)
/cut1	0.198	***/cut1***	11.883	***/cut1***	10.090	***/cut1***	3.359
	(3.643)		(10.259)		(3.237)		(5.241)
/cut2	6.458	***/cut2***	19.323	***/cut2***	16.374	***/cut2***	8.633
	(3.784)		(5.675)		(3.700)		(5.483)
Log likelihood	-103.61134	***Log likelihood***	-31.748	***Log likelihood***	-49.260	***Log likelihood***	-19.018

Likelihood ratio χ^2	209.95***	***Likelihood ratio χ^2***	117.14***	***Likelihood ratio χ^2***	103.20***	***Likelihood ratio χ^2***	133.95***
Pseudo R^2	0.5033	***Pseudo R^2***	0.649	***Pseudo R^2***	0.5116	***Pseudo R^2***	0.779

Note: dur_drou = Duration of drought, int_drou = Interval of drought, loss_drou = Loss due to drought, sur_drou = Survival of crop under drought; dur_ff = Duration of flash-flood, int_ff = Interval of drought, loss_ff = Loss of crop due to flash-flood, sur_ff = Survival of crops under flash-flood; dur_rf = Duration of regular flood, int_rf = Interval of regular flood, loss_rf = Crop loss due to regular flood, sur_rf = survival of crop due to regular flood; dur_er = Duration of extreme rainfall, int_er = Interval of extreme rainfall, loss_er = Loss of crops due to extreme rainfall, sur_er = survival of crops under extreme rainfall, liv_div = livelihood diversities, main_prof = main rofession, crop_div = crop diversities, lan_cul = land cultivation. 1 = least effect on crops, 2 = moderate effect on crops, 3 = extreme effect on crops *$p < 0.1$, **$p < 0.05$, ***$p < 0.001$; standard error is in parentheses.

Table 3.6. Odds ratios of exposure determinants of Tanguar *haor* communities.

Drought		Flash-flood		Extreme rainfall		Regular flood	
Variables	**Odds ratio**	**Variables**	**Odds ratio**	**Variables**	**Odds ratio**	**Variables**	**Odds ratio**
dur_drou	1.097**	***dur_ff***	0.974	***dur_er***	1.327***	***dur_rf***	1.039
	(0.044)		(0.124)		(0.129)		(0.031)
int_drou	0.956	***int_ff***	0.552	***int_er***	3.930	***int_rf***	0.637
	(0.422)		(0.287)		(1.953)		(0.516)
loss_drou	36.448***	***loss_ff***	2.02***	***loss_er***	2.004***	***loss_rf***	18.794***
	(33.189)		(2.09)		(2.894)		(26.946)
surv_drou	0.859*	***surv_ff***	1.099	***surv_er***	0.898	***surv_rf***	0.835*
	(0.076)		(0.161)		(0.071)		(0.085)
liv_div	1.348	***liv_div***	2.471*	***liv_div***	1.068	***liv_div***	0.690
	(0.544)		(1.303)		(0.452)		(0.522)
main_prof	0.125	***main_prof***	1.37	***main_prof***	0.672	***main_prof***	0.248
	(0.213)		(1.89)		(1.077)		(0.666)
crop_div	1.862	***crop_div***	2.38	***crop_div***	6.464**	***crop_div***	8.793**
	(1.453)		(2.644)		(5.465)		(10.064)
rot_crop	0.477	***rot_crop***	1.66	***rot_crop***	0.235**	***rot_crop***	0.707
	(0.315)		(1.14)		(0.166)		(0.546)
lan_cul	0.647	***lan_cul***	8.354	***lan_cul***	1.632	***lan_cul***	0.791
	(0.565)		(1.14)		(1.540)		(0.980)

Table 3.3 and Table 3.5 provide the descriptions of the ordered logistic regression results for how the respondents considered the stress intensity of different climatic events in the Hakaluki and Tanguar *haors* respectively, while Table 3.4 and Table 3.6 report the odds ratios of the models. We find that in the case of drought, natural resource dependency for main livelihood activities, duration of drought, crop loss and crop survival capacity are statistically significant in Hakaluki, while in Tanguar the duration of drought, crop loss and crop survival capacity are statistically significant. Hence, it is observed that commonalities between the cases in identifying drought stress determinants. Notably, the respondents emphasized the length of drought and the extent to which their crops can survive in the stressed period as key, which are interactive in nature and indicates that drought perception is built upon their crop's resilience to drought. However, in the case of flash-flood both study areas showed that livelihood diversity and crop loss due to flash-flood are statistically significant, although there were perceptional differences. The models suggest that livelihood diversity is negatively related to stress intensity in Hakaluki, which is opposite to the finding for Tanguar *haor*. This is likely due to an over dependency on natural resources in the Tanguar *haor* communities, which is comparatively lower in Hakaluki. On the other hand, unlike drought, crop resilience against flash-flooding does not contribute to perceptions of its intensity since it often causes total crop loss. Thus, crop loss appears as the significant determinant variable for perception of the intensity of flash-floods.

We observe large differences in the extreme rainfall models between the study areas. While crop loss due extreme rainfall is the only significant variable in the case of Hakaluki, the Tanguar *haor's* model suggests that crop diversity, rotation of crops, duration of extreme rainfall and crop loss are the significant variables. These differences likely occur because of the proximity of Tanguar *haor* to the Meghalayan mountain region of India. Extreme rainfall in this area, accompanied by similar stress within the territory of Bangladesh, increases the potential of high water flow levels. In contrast, Hakaluki *haor* has diverse surrounding land forms and resource use practices which would reduce the negative impacts of extreme rainfall. In the case of regular flooding, the models indicate that flood interval and loss are significant for Hakaluki, while crop diversity, loss and survival capacity are significant for Tanguar. Notably, the stress interval is only statistically significant for regular flooding in Hakaluki *haor*, since this area is highly affected by siltation loads in its major water channels resulting in water stagnancy (see Section 3.5.3). The models show that despite considerable perceptional differences between the two cases, both communities considered crop loss as an important determinant for all the stresses, while other non-climatic variables were important based on stress type. Nevertheless, the community members also valued climatic variables in describing stress, which indicates that the stress exposure perceptions of the communities are determined by both climatic and non-climatic variables, supporting the third proposition.

3.6 Discussion

Livelihood exposure to different climatic extremes is a product of interactions between the climatic (e.g., nature of extreme, frequencies and extent) and non-climatic properties (e.g., resource use behaviors, seasonality of livelihood activities and geographic properties) of a system. The results reported in this study suggest that a climatic extreme appears as a stress when it directly influences the major livelihood activities and production systems. They also suggest that the exploitation of capital assets for future livelihood sustainability depends on these interactions.

3.6.1 Interactions between climatic and non-climatic forces determine the nature of stresses

While the double exposure of livelihoods to climatic uncertainties and socio-economic disparity is well documented (Leichenko and O'Brien, 2002; Leichenko and O'Brien, 2008; McDowell and Hess, 2012), we argue that along with these two conditions the use patterns of available resources and the social-ecological properties of a system may significantly contribute to the experience of a stress. Our results suggest that winter rice is considered the most important crop, which is also subjected to the impacts of flash-flooding. However, we also find that crop loss in the wetlands is not a regular phenomenon, instead occurring when climatic stresses are temporally unexpected, and it is here that the community perceptions drew a boundary between extreme climatic events and climatic stress to livelihoods. By differentiating stress and extreme events, our results also identify specific time periods requiring adaptation actions (e.g., protecting *Boro* rice from flash-flooding for 10-15 days). Community members reported relying primarily on expanding their livelihood diversity rather than changing their main livelihood opportunities (e.g., farming and fishing) to reduce capital asset losses (Goulden et al., 2013). On the other hand, the government has established some permanent and temporary clay embankments (also known as submersible embankments) that require renovation every year (Rahman and Mondol, 2015; Haque et al. 2017) particularly to protect the *Boro* rice from flash-flooding. These embankments were reported as supporting crop protection from flooding in short-term (Rahman and Mondol, 2015) and have been suggested as contributing to the siltation of rivers in the long run (Haque et al., 2017). As a result, such protective infrastructure may actually be contributing to local bio-physical changes affecting water availability during drought stress periods.

Rapid environmental and geographic changes due to uncoordinated adaptation actions, human intervention and natural phenomenon can compound the intensity of climatic extremes (Grimm et al., 2008). The results suggest that the depletion of natural water channels increases the chance of drought, loss of fishing grounds and flood effects in both Hakaluki and Tanguar *haors*, previously argued by Huq et al. (2004) (see Section 3.2.2). Consequently, a stress event could occur without extreme climatic events, suggesting that climatic impact characterization and forecasting based on historical data may not be sufficient for policy responses. Recognizing this limitation, Grimm et al. (2008) suggested that spatially continuous information containing land cover change is necessary for monitoring such effects. Such approach has wider implications for assessing future vulnerability, because climate models have limited application to derive the impacts of land cover change, and are more useful for understanding changes to mean conditions. Moreover, land cover changes have the potential to alter the available ecosystem services either by reducing productivity (e.g., agricultural and fishery productivity) or by creating new opportunities for production (e.g., conversion of agricultural land to shrimp farms due to increased salinity in the southern part of Bangladesh).

3.6.2 Communities determine the severity of climatic stress based on production losses and contextual features

Although the IPCC (2012) considers exposure as the extent, frequency and duration of climatic extremes, communities in the study areas also strongly considered the potential of any climatic extreme to cause investment and production loss when determining their livelihood exposure. For example, this study observed that the effects of flash-flooding—which is short-term but often considered the most destructive climatic event in the study area—were determined by the amount of production loss. The results suggest that when we observe livelihood exposure to climatic stresses, it is equally important to know the failure of production arising from the stress rather than concentrating only on the nature of the climatic events (e.g., extent, frequency and duration).

Not surprisingly, stress perceptions are also context specific (Wei, 2015). For example, the communities of Hakaluki *haor* differed from the communities of Tanguar *haor* in perceiving their exposure to stresses. This was found to be largely dependent on the extent to which their livelihood activities were dependent on natural resources. Consistent with this observation, Bele et al. (2013), in the case of Cameroon, observed that communities' perception regarding climatic stresses differ from that of meteorologists because of the use of different sets of parameters. In this study, communities' responses to the stresses are responsive to the extent to which the stresses affect their production activities. The results highlight the potential for perceptional studies to help capture the contextual nature of climate stresses when identifying local-level adaptation priorities.

3.6.3 Contribution of participatory stress assessment

Roncoli (2006) suggested that participatory approaches can elucidate the cause and consequences of climatic stresses, and further facilitate knowledge co-production. Through the purposive use of participatory stress assessment, this study contributes three major lessons for future research and policy in the study areas and beyond. First, local human-induced environmental degradation can exacerbate stress effects. For example, although historically Bangladesh has relied on infrastructure solutions for reducing climatic stresses like floods (Ayers, 2011; Brammer, 2010; Araos et al., 2017), the results suggest that local environmental conservation measures like soil protection and watershed management may need more attention in combination with the development of shorter rotation rice varieties. Secondly, human perceptions regarding climatic stresses are not static, and can be influenced by adaptive learning and innovation. For example, stresses like flash-floods, regular floods, drought and extreme rainfall are all 'normal' climatic events in the northeastern floodplain of Bangladesh. However, this study observes that innovations such as diversifying livelihoods, crop diversity and multiple rotation of crops can curb communities' perceptions regarding stress intensity. Thus, it is important to concentrate on how these interventions can be sustained under market, social, economic, ecological and climatic uncertainties. Last, Roncoli (2006) and van Aalst et al. (2008) suggested that meteorological observation and community perceptions can together better describe stress nature and impacts. Using a regional climate model Nowreen et al. (2015), Masood and Takeuchi (2016) and Nury et al. (2017) provided a detailed account of changes in climate variables in the northeastern floodplain of Bangladesh and suggested that the probable affected area is shifting from northeast to farther north with a potential of frequent future flash-flood events. This study also observed that Tanguar *haor* is more affected by flash-flood in comparison to Hakaluki. However, bio-physical changes in Hakaluki are the strong drivers of transforming low impact stress to a high impact one, which cannot be captured using the climate models. Thus, together with Nowreen et al. (2015), this study provides a fuller description of climatic stresses and their impacts on the study area.

It is important to note that community perceptions can be misleading because of inadequate and inefficient knowledge dispersal mechanisms (Fazey et al., 2011; Jones and Boyd, 2011; Lata and Nunn, 2012), which is a common issue in developing areas (Tschakert et al., 2010). Further, Roncoli (2006) identified that community perception can be driven by culture, belief and experience. While relevant to the findings, the community members who participated in the study took climatic stresses as an obvious event of nature, and emphasized more on their production losses rather on the climatic variables. This is an area that would benefit from future research to assess the extent of community understanding of different stress properties (Mertz et al., 2009).

3.7 Conclusion

Climate change, as a locally felt global phenomenon, requires a considerable degree of contextualized knowledge in order to inform the design, implementation and evaluation of adaptation actions. This reality has led to an increasing focus on how community members interact with climatic stresses when sustaining their living based on their own understandings of such stresses. This paper offers a range of empirically-grounded insights to how the spatio-temporal properties of local resource systems influence the exposure of rural livelihoods to climatic stresses in the northeastern floodplains of Bangladesh, and how these serve to mediate communities' perceptions of such stress. Specifically, we found that the climatic stresses on rural livelihoods were catalyzed by human-induced environmental degradation and local resource use behaviors, contextual features which include both socio-economic and bio-physical properties. Moreover, a climatic event appeared as a stress to livelihood sustainability when it happened in an untimely manner and directly affected the production process. We also found that human stress perceptions varied with the level of locally-driven innovation and adoption of new technologies, which supports the important role of local experience and knowledge in adaptation planning. In order to make local adaptation planning more effective, equitable and sustainable in the northeastern floodplain region of Bangladesh, there remains an urgent need for more empirical research to further assess the extent to which local livelihoods are affected by different climate stresses, and how different communities in the region are adapting in response to perceived exposure. Specific knowledge needs of relevance to local adaptation policy likely include: how different communities are already managing their perceived stresses through fostering traditional knowledge systems, supporting local innovation networks and adapting livelihood practices.

Acknowledgements

We would like to acknowledge the generous funding support provided by the William Dawson Scholar Award, McGill University, the Prince Albert II of Monaco Foundation, Inter-governmental Panel on Climate Change (IPCC), South Asian Network for Development and Environmental Economics (SANDEE) and Asian Centre for Development (ACD) to support this research. The comments are solely the responsibility of the authors and under no circumstances may be considered a reflection of the position of the Prince Albert II of Monaco Foundation, IPCC, SANDEE and/or the ACD. We would also like to acknowledge Shiplu Chanda Avi and Kazi Newaz Mustofa for their important contribution to digitize the stress maps and field data collection. Special thanks to Dr. Arlette Saint Ville for providing comments on an earlier draft of this manuscript.

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Linking statement

Chapter 3 describes how climatic stresses are experienced by wetland resource-dependent communities in terms of spatial, temporal and resource use aspects to capture local environmental and bio-physical changes and seasonality of resource use. Such contextual stress impacts can have large impacts on community stress perceptions, which may have significant implications for their adaptation decision-making. Building on this perspective, Chapter 4, examines how community members are reducing their perceived climate sensitivity in order to sustain their livelihood activities.

CHAPTER 4: HOW DO CAPITAL ASSET INTERACTIONS AFFECT LIVELIHOOD SENSITIVITY TO CLIMATIC STRESSES? INSIGHTS FROM THE NORTHEASTERN FLOODPLAINS OF BANGLADESH

Abstract

This paper offers a novel methodological approach for better understanding how different capital assets can be organized, transformed, and used in different combinations to reduce livelihood sensitivity to climatic stresses – an area that requires greater research attention in the context of adaptation policy. Research was conducted in the northeastern floodplain communities of Bangladesh, regarded as one of the most climate sensitive, resource poor, and highly understudied areas of the country. This wetland-dominated ecosystem is home to diverse resources user groups (e.g., farmer and fisher) who are subjected to regular seasonal flooding, excessive rainfall, drought, and flash floods. Working in 12 adjacent villages of two significant wetlands (Hakaluki *haor* and Tanguar *haor*), qualitative and quantitative data were collected through 15 focus groups (n=15), 35 key informant interviews, and 356 household surveys to better understand how community members adapt in response to their livelihood sensitivity to the climatic stresses. Results indicate that community members organize and transform capital assets in diverse way to escape climate-induced 'poverty traps'. Findings also reveal that interventions from external agencies (e.g., government, non-governmental organizations and market institutions) are an important key to livelihood sustainability for many households.

Keywords: Asset combination; Adaptive capacity; Livelihood strategies; Thresholds; Wetland systems.

4.1 Introduction

Sensitivity, a component of climate vulnerability, indicates the degree to which a system is either positively or negatively affected by climatic stresses (IPCC, 2012). In other words, it is the measurement or exploratory description of a system's stability under stress. However, since sensitivity depends on context-specific system properties and their responses to stresses, there is no 'rule of thumb' for describing it in different contexts (Ford et al., 2010). For example, rural smallholders in developing countries are considered to be among the most climate-sensitive livelihood groups since they depend on social-ecological systems for their living (Bele et al., 2013; Ford et al., 2014). While the livelihood activities of, and opportunities for, rural smallholders are governed by the availability and productivity of ecosystem resources and socio-economic processes (Bele et al., 2013; Etzold et al., 2014), climatic uncertainties directly impact the ecosystem and influence livelihood sustainability (Bunce et al., 2010; Eitzinger et al., 2014).

According to the sustainable rural livelihoods (SRL) framework, livelihood resources, which are derived from social-ecological systems, are grouped into five capital asset categories: financial, manufactured, human, social, and natural capital (Ellis, 2000; Reed, et al., 2006; Birkmann et al., 2013; Speranza, et al., 2014). These asset categories are widely used as the basis for sensitivity-measuring indicators (Binder, et al., 2013; Marshall, 2011) that operate on the underlying assumption that the degree of access to assets directly influences a household's sensitivity to various stresses (Barua et al., 2014). However, the selection of indicators is highly contextual (Birkmann, 2006; Polsky et al., 2007; Füssel, 2010). For example, three very different sets of indicators were used to conduct assessments of the sensitivity of river basin management in Taiwan, marine-fisheries-based livelihoods in Bangladesh, and water resource systems in the eastern Nile basin (Hamouda et al., 2009; Hung and Chen, 2013; Islam et al., 2014). Notably, the selection of indicator sets is often guided by indicator selection principles and is grounded either in the existing literature or derived from field studies (Adger et al., 2004; Birkmann, 2006).

Despite the theoretical rigor and methodological robustness of indicator-based analysis, some researchers remain skeptical about its usefulness. For example, Below et al. (2012) noted that indicator approaches provide normative arguments (e.g., which conditions are good and which are bad) but cannot offer context-specific conclusions when applied to assess a poorly-defined system. Moreover, O'Brien et al. (2007) suggested that context-specific sensitivity is an assimilation of political, institutional, social, and economic structures, many of which are external to the context. These findings are extended by Hinkel (2011) who identified this feature as a major challenge to defining the boundary of a system. In addition to these observations, we also note that the indicator-based approach often fails to reflect the theoretical background of individual (or groups of) indicators. For example, according to the SRL framework, capital assets are connected to each other in different ways (Fang et al., 2014). Notably, each of these assets has its own observed variables, and variables of one asset may interact with those of another. In this paper, we assume that livelihood sensitivity is governed by these overlapping interactions, but that it cannot be adequately captured by their independent assessment.

This paper goes beyond widely used indicator-based measurements and offers a methodological approach that aims to addresses three key livelihood sensitivity-related questions: i) To what extent are capital assets connected to each other? ii) What is the nature of their interconnectivity? and iii) How do the interactive associations of capital assets contribute to reducing climate sensitivity?

Thus, this study contributes to filling a research gap that limits our understanding of how resources can be better invested to reduce livelihood sensitivity to climate change (Ribot, 2014).

4.2 Conceptual background

4.2.1 Characterizing capital assets

Rural development literature suggests that capital assets enhance the ability of smallholders to sustain their livelihoods, while climate adaptation studies identify them as buffers against risk and uncertainty (Devereux, 2001; Cinner et al., 2013; Speranza et al., 2014). However, the characterization of capital assets in relation to climate sensitivity is dynamic and complex. Although overlooked in much of the adaptation literature, development economics and resilience theories provide two necessary concepts that can assist with better describing these relations: poverty and rigidity traps.

Development economics describes a poverty trap as self-reinforcing, persistent poverty that occurs because of three conditions (Maru et al., 2012). The first condition is the *threshold effect*, which suggests that poverty persists because one or more capital assets remain under a critical level, consequently slowing development growth. The second condition, *institutional dysfunction*, may arise due to socially-embedded power asymmetries, the political exclusion of marginalized sects of society, and economic inequality. The third condition, *neighborhood effect*, results from socio-economic inequalities that separate society into several sub-groups based on economic status. This condition describes a socio-economic situation wherein affluent groups are able to afford better opportunities, whereas less affluent groups cannot; the result is that poorer groups tend to inherit their economic status, which is passed down from generation to generation.

As described in Holling (2001) and Moore and Westley (2011), resilience theory suggests that a community becomes stuck in a poverty trap as a consequence of poor potential (i.e., assets), poor connectivity (i.e., network and institutional connectivity), and poor resilience (i.e., the capacity to consume external shocks like climatic stresses). For example, Maru et al. (2012) and Crona and Bodin (2010) suggest that indigenous communities often fall into poverty traps because of economic and social inequity resulting from insufficient and unorganized capital assets, and that this situation of limited resources leads to unfocused and myopic innovations.

Although discussed primarily in resilience theory, a rigidity trap is considered a consequence of high levels of potential, over connectivity among institutional actors, and high resilience (Carpenter and Brock, 2008). When a system falls into a rigidity trap, an innovation vacuum is created, which can lead to lower diversity and change within the community (Allison and Hobbs, 2004; Carpenter and Brock, 2008; Holling, 2001). For example, Amekawa (2011) argued that households with higher levels of capital asset endowment for agricultural activities tend to show poor innovation when it comes to generating non-agricultural livelihood activities. Despite this, Maru et al. (2012) concluded that, between the poles of the poverty and rigidity trap, there is an optimal range of potential, connectivity, and resilience that supports the development of innovation, self-organization, and flexibility to reduce sensitivity. However, while the identification of this range is critical, it is often very difficult. For example, it is unclear what level of assets constitutes the threshold of this range, which assets can be categorized as having 'low' or 'high' potential, or what level of connectivity indicates functioning institutions.

Both development economics and resilience concepts consider such traps from different perspectives, yet together they propose that homogeneity in asset ownership across a community (a development economics perspective) and functional connectivity among them (a resilience perspective) are necessary for escaping traps and generating and sustaining multiple livelihood activities (Moore and Westley, 2011; Maru et al., 2012). Both concepts also emphasize the capital assets required to sustain a livelihood through generating necessary feedbacks when stresses occur (Haider et al., 2018). Here, the SRL framework focuses on three potential relationships among assets. First, assets may be sequentially related, which means that one capital asset ensures the availability of others and vice versa. For example, Barua et al. (2014) noted that the loss of human capital increases the susceptibility of natural capital loss, while households with higher levels of financial capital can bear the cost of innovation by experimenting with new technologies and learning new skills (van den Berg, 2010). Second, one asset may be substitutable for another. For example, Tacoli (2009) and Etzold et al., (2014) point out that, in the absence of sufficient natural capital, the climate-stressed rural poor in Bangladesh adopt migration—which requires a high degree of social capital—as a livelihood strategy. Third, a combination or cluster of different assets sustains livelihood activities. For example, Deressa et al. (2009) noted how Ethiopian farmers depend on all five capital assets in order to adapt, while Dorward et al. (2009) concluded that capital assets are used in specific combinations for generating different livelihood strategies.

4.2.2 Capital assets and livelihood diversities

Chambers (1989) and Amekawa (2011) have suggested that rural smallholders do not invest all their assets in a single livelihood practice; rather, they distribute them among multiple activities to reduce the risk of investment failure. Therefore, rural communities construct a portfolio of practices, which Cinner and Bodin (2010) define as a livelihood landscape. Livelihood opportunities are dependent on a household's 'bundle of rights' in relation to the assets (Ribot and Peluso, 2003), although access rights are often challenged by the poverty that results from social exclusion, skewed market access, powerlessness, and exclusion from policy processes (Goulden et al. 2013; Ribot, 2014). Thus, it has been argued that the impact of climatic uncertainties is compounded by socio-political and socio-economic entities, which in turn creates a group of people who are highly sensitive to climatic stresses (Kelly and Adger, 2000; Scoones, 2009). As a result, the exclusion of socio-political and socio-economic entities from the description of climate sensitivity is conceptually difficult.

4.2.3 Measuring livelihood sensitivity

Although an explicit connection exists between climatic and non-climatic entities (McDowell and Hess, 2012), Cinner et al. (2012) were able to offer a livelihood sensitivity measurement technique that is solely based on natural resources dependency. This technique is based on the concept that sensitivity results from over-dependency on natural resources, which then leads to poverty or rigidity traps; however, Cinner et al. (2012) suggest that these traps can potentially be escaped via livelihood activities that are not dependent on natural resources (Cinner et al., 2013; Fang et al., 2014). Despite the risks of stresses, rural smallholders continue to engage in climate-sensitive livelihood activities for three main reasons: i) the lack of alternative livelihood sources and inadequate skillsets that prevent participation in non-natural-resource-dependent activities (Bhandari, 2013); ii) a cultural and historical connection to the natural resources (Daskon and Binns, 2009); and iii) concerns about food security that are rooted in the tendency for natural-resource-dependent households to be more food secure than wage earners because of unstable food market mechanisms in many developing countries (Knueppel et al., 2010). In contrast, crop failure due to climatic stress is a probabilistic phenomenon that depends on timing and frequency. Hence, based on the ideas of Cinner et al. (2012), we have developed a household-level climate sensitivity measurement technique that incorporates the probability of crop failure and non-natural-resource-dependent livelihood diversities (for more detail see Section 4.2.2).

4.3 Study setting: Northeastern floodplain of Bangladesh

The northeastern floodplain of Bangladesh is a wetland-dominated ecosystem that is characterized by natural depressions locally known as *haors* (MPHA, 2012). These depressions are usually flooded during the rainy season from June to September before drying up during the winter. However, some water remains in ditches (known as *beels*) that are non-uniformly distributed across the *haors* (MPHA, 2012). During the dry season, most of the wetland areas serve as agricultural land while the *beels* serve as a habitat for diverse fish resources. Thus, these wetlands provide multiple livelihood opportunities for the natural-resource-dependent communities of the adjacent villages (Salam et al., 1994). However, these wetlands are highly susceptible to different climatic stresses like flash floods, seasonal flooding, excessive rainfall, and drought (Nowreen et al., 2015). Flash floods generally occur between mid-March and mid-April, which is the harvesting period of the area's major agricultural crop, *Boro*, or winter rice. Prolonged regular flooding and excessive rainfall affect both monsoon rice and fishing, while long term drought affects the early growth of *Boro* rice. The Hakaluki and Tanguar *haors* are considered to be the two most important wetland systems in this area due to their richness in biodiversity and natural resources.

4.3.1 Hakaluki *haor*

The Hakaluki *haor* is the largest freshwater wetland in Bangladesh, and it has been designated as an Ecologically Critical Area under the Environment Conservation Act (1995). This *haor* is located between 24º35′ to 24º44′ north and 92º00′ to 92º08′ east, and covers an area of 41,614 ha with a permanent inundation area (e.g., *beels*) of 4,635 ha (Choudhury and Nishat, 2005). It stands in between two districts, including Sylhet and Maulavibazar of Sylhet division. In addition, there are 5 sub-districts around the *haor* which include Golapganj and Fenchuganj of Sylhet district, and the Kulaura, Juri, and Baralekha sub-districts of Maulavibazar. In total, 11 unions (cluster of villages and the smallest administrative unit of Bangladesh government) of these five sub-districts are located around the *haor*.

The communities living in the villages surrounding the *haor* mostly depend on agriculture and fishing for their livelihood. *Boro*, or winter rice, is the major agricultural crop in the area, although multiple rotations of rice are also cultivated. In contrast, fishing is practiced throughout the year. However, obtaining fishing rights, which are categorized as either common or open, can be a complicated matter. Open fishing rights are granted to all community members, and these rights authorize residents to fish in rivers and canals only. Conversely, common fishing rights are only granted to community members who belong to fishermen's organizations, and these rights allow them to fish in the *beels* during winter (Rahman et al., 2015). Again, non-natural-resource-dependent activities like wage and day labor are also common. Notably, most villages in this area have access to drivable roads that are connected to sub-district level towns, which provides community members with more opportunities to participate in externally available livelihood activities.

4.3.2 Tanguar *haor*

Tanguar *haor* has also been designated as an Ecologically Critical Area by the government of Bangladesh. Moreover, this wetland is one of two Ramsar sites in Bangladesh because of its high biodiversity value. It is located between 25°05' to 25°12' north and 91°01' to 91°07' east, and covers an area of around 9,527 ha. India's Meghalayan foothills are located on the northern boundary of the wetland, and this area falls under the jurisdictions of Tahirpur and Dharmapasha sub-districts of the Sunamganj district. The adjacent villages are distributed among four unions: Uttar Sripur and Dakshin Sripur, which are located in the Tahirpur sub-district; and Uttar Badepasha and Dakshin Badepasha, which are part of the Dharmapasha sub-district.

Winter rice cultivation is the main agricultural practice in this wetland, and multiple rotations of rice are absent. However, fishing is more extensive in this wetland than in Hakaluki because of the government's wetland co-management project. In addition, non-natural-resource-dependent livelihood activities are common in this area (e.g., day labour, small business). Other livelihood activities like wage-based employment are uncommon due to generally low levels of education among community members and insufficient networks linking villages to nearby urban areas. Travel by boat is the only mode of transportation during monsoon season, and drivable roads are almost non-existent. Thus, this wetland is more remote than Hakaluki *haor*.

4.4 Methods

We adopted a comparative case study research approach using a mixed-method data collection strategy. Case study research is a common practice used for context-specific data collection and analysis (Ford et al., 2010). However, these studies do not ensure generalizability; rather, they support in-depth, locally-based climate sensitivity analysis (Gerring, 2004). Moreover, this approach provides opportunities to deal with a large number of variables. This mixed-method data collection strategy involves both qualitative and quantitative data to facilitate triangulation and maximize reliability (Bergman, 2011).

4.4.1 Data collection

We used five criteria in selecting the twelve case study villages from the two study areas: i) the selected village should be on the bank of the *haor*; ii) one village should be selected from each union; iii) villages with a recent history of experiencing climatic stresses should be selected; iv) villages having common boundaries and similar stress histories should be avoided; and v) the village's community should depend on wetland resources for their livelihood activities to some degree. Eight villages from Hakaluki and four villages from Tanguar *haor* were subsequently selected in close consultation with local government representatives (e.g., local government chairman and members), local leaders, and key community informants.

We surveyed randomly selected households to collect quantitative data. At least 25% of the total households from each village were surveyed, with the average size of Hakaluki *haor* villages ranging between 100-150 households, and the average size of Tanguar *haor* villages ranging between 70-100 households. Thus, a total of 354 households were surveyed (236 households from Hakaluki *haor* and 118 households from Tanguar *haor*). We interviewed the head of each household; if they were absent, we interviewed the most senior present adult household member instead. We asked 29 household capital asset-related questions using a pretested, semi-structured questionnaire (Table 4.1). These questions were initially selected from the Bangladesh Climate Change Adaptation Survey Round I questionnaire, which were then cross-checked in the field for contextual adjustment prior to final data collection. Before asking these questions, we listed the livelihood activities performed by the household members, and identified the household's major livelihood activities based on the self-reported income contribution of each activity. We also asked respondents to discuss how climate stresses had impacted their major livelihood activity during the past 10 years. We identified this time range to ensure that responses were both experience-based and could be reliably recalled, recognizing that the various climatic stresses are not experienced regularly, although they are becoming more frequent in each of the study areas [see also Shahid (2011) and Nowreen et al. (2015)].

Qualitative data were collected through focus group discussions (FGD) and key informant interviews (Freeman, 2006). The selected participants were invited to take part in these interactive sessions, which allowed us to collect community members' opinions (Wong, 2008; Freeman, 2006). Participants were asked about the village climate history, their knowledge about climatic stresses, the effects of these stresses on their livelihoods, and what initiatives and innovations had been undertaken by community members to adapt. Following the FGD best practices as suggested in Krueger and Casey (2009), each focus group was comprised of 8-10 members and lasted for 1-1.5 hour. A total of 15 FGDs were conducted during two different time periods (the post-monsoon period of 2015, and the pre-monsoon period of 2016).

One of the objectives in interviewing the key informants was to supplement FGDs, especially for the livelihood groups who were smaller in size and underrepresented (e.g., day labor, wage earners). Some of the interviews were conducted to triangulate FGD outcomes, while others obtained supporting perspectives from national and local government officials regarding the issues that were discussed in the FGDs. Thus, key informants were also selected purposively (DiCicco-Bloom and Crabtree, 2006). Since we had a diverse cross-section of informants, the interviews were limited to 7-8 open-ended questions after pre-testing, which were similar to the FGD questions (Johnson, 2002).

Table 4.1. Description of the variables.

Capitals	Variables	Description of the variables	Hakaluki	Tanguar
Financial	mon_inc	Monthly income: Calculated from self-reported approximate yearly income (in thousand taka)	16.15 (±10.55)	10.28 (±4.95)
	mon_expen	Monthly expenditure: Self-reported monthly expenditure for household maintenance and consumption purpose (in thousand taka)	15.28 (±9.65)	10.62 (±4.74)
	amt_loan	Amount of loan: Amount of present loan taken from formal, informal or both sources (in thousand taka)	27.63 (±54.30)	42.53 (±64.40)
	mon_inst	Monthly installment: Monthly installment of money against loan (in thousand taka)	1.99 (±3.57)	4.15 (±9.69)
	prod_cost	Production cost: Total yearly cost for production activities (e.g. agriculture, fisheries, domestic animal) (in thousand taka)	37.75 (±46.28)	33.17 (±29.33)
	loan_sour	Loan source: Loan taken from formal sources (e.g. micro-credit organization, formal banking system)	154 (65%)	63 (53%)
	sav_org	Saving in organization: Amount of money saved in the organizations	4.38 (±16.19)	1.07 (±2.75)
Natural	high_land	High land: Amount of land privately or permanently owned by a household that is not affected by regular seasonal floodwater, and usually used for housing, gardening and sometimes for agriculture	0.97 (±2.53)	0.37 (±0.57)
	low_land	Low land: Amount of land privately or permanently owned by a household that is fooled by regular seasonal floodwater, and usually used for agriculture and fishing	4.21 (±8.93)	5.03 (±8.80)
	am_sh_lan	Amount of shared cropping land: Amount of land that is taken with shared agreement that a cropper will provide with a portion of production to the private owner of the land	7.75 (±9.49)	2.59 (±4.22)
	pr_dom_an	Price of domestic animals: Present market price of domestic animal (in thousand taka)	37.84 (±51.55)	35.78 (±53.95)

	tyo_fis_rgt	Type of fishing right: Households enjoy common fishing property right	19 (8%)	54 (46%)
	hh_gr	Homestead garden: Households have homestead gardens	63 (27%)	3 (2%)
	own_pon	Ownership of pond: Households have ponds	60 (25%)	2 (1.6%)
	pr_hh_res	Price of household resources: Household level saleable natural resources like trees	23.27 (±22.08)	0.00 (±0)
Manufactured	pr_hh_prod	Price of household products: Approximate price of domestic assets (e.g. television, bi-cycle, motor cycle, mobile phone etc.)	8.41 (±30.80)	16.31 (±11.68)
	pr_prod_equip	Price of production equipment: Present market price of privately owned agricultural and fishing equipment or the amount of money spent for production equipment services (e.g. lending tractors, harvesters) each year (in thousand taka)	24.86 (±42.48)	22.03 (±24.69)
Social	num_org_mem	Number of organization membership: Total number of membership of household members in community level, NGO and government driven organizations	0.72 (±0.73)	1.30 (±0.94)
	num_part	Number of participation: Number of days the organization members spend for participating in the different activities in a month	5.12 (±5.54)	6.5 (±4.68)
	act_scor	Activeness score: Activeness of participation in organizational decision-making	1.35 (±1.28)	1.87 (±1.11)
	org_bsc	Bonding social capital based organizations: Member of organizations developed by the community members through collective actions	76 (32%)	65 (55%)
	org_lsc	Linking social capital based organizations: Member of organizations developed by non-government and government organizations	69 (29%)	72 (61%)
	brsc	Bridging social capital: Opportunities to work outside the community using personal network	157 (67%)	45 (38%)
Human	hh_siz	Household size: Total number of household members	7.23	6.46

		(±3.06)	(±2.26)
age_hh	Age of household head	49.67	48.30
		(±13.11)	(±14.38)
prof_ex	Professional experience: Years a household head employed in his/her primary livelihood activities	27.83 (±14.64)	27.43 (±13.87)
adq_prof_ex	Adequacy of professional knowledge: the household heads think that he has sufficient knowledge for primary production activities	167 (71%)	89 (75%)
typ_liv_kno	Type of livelihood knowledge: Type of knowledge for primary production activities (e.g. training, self-learning through experiment, traditional, knowledge sharing)	1.14 (±0.39)	1.04 (±0.2)

This research project was reviewed and approved by the McGill University Research Ethics Board. Informed consent of research participants was obtained prior to data collection, with the interviewers explaining the aims and implications of the research in the native language of the participants.

4.4.2 Data analysis

Because of mixed data types, we applied both qualitative and quantitative analysis followed by convergent-type integration of the outcomes (Feilzer, 2009; Johnson et al., 2007). This approach is commonly used to supplement quantitative analysis with qualitative observations and vice versa. Hence, this analytical approach ensures observational and analytical triangulation (Östlund et al., 2011).

4.4.2.1 Detecting different associations of asset variables

A common problem in statistical modeling is multicollinearity which arises because of the interconnected nature of independent variables (Alin, 2010). Hence, variable reduction based on data similarity is widely used to avoid this problem (Chong and Jun, 2005). Since one of our objectives is to better understand overlapping associations among different capital assets, we conducted exploratory factor analysis using the principal axis factor analysis technique with varimax rotation, and then used a regression technique for factor score calculation (Fabrigar and Wegener, 2011). Factor analysis is used to reduce a large number of observed variables to factors that represent underlying (unobserved) variables (Tinsley and Tinsley, 1987), considered particularly relevant to climate vulnerability and adaptation research (Jones et al., 2011; Below et al., 2012). Principle axis factor analysis was chosen because it provides better results when the observed variables are not normally distributed (DiStefano et al. 2009; Costello and Osborne, 2005; de Winter and Dodou, 2012). To determine how many factors should be retained for obtaining maximum variability, we estimated eigenvalues. Factors with an eigenvalue of more than 1 were considered for further analysis (Fabrigar et al., 1999), and it was observed that 5 factors were sufficient for explaining the maximum variability (cumulative variability 68% and 63% for Hakaluki and Tanguar *haors* respectively) of data for each study area. Hence, we calculated factor loading of each variable with each principle axis, and the highest value which indicated each variable's relation with each axis. We also preserved factor scores for each principle axis for further analysis (see Section 4.2.2). Cronbach Alpha values were also calculated for each factor; these values were more than or close to 0.7, which is the accepted level of data reliability (Bland and Altman, 1997). In addition, the Tucker Lewis Index of factoring reliability and the root mean square error of approximation index were also calculated.

4.4.2.2 Calculating livelihood sensitivity to climatic stresses and its relation to capital assets

Cinner et al. (2012) developed a sensitivity estimation equation for the coral-reef fishing communities in five western Indian Oceanic countries. Their equation was developed at a community level and was based on the community members' proportional dependence on fishing- and non-fishing-related activities. In this paper, we offer another equation for estimating sensitivity at the household level. Following Cinner et al. (2012), we calculated sensitivity based on natural resource and non-natural-resource-dependent livelihood activities. Here, we defined natural-resource-dependent livelihoods as activities that were directly related to wetland resources (e.g., agriculture, fisheries, and herding), with all other activities falling into the category of non-natural-resource-dependent activities (e.g., small business, day labor, wage labor etc.). We listed different livelihood activities that are performed by the household's members throughout a year. We also determined each household's livelihood identity based on which activity contributed the most income, which helped us to incorporate the household's socio-economic context into the equation.

$$S = \frac{NRA}{NRA+NNRA} \times \frac{NDsH}{NHC} - \frac{NNRA}{NRA+NNRA} \qquad (1)$$

Here,

S = Sensitivity

NRA = Number of natural-resource-dependent activities

NNRA = Number of non-natural-resource-dependent activities

NDsH = Number of years with dissatisfactory harvest

NHC = Number of harvesting years under consideration

This equation considers the number of natural- and non-natural-resource-dependent activities instead of the number of persons involved in these activities. Therefore, the equation helps to capture livelihood diversity rather than simply incorporating the employment status of household members. This is significant because, during the field survey, we observed that a person might have multiple livelihood activities or that more than one person from same household might sometimes be involved in same activity. Furthermore, to capture the historical nature of climatic stresses and their influence on natural-resource-dependent livelihood activities, we considered self-reported historical accounts of dissatisfaction with crop or resource harvests over the preceding ten years (see also Zheng et al., 2012). Recognizing these accounts were likely to be influenced by recall bias, we also asked respondents how many times their yearly harvests had been affected by different climatic stresses in order to help increase reliability. Although this historical account does not indicate the future trajectories of climatic stress, it helped us to understand the experience-based adaptation actions of the community members (Kelly and Adger, 2000). Notably, the first section of this equation describes the proportion of natural resource dependency, the second section captures the historical propensity of crop failure due to climatic stresses, and the final section represents the proportion of non-climate-sensitive livelihood activities. The value of each section of the equation varies between 0 to 1, while the value of sensitivity ranges from +1 to -1.

Dorward et al. (2009) identified three types of livelihood strategies based on asset combinations and performed activities. In the first strategy, 'hanging in', household assets remain the same and the assets are used to maintain livelihood strategies during the stress. This asset combination strategy keeps livelihood strategies stable and does not encourage experiments and innovations (Dorward et al., 2009). In the second strategy, 'stepping up', households invest in assets to increase productivity in their current activities. This strategy is particularly observed among highly natural-resource-dependent communities (Cramb et al., 2009). Although, resource use intensification may contribute to farm productivity, the livelihoods of households that employ this strategy always remain sensitive to climatic and non-climatic (e.g., environmental degradation) stresses (Paavola, 2008). In the third strategy, 'stepping out', households accumulate assets in order to move on to different livelihood activities. This strategy reduces natural resource dependence, which thus reduces sensitivity (Cinner et al., 2012). Consistent with these concepts, this equation suggests that those households that indicate a positive sensitivity value will tend towards the 'stepping up' strategy, those indicating a negative sensitivity value will follow a 'stepping out' strategy, and those indicating 0 will follow a 'hanging in' strategy. In addition, a household sensitivity value of 1 indicates that all of the livelihood activities of the household depend on natural resources, and its all harvests in last 10 years were dissatisfactory due to climatic stresses. To the contrary, a value of -1 suggests that the household's livelihood activities are completely non-natural-resource dependent with no climate sensitivity. Also, value 0 indicates that the negative effects of climatic stresses are neutralized by non-natural-resource-dependent activities.

We used the equation to calculate each household's sensitivity to climatic stresses and classified them into two groups using agglomerative hierarchal cluster analysis with Euclidian distances between individual observations to detect context-specific sensitivity thresholds. We considered two clusters to detect the sensitivity threshold for each study area based on its own range of sensitivity with an expectation that the sensitivity threshold would be 0 or the 'hanging in' strategy. The underlying concept for this expectation was that the community members do not show any response to the climatic stresses. Therefore, any threshold value other than 0 will indicate that the community members are showing adaptive responses either through 'stepping up' (values with '-' sign) strategies or by adopting 'stepping out' (values with '+' sign). Hence, we considered that values above or equal to the threshold level were identified as highly sensitive group, while the lower values were considered as lower sensitive group. We developed logistic regression models to observe the probabilistic relation between sensitivity level (higher sensitive group = 1 and lower sensitive group = 0) and the latent capital asset factors obtained from factor analysis. We used factors scores of each asset factor to develop the regression models. To test the significance of independent variables, we calculated Wald's χ^2 (Kyngäs and Rissanen, 2001).

4.4.2.3 Triangulation of quantitative results using qualitative data

We used content analysis in describing the qualitative data obtained from the FGDs and key informant interviews. Content analysis is a systematic and objective means of context-specific data analysis (Elo and Kyngäs, 2007). Following this analytical approach, we summarized the data using a coding protocol, which was developed after analyzing the quantitative data and identifying the key outcomes. The qualitative data were represented by depicting the indicative quotes from the interviews and FGDs, which was then merged with the quantitative observations on the basis of similarities and dissimilarities among the observations for triangulation. Thus, given their focus on similar issues, the qualitative and quantitative analysis ensured the desired validity of the study.

4.5 Results and discussion

This Section begins with an explanation of the interactive nature of capital assets, which is one of the major objectives of this study. After exploring the overlapping properties of the asset variables, the analysis goes on to identify how capital assets can serve as a buffer against climate sensitivity.

4.5.1 Associations among capital asset variables

Badjeck et al. (2010) posited that sustainable livelihoods require an analysis of how community members organize, transform, and combine their capital assets. The results of our factor analysis presented in Tables 4.2 and 4.3 help us to understand associations between different capital assets for Hakaluki *haor* and Tanguar *haor*, suggesting that the observed variables group into 5 factors in each case. Building on these results, we consider the nature of the different asset associations in each hoar and the implications for livelihood sustainability.

4.5.1.1 Hakaluki *haor*

i. Resource ownership facilitates access to other assets: In the case of Hakaluki *haor* (Table 4.2), we observe that natural-resource-dependent household productivity related variables (e.g., cost of natural-resource-dependent production, household savings with community or non-government organizations, high and low land ownership rates, amount of shared cropping land, total price of domestic animals, ownership of ponds, price of agricultural equipment, and price of household resources) were nested under the first principle axis, and were therefore named as 'primary production variables'. Usually, households that are more dependent on natural resources (e.g., land, pond, domestic animals) for household productivity require higher production input (e.g., fertilizer, pesticide, payment for fishing, fodder for domestic animals during rainy season), which we presume to be the underlying reason for the association among the natural, financial, and manufactured capital variables.

ii. Social capital complements the lack of financial capital: The second principle axis, which we label as 'credit access', is comprised of variables from both the financial (e.g., loan sources, loan amounts, monthly loan payments) and social capital groups (e.g., linking social capital and activeness score). Microcredit, which is provided by locally-operated non-governmental organizations, is necessary if smallholders wish to financially invest in productive activities in order to supplement losses due to climatic and non-climatic stresses. This association of variables indicates that the credit recipients must also possess sufficient linking social capital in order to establish communication with these organizations. However, several studies have suggested that poor households often have a deficit of linking social capital because of bureaucratic processes and authoritative governance (Woolcock, 1998; Dale and Newman, 2010). Notably, the microcredit organizations in Bangladesh work in a deliberative way; in addition to providing support to the villages, the organizations also practice relationship-marketing by interacting with loan recipients on a personal level, which is a common, modern day business strategy (Peppers et al., 1999).

iii. Local-innovation and experience reduce dependence on external support for human capital: The third axis hosts knowledge-related variables (e.g., age of household head, professional experience, and adequacy of professional knowledge), which we label as 'production knowledge'.

Although expected by the community members, non-governmental organizations do not usually provide any support (e.g., dissemination of agricultural knowledge, agricultural inputs or aid) other than microcredit. Conversely, different government agencies (e.g., Agricultural Extension Department and Bangladesh Agriculture Development Corporation) provide several programs that offer training in advanced agricultural techniques and technologies. However, many household heads have much experience dealing with and persevering through climatic stresses, and this leads them to believe that their knowledge is adequate to maintain their livelihoods and continue to deal with climatic stresses- a belief that only grows stronger with age and continued involvement in these activities. For example, one elderly farmer noted that,

> *"Many people ask me about the cultivation process since I experiment with new varieties and keep notes on when to intervene in different operational activities in the field. ……… I also consult with seed, fertilizer, and pesticide sellers to learn about new seed varieties."*

Table 4.2. Connectivity among the capital asset variables in Hakaluki *haor*.

Asset variables	**PA1 (primary production variables)**	**PA2(credit access)**	**PA3 (production knowledge)**	**PA4 (community organizations)**	**PA5 (production support variables)**
prod_cost	**0.80**	0.23	0.05	0.27	0.13
sav_org	**0.56**	0.2	-0.03	0.2	0.1
high_lan	**0.57**	-0.01	0.01	-0.03	0.17
low_lan	**0.76**	0.04	0.08	-0.02	0.05
am_sh_lan	**0.58**	0.22	0.05	0.11	0.17
pr_dom_an	**0.55**	0.14	0.02	-0.02	0.19
own_pon	**0.51**	0.02	-0.02	0.03	0.30
pr_prod_equip	**0.74**	-0.02	0.03	0.08	0.12
pr_hh_res	**0.57**	0.01	0.13	0.08	0.27
loan_sour	-0.01	**0.75**	0.02	0.11	-0.08
amt_loan	0.33	**0.57**	0.09	0.11	0
mon_inst	0.31	**0.59**	0.16	0.11	-0.01
act_scor	0.03	**0.57**	-0.01	0.53	-0.11
org_lsc	-0.17	**0.87**	0.06	0.13	0.05
age_hh	-0.01	0.04	**0.64**	-0.01	0.15
prof_ex	0.06	0.06	**0.97**	0.01	-0.02
adq_prof_ex	0.15	0.05	**0.57**	0.04	0.08
num_mem_org	0.08	0.32	0	**0.86**	0.05
num_par	0.04	0.43	0.02	**0.71**	0.09
org_bsc	0.32	-0.29	-0.06	**0.82**	-0.09
typ_liv_kno	0.02	0.11	0.06	**0.58**	0.14
tyo_fis_rgt	0.06	-0.07	-0.12	0.02	**-0.51**
hh_gr	0.27	-0.02	0.03	-0.05	**0.59**
pp_hh_prod	0.19	-0.12	0	0.08	**0.58**
Brsc	-0.06	-0.09	0.03	0.08	**0.51**
hh_siz	0.07	0.01	0.11	0.03	**0.64**
Inc	0.36	-0.09	-0.04	0.07	**0.72**
Expen	0.24	0.02	0.06	0.05	**0.57**

Note: Tucker Lewis Index of factoring reliability = 0.703; RMSEA index = 0.093 and the 90 % confidence intervals are 0.09 and 0.096; BIC = -416.7. Highest factor loading values are marked in bold letters.

iv. Collective actions fail because of poor connectivity and networks: The fourth axis is the location of bonding social-capital-based collective action variables (e.g., number of members in community organizations, number of participants in different collective actions and decisions, bonding social-capital-based community cooperatives, and types of livelihood knowledge), which has been labeled, 'community organizations'. Despite the fact that collective interventions are often considered to be effective actions for obtaining property rights and other adaptation measures (Adger, 2003), they appear to be less effective or in their infancy in Hakaluki *haor*. It was observed in the field that large farm holders are unwilling to participate in these actions since the activities involve resource sharing (e.g., agricultural equipment, labor, and knowledge) and small saving. However, these farm owners could assume the vital role of 'mediator' between government and community due to their social and political position (Ballet et al., 2007). In support of this observation, we note a comment of a local leader who owned a relatively large farm and had a high income.

> *"You will find that most of the rich farmers are engaged in different political parties. You will also find them participating in different village- and union-level development activities like school, mosque, or temple building. However, they usually do not take part in farmer's cooperatives because these are usually established by the poor farmers who have low income and savings. Thus, active engagement pays little."*

Moreover, these large farm holders usually have access to the alternative services (e.g., formal banking services, hired labor, or communication with government offices for agricultural knowledge). Sometimes, their active communication with the government leads to opportunities to obtain collectively available incentives like mechanical irrigation and harvesting systems. One conversation with such a farmer, who was not a member of any farmer cooperative but held a position in a government-driven community-based flood control organization, exemplifies the situation.

Interviewer: "Do you possess agricultural equipment like irrigation machines, harvesters or tractors?"

Respondent: "I have a tractor and an irrigation pump."

Interviewer: "How much money did you spend to buy them?"

Respondent: "Actually, I got them from Bangladesh Agriculture Development Corporation."

Interviewer: "Do you have a membership in farmer cooperatives, because as far as I am informed this equipment is usually distributed among the farmer cooperatives"

Respondent: "Not really. Actually, the government officers know me very well, and they have given them to me since the people in my village respect me, and I sometimes share them with my neighbors. Otherwise, the farmers would end up with conflict."

This conversation indicates the way in which richer local leaders enjoy strong control of incentivized supports, which increases frustration among the poorer community members. For example, in a focus group discussion with members of a farmer's cooperative in another village, one person stated that:

"After a year-long conversation with government officials, this year we finally received an irrigation pump for our forty-member cooperative. However, we see some people, who do not even need these things, and obtain them with relatively less effort. We cannot complain a lot because these people are more powerful, and sometimes some of our members need to depend on them for many non-livelihood-related issues."

Moreover, the government agencies that distribute the incentives do not have any institutional mechanism for identifying the most climate-affected poor farmers. Thus, they rely on local government channels and receive suggestions from Union Councils. One government official noted that:

> *"Many community organizations do not have formal registration, a prerequisite for obtaining relatively larger incentives like irrigation pumps and harvesters. We support individual farmers with seeds and fertilizers. However, we do not maintain any farmer database, and we do not have any centrally developed beneficiary selection guidelines, although we are suggested to distribute the incentives among the poor farmers. Thus, we need to depend on local government representatives."*

However, the community members reported less trust in the local government apparatus, since local-level politics are often subjected to elite capture. Hence, the absence of mediators from the community, and the failure of local governments to assume that role, has created an 'institutional gap' that leads to poor networks and connections (Rahman et al., 2014a; Goulden et al. 2013). This situation is particularly observable in the case of fisheries resources, which is a common phenomenon in wetland resource management in Bangladesh (for more detail see Rahman et al., 2012; Rahman, et al., 2015).

v. Clustering of financial investment and social capital increases income, but may reduce natural capital: The remaining variables (types of fishing rights, household gardens, price of household products, bridging social capital, household size, household income and expenditure) that mostly relate to 'production support variables', belong to the fifth axis. Notably, fishing rights show negative loading with this axis because most households in the study area primarily engage in farming, which makes them ineligible to participate in common fishing property ownership according to the government's fisheries resource management policy (Rahman et al., 2015). Again, most of the households largely depend on bridging social capital and financial capacity to generate alternative livelihood practices in both peripheral urban areas and abroad, which has also been reported in the case of northern Bangladesh (Etzold et al., 2014). There is a considerable difference in income between laborers in local areas and laborers who work abroad. Laborers who work abroad earn significantly higher wages than local laborers, which has made migratory work popular among people in poorer rural areas. To bear the cost of sending a family member to work abroad, poor households often sell some or all of their land, and become landless and non-natural-resource-dependent. This indicates that community members are willing to make a 'trade-off' among the capital assets to enhance income generation (Chambers, 1989; Scoones, 1998). For example, one focus group discussion involving local farmers revealed that,

> *"It is not like the landless farmers were always landless. People sell their land for many reasons. However, the most common reason nowadays is for sending one or two household members to work abroad. For example, a person who has two bighas of low land (local land measurement unit; 1 bigha = 0.33 acre), can harvest at most thirty-five to forty monds (local weight measurement unit; 1 mond = 40 kilogram) of rice. In the present market, this production is equivalent to 24,000 thousand takas at best (1 taka = 0.0125 USD). After calculating the production cost, the profit is minimal, and sometimes we experience a loss. It's true that farming ensures us rice (staple food of the Bangladeshi people) for consumption. However, if a household sells the land, and sends one member abroad, he can send at least 10,000-15,000 taka back home each month. So, if anyone gets such opportunity, he does not care about land ownership."*

4.5.1.2 Tanguar *haor*

In the case of Tanguar *haor*, we observed some common and contrasting features with Hakaluki, which is probably attributable to the social-ecological and socio-economic differences.

i) Access to natural capital facilitates access to manufactured capital: Within variable block analysis using factor analysis on Tanguar *haor* data (Table 4.3) suggested that 'household resource' related variables (e.g., production cost of the natural resource based activities, amount of shared cropping land, price of domestic animals, agricultural equipment and price of household resources) nested under the first principle axis. Field observation revealed that most of the shared croppers in Tanguar *haor* were landless and that they gained access to land through shared cropping, which particularly motivates them to obtain manufactured capital. Despite having a low amount of high lands, these households usually keep natural capital like domestic animals so they can sell them during periods of stress.

ii) Institutional development facilitates access to natural and financial capital: 'Organizational participation'-related variables (e.g., organization membership number, activeness in the organization, number of days participating in organizations, and loan sources) are grouped on the second axis. Unlike Hakaluki, Tanguar *haor* is managed under a co-management scheme, where the community members directly participate in wetland resource management activities under the guidance of the local government and the non-governmental organization responsible for implementing the co-management project. Along with maintaining the system, the organization supports the community with micro-credit. However, similar to Hakaluki, Tanguar *haor* communities also develop collective-action-based community organizations for saving money.

Table 4.3. Connectivity among the capital asset variables in Tanguar *haor*.

Asset variables	**PA1 (household resources)**	**PA2 (credit access)**	**PA3 (production knowledge)**	**PA4 (primary production variables)**	**PA5 (production support variables)**
prod_cost	**0.95**	-0.03	0.08	0.06	0.11
am_sh_lan	**0.51**	0.16	0.12	-0.25	0.14
pr_dom_an	**0.51**	0.13	-0.01	0.17	0.09
pr_prod_equip	**0.77**	-0.05	0.04	0.2	0.07
pr_hh_res	**0.55**	0.13	0.17	0.45	0.06
loan_sour	0.01	**0.67**	-0.1	0.2	-0.04
hh_gr	0.01	**0.57**	-0.1	0.01	-0.02
num_org_mem	0.12	**0.84**	-0.08	-0.04	0.23
num_part	0.1	**0.83**	-0.13	-0.02	-0.03
act_scor	-0.02	**0.68**	-0.08	0	-0.21
org_bsc	0.08	**0.52**	-0.03	-0.12	0.29
org_lsc	0.02	**0.81**	-0.19	0.14	-0.18
age_hh	0.08	-0.16	**0.86**	-0.09	0.05
prof_ex	0.13	-0.08	**0.95**	-0.04	-0.04
adq_prof_ex	0.09	-0.1	**0.62**	0.2	-0.07
mon_inst	-0.03	0.2	**-0.54**	0.12	0.3
sav_org	0.21	0.21	0.04	**0.52**	-0.01
high_land	0.05	0.01	-0.05	**0.56**	-0.07
low_land	0.24	-0.1	0.06	**0.82**	0.02
amt_loan	0.23	0.27	-0.03	**0.53**	0.26
typ_liv_kno	-0.09	0.06	-0.02	**0.52**	0.2
tyo_fis_rgt	0.06	0.22	-0.03	-0.27	**0.52**
own_pon	0.05	-0.05	0.03	-0.03	**0.56**
Inc	0.36	-0.02	0.12	0.49	**0.61**
expen	0.31	0.04	0.16	0.41	**0.72**
brsc	-0.01	0.11	0.05	0.03	**-0.59**
hh_siz	0.26	0	0.23	0.11	**0.58**

Note: Tucker Lewis Index of factoring reliability = 0.775; RMSEA index = 0.091 and the 90 % confidence intervals are 0.066 and 0.092; BIC = -684.4. Highest factor loading values are marked in bold letters.

iii) Experience is considered before taking financial supports: The third axis hosts 'production knowledge' related variables such as the age of household heads, professional experience, and knowledge adequacy. Interestingly, monthly loan installments negatively loaded in this axis because older household heads were more unwilling to take loans from external agencies. Perceptions of risk and prior experiences may influence these decisions. For example, one elderly farmer noted that,

> *"Taking a loan from microcredit organizations is risky to us because of production uncertainty. If we face loss, monthly installments become an extra burden on us. A young man can go to work anywhere, but it is difficult for us."*

iv) Different clusters of natural capitals are used for achieving financial capital: 'Primary production variables' (e.g., high and low land ownership, production knowledge, financial saving, and loans) are clustered under the fourth principle axis. Larger land owners have more access to and familiarity with different services like training facilities, government subsidized agricultural equipment, and formal banking systems that are usually only available in urban areas. However, due to insufficient communication networks and remoteness, poor households have insufficient access to these facilities. Moreover, government interventions to serve these segments of society are also inadequate. For example, one local leader noted that,

> *"Our communication system, particularly in dry season, is terrible. If a farmer plans to take bank loans or wants to participate in any government-related activities, he has to travel all the way to Tahirpur (Sub-district), which is almost 20-30 kilometers away. He also needs to spend at least 800 takas just for travel. One cannot finish their daily work. Thus, he has to travel frequently. The daily income of most villagers less than 300 takas.*

So, how can you expect that they will participate in these activities? Moreover, it is also difficult for government officials to come to these villages, often for the same reasons."

v) Access to locally available resources reduces bridging social capital: 'Production support variables like fishing rights, income, expenditures, household gardens, pond ownership, and number of household members are grouped under fifth principle axis. These variables are negatively associated with bridging social capital. This cluster best describes fishing communities. The co-management scheme in Tanguar *haor* increases income contribution from fishing. However, locally available natural-resource-dependent livelihood activities and income generating opportunities reduce community members' enthusiasm to build bridging social capital, likely because finding local opportunities requires lower transaction costs. Additionally, geographic isolation may also be an important issue.

4.5.2 Calculating climate sensitivity and its relation to estimated capital asset variables

Our results in Section 5.1 describe that the assets are mostly positively related to each other, although some relations are negative. This suggests that the assets are not in a 'rigidity trap' as described in resilience literature (Holling, 2001). This Section also identifies that the asset variables are organized in a diverse way, and the variables are not highly independent from each other, suggesting that the assets are not in a 'poverty trap'. While the asset properties indicate favourable conditions for innovation and adaptation, socio-economic disparity, inadequate amount of assets and poor institutional and organizational functioning may limit the potential of asset combinations in sustaining livelihood activities (Maru et al., 2012).

In this Section, we calculate sensitivity levels by applying Equation 1. We classified the observations into two clusters, and we identified -0.15 and 0.12 as the thresholds for Hakaluki and

Tanguar *haors*, respectively (Table 4.4). Thus, the observations with values equal to or above the threshold values were considered highly sensitive, and the remaining observations were classified as the less-sensitive group. We can also observe that threshold values were close to 0, which indicates that the households are responding to stresses by avoiding the 'hanging in' approach to asset use. For example, the Hakaluki *haor* communities exemplify the 'stepping out' approach by using assets to move to non-natural-resource-dependent activities. Conversely, the Tanguar *haor* communities appeared to employ 'stepping up' strategies in using assets to intensify natural resource use.

Table 4.4. Properties of equations for the cases.

Variables	Hakaluki *haor*	Tanguar *haor*
Natural resource dependent activities	1.547 (±0.972)	2.152 (± 1.767)
Non-natural resource dependent activities	0.795 (±0.874)	0.780 (±0.859)
Total livelihood activities	2.342 (±1.271)	2.932 (±1.920)
Number of dissatisfactory harvest years in last 10 years	4.427 (±1.449)	4.765 (±1.696)
Sensitivity	0.025 (±0.449)	0.0775 (±0.434)
Estimated threshold	-0.15	0.12
Highly sensitive	125	59
Low sensitive	109	59

Table 4.5. Climate sensitivity and the capital asset factors.

Hakaluki *haor*			Tanguar *haor*		
Variables	**Coefficients**	**Odds ratio**	**Variables**	**Coefficients**	**Odds ratio**
intercept	0.19976 (0.1381)	1.2116	***intercept***	-0.0215 (0.1949)	2.5866
primary production variables	0.20206 (0.1754)	1.2127	***household resources***	0.0178 (0.2497)	0.8316
credit access	0.39881*** (0.14131)	1.5025	***credit access***	0.12829 (0.18212)	1.3494
production knowledge	0.08425 (0.13386)	1.0519	***production knowledge***	-0.15555 (0.19239)	0.9114
community organizations	0.3773** (0.16558)	1.2744	***primary production variables***	-0.66472** (0.27629)	0.6553
production support variables	-0.1526 (0.13761)	0.8568	***production support variables***	0.04908 (0.22255)	0.8932
Wald's χ^2	6.8**		***Wald's*** χ^2	17.6***	

Note: $*p < 0.1$, $**p < 0.05$, $***p < 0.001$; standard error is in parentheses

Logistic regression models, which were developed for understanding the relation between sensitivity level and the principle axis variables obtained from factor analysis (Table 4.2 and Table 4.3), further elaborated these findings (Table 4.5). These newly calculated variables also represent different asset combinations, and thus, allow us to observe which variable combinations are influential in reducing climate sensitivity. For example, in Hakaluki, climate sensitivity increases when the primary production (primary production variables in Table 4.5) of households depends on natural resources whereas private ownership of natural resources (primary production variables in Table 4.5) reduces sensitivity in Tanguar. As stated earlier (see Section 5.1.1), Hakaluki households require the private ownership of natural resources in order to generate non-natural-resource-related activities, which is a scenario that has also been reported in the case of China (Fang et al., 2014). However, landlessness or poor land holdings reduce the capacity to 'step out' from climate-sensitive activities. One useful strategy that might aid landless or those with small land holdings could be the use of microcredits. However, the models suggest that microcredit is positively related to climate sensitivity. Field observations suggest that the microcredit was invested in agriculture in both study areas, and more climate sensitive households require more credit access if they encounter frequent stresses. Pitt (2000) posited that investment in agriculture facilitates shared and rental cropping practices, which are the two different modes of agricultural self-employment. However, considering how susceptible these activities are to climatic stresses, Cinner et al. (2012) have appropriately identified them as highly sensitive livelihood strategies. Moreover, Mallick (2012) found that tight payment schedules and unavailability of seasonal working capital increase the potential for farmers to become dependent on informal money lenders who charge high interest. On the other hand, Anderson et al. (2002) have noted that microcredit organizations can contribute to human capital generation, which can in turn improve natural capital. However, the tendency of households to rely on their own knowledge and the absence of human capital generation programs in both study areas may be responsible for poor innovation in non-natural-resource-dependent activities through the use of microcredit. Therefore, it can be argued that, despite the equal levels of stress, private resource owners can reduce sensitivity more efficiently than can poorer households. Hence, climatic stresses contribute to socio-economic inequality and persistent poverty, which Dow et al. (2006, pp. 79-96) identify as one of the root causes of injustice in adaptation. Again, we found that community organizations were positively related to climate sensitivity in Hakaluki, possibly because of less effective organizations to support communities' demands, and also the potential for elite dominance in decision-making as previously discussed.

Although it was observed that the communities in both study areas were close to a 'hanging in' situation, we found that both internal and external interventions were contributing to reducing sensitivity. Chambers (1989) has suggested that poorer households reduce vulnerability not by increasing income, but by diversifying livelihood strategies and reorganizing asset combinations. Consistent with these observations, we found that households in both the study areas relied on different asset combinations based on their availability. Although it is not clear which combination is most supportive, we can argue that it depends on which type of livelihood strategy is adopted by the community members. However, regardless of which livelihood strategies are chosen, external supports like market integration and the active involvement of government and non-governmental organizations are necessary. Thus, it is important to note the effectiveness of externally designed institutional structures (Rahman et al., 2014b). For example, the qualitative degradation of natural resources due to intensive use has been well-documented in many areas of the world. Thus, the ecological carrying capacity of resource systems should be assessed in order to identify the limits of adaptation support, and further attention should be given to identifying how this concern has been considered in internally and externally supported initiatives. More specifically, future research should focus on whether the current sensitivity reduction practices have the potential to cause future resource and opportunity decline. For example, migration to urban areas for non-natural-resource-dependent activities in Bangladesh has the potential to expose migrants to unfamiliar urban climate stress (Braun and Aßheuer, 2011; Rotberg, 2010).

4.6 Conclusion

According to the SRL Framework, capital assets are the cornerstones of livelihood sustainability in the face of risks and uncertainties like climatic stresses. It is widely recognized that these assets are key in enabling alternative livelihood activities (e.g., non-natural-resource-dependent livelihood activities like day labor, wage earning, small business ownership) that have less or no sensitivity to stresses. However, the organization of assets follows a complex process that is often influenced by socio-economic and socio-political factors - a process that is relatively underexplored in both development and adaptation literature. Both resilience thinking and development economics posit that lower levels of assets and poor connectivity ensnare rural communities in a 'poverty trap', while the SRL framework contends that poor organization, transformation, and combinations of assets impede innovation and adaptability. This paper borrows from both concepts, and offers a novel methodological approach in an attempt to understand how different asset combinations contribute to innovations in livelihood opportunities that can reduce sensitivity to climatic stresses.

We applied a mixed methods research design to collect data from the two study areas of the wetland-dominated northeastern floodplain of Bangladesh, and we analyzed the interactive associations among the capital assets. Once the data had been collected, we calculated sensitivity levels using an equation that was specifically designed for this purpose. After identifying the sensitivity thresholds for each study area, we determined the probabilistic relations of livelihood sensitivity with different asset portfolios. This systematic approach helped us to identify the asset use strategies that directly and efficiently contribute to reducing livelihood sensitivity, providing valuable insights that are relevant to both adaptation policy and practice. For example, we observed that community members in our study areas were combining, substituting and organizing assets for adapting and innovating new livelihood activities. Although the community members have not advanced to a large extent in securing non-natural-resource-dependent livelihood activities, active interventions into the communities are supporting them in escaping a climate-induced 'poverty trap'. As a whole, we observed that two major strategies were commonly being used in our study areas: i) communities in Hakaluki *haor* were mobilizing their networks with large-scale socio-economic systems (e.g., sub-national, national and, international) to generate alternative livelihood activities; and ii) Tanguar *haor* communities were intensifying natural resource use, which was being facilitated by active government interventions. Building on the methodological approach presented in this paper, future research could incorporate the outcome dimensions of the different asset combinations (e.g., monetary and non-monetary outcomes from different asset portfolios) in order to further justify and enhance the insights for adaptation policy.

Acknowledgements

We would like to gratefully acknowledge the funding support received from the William Dawson Scholar Award, McGill University, the Prince Albert II of Monaco Foundation, the IPCC for this research, South Asian Network for Development and Environmental Economics (SANDEE) and Asian Centre for Development. The comments of the paper are solely the responsibility of the authors and under no circumstances may be considered a reflection of the position of the Prince Albert II of Monaco Foundation, the IPCC, SANDEE and/or ACD.

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Linking statement

Chapter 4 analyzed how wetland resource-dependent community members in the northeastern floodplain region of Bangladesh organize, transform and combine different capital assets to generate different livelihood portfolios in order to reduce their sensitivity to climatic stresses. However, community members are also dependent on external support structures that are the responsibility of government. Building on this finding, Chapter 5 examines the extent to which government interventions are supporting the adaptation demands of community members. Here the aim is to understand recent advances in Bangladesh adaptation-related public policy and identify potential areas requiring further attention and reflection.

CHAPTER 5: ASSESSING INSTITUTIONAL RESPONSES TO CLIMATIC STRESSES IN THE NORTHEASTERN FLOODPLAINS OF BANGLADESH

Abstract

Bangladesh, as one of the most climate vulnerable countries in the world, encounters diverse climatic disturbances at different scales which can severely impact rural communities and livelihoods. In response, the government of Bangladesh has initiated a number of institutional responses through development plans to better support sustainable development. There have, however, been relatively few assessments of how these responses have impacted local sustainable development. Focusing on the highly climate-affected northeastern floodplain of Bangladesh, this paper presents the results of a synthesis of the existing literature supported by primary field data to identify how existing policy barriers threaten institutional responses to climatic stresses, while institutional rigidity and the non-inclusiveness of bureaucratic polity work to undermine efficiency, effectiveness and equitability. Our results point to the need for further policy revision to enable broader public participation in the design, implementation and evaluation of development plans.

Keywords: Community-based development; Agriculture, Fisheries, Livelihoods, Decentralization.

5.1 Introduction

Climate change is a global phenomenon whose impact is felt locally (Wilbanks and Kates, 1999). However, most adaptation-related decisions are generally taken at broader scales (e.g., international negotiation, national policies) based on historic climatic data, future climate forecasts, and generalized climate impact studies. This approach has an important limitation, particularly in the context of developing areas, where local communities largely depend on natural resources for their subsistence. Every natural resource system has its own climatic influences, ecological structures and embedded resource-use politics requiring locally-applicable adaptation schemes and processes (Tol et al., 1998). Defining the appropriate scale for planning is therefore an important aspect of sustainable adaptation management (Smit et al., 1999; Cash et al., 2006). Institutions, as regulatory regimes and decision making instruments (North, 1991; Fukuyama, 2013), enable governments to respond to the climate-related challenges facing society (Adger et al., 2005). However, it has often been observed that conventional governance systems, with generally high degrees of institutional rigidity and authoritative bureaucracy based on centralized control, can be counterproductive to this mission, particularly in the area of local development (Larson and Soto, 2008). When crafting responses to locally-experienced climate stresses such as flooding, storms and drought, both long- and short-term preparedness is necessary; requiring the equitable inclusion of different social groups in decision making and implementation process (e.g., gender, ethnicities, religious identities); technological innovation and knowledge dispersal; information access and community empowerment (Adger et al., 2006; Paavola and Adger, 2006; Few et al., 2007; Gupta and Van Der Grijp, 2010). Recognizing the significance of this challenge, many governments have initiated more locally-based planning processes to strengthen national institutional responses to the potential impacts of climate change (Comfort, 2007; Huq and Rabbani, 2011; Rodima-Taylor et al., 2012).

However, local planning and implementation processes generally follow a polycentric governance structure where multiple actors and agencies are involved (Ostrom et al., 1961; Gibson et al., 2000). As a result, achieving local sustainable development adaptation in the face of climate change largely depends on the extent to which national institutions can account for spatially and temporally distributed decision-making politics (Ostrom, 1990; Gibson et al., 2000; Adger et al., 2005; Termeer et al., 2010), an area of study that generally lacks empirical exploration. In this paper, we assess the recent advances made by the Bangladesh government to promote institutional responses to climatic stresses in the climate vulnerable wetland systems the northeastern floodplains through different adaptation-related planning processes at the local level (Barnett et al., 2015). Our aim is to generate insights of relevance to international, national and regional research and development initiatives seeking to foster community resilience to climate change-related stresses.

5.2 Climate -related stress features of the northeastern floodplain of Bangladesh

Bangladesh is one of the most climate vulnerable countries in the world due to its geographic location, ecological characteristics, economic conditions and social features (Ahmed et al., 1999; Ayers, 2011). Climate-related stresses affecting Bangladesh include: widespread flooding, except in the southeastern hilly areas; flash-flooding and seasonal flooding in the northeastern and northwestern regions; droughts in the northwestern regions; land erosion along river banks and in the hilly southeastern and northwestern regions; and sea level rise and cyclones along the long southern coastline (Ruane et al., 2013; Islam et al., 2013a). The impacts of such multi-dimensional climate stress include declining ecosystem productivity, forced migration of people, health hazards, unexpected changes in livelihood patterns, social injustice and conflict, economic stratification across societies, destruction of infrastructure and significant loss of human life (Kunii et al., 2002; del Ninno and Lundberg, 2005; Banerjee, 2007; Penning-Rowsell et al., 2013).

Geographically, the northeastern floodplain of Bangladesh is located within the upper Meghna river basin (one of the three major river basins of the county; also known as Surma-Kushiyara river basin); surrounded by the Assam and Meghalaya provinces of India on the eastern and northern sides respectively, Tripura to the south and the Brahmaputra river basin on the west. Topographically, this region consists of small foothills along the eastern border and the Meghalayan hills along the southern border (Bangladesh Haor and Wetlands Development Board (BHWBD, 2012). Beyond this area, wetlands (locally known as *Haor*) cover the floodplain, with 373 *Haors*[1] covering an area of 858,460 hectares (BHWBD, 2012). On the basis of their geographic positions and level of inundation during the rainy season, these wetlands are classified into three groups: 1) foothill and near foothill, 2) floodplain area and 3) deeply flooded area. During the rainy season, all wetlands remain under water and as a result, physical boundaries prove difficult to identify; while in the winter, only the lowest-lying areas remain under water. In addition to its extensive area of wetlands, the northeastern floodplain is home to one of the most complex river systems in South Asia, comprising 23 trans-boundary rivers that originate from India's Barak and Tripura river systems (MPHA, 2012).

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[1] *Haors*, as defined in Bangladesh Haor and Wetlands Development Board (BHWBD, 2012), *are the bowl-shaped depressions of considerable aerial extent lying between natural levees of rivers or high lands of the northeast region of Bangladesh. In most cases haors have been formed as a result of peripheral faulting leading to the depressions.*

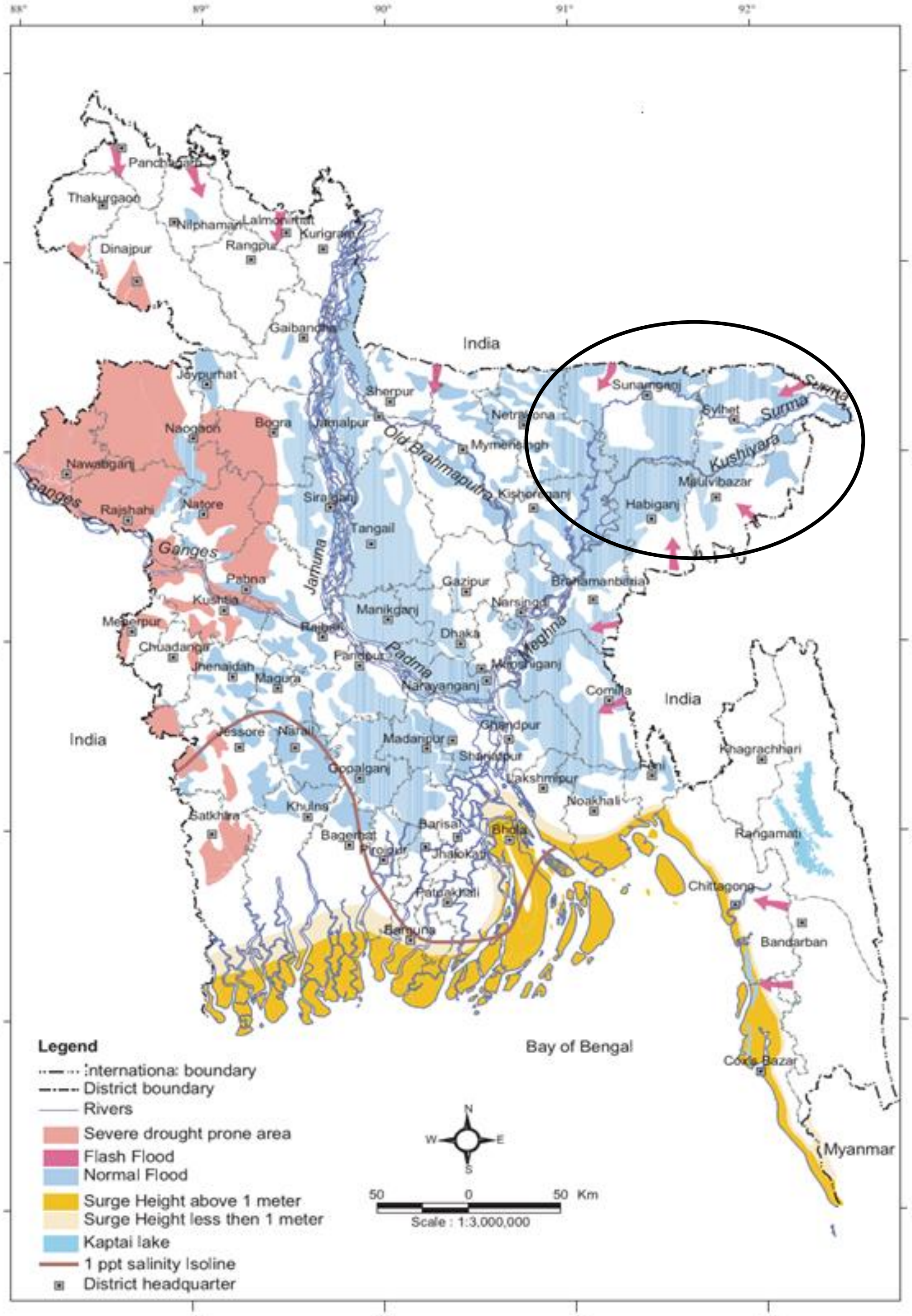

Figure 5.1. Distribution of climatic stresses in Bangladesh and the study area (Source: CEGIS, Dhaka).

Due to these outstanding geographic and climatic features, the floodplain experiences significant rainfall levels and seasonal flooding at varying intensities. Moreover, rainfall in the border areas, especially in Meghalayan hills (which receives the highest rainfall in the world) and associated rain water flow contributes to seasonal flooding of the area. Classifications based on annual flooding intensity and flood return intervals calculated by Ahmed and Ahmed (2003) for Bangladesh suggest that extreme flooding takes place once every 60 years, and normal flooding once every two years. However, in the last three decades, Bangladesh has experienced four extreme flooding events within a 10 year interval (1987, 1988, 1998, 2007 and 2017). Mirza (2003) and Chowdhury and Ward (2004) identified the major causes of these floods in the northeastern floodplain as being heavy rainfall within the region, upstream flows from the Barak tributaries and Assam range, and tectonic forces along with tidal effects.

Flash-flooding also occurs in the region (Shahid, 2011; Nowreen et al., 2015), primarily due to sudden, elevated river flows as a result of heavy rainfall in the Indian territory (particularly in Meghalaya and Tripura) resulting in loss of livelihoods severe damage to property and infrastructure (Figure 5.1). Nowreen et al. (2015), Masood and Takeuchi (2016) and Nury et al. (2017) provided a detailed account of the changing climatic patterns and flash-flood regimes in this area, and revealed that the area will likely face more frequent flash-flood events in near future. Resident communities in the northeastern floodplain depend primarily on agriculture and fisheries for their livelihood, which are both highly sensitive to flash-flood events (Paul and Rasid, 1993; Banerjee, 2010). Subsequently, the impacts of flooding on local social and economic conditions are extensive, multi-sectoral and uneven (Banerjee, 2007).

5.3 Methods

5.3.1 Conceptual framework

Ostrom et al. (1994) proposed a three-tier process of institutional decision-making and implementation, which comprises: constitutional, collective and operational choice levels (Carlsson and Berkes, 2005; Ostrom, 2011; Mincey et al., 2013). Building on this multi-tier institutional structure, Fischer et al. (2007) identified three hierarchically organized institutional instruments for addressing environment and natural resource issues: *policy* (constitutional choice actions), *polity* (collective-choice actions) and *politics* (operational choice actions).

Policy as an institutional process generates directives or plans that identify priority actions deemed necessary for addressing a particular problem (e.g., different adaptation projects designed under an adaptation plan). The execution of government policy directives requires synchronization of the institutional organizations, or bureaucratic polity, which generally follows a hierarchical organizational model (Hajer, 2003; Adger et al., 2005). The bureaucratic polity generally performs a key mediation role between policy and politics through information exchange and knowledge generation, particularly in multi-faceted policy environments such as climate change adaptation (Hajer, 2003). Politics as an institutional process experiences the implementation of policy directives through bureaucratic polity. In a democratic system, policy instruments ideally manifest the political choices of climate-challenged communities. Here, political choices can be seen as arising from the economic and the social demands of sustainable development under climatic stresses (Eakin et al., 2014). Importantly, politics as an institutional component pertains to every layer of institutional structure, including policy and polity. For example, government decisions in a democratic system are derived from the choices of elected politicians. We further recognize that polity is motivated by both the policy and local-level politics. However, an analysis of embedded politics in the policy and polity levels of governance is beyond the scope of our present study. Our analysis instead focuses on politics at the local level.

Adopting this conceptual framework, we subsequently developed three analytical criteria for each of Fischer et al.'s (2007) instruments adapted from the work of Adger (2003); Adger et al. (2003); Mog (2004); Maru et al. (2012); Adger et al. (2005); Füssel (2007) and Smith et al. (2009) in order to enable a more systematic explanation of institutional change in our study area (see Figure 5.2).

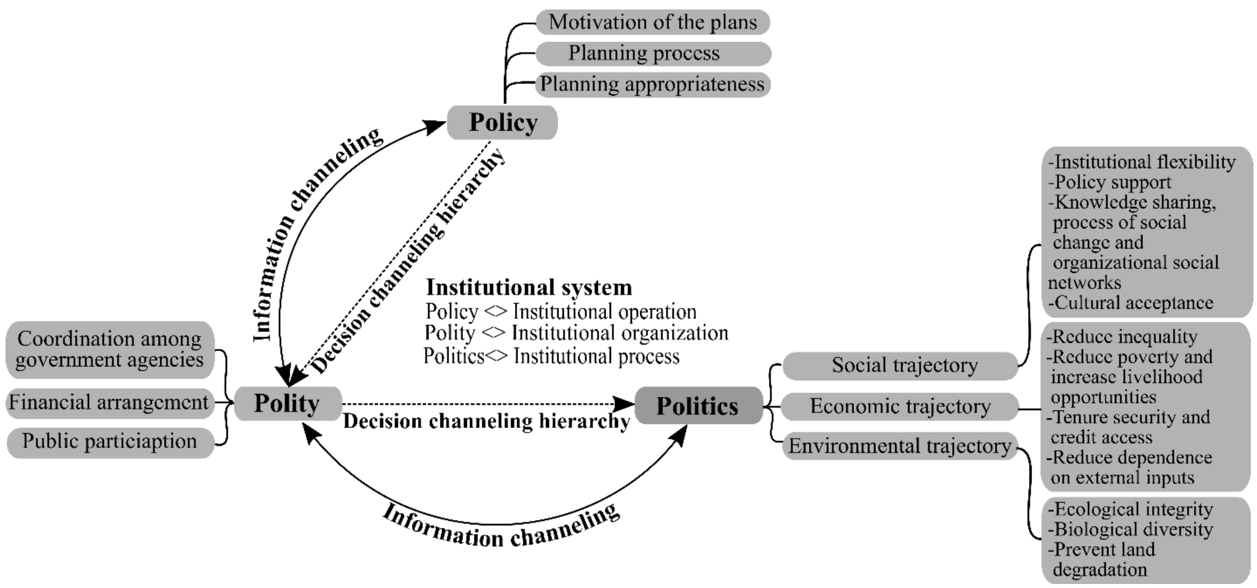

Figure 5.2. Analytical framework to study institutional adaptation.

5.3.2 Research design

We used a multiple methods approach (Bergman, 2011) to study institutional responses to climatic stresses in the northeastern floodplains for Bangladesh. In order to understand institutional change at the policy and polity levels, we analyzed five adaptation-related development plans using a synthesis approach. Synthesis is a study technique used to accumulate the outcomes of a number of qualitative studies (Suich, 2010). More specifically, it enables a 'greater view' to be created of a target domain and reveals new insights from primary qualitative studies through grand narratives and interpretive generalizations (Xu, 2008). In environmental management, synthesis is often necessary for public policy, providing options and insights on a wide range of issues beyond the scope of any individual study. It can also indicate focal areas that may require further research. However, the synthesis of primary studies has two major limitations: data quality and the sole dependence on primary studies. Data quality problems arise from the use of inappropriate methods, insufficient data and/or analytical weaknesses in the primary studies being used. To avoid the data quality problem, Whittemore and Knafl (2005 p. 549) suggest the '*…extraction of specific methodological features of primary studies*' for assessing authenticity, methodological quality, informational value and the representativeness of primary sources, although a standard criterion has not been developed.

Recognizing the relative deficit of primary studies in our chosen study area, we also conducted primary data collection through focus group discussions (Krueger and Casey, 2009) and key informant interviews (DiCicco-Bloom and Crabtree, 2006) in the two most important wetland systems in the northeastern floodplains: Hakaluki and Tanguar *haors*. During these sessions, we asked questions that emerged from the synthesis analysis in order to assist with issues of validity and reliability.

5.3.2.1 Data collection

The synthesis was conducted using a systematic approach (Walsh and Downe, 2005; Xu and Lu, 2011). Focusing on the broad policy issues of 1) climate change impacts and 2) sustainable development, we systematically extracted data from primary sources using the following search terms in Web of Knowledge and Scopus database: “climate change”, “adaptation”, “Bangladesh”, “institutions” AND “planning”.

We subsequently identified 98 studies of relevance to the scope of our research. Based on three selection criteria, including the methods used in each study, the relevance of the study to local development plans, and the relevance to our study area, we then reviewed each paper for acceptability, resulting in 45 primary studies being selected for detailed analysis. We also thoroughly studied different government documents identified as having high relevance to the study (e.g., Flood Action Plan reports) to support our analysis.

Primary data collection involved 14 focus group discussions in the peripheral villages of the wetlands (10 focus groups in Hakaluki and 4 focus groups in Tanguar *haor*, participant n = 8 to 10) and 20 key informant interviews with local community members (7), government officials (7), non-government officials (3) and local experts (3).

5.3.2.2 Analytical method

We followed an inductive approach to data analysis for our synthesis, allowing us to condense data from large and diverse texts in order to indicate relational structures which could then enable generalization to, and abstraction of theories (Zimmer, 2006). Based on our analytical framework and analytical criteria (Figure 5.2), we defined categories to extract relevant data through coding (Thomas, 2006), where the coding protocol followed the assessment criteria described in Section

5.3.1. We then screened the codified data by relating, comparing and contrasting to produce findings on the basis of relative importance. Moreover, to enable data triangulation, we codified the qualitative data using the same protocol, and compared them with the synthesis outcome (Bergman, 2011).

5.4 Institutional responses in the northeastern floodplain of Bangladesh

5.4.1 Policy

5.4.1.1 Motivations of the adaptation plans

While several development plans exist in Bangladesh, few have been devised to specifically confront climate change-related stresses (NAPA, 2005; BHWBD, 2012). Notably, most development plans are components of different national development policies (see MPHA, 2012), placing a greater emphasis on ensuring the socio-economic stability of communities under climatic stress as opposed to sustainable development. After reviewing all active plans related to sustainable development and flooding, we identified the following five as being the most important to our study area:

i. *National Flood Action Plan, 1990 (FAP)* is the first national level, extensive and long term plan to protect Bangladesh from flood stress (Thompson and Sultana, 1996). Bitter experiences from extreme floods in 1984, 1987 and 1988 fuelled the government's desire to develop this plan (Paul, 1995). The FAP sought flood protection through structural solutions such as engineered embankment and hydraulic structures (Rasid and Mallik, 1995), and comprised a large number of micro projects executable over a 20 year period (Sultana and Thompson, 2010). Establishment of flood protection infrastructures are not new in Bangladesh, which began in the 1960s. FAP is the extension of such interventions based on greater scientific understanding. Protection of agricultural productivity from flood stresses appeared to be a major objective as was the provision of agricultural irrigation during the dry season through water conservation (Mirza and Ericksen, 1996; Boyce, 1990). Strategically, this plan tried to regulate flooding within desired levels by maneuvering flood water flow within canals, channels, water reservoirs and ditches, a process known as flood compartmentalization (Paul, 1995); although such intervention was not executed in the northeastern floodplain. The structural developments under this plan, along with pre-existing embankments, have led to a significant alteration of cropping patterns throughout the country (Rasid and Mallik, 1995).

ii. *National Adaptation Program of Action, 2005 (NAPA)* is the national level adaptation plan committed to at the Conference of Parties (COP) 7 in Marrakesh, 2001 (Islam et al., 2013b). It was designed to initiate urgent adaptation needs (Zaman, 2011). The plan involves 15 adaptation strategies covering diverse actions across the country (NAPA, 2005; Islam et al., 2013b), with numerous location-specific initiatives (Ayers, 2011). The NAPA planning process made significant advancements in Bangladesh's national planning by revising and adjusting many pre-existing policies and plans. Ayers and Huq (2009) identified this plan as an important step forward to 'mainstreaming adaptation' in national development planning. The plan includes criteria-based prioritization of adaptation interventions in different areas of the country (Islam et al., 2013b).

iii. *Bangladesh Climate Change Strategy and Action Plan, 2009 (BCCSAP)* developed in response to the resolutions of COP 13 in Bali, 2007, commonly known as the Bali Action Plan (Alam et al., 2013). In developing BCCSAP, it appeared that NAPA 2005 was not a long term plan for combating climatic challenges largely because it lacked mitigation measures (Ayers and Huq, 2009). As a response, the development of BCCSAP 2009 was considered a revised version of NAPA, 2005, representing a national 'roadmap' to confronting and reducing the impacts of climate change (Alam et al., 2013), and was described as 'a comprehensive and integrated example of adaptation planning' (Ayers et al., 2014a, pp. 301). This plan was based on six major themes: 1) social security, 2) structural solutions, 3) capacity building of formal institutions, 4) knowledge management systems, 5) comprehensive disaster management and 6) development through carbon emission mitigation management (Islam et al., 2013a). Over a 10-year implementation period, the plan identified 44 programs under the six themes to be funded by both national government and international donor agencies, and implemented by both government and non-governmental organizations (BCCSAP, 2009).

iv. *National Plan for Disaster Management, 2010-2015 (NPDM)* is a national and international response to the intensified natural disasters affecting Bangladesh. Hierarchical institutionalization and action for disaster preparedness is at the core of the plan, which categorized activities of disaster management into national, district, sub-district and local levels with strong emphasis on monitoring and evaluation (Khan and Rahman, 2007). In addition to post-disaster interventions such as rapid supply of relief and infrastructure re-installation, the plan urges disaster preparedness through the capacity building of affected people to respond to the impacts through socio-economic improvement and widespread awareness building. As with other geographic areas, the northeastern floodplain has been given special treatment because of its propensity for flooding, and the need to enhance the capacity of affected people to safeguard life and livelihood through adaptation measures (NPDM, 2010).

v. *Master Plan for Haor Areas, 2012 (MPHA)* is the only locally-based integrated development plan for the northeastern floodplain. It identified 18 different development sectors (e.g., water resource management, agriculture, fisheries, livestock, health, transportation etc.), and was designed to be implemented over 20 years through 166 development projects, divided into three priority classes: very high, high and medium. activities are highly natural resource dependent, issues related to climate change stresses, particularly flood protection through water resource management, have been given special priority (MPHA, 2012). The MPHA benefitted from previous planning experiences, and focused on institutional structuring, by establishing an implementation body and an independent monitoring and evaluation unit.

5.4.1.2 Planning process

Climate change adaptation planning in Bangladesh has been evolving since the early 1990s, from highly centralized processes based on authoritative control by national government (Hanchett, 1997; Rasid and Haider, 2003; Alam et al., 2013) to more participatory and decentralized processes. For example, most of the projects under the FAP were developed and commenced with support from donor agencies but without prior consultation with the affected communities (Rasid and Haider, 2003; Alam et al., 2013). Reviewing FAP 6, 1995, which particularly studies the northeastern floodplain, we observed that public participation was not ensured throughout the study process. Following the NAPA, 2005, guidelines, Bangladesh developed its national adaption plan through a participatory planning process, which comprised different stakeholder representation. Although there were no formally incorporated community representatives in the NAPA team, planners consulted with the affected people from different parts of the country to assess their climate change perceptions and need-based prioritizations (Huq and Rabbani, 2011;

Islam et al., 2013b). The BCCSAP, 2009, has been criticized for a lack of public participation (Alam et al., 2013), due to the lack of community empowerment in project prioritizations, although it incorporated participatory learning from the NAPA process (Rai et al., 2014). In the cases of MPHA, 2012, and NPDM, 2010, planners worked harder to engage communities in order to capture their views and demands. Despite these community engagement activities, none of the plans placed community representatives in a decision-making role (Huq and Khan, 2006; Alam et al., 2013). A summary of each of these development plans is presented in Figure 5.3.

Overall, it appears that the global recognition of sustainable development has influenced the planning process in Bangladesh (NSDS, 2010). The incorporation of cross-scaler actors including civil society, expert panels, NGOs and affected communities in national development planning processes reflects this changing reality. We can identify this participatory approach as a move toward networked governance-driven institutional adaptation for decision-making (Adger et al., 2003; Adger et al., 2005; Eriksen et al., 2011). However, despite a greater representation of public preferences in many development plans, the extent to which these preferences were reflected in implementation remains unclear (O'Donnell et al., 2013).

	Theme	Planning process	Strategic appropriateness
FAP, 1990	• Structural solution to flood problems • Protection of agricultural productivity • Water conservation for dry season through compartmentalization	• Highly centralized with governmental authoritative control • Influenced by donor agency decisions	• Highly criticized for the inappropriateness of structural solutions • Found to be incompatible with the geomorphological nature of river systems • Poorly manifested community demand
NAPA, 2005	• Locally based adaptation initiatives • Criteria based prioritization of adaptation interventions	• Involvement of multiple stakeholders and interest groups • Consultation with community members	• Successful in providing short-term income generation opportunities • Insufficient for long-term adaptation options
BCCSAP, 2009	• Development of national adaptation roadmap • Activities based on national adaptation demand	• Absence of multiple stakeholders in the planning process • Consulted with the NAPA, 2005 experience	• Highly generalized in structure • Contradicts other national policies and plans
NPDM, 2010	• Institutional reorganization • Capacity building for disaster preparedness and post disaster management	• Participatory planning process • Consultation with community members for their views and perspectives	NA (insufficient information)
MPHA, 2012	• Locally-based development intervention • Water resource management for livelihood security • Developing alternative livelihood activities	• Participatory planning process • Consultation with community members for their views and perspectives	NA (insufficient information)

Figure 5.3. Policy matrix for selected climate change-related development plans in Bangladesh.

5.4.1.3 Appropriateness of the plans

The successful use of sustainable development plans for flood-affected communities and their potential ability to support adaptive learning needs to be critically examined. The FAP, 1990, faced heavy criticism by researchers, civil society groups and communities due to its focus on technically inappropriate structural solutions (Boyce, 1990; Brammer, 2000; Sultana and Thompson, 2010; Ayers, 2011). River morphology, flood patterns and land use changes in Bangladesh are generally ill-suited for the application of large-scale structural solutions (Brammer, 2010). Excessive rainfall during peak river flows has been identified as an important reason for extreme floods in Bangladesh, while river channel destruction through encroachment and filling-in river banks by local elites adds pressure to natural water flows (Cook and Lane, 2010). In the case of wetland ecosystems, flood regulation through embankments limits water flow and reduces the diversity of ecosystem services available to society (Custers, 1993). Importantly, the creation of embankments and similar engineered establishments are generally suitable in serving only a single objective (in this case, agriculture) (Thompson and Sultana, 1996). In a complex social-ecological system where people rely on resource-use multiplicity and encounter multiple stresses, such linear structural solutions are often inappropriate. Hence, this kind of transformational responsive adaptation may contribute to short-term impact management, but its long-term applicability is questionable. Due to widespread criticism, and the failure of the FAP to provide direction for flood adaptation, the government shifted its attention away from flood protection through structural establishment (Cook and Wisner, 2010; Sultana and Thompson, 2010).

In the context of NAPA (2005), Ayers (2011) concluded that funded projects were only able to generate short-term employment and protection opportunities for affected communities. She added that the NAPA development plans focussed too heavily on protecting physical barriers to reduce climate change impacts, at the expense of reducing exposure, which indicates that the policy process has not incorporated learning from FAP in the contemporary adaptation plans (Naser, 2015). Consistent with this observation, Alam et al. (2013) suggested that projects funded under NAPA generated short-term financial benefits for the community members, as there were no future directives after the completion of a project. As a result, the NAPA projects were not likely to have a dramatic effect on fostering the adaptive capacity of local communities and households who are vulnerable to climate stress.

Two major operational challenges have been identified in the implementation of the BCCSAP, 2009. First, the plan is highly generalized, and therefore inadequate to meaningfully address the diverse natural disasters and geographic areas in Bangladesh. Secondly, the plan suffers from significant contradiction with other national plans and policies (e.g., the National *Jalmahal* (Wetlands) Management Policy, 2009), leading to inter-institutional conflict. These issues are common in Bangladesh and many other parts of the world (Khan and Rahman, 2007; Durigon et al., 2012) and present an ongoing challenge for polity.

5.4.2 Polity

5.4.2.1 Coordination among governmental agencies

Achieving the government's sustainability objectives under flood stress is a multi-sectoral issue, requiring integrated institutionalization through inter-organizational coordination (Hickey et al., 2013). The government of Bangladesh has made good progress in this regard, driven partly by international support and partly by adaptive learning at local levels (Alam et al., 2013). For example, the Bangladesh Water Development Board under the Ministry of Water Resources operated as the main actor in the implementation of FAP. However, this organization failed to maintain coordination with other government organizations who had important responsibilities and roles in sustainable resource management (Sultana and Thompson, 2010), including the Department of Agriculture, Department of Forest and Environment and Department of Fisheries. While the Water Development Board worked to curtail flood impacts on agriculture, it paid less attention to other environmental services (e.g., fisheries) and livelihood economic activities (e.g., fishers, boatmen, labour). Consequently, structural solutions sought for agricultural development created negative externalities on other sectoral interests due to non-coordination resulting in a lack of opportunities for arbitration, negotiation and communication (Mirza and Ericksen, 1996; Sultana and Thompson, 1997; Barnett and O'Neill, 2010).

More contemporary development plans (devised after 2000) focused primarily on hierarchical institutionalization. In order to assess climate change impacts on different development sectors, and to foster inter-organizational cooperation, the government of Bangladesh established climate change focal points in each relevant ministry. Coordinated by a Climate Change Unit, these focal points were managed by the Ministry of Environment and Forests. As a result, the channelling of information, negotiation over task prioritization, and the reduction of unacceptable negative externalities on other sectors became facilitated through central government. This innovation resulted in more multi-sectoral development plans like NAPA, BCCSAP and MPHA (Huq and Rabbani, 2011; Islam et al., 2013a; Islam et al., 2013b). Additionally, the government accomplished significant advancement in regional development institutionalization. The establishment of the Bangladesh Haor Development Board (2000) under the Ministry of Water Resources represented an important advancement in this regard. Solely devoted to the development of wetland areas in Bangladesh, its activities are highly concentrated in the northeastern floodplain region. All development activities under the MPHA (2012) are expected to be implemented through multi-organizational cooperation (MPHA, 2012) (see Figure 5.4). However, how the multi-organizational cooperation will be achieved is not clarified in the plan, although experience from previous plans suggests that such multi-sectoral cooperation has not been obtained.

Despite these institutional interventions, O'Donnell et al. (2013) observed that these advancements have considerably augmented central administrative ability in climate governance, but have failed in funnelling these advancements to local governance. Except for MPHA, none of the plans offer clear directives or guidance on structuring local governance. Consequently, implementation difficulties have arisen. Further O'Donnell et al. (2013) suggested that this gap between central and local governance serves to impede the implementation of plans, driven by poor empowerment, autonomy of local governance systems and power conflicts between bureaucrats and elected members of local communities.

5.4.2.2 Financial arrangement for executing plans

FAP was mostly funded by external agencies, although the government has its own financing mechanism for MPHA and NPDM under the national development plan. On the other hand, two parallel funding institutions operate in Bangladesh to manage climate change impacts and local development issues (Huq and Rabbani, 2011). One is supported with funding from donor agencies and the other established by the government, funded from the national annual development plan. Here, the donor agencies' funding institutions work with plans that are focused on climate change issues, while the government funding institutions work with both climate change and national development issues (O'Donnell et al., 2013).

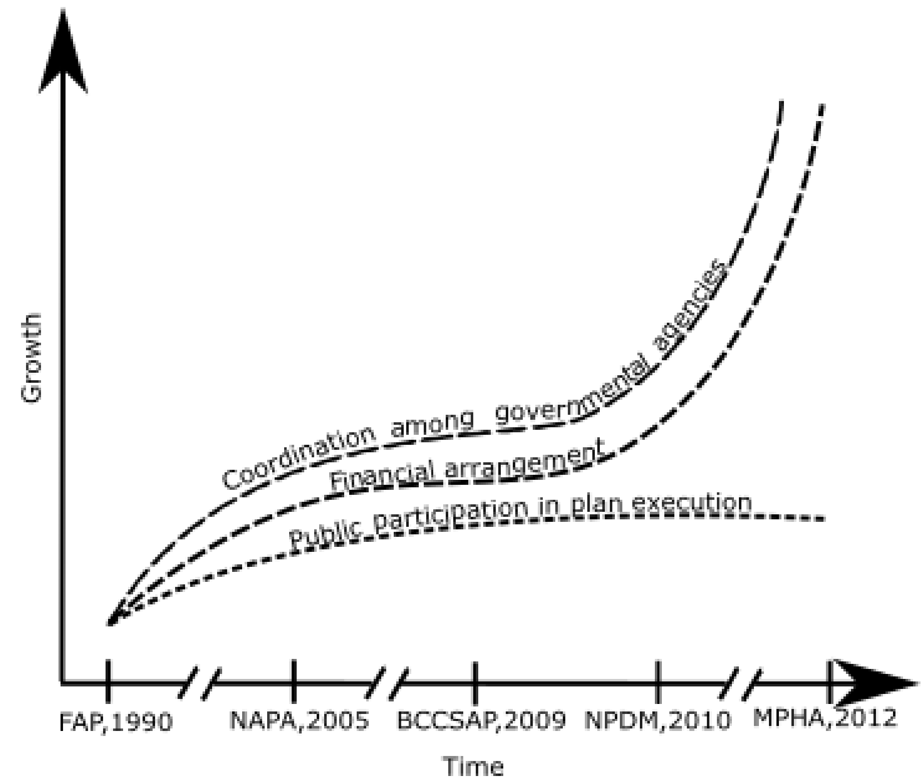

Figure 5.4. Evolution of bureaucratic polity in the development plans. (Note: Coordination on development agencies was poor in FAP. However, later plans concentrated on this issue, which indicates an upward movement. FAP was dependent on foreign aid for financial arrangement, while NAPA and BCCSAP both depend on government and foreign support. On the other hand, NPDM and MPHA are fully government funded. Public participation in the planning process has increased in more contemporary plans, but it remains insufficient in plan implementation. Consequently, we show that this trend follows a straight line after FAP.)

Established by the government of Bangladesh, the Bangladesh Climate Change Resilience Fund, 2010, which is donor-funded, ensures the well-coordinated, fair and transparent use of donor funds. Donor agencies from UK, Sweden, Denmark and the European Union have contributed a total of $110.2 million USD to the fund (Ahmed and Islam, 2013; O'Donnell et al., 2013). While the Fund is administered by the government, the World Bank provides technical support to ensure transparency and appropriateness in financial allocations to different projects (Huq and Rabbani, 2011).

National government funding for climate impact management is administered through the Bangladesh Climate Change Trust Fund, 2009. This fund represents an adaptive institution created in response to the immediate climate change risks facing Bangladesh (Alam et al., 2013). The government allotted 300 million USD to this fund, which is governed by a Board of Trust and a technical committee, with monitoring mechanisms for financial transparency (Huq and Rabbani, 2011). The incorporation of climate change adaptation concerns in the national development plan and financing is a clear indication of its mainstreaming, which is particularly sought for sustainable adaptation practices (Ayers et al., 2014b).

5.4.2.3 Public participation in plan execution

Public participation in development planning is necessary because it can ensure the integration of highly vulnerable people and their concerns into the development process (Hanchett, 1997). In other words, public participation facilitates fairness in adaptation (Adger et al., 2006). Reflecting this, most of the contemporary development plans we reviewed acknowledged public participation as an important part of the planning process (Huq and Khan, 2006). However, public participation in plan execution has not been similarly emphasized. For example, Sultana and Thompson (2010) reported that public participation through local institutionalization was tried in some of the small-scale flood management projects, with relative success. In addition, contemporary plans open space for the participation of non-government organizations in project implementation. These organizations have created individual project-based opportunities. Alam et al. (2013) suggested that local governments should be further empowered in Bangladesh so that democratic decentralization can facilitate the execution of plans at local levels. However, broad-based public participation remains scarce because most plans have failed to design institutional structures suitable for encouraging local institutionalization (Haq and Khan, 2006).

We can identify two reasons behind this situation: existing resource management policies and the absence of institutional decentralization provisions in the development plans (Rahman et al., 2012; Alam et al., 2013). Huq and Khan (2006) suggested that vulnerability is a social construct that arises from inequitable resource distribution. Rahman et al. (2012) added that existing policy has guided resource management institutions and subsequent power structures to limit the access of vulnerable people to resources. Hence, existing resource management policies are likely impeding the fair implementation of development plans. Studying the implementation of the first NAPA project in the coastal area of Bangladesh, Ayers (2011) and Bhuiyan (2015) observed that the demands of vulnerable local communities were not addressed and that when the projects were implemented without consultation with local communities, social vulnerability could increase (see also Alam et al., 2013). This suggests that the implementing institutions may not be adequately decentralized in the existing plans (Figure 5.5).

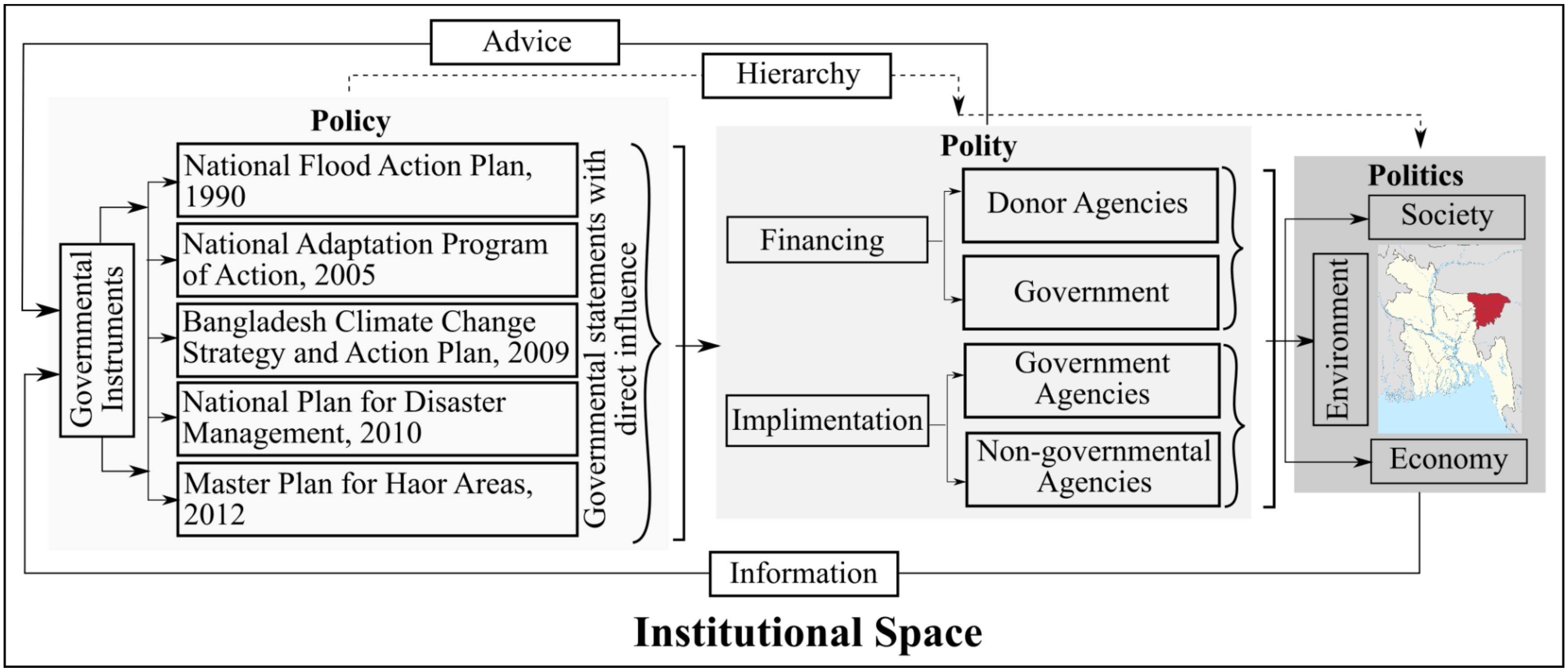

Figure 5.5. Structure of adaptation institutions in the northeastern floodplain of Bangladesh.

Table 5.1. Generalized assessment of plans against sustainability criteria.

Criteria	FAP	NAPA	BCCSAP	MPHA	NADP
Social trajectory					
Institutional flexibility	X	X	X	X	✓
Policy support	X	X	X	X	✓
Knowledge sharing and organizing social network	X	X	✓	X	✓
Cultural acceptance	X	X	✓	✓	O
Economic trajectory					
Reduce inequality	X	X	X	X	O
Reduce poverty and livelihood opportunity	X	✓	✓	✓	O
Tenure security	NA	X	X	X	NA
Credit access	O	X	✓	✓	NA
Reduce dependency on expensive external inputs	O	X	✓	X	NA
Environmental trajectory					
Maintaining ecological integrity	O	X	X	X	NA
Maintaining biological and genetic diversity	NA	X	✓	✓	NA
Prevent land degradation	✓	✓	✓	✓	NA

5.4.3 Politics

Relatively little research has been conducted in the northeastern floodplain of Bangladesh, and the area is under-represented in national development plans. Hence, it is difficult to assess the influence of the plans on local sustainability in our study area. Mog (2004) and Adger et al. (2003) suggest that sustainable development planning requires continuous learning, and offer a set of criteria for assessing development interventions in a local context. Based on this set of criteria, we assess local sustainability trajectories under the influences of the development plans. A generalized interpretation of the plans against the selected criteria described in section 5.4.3.1, 5.4.3.2 and 5.4.3.3 has been presented in Table 5.1. When conducting the review of plans '**✓**' has been given to indicate positive relation between a plan and a criterion, while '**X**' has been placed for a negative relation**.** '**O**' has been used to indicate where there is insufficient data to assess while '**NA**' has been used when the criterion is not relevant to the plan. The results are further discussed below.

5.4.3.1 Social trajectory

Based on the set of criteria mentioned above we have analyzed the social trajectory of the plans from the perspectives of: institutional flexibility, policy support, knowledge sharing, organizing social network and cultural acceptance. Here, institutional flexibility in the context of our study area encompassed formal-informal institutional linkages for enhancing social resilience. Compatibility between national development priorities and adaptation plans is an important consideration for sustainability at the local context, with implications for knowledge sharing and communication (Cash et al., 2006). The extent to which plans foster the development of social networks among local community members and other actors to support inter-institutional linkages, adaptation and knowledge sharing is also important (Rahman et al., 2015; Rahman et al., 2017).

Institutional flexibility: The adaptation and development plans for the northeastern floodplain face constraints mainly due to poor inter-institutional linkages. Adger et al. (2005) defined institutional linkage as direct communication through a network for exchanging information and knowledge in support of tangible resource management. A common tendency of formal institutions in Bangladesh is a lack of acknowledgement of local, informal, or traditional resource management institutions. At the same time, these institutions sustain resource use through the development of operational rules and norms for resource access, dispute settlement, organization development and collective actions (Rahman et al., 2014). In particular, the northeastern floodplain is home to diversified resource user groups, many of whom depend on common property resources for their subsistence activities (e.g., fishing, grazing ground, wild edible food collection, etc.) (Ahmed et al., 2008; Rahman et al., 2012). As a result of the longevity of these informal resource management institutions, considerable information on community needs in support of adaptation is available through this institutional regime. However, due to their institutional rigidity, formal institutions generally exclude this valuable information and maintain the dominance of conventional 'top-down' technocratic management approaches in development plans.

Policy support: The government has emphasized enhancement of local government capacity in support of local development (NPDM, 2010; Younus, 2017). While local government has an important role to play in a democratic system (Acheson, 2006), in reality, local government positions tend to be dominated by local elites in Bangladesh (Ayres, 2011; Rahman et al., 2015). In particular, the common property management policy of Bangladesh has facilitated their control of local natural resources (Sultana and Thompson, 2010; Rahman et al., 2015), providing considerable potential for the misappropriation of development interventions.

Knowledge sharing, process of social change and organizing social network: Government strategies in the development plans also indicate non-pragmatic approaches to community resilience building. For example, there are two projects suggested under NAPA in the floodplain: the enhancement of potato cultivation as an adaptive agricultural practice, and alternative fishing practices, both of which are technology intensive. Interestingly, Anik and Khan (2012) and Pavel et al. (2014) reported that the floodplain communities had already adapted sixteen agricultural, fisheries and other livelihood techniques before the implementation of the projects, and that they should have been included in the plans. Notably, most of them are less technology intensive and more adaptive knowledge driven. We can identify government interventions as transformational, although incremental adaptation is possible (Kates et al., 2012). Mismatches between practice and plan sub-project interventions suggests knowledge gaps and poorly networked formal and informal institutional systems. This issue was also highlighted by a sub-district level fisheries officer from Tanguar *haor*,

> *"We usually report to the higher level authorities using a specific reporting format, which was developed long ago. We do not add any new information unless it is requested".*

More explicitly, NAPA emphasized the need for information channeling from top to bottom levels. This means that government agencies will develop adaptive technologies and disseminate them among the affected communities using their formal administrative system through development projects. However, opportunities for 'bottom-up' information flow are absent under this plan (Urwin and Jordan, 2008). Consequently, there remains a question about how project planners will be informed about already existing local innovation and existing local demands. Likewise, BCCSAP relies on externally-developed adaptation technologies like structural solutions (e.g., river excavation and embankment building) to climate induced flood stress and their implementation and dissemination, although it makes some provision for adaptation through scientific exploration like developing climate-resilient crop varieties (Haque et al., 2017). Further, in the MPHA, the national government plans to use local government as the dissemination agencies for externally devised technologies, rather than using them as information gathering agencies.

Cultural acceptance: While the northeastern floodplain is ethnically diverse, none of the development plans made provision for the impact of culture on adaptation and social incorporation. These distinct ethnic communities have their own institutional structures and agricultural practices that are different from formal governance structures. Consequently, externally imposed institutional and cultural practices would likely increase their vulnerability and decrease resilience. Further, Sultana (2010) and Shabib and Khan (2014) reported that contemporary development plans (e.g., NAPA, BCCSAP and MPHA) poorly addressed gender issues, including discrimination. For example, a local community leader from Hakaluki *haor* stated that

> *"Unlike the other parts of Bangladesh, you'll barely see women involved in income generating activities in this region because this is not socially acceptable. People will rather starve than allow women family members to work outside".*

In support of this observation, another key informant, who is a local government representative (*Union Parishad* - the lowest administrative unit of Bangladesh government) noted that

> *"…….. women cannot be equally judged with men … their involvement in income generating activities will reduce the efficiencies of men".*

Both these statements indicate strong social and cultural opposition to pro-women adaptation actions, which indicates not only a policy barrier but also a social barrier to adaptation (Barnett et al., 2015). However, it is not clear from existing plans how these issues will be addressed, although

Sultana (2010) suggested that women empowerment could be fostered by reducing social disparity, mainstreaming women's contribution to the local economy and recognizing their household contribution during and after times of stress.

5.4.3.2 Economic trajectory

We have analyzed economic trajectory using five criteria: 1) reduce inequality in terms of wealth, ethnicity, gender and social position; 2) reduce poverty through income generation, productivity and livelihood opportunities; 3) tenure security; 4) increase credit access through long term investment; and 5) reduce dependency on expensive external farm inputs like chemical fertilizer, pesticide and other non-indigenous inputs.

Reduce inequality: Khan et al. (2012) suggested that economic inequality is not a major issue in the floodplain, however the majority of people are characterized as being poor based on their fixed asset ownership (MPHA, 2012). The economic inclusion of women in the study area is very low, with most of their economic activities, like wild food collection, catching fish for household consumption and homestead gardening, having use value, but no formal market value (Sultana, 2010). Reflecting this bias, none of the plans sought to institutionally manifest women as an economically functioning group, although NAPA and MPHA did incorporate women in the planning process. This situation is also true for minority ethnic communities. These planning oversights further drive poverty, social-economic exclusion and inequity within local communities. However, this alienation has been supplemented to some extent by women focused micro-credit programs often organized by non-government organizations, which invest in household-based small income generating activities like poultry and animal husbandry. However, Kabeer (2011) posited that it is unlikely that marginalized groups will be included in policy processes until they are treated equally in the socio-economic sphere.

Reduce poverty and increase livelihood opportunity: Poverty reduction is inextricably related to livelihood opportunity, while livelihood sustainability depends more on the development of capital assets (e.g., social, human, financial, physical and natural) (Ellis, 2000). The MPHA has adapted a number of strategies for reducing poverty through sectoral development (e.g., agriculture, fisheries, livestock), however it is highly dependent on NAPA and BCCSAP for climate-sensitive livelihood activities. Importantly, neither of these national development plans are focused on the northeastern floodplain, with only two local development processes under NAPA and no specific project under BCCSAP in the region. In the context of NAPA's strategic basis, Huq and Khan (2006) suggested that the Bangladesh government should focus on livelihood-based (e.g., peasantry, fishery, business, livestock farming, agricultural labor) development plans rather than concentrating on sectoral development (e.g., agriculture, fisheries, energy supply, forestry) to better localize the process and increase accessibility to climate-stressed people. On the other hand, institutional and organizational structuring and specification is necessary for the development of capital assets (e.g., establishing training facilities for human capital development, scientific and innovative agricultural practice facilitation, cross-community information channeling). Data collected through focus groups and interviews suggested that community members develop their collective action through small cooperatives, which facilitate their access to different government incentives, particularly for agricultural development. Notably, according to a regional level officer from the Department of Agriculture, most of these supports stem from national agricultural extension programs, which are not often sensitive to local climatic context.

Tenure security and credit access: According to De Soto (2001), access to institutional credit creates an economic peril for the poor in most developing countries because they generally use resources without formal property rights. According to the MPHA (2012), only 52% of households owned land in the study area, with the remaining farmers relying either on shared cropping or work as agricultural laborers. In these cases, shared-cropping practices and labor wages are managed through informal institutions. Fisheries tenure security is also unclear (Khan and Haque, 2010), with resource access often controlled by local elites (Rahman et al., 2012). Since many farmers, laborers and fishers do not have clear property rights in the study area, they do not have access to formal credit sources. Importantly, development plans have a certain political lifespan and often cannot address long-term resource ownership disputes or unresolved settlement issues affecting both agriculture and fisheries livelihoods. Such challenges may, however, limit the ability of such plans to have meaningful impact because without clear property rights (Adger et al., 2005), community members cannot access formal credit (e.g., bank loans). Consequently, community members remain dependent on informal lending organizations or individual money lenders for their financial capital, particularly for larger investments (e.g., fisheries) (for more details see Rahman et al., 2015).

Reduce dependency on external inputs: As previously mentioned, NAPA conducted development projects in the floodplain. One of these projects involved the promotion of potato cultivation as an alternative agricultural practice. Potato is cultivated across Bangladesh during winter with the lowest production contribution coming from the northeastern floodplain (Uddin et al., 2010). Per acre potato production is the lowest in this area because of unsuitable land properties, particularly in the wetlands (BBS, 2013; Uddin et al., 2010). One key informant, who is a local level agriculture extension officer in Hakaluki *haor*, suggested that

> *"Potato cultivation in this area is subjected to late blight disease because of foggy winter conditions, and winter rain is also not uncommon here. Thus, it requires extra costs for pesticides, which discourage the farmers from cultivating potato".*

According to Mog (2004), climate sensitive economic development requires reducing dependency on expensive external inputs. Ironically, by encouraging people to increase their use and dependence on external inputs, this plan exacerbates potential resource-use conflicts. On the other hand, BCCSAP noted the expense of external inputs, yet still retained the concept of potato cultivation, arranging short-term credit access for potato cultivation to help farmers bear the costs through micro-credit. Alternatively, some farmers have innovated with alternative crops, particularly in Hakaluki, including kidney beans, mustard and coriander. One such farmers posited that

> *"I have 100 bighas (33 acres) of land, and I have allotted most of them for cultivating mustard, coriander, bean and cucumber because I can harvest these crops much earlier than others like rice. Furthermore, these crops are more profitable so I can easily buy rice for consumption".*

Consistent with this observation BCCSAP promoted locally-adapted crops and went further than NAPA. MPHA also largely enhanced locally adapted technologies like cage fisheries and floating gardens.

5.4.3.3 Environmental trajectory

We also analyzed the plans based on three environment related criteria: maintaining ecological integrity by promoting the health and stability of biodiversity and key ecosystems; protecting and increasing biological and genetic diversity; and preventing land degradation.

Maintaining ecological integrity: It is noticeable that plans including NAPA, BCCSAP and MPHA emphasize the expanded production of high-yielding crop varieties that are fertilizer intensive to support food security and local agricultural development (Hossain et al., 2006). However, impacts associated with this practice on the agro-ecosystems of the northeastern floodplain area are under-researched. After a comparative study between chemical and organic fertilizer use in rice cultivation in the central part of Bangladesh, Rasul and Thapa (2004) and Rasul and Thapa (2003) concluded that there was no significant difference in rice production between these two modes of fertilizer use, and that organic fertilizer use enhanced ecological functioning. This observation is not reflected in the plans we reviewed. On the other hand, the establishment of embankments under FAP caused considerable ecosystem disturbance for fisheries resources (Halls et al., 1998). Further, repairing and reconstructing embankments were given priority in all the contemporary development plans without the need for environmental assessment. This was reflected in our study area, where a number of embankments have been constructed involving local community members as paid labors under a donor aided Climate-Resilient Ecosystems and Livelihoods (CREL) project implemented by a local NGO. As expected, this project has created short-term alternative livelihood opportunities for the community members. However, a local leader, who volunteers for environmental conservation, stated that:

> *These embankments will not protect us all from flash-flood. One side will be protected and the other side will be flooded. Our main problem is the reduced water channeling capacity of rivers and canals. So, it would be much better if we could manage it somehow.*

A similar observation was also reported by a local Department of Environment officer, who stated that:

A number of natural canals have been dried up because of excessive siltation, which has increased the land for agriculture but reduced water conservation capacity, and directly impacted the flash-flood situation and wild fisheries.

Wetland fisheries resource management in Bangladesh is highly capital-intensive, with the resource ownership rights are available to private investors (Khan and Haque, 2010). Consequently, private investors try to maximize their profits from investment by exploiting available fish resources, which adversely affects natural regeneration (Rahman et al., 2012). These management strategies often have adverse effects, including the overexploitation of fish resources resulting in ecosystem degradation; and many marginal fishers not getting access to resources for ecosystem based adaptation. Although wetland co-management has proved successful elsewhere in the country for resolving this problem, most development plans pay very little attention to this institutional alternative.

Maintaining biological and genetic diversity: Monwar et al. (2014) cautioned that climate change poses a threat to local biological diversity (e.g., agro-biodiversity and fisheries), reducing local livelihood opportunities and household food security. For example, fisheries diversity is directly related to protein intake in many rural communities. Consequently, the loss of biodiversity will likely directly affect dietary diversity and household food and nutrition security levels (Hickey et al., 2016). In this region, the livelihoods of poorer fishermen tend to be dependent on small and diversified fisheries (Thilsted, 2013) that have been shown to be highly susceptible to climate change (Allison et al. 2009). Although the MPHA contains some ambitious interventions intended to conserve biodiversity (e.g., the establishment of fish sanctuaries and supporting wetlands co-management) the existing wetland management system will likely undermine the effectiveness and efficiency of the plan (Rahman et al., 2012). Moreover, none of the plans pay explicit attention to the conservation of agro-biodiversity, instead focussing on increasing cultivated crop diversity.

Prevent land degradation: A particularly important natural feature associated with the floodplain is siltation, a common river hydrological scenario in Bangladesh (Mirza and Ericksen, 1996). Prolonged flood periods cause an overload of silt that reduces river depths; while contamination of rivers from excessive use of chemical fertilizer and pesticide for the cultivation of high yielding variety rice may reduce land quality (Byomkesh et al., 2009). The NAPA, BCCSAP and MPHA have provisions to reduce siltation and erosion problems by dredging, repairing and constructing embankments in critical areas.

5.5 Conclusion

This paper explores institutional responses to climate-related stresses in the northeastern floodplain of Bangladesh using a literature synthesis research approach combined with primary field data from the region under study. The results reveal that existing national development plans have resulted in considerable institutional reform at the administrative levels in support of more climate-sensitive sustainable development. However, the generalized nature of the plans poses serious obstacles to their implementation and potential impacts at local levels. Hence, we reveal that institutional reforms will not lead to sustainable climate adaptation outcomes without taking adequate account of locally-embedded adaptation politics. In the case of the northeastern floodplain which is dominated by wetland ecosystems providing diverse livelihood opportunities for resident communities, the generalized policy of sectoral development (e.g., water resource development through building embankments) is likely not suitable for local sustainable adaptation needs. In addition, the plans insufficiently address important local institutional issues such as access to resources and credit, despite their role in driving local-level development politics. Based on these findings, we suggest five focal areas for the further advancement of adaptation planning: i) the planning process needs to ensure the active incorporation of community members in problem identification, decision making and implementation, which cannot be done adequately through consultation processes designed to derive their perceptions; ii) a well-structured institutional form needs to be established for facilitating two way information and knowledge flows among different communities and different modes of governance (e.g., local governance), something already present among different government agencies; iii) detecting locally developed technologies (e.g., fishing techniques, use of new form of agricultural and land use practices) and strategies (e.g., diversifying livelihoods, seasonal migration) and looking to out-scale them will likely reduce the cost of adaptation, something already present in MPHA but absent in other plans; iv) future projects need to begin from local contexts in order to better navigate functioning political, cultural and social barriers; and v) there is need to revisit prior complementary and conflicting resource management policies with a view to revising them to ensure pragmatic and coherent implementation.

Acknowledgements

We would like to gratefully acknowledge the funding support received from the William Dawson Scholar Award, McGill University, the Prince Albert II of Monaco Foundation, the IPCC, South Asian Network for Development and Environmental Economics (SANDEE) and Asian Centre for Development (ACD) for this research. The comments of the paper are solely the responsibility of the authors and under no circumstances may be considered a reflection of the position of the Prince Albert II of Monaco Foundation, the IPCC SANDEE and/or ACD.

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CHAPTER SIX: GENERAL CONCLUSION

6.1 Introduction

The main objective of this research was to gain an understanding of how locally observed climatic stresses affect livelihood vulnerability in Bangladesh. By combining scientific, community and policy perspectives, this thesis offers an approach that helps to better understand livelihood vulnerability for the purpose of creating more locally-connected adaptation policy (see Figure 1.3). Drawing upon the human dimension of vulnerability and sustainable rural livelihood discourses, this thesis identified four interconnected aspects of vulnerability and adaptation policy making: i) a scientific understanding of context-specific vulnerability, and the dynamics of generating usable science to support adaptation-related policy making in Bangladesh; ii) community perceptions of locally-observed climatic stresses and their influences on rural livelihoods; iii) strategic uses of household assets for generating opportunities that are conducive to sustaining livelihoods under the perceived stresses; and iv) the efficiency and effectiveness of policy changes and actions in creating adaptation interventions (see Figure 6.1 for an overall summary of this thesis). Together, these aspects help to answer policy questions related to which area's (e.g., geographic region, sector) vulnerability should be studied, and how should that vulnerability be understood.

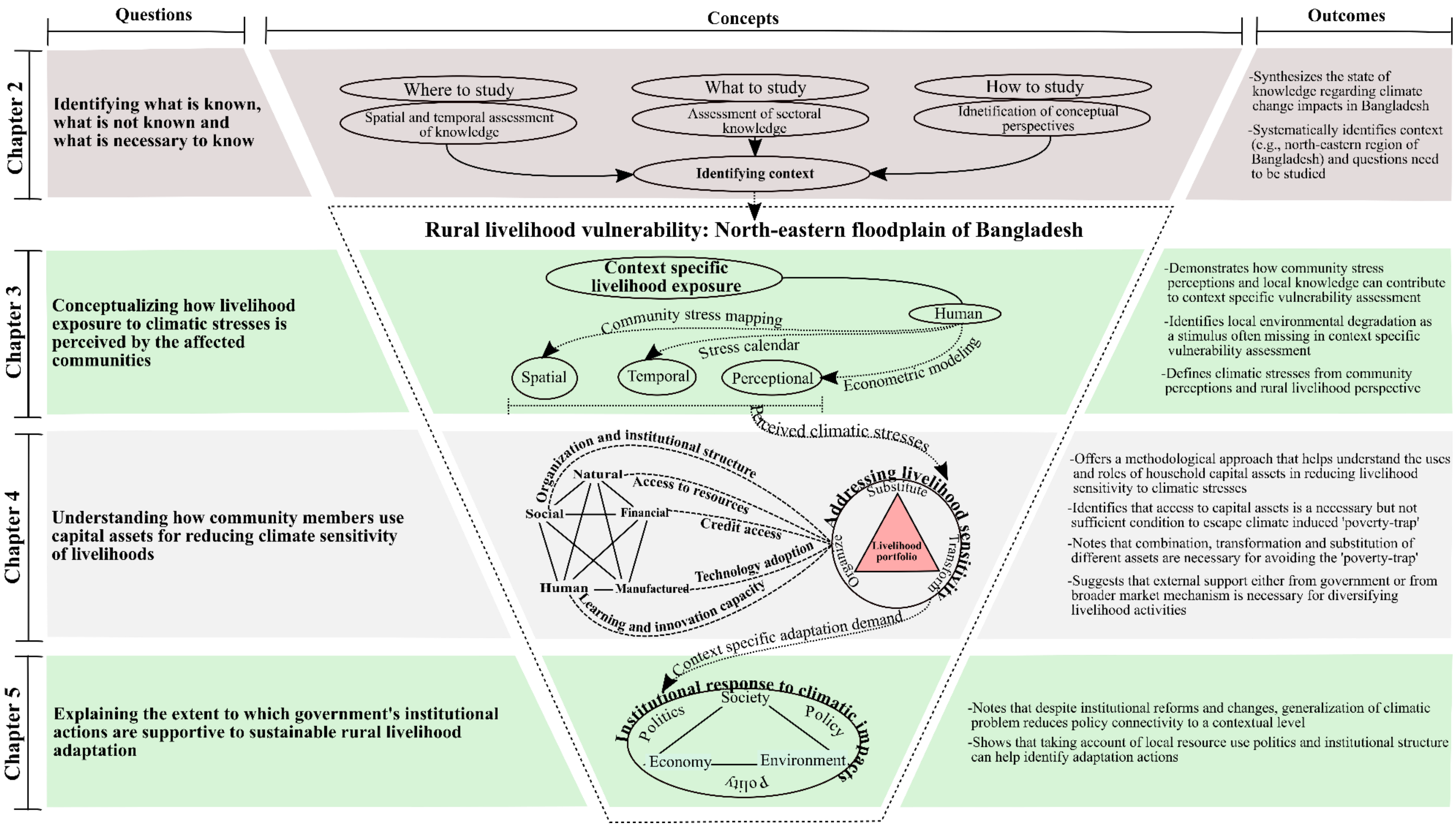

Figure 6.1. Summary of thesis outcomes.

6.1.1 Thematic summary

This thesis is based on a case study research approach that utilized a mixed methods research design wherein both qualitative and quantitative data were collected and analyzed. Both secondary and primary data were collected and analysed at different stages of the study. First, a systematic review was conducted using climate change studies focusing on Bangladesh that were published in peer-reviewed scientific journals between 1994 and 2017 (April). These studies were organized and categorized into an original dataset that was then analysed with respect to various features, including scale, trend, sectors, multidisciplinary approach and geographic connectedness. This multi-dimensional analysis, presented in Chapter 2, aimed to identify specific research questions and contexts that require further study and serves as the foundation for the remaining sections of the thesis. A questionnaire was developed based on the questions identified in Chapter 2. This questionnaire was then contextually adjusted through consultation with research participants prior to undertaking extensive primary data collection in the field. The resulting primary data were then further validated using secondary data. This thesis presents a methodological approach that not only facilitated credible data collection and analysis, but also considered potential usability by identifying where its outcomes might be applied in response to the knowledge needs of policy makers and affected communities (see also Cash et al., 2003).

Table 6.1. Cross-comparison of results.

Components	Knowledge gap identification	Exposure	Sensitivity	Institutional change
Knowledge gap identification	• Northeastern floodplain is most understudied area • Cross-scale dynamics of climate vulnerability management • Livelihood vulnerability of multiple use natural resource users			
Exposure	• Bio-physical changes and their influences on climatic impacts • Community perceptions regarding climatic stresses and their implications in adaptation policy making	• A regular climatic phenomenon can be turned to a stress because of local environmental degradation • Affected communities define climatic exposure in terms of climatic phenomenon and non-climatic features like land use practices, level of dependence on natural resources for livelihoods • Affected communities are habituated with extreme climatic events, and consider them as stress if they occur in crop harvesting periods		

Sensitivity	• Use of available resources for innovating adaptation options, and their efficiency in reducing climatic risks • Identification of capital use strategies that help generating non-natural resource dependent livelihood activities	• Livelihood portfolios work as buffer during and post stress situations • Livelihood portfolios' main function is to reduce loss and generating resources for surviving during the stress • Repeated stress events may encourage affected community members to convert natural capital to financial capital for investing in non-natural resource dependent activities	• Affected communities respond to stresses by either seeking livelihood opportunities in distant places or by intensifying natural resource use • Affected communities' main strategy is to organize, transform and substitute assets for developing livelihood portfolios • Poor access to resources may limit the capacity of the affected communities to respond to the stresses	
Institutional change	• Salience and usability of scientific studies are questionable • Policy implications of cross-scaler climatic knowledge • Multilevel institutional linkages for adaptation policy making	• Government's perceptions regarding climatic stresses differ from communities' perception • Government invests more on structural solutions for managing stresses • Growing consensus has been observed among government policy making practices for incorporating local climate change knowledge	• External supports coming from government and labor market mechanism are necessary for adaptation actions	• Intensive climate sensitive development plans have been made • Lack support from saline and usable scientific knowledge • Public participation in policy making has been intensified • Institutional changes have been made for managerial and financial support to adaptation actions • Local level decision implementation lacks cross-scaler institutional linkages

The analysis presented in Chapter 2 identified Bangladesh’s northeastern floodplain as the most understudied and least policy-focused area in the country. Chapter 3 and Chapter 4 provide a comparative analysis of two purposively selected cases located in the northeastern floodplain of Bangladesh. This analysis reveals that stress perceptions among affected community members and the resultant locally-innovated adaptation actions may vary significantly within a single political and geographic boundary. The analysis presented in these two chapters reveals that differences in vulnerability across cases are determined by geographic location, local biophysical properties, proximity to resource-rich areas wherein more livelihood opportunities are available (e.g., urban or industrialized areas), governmental resource-management policies, local politics surrounding resource use, and relative levels of socio-economic disparity. Chapter 5 then identifies policy limitations in order to understand the properties that differentiate one context from another, suggesting that efforts to generalize contextual properties within a single policy umbrella may restrict the development of effective adaptation policies. In order to further illustrate the various results of these analyses, a cross-comparison of results is presented in Table 6.1.

Chapter 2 reveals a heterogeneous understanding of context-specific vulnerability, presumably resulting from disconnects between scientists, communities and policy makers. These disconnects may influence policy makers to give preferential treatment to particular geographic areas and sectors, and to circumscribe the equitable distribution of scarce resources for effective adaptation actions. A stark reflection of this potential can be observed in Bangladesh’s climate change adaptation plans. These plans are dedicated to creating practical solutions to climate impacts that are grounded in an “outcome-based” understanding of vulnerability. As detailed in Chapter 5, a policy analysis of Bangladesh’s adaptation plans shows that simplifying climatic impacts to general development obstacles may inspire policy makers to focus too heavily on engineered and structural solutions while failing to give sufficient attention to societal adaptation demands. Thus, in acknowledging local biophysical and socio-economic properties as the central avenues to understanding context-specific vulnerability, this thesis draws two general insights: i) the understanding that contextual vulnerability must go beyond climatic and socio-economic analysis; and ii) the realization that adaptation-related policy should focus on locally-embedded politics related to resource use, and that it should also focus on developing strategies for creating more pro-societal adaptation policies.

In Section 6.2, I relate the thesis findings back to its central objective in order to extend the theoretical discussions surrounding vulnerability and sustainable livelihoods. In so doing, I demonstrate its contributions to theory, particularly in relation to three main concepts: i) the dilemma of assessing vulnerability for adaptation policy making; ii) the understanding of vulnerability vis-a-vis locally-connected adaptation planning; and iii) the political and socio-economic determinants of local innovation for adaptation actions. Building on the empirical observations, I then identify how this thesis contributes to policy and practice in Section 6.3 by focusing on pragmatic policy making based on scientific and community innovations. In Section 6.4, I end the dissertation with future research directions, and consider how adaptation-related policy might be transformed to better incorporate multiple perspectives, and why this transformation needs to take place in Bangladesh.

6.2 Contribution to theory

The conceptual framework for this thesis combines vulnerability assessment and Sustainable Rural Livelihoods (SRL) frameworks with the aim of better understanding rural livelihood adaptation to multiple climatic stresses. While a number of studies have adopted components of the SRL framework in order to quantify vulnerability (e.g., Hahn et al., 2009; Shah et al., 2013; Simane et al., 2016), the conceptual framework presented in this thesis emphasizes the interactive dynamics of these components and their functions to sustain livelihoods. This conceptualization helps us to better discern how communities make adaptation-related decisions through tradeoffs between their available household assets and their level of understanding and learning regarding climatic stresses. More specifically, it helps to identify differences between more locally context-specific adaptation actions and more regional and national-level adaptation actions (policies). In what follows, I further discuss the contributions of this thesis to climate change and adaptation-related theory.

6.2.1 The dilemma of assessing vulnerability for adaptation-related policy

Chapter 1 reviewed and analysed the literature related to contextual vulnerability in order to identify its key properties and demonstrated how an understanding of these properties is necessary for effective adaptation-related policy making. Many developing countries have centralized and hierarchical systems of policy making that are prone to problems of generalization and limited information that inspires more linear and outcome-based interpretations of vulnerability (Paul, 1997; Choudhury et al., 2004). In contrast, contextual vulnerability tends to be more locally connected, decentralized, and dependent on both local and expert knowledge systems (O'Brien et al., 2007). Nevertheless, the importance of outcome-based approaches—which are generally founded on "scientific framing"—cannot be ignored, despite the relative advantages of more contextual approaches to help address the root causes of vulnerability (e.g., poverty, power differentials, political and cultural choices) (O'Brien et al., 2007). Many studies have shown that outcome-based adaptation actions, such as embankment building, irrigation schemes and housing improvements, can help reduce livelihood vulnerability (Rasid and Mallik, 1993; Rasid and Mallik, 1995; Brouwer et al., 2007). Again, climatic impacts on rural livelihoods vary within and between societies, and many of these impacts cannot be immediately responded to without at least a case-based generalization (Adger, 2006; Ford et al., 2010). Thus, an important question to ask is: which of these outcome-based and context-specific interpretations of vulnerability will most effectively contribute to the formation of adaptation-related policies and practices. Here, O'Brien et al. (2007) argued that the political and scientific differences between the two approaches are too great to overcome and instead suggested a parallel and co-existing comprehension of both.

This thesis extends this discussion by postulating that other potential answers may be rooted in the scale of problem generalization and the congruence of interpretation between the two approaches. For example, Chapter 2 notes that the outcome-based questions asked in national-scale studies are more related to understanding how different stresses directly impact different sectors (e.g., agriculture, fisheries, health). However, Chapter 2 also highlights that similar stresses produce significantly different outcomes for different locations, which is a phenomenon that is not directly accounted for by national-level vulnerability assessments. In general, the more that studies moved from a local to a national scale, the more they failed to capture the nature of the local impacts of stresses. This may be because it is difficult to generalize micro-level political and socio-economic variabilities (Rudel, 2008; Ford et al., 2010). Thus, this thesis argues that it is necessary to go beyond single-scaler vulnerability assessments (e.g., national or sub-national or local), and to apply both context-specific and outcome-based approaches across scales (e.g., national and sub-national and local). Such an approach is also presented in the conceptual framework of this thesis. However, I excluded conducting an outcome-based vulnerability assessment since such studies have already been done in the northeastern part of Bangladesh (see Nowreen et al., 2015; Masood and Takeuchi, 2016; Nury et al., 2017).

Participatory policy making processes are often considered to be a useful way to incorporate multiple opinions and perspectives into a single scheme (van Aalst et al., 2008) and decentralize power and authority in order to establish more democratic policy options (Newig and Fritsch, 2009; Ayers, 2011). The National Adaptation Program for Action (NAPA)—which is a process that enables the Least Developed Countries to identify priority adaptation activities—drew upon the participatory policy making approach in order to facilitate greater levels of locally-connected policy (Ayers, 2011). As Chapter 5 highlights, the Bangladesh government has made considerable progress in advancing public participation opportunities in adaptation-related policy and planning processes. However, certain questions remain unanswered; for example, who is able participate, and how is their participation managed? Ayres (2010) provided a detailed description of public participation-related politics in adaptation planning in Bangladesh, stating that policy participants may have diverse understandings of vulnerability, and that the decisions made in this competitive environment may be influenced by power differentials among the participants. As a result, I argue that both context-specific and outcome-based views need to be considered in order to minimize the potential impact of power differentials. Moreover, the understanding achieved through considering both viewpoints can be used to design more meaningful, finer-scale adaptation planning. For example, the synthesis of climate forecast studies in northeastern Bangladesh, presented in Chapter 2, identifies the future potential for repeated flash-flood events, which was reflected in the community stress perception study presented in Chapter 3. However, community members associated their stress experiences with local biophysical and socio-economic properties. Interestingly, the outcomes of both perception-based and forecast-based studies were generally better reflected by the more context-specific adaptation plan (e.g., Master Plan for *Haor* Areas (MPHA)) than they were by the national-level plans (e.g., National Plan for Adaptation Action (NAPA) and the Bangladesh Climate Change Strategies and Action Plan (BCCSAP)) (see Chapter 5).

6.2.2 Understanding vulnerability for local adaptation-related policy making

Chapter 3 illustrates the need to for multiple-perspective-based vulnerability assessments by showing how perceptions of climate vulnerability at a local scale vary more greatly than those at the national and global scales. Better identifying the components that are used to construct local vulnerability perceptions may facilitate an improved understanding of locally-embedded vulnerability, which in turn may allow for more effective and locally-connected adaptation policy formation.

Frank et al. (2011) and Safi et al. (2012) posited that community perceptions are not only motivated by information about any particular stress; rather, they are also motivated by community members' direct experiences of the stress events. Community members tend to interpret information based on the intensity of the stress, their subjective experience of the stress, their memories surrounding those experiences and their capacity to respond (Frank et al., 2011; Wachinger et al., 2013). Measuring a household's response capacity is a highly complex task due to its inter-relationship with environmental, geographic, social, demographic, economic and political factors (Frank et al., 2011). In the case of rural livelihood vulnerability, Sánchez-Cortés and Chavero (2011) and Bele et al. (2013) linked stress perceptions to livelihood practices, cropping patterns, seasonality and cultural practices. Both the climatic (e.g., the frequency, extent and duration of stresses) and non-climatic factors (e.g., social, cultural, economic, geographic) listed above are taken into account in Chapter 3, and the results indicate that non-climatic factors play a greater role than climatic factors in constructing community stress perceptions within the study areas. I therefore posit that a community's long-standing experience with seasonal stresses allows it to specifically identify which extreme climatic events are potential livelihood stressors and which are not. For example, the community members in the study areas view an extreme climatic event as a stress to livelihood if it appears during their crop harvesting period. This observation not only indicates that policy could benefit from focusing on more specific adaptation actions that will allow local communities to effectively respond to livelihood stresses, but also that actions aimed towards adaptation to extreme climatic events also need to be pursued.

The concept of "multiple exposure" is another approach that captures the multidimensional nature of climatic impacts, and it has been widely used to understand how both climatic and non-climatic factors (e.g., local socio-economy, government policy, global market mechanism) contribute to vulnerability (O'Brien et al., 2000; O'Brien et al., 2004; Silva et al., 2010; Leichenko et al., 2010). Tucker et al. (2010) and Wachinger et al. (2013) build upon the concept of multiple exposure, suggesting that external factors like product price uncertainty are stronger drivers of adaptive responses than the stress perceptions of community members. Thus, I argue that non-climatic factors act as stimuli that intensify vulnerability, and, therefore, influence the selection of adaptive responses. This thesis has examined the local bio-physical, seasonal, socio-economic and climatic factors affecting vulnerability from a community perspective, finding that vulnerability was amplified as a result of interaction between multiple drivers or stimuli. More specifically, Chapter 3 finds that local environmental degradation, cropping and land-use practices are some of the stronger non-climatic stimuli that have been insufficiently explored in the wider vulnerability literature. The results of the analysis presented in Chapter 3 suggest that environmental degradation can cause a general climate event to transform into a stress, which is a process that cannot be adequately captured by climate-variable-based (e.g., precipitation, temperature, water flow) forecast models. Participatory research based on local knowledge and community perception can help to identify these latent stimuli. For example, river siltation in the wetland systems studied in this thesis causes water stagnancy; this indicates that the system's internal capacity for absorbing stress effects is being degraded by non-climatic stimuli (e.g., river siltation is reducing the river's water discharge capacity).

Taken together, the results presented in this thesis suggest that context-specific vulnerability assessment that is guided by multiple exposure thinking also needs to assimilate local bio-physical properties and resource use practices in its analytical domain. Socio-economic stimuli are also key to understanding the extent to which socio-economic factors maintain local livelihoods through local innovation and practices.

6.2.3 Political and socio-economic determinants of adaptation actions

Chapter 1 reviewed household investment strategies vis-à-vis their capital assets, noting that rural households often use their assets to diversify their livelihoods rather than investing them all into a single activity (Chambers, 1989). Since most natural-resource-dependent livelihood activities (e.g., fisheries, agriculture) are sensitive to climatic stresses, the livelihood vulnerability literature posits that a balance between natural and non-natural resource-dependent activities (e.g., wage earning, small business, migration) should help to maintain livelihood sustainability (Cinner and Bodin, 2010; Cinner et al., 2012). However, how different assets are used and how they function to diversify livelihoods are two important questions that have been relatively understudied. Although a number of studies have hypothesized that having access to different assets is a critical component to diversifying rural livelihoods (Bebbington, 1999; Rakodi, 1999; Ellis, 2000; Fang et al., 2014), in this thesis I argue that access to assets is a necessary, but not sufficient, condition for livelihood diversification. Building on the Sustainable Rural Livelihoods framework, Chapter 4 suggests that rural households combine, transform and substitute available assets in order to create different livelihood activities. For example, Chapter 4 identifies that households have increasingly begun to link social capital and to transform natural capital into financial capital in order to obtain livelihood opportunities abroad.

This dissertation also provides evidence in support of the claim that external support is another necessary condition for livelihood diversification. Such external support may come from the government, donor agencies, broader labor-market mechanisms, or larger socio-economic systems. For example, Chapter 4 shows that rural household members can engage in non-natural resource-dependent livelihood activities in urban areas or abroad if there is a labor market demand. Again, natural resource use intensification, another source of diversifying livelihoods, depends on institutional processes that can provide rural community members with access to natural resources. One example of this is access to wetland fisheries resources, which was discussed in Chapters 4 and 5. Overall, the results indicate that livelihood sustainability is a function of access to assets, systematic use of those assets, and external interventions that can create opportunities for diversification.

6.3 Insights for policy and practice

6.3.1 Managing gaps between science and policy

To better incorporate diverse vulnerability perspectives in adaptation plans, Lemos et al. (2012) suggested that more attention should be paid to establishing linkages among different knowledge sources and how they can inform policy recommendations. This is particularly relevant in developing area contexts where research infrastructure is generally inadequate. For example, most of the climate change studies that focus on Bangladesh were conducted after the finalization of the two most important adaptation plans (i.e., NAPA and BCCSAP), and no formal initiatives have since been identified to better link and translate scientific and community knowledge in the country.

Many governments have attempted to establish organizational structures that are dedicated to identifying and prioritizing research agendas to help generate useful scientific knowledge (Dilling and Lemos, 2011; Ford et al., 2013). For example, the U.S. Congress has enacted the United States Global Change Research Program, which aims to guide science towards practical applications in policy making (Dilling and Lemos, 2011). Scientific communities across the world are working to synthesize the current bodies of scientific knowledge available on climate change vulnerability and adaptation, with the identification of research gaps being one of their key objectives (Ford et al., 2013; Ford and Pearce, 2010; Berrang-Ford et al., 2011; Singh et al., 2017). Although this thesis attempts to synthesize existing climate change studies in Bangladesh, scientists and policy makers will need to consider similar initiatives across scales and sectors in order to enable evidence-based policy.

6.3.2 Community participation for context-specific adaptation policy

Valuing and comprehending community perspectives and integrating them into policies is generally far more time consuming than obtaining a scientific understanding of context-specific vulnerability and integrating it into policies. Klenk et al. (2015) suggested that stakeholder participation is not a sufficient condition for a participatory climate impact assessment. They argue that empowering research stakeholders by actively involving them in all stages of the research—from the development of the research question to the analysis—can engender problem-oriented knowledge (Dilling and Lemos, 2011; Klenk et al., 2015). My thesis has made such an attempt by validating the research questions through stakeholder consultation, and inviting community members to be part of the research process, not only as information and data providers, but also as knowledge co-producers (e.g., a community member who was highly knowledgeable regarding the study's context participated as a collaborator in the study presented in Chapter 3). Interestingly, adopting this approach helped us to identify pragmatic issues related to climate exposure that were generally missing from the literature, but that have large implications for both policy and action. For example, the previously-mentioned river siltation problem and the construction of embankments to protect agriculture from floods have been identified as major reasons for drought and the destruction of fish habitats. This local observation points to the need for more systems-based management strategies (see for example Moser and Ekstrom, 2010; Cinner et al., 2013). Thus, rather than supporting sector-specific and single-problem-oriented actions, the community participants advocated the use of watershed management strategies in order to increase both the water retention and discharge capacities of the rivers, channels, creeks and canals that pass through the wetlands.

6.3.3 Context specificity for avoiding a maladaptive trajectory

Chapter 1 noted that maladaptation is the result of unintended consequences of adaptation actions that may shift vulnerability from one sector, community or system to another. Barnett and O'Neill (2010) identified five types of maladaptation that can arise as a consequence of sector-specific adaptation actions: i) increased greenhouse gas emissions; ii) disproportionate burdens placed upon the most vulnerable populations; iii) high opportunity costs; iv) reduced incentive to adapt; and v) path dependency. Chapter 5 shows that many of the adaptation actions included in Bangladesh's national-level plans may be construed as comprising a maladaptive trajectory, with at least four of the five above-identified maladaptive actions being present in the current adaptation practices being employed in the studied areas.

Chapter 4 and Chapter 5 both identify that a number of interventions have been undertaken in the flood-prone, northeastern part of Bangladesh. In particular, Chapter 5 notes that some of these interventions are likely deleterious (e.g., embankment building, promotion of fertilizer- and pesticide-intensive high-yielding rice varieties) to the natural ecosystem. Moreover, existing fisheries management policies can make it difficult for resource-dependent communities to obtain fishing rights, which limits their capacity to diversify their livelihoods (Moser and Ekstrom, 2010). Thus, successful vulnerability reduction strategies and adaptation plans should include the revision of other resource management policies upon which livelihood diversification largely depends.

In addition, Chapter 4 notes that, since climatic stresses are common and obvious within the studied areas, these communities are adapting by expanding their non-natural-resource-dependent livelihood activities. However, most of these interventions are hindered by a lack of human, social and financial capital. While adaptation actions should be designed based on local resource availability as well as local socio-political and socio-economic structures, Chapter 5 points out that government-designed adaptation strategies have the potential to increase opportunity costs due to a disconnect with local biophysical properties (e.g., promotion of potato cultivation) and cultural practices (e.g., inefficient strategies for women participation in economic activities).

The adaptation actions included in the NAPA and the BCCSAP are extensions of sector-specific development interventions; thus, they are isolated in nature, which impedes the conditions necessary for their successful execution. For example, Chapter 4 notes that power asymmetries, socio-economic disparities, and the inefficiency of local government serve to undermine adaptation interventions and often create opportunities for the community's rich and elite to obtain government support (e.g., elite control of the technological supports provided by government). Consequently, the poorer sections of society are generally left behind, resulting in a situation that traps them in poverty. There is therefore a need for interventions that can create inclusive and participatory adaptation and resource governance systems, particularly at local levels in our study area.

Finally, the impacts of path-dependent adaptation actions, such as embankment and irrigation system construction, have been identified and discussed in several parts of this thesis. Although engineered infrastructure has been successful in solving immediate problems, Barnett and O'Neill (2010) have suggested that such interventions actually decrease the ability of adaptation actions to respond to unforeseen changes in economic, social, environmental and climatic properties.

6.4 Future directions

This research has identified the contextual nature of climatic stresses and their influence on rural livelihoods in Bangladesh's northeastern floodplains with a view to informing government efforts to better contextualize adaptation-related planning and policy formation. Building on the findings presented in the thesis, the following potential directions for future research warrant further attention.

- Recognizing the incongruence between climate change research and adaptation-related policy formation processes in Bangladesh, further research is needed to help identify and develop appropriate institutional mechanisms for enhancing the national innovation system.

- While this study has assessed vulnerability in terms of livelihood exposure and sensitivity, it has not examined adaptive capacity. Further research is needed to describe the locally-embedded political institutions and power structures that support or prevent the development of an adaptation mechanism. Future policy reform efforts also need to explore this aspect, particularly for its potential to help ensure equity and justice in adaptation processes.

- Further research to assess climate vulnerability in Bangladesh using other perspectives would be valuable, including issues such as the limiting influences of labor, economic and political processes on adaptive actions, particularly since migration is an adaptation option for affected communities.

- There is a need to further explore the trans-boundary policy dimensions of the river network in the context of climate change and adaptation. Since trans-boundary resource management between Bangladesh and its neighbouring countries is often disputed and uncoordinated, it will be important to consider how vulnerability dynamics intersect with trans-national political processes.

6.5 Conclusion

This thesis demonstrates how national policy processes often fail to respond to context-specific adaptation demand using the case of northeastern Bangladesh. The systematic identification of study areas and research questions, the use of multiple methods, and the synthesis of different perceptions formed the foundations of my research. Cash et al. (2003) and Kirchhoff et al. (2013) suggested that climate change vulnerability studies need to be more policy-relevant and that the produced knowledge should be adaptable to practical problems. This dissertation attempts to respond to this call. The research approach used in this study has enabled the identification of gaps among societal, scientific and policy perspectives relating to climatic vulnerability. Although this thesis advocates for greater contextual assessment of vulnerability, its theoretical observations have wider implications beyond the case study context. By focusing on rural livelihoods, this research shows how more integrative approaches gaps might help to improve the identification and selection of adaptation options and, in turn, the outcomes for rural livelihoods. Future rural livelihood adaptation policies in Bangladesh will need to be flexible enough to embrace both climatic and non-climatic factors rooted in diverse stress contexts, and specific enough to enable the identification of locally appropriate adaptation actions before making resource allocation decisions.

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Appendix 2.1 (List of the papers reviewed in this study)

Author	Journal	Title of the paper	Year of publication
Ortiz	Ocean and Coastal Management	Sea-level rise and its impact on Bangladesh	1994
Ahmed et al.	Ambio	An inventory of greenhouse gas emissions in Bangladesh: Initial results	1996
Karim et al.	Water, Air, and Soil Pollution	Assessing impacts of climatic variations on food grain Production in Bangladesh	1996
Begum and Fleming	Marine Geodesy	Climate change and sea level rise in Bangladesh, part II: Effects	1997
Begum and Fleming	Marine Geodesy	Climate change and sea level rise in Bangladesh, part I: Numerical simulation	1997
Mahmood	Agricultural and Forest Meteorology	Impacts of air temperature variations on the Boro rice phenology in Bangladesh: implications for irrigation requirements	1997
Mahmood	Theoretical and Applied Climatology	Thermal climate variations and potential modification of the cropping pattern in Bangladesh	1998
Mahmood	Ecological Modelling	Air temperature variations and rice productivity in Bangladesh: a comparative study of the performance of the yield and the CERES-rice model	1998
Ali	Climate Research	Climate change impacts and adaptation assessment in Bangladesh	1999
Khan et al.	Marine Geodesy	Recent sea level and sea surface temperature trends along the Bangladesh coast in relation to the frequency of intense cyclones	2000
Adel	International Journal of Climatology	Man-made climatic changes in the Ganges basin	2002
Rodo et al.	PNAS	ENSO and cholera: A nonstationary link related to climate change?	2002
Mirza	Global Environmental Change	Global warming and changes in the probability of occurrence of floods in Bangladesh and implications	2002
Mahmood et al.	The Professional Geographer	The CERES-Rice Model-Based Estimates of Potential monsoon season rain fed rice productivity in Bangladesh	2003
Mirza et al.	Climatic Change	The implications of climate change on floods of the Ganges, Brahmaputra and Meghna rivers in Bangladesh	2003
Nelson	Environmental Impact Assessment Review	Health impact assessment of climate change in Bangladesh	2003
Goodbred et al.	Sedimentary Geology	Controls on facies distribution and stratigraphic preservation in the Ganges-Brahmaputra delta sequence	2003
Faisal and Parveen	Environmental Management	Food security in the face of climate change, population growth, and resource constraints: Implication for Bangladesh	2004
Mahmood et al.	Applied Geography	The role of soil water availability in potential rainfed rice productivity in Bangladesh: applications of the CERES-rice model	2004
Chowdhury	Environmental Management	Consensus seasonal flood forecasts and warning response system (FFWRS): An alternate for nonstructural flood management in Bangladesh	2005
Jakobsen et al.	Water International	Evaluation of the short-term processes forcing the monsoon river floods in Bangladesh	2005

Koelle et al.	Nature	Refractory periods and climate forcing in cholera dynamics	2005
Koelle et al.	Proceedings of the Royal Society B	Pathogen adaptation to seasonal forcing and climate change	2005
Mallick et al.	IDS Bulletin	Case study 3: Bangladesh Floods in Bangladesh: A shift from disaster management towards disaster preparedness	2005
Azad et al.	Ambio	State of energy consumption and CO_2 emission in Bangladesh	2006
Gopal and Chauhan	Aquatic Science	Biodiversity and its conservation in the Sundarban Mangrove Ecosystem	2006
Khan and Rahman	Natural Hazards	Partnership approach to disaster management in Bangladesh: A critical policy assessment	2007
Alam and Rabbani	Environment and Urbanization	Vulnerabilities and responses to climate change for Dhaka	2007
Brouwer et al.	Risk Analysis	Socioeconomic vulnerability and adaptation to environmental risk: A case study of climate change and flooding in Bangladesh	2007
Hashizume et al.	International Journal of Epidemiology	Association between climate variability and hospital visits for non-cholera diarrheas in Bangladesh: effects of vulnerable groups	2007
Pascual et al.	Climate Research	Predicting endemic cholera: the role of climate variability and disease dynamics	2008
Rahman et al.	International Journal of Remote Sensing	Satellite estimation of forest carbon using regression models	2008
Hashizume et al.	Epidemiology and Infection	Rotavirus infections and climate variability in Dhaka, Bangladesh: A time series analysis	2008
Hashizume et al. a	Epidemiology	The effect of rainfall on the incidence of cholera in Bangladesh	2008
Islam et al.	International Journal of Climatology	Calibration of PRECIS in employing future scenarios in Bangladesh	2008
Karim and Mimura	Global Environmental Change	Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh	2008
Matsuda et al.	Epidemiology and Infection.	Prediction of epidemic cholera due to Vibrio cholera O1 in children younger than 10 years using climate data in Bangladesh	2008
Rahman	Regional Health Forum	Climate change and its impact on health in Bangladesh	2008
Cash et al.	Journal of Climate	Links between tropical pacific SST and cholera incidence in Bangladesh: Role of the Eastern and Central tropical pacific	2008
Halls et al.	Hydrobiologia	Impacts of flood control schemes on inland fisheries in Bangladesh: guidelines for mitigation	2008
Koelle	Clinical Microbiology and Infection	The impact of climate on the disease dynamics of cholera	2009
Shahid and Khairulmaini	Asia-Pacific Journal of Atmospheric Sciences	Spatio-temporal variability of rainfall over Bangladesh during the time period 1969-2003	2009
Ayres and Huq	Environmental Management	The value of linking mitigation and adaptation: A case study of Bangladesh	2009
Ismal et al.	Transactions of the Royal Society of Tropical Medicine and Hygiene	Effects of local climate variability on transmission dynamics of cholera in Matlab, Bangladesh	2009
Pouliotte et al.	Climate and Development	Adaptation and development: Livelihoods and climate change in Subarnabad, Bangladesh	2009

Roy	Habitat International	Planning for sustainable urbanisation in fast growing cities: Mitigation and adaptation issues addresses in Dhaka, Bangladesh	2009
Cash et al.	Journal of Climate	Links between tropical pacific SST and cholera incidence in Bangladesh: Role of the Westerna and Central extratropical pacific	2009
Das	Integrative Zoology	Conserving the zoological resources of Bangladesh under a changing climate	2009
Lara et al.	Ecohealth	Influence of catastrophic climatic events and human waste on vibrio distribution in the Karnaphuli estuary, Bangladesh	2009
Mynett and Vojinovic	Journal of Hydroinformatics	Hydroinformatics in multi-colours—part red: Urban flood and disaster management	2009
Belal et al.	Research in Accounting in Emerging Economies	Corporate and environmental and climate change disclosures: Empirical evidence from Bangladesh	2010
Chaturvedi and Doyle	Journal of the Indian Ocean Region	Geopolitics of fear and the emergence of 'climate refugees': imaginative geographies of climate change and displacements in Bangladesh	2010
Haque et al.	PlosOne	The role of climate variability in the spread of malaria in Bangladeshi highlands	2010
Hossain et al.	International Journal of Climate Change Strategies and Management	Manifestations of climate change impacts affecting socio-economy in Bangladesh Looking through the framework of sustainable development	2010
Miah et al.	Energy Policy	Global observation of EKC hypothesis for CO2, SOx and NOx emission: A policy understanding for climate change mitigation in Bangladesh	2010
Mondal et al.	Water Resource Management	Risk-based evaluation for meeting future water demand of the Brahmaputra floodplain within Bangladesh	2010
Rahman et al.	Journal of Tropical Medicine	Comparative analysis on applicability of satellite and meteorological data for prediction of malaria in endemic area in Bangladesh	2010
Rahman	The International Journal of Interdisciplinary Social Sciences	Salt is bitter: Salinity and livelihood in a Bangladesh village	2010
Rana et al.	International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science	Application of remote sensing and GIS for cyclone disaster management in coastal area: A case study a Barguna district, Bangladesh	2010
Shahid	Climate Research	Recent trends in the climate of Bangladesh	2010
Loucks et al.	Climatic Change	Sea level rise and tigers: predicted impacts to Bangladesh's Sunderbans mangroves	2010
Shahid	International Journal of Climatology	Rainfall variability and the trends of wet and dry periods in Bangladesh	2010
Shahid	Asia-Pacific Journal of Public Health	Probable impacts of climate change on public health in Bangladesh	2010
Alam and Collins	Disaster	Cyclone disaster vulnerability and response experiences in coastal Bangladesh	2010
Brouwer and Akter	Environmental Hazards	Informing micro insurance contract design to mitigate climate change catastrophe risks using choice experiments	2010
Jabeen et al.	Environment and Urbanization	Built-in resilience: learning from grassroots coping strategies for climate variability	2010
Ohtomo et al.	Epidemiology and Infection	Relationship of cholera incidence to El Nin˜o and solar activity elucidated by time-series analysis	2010
Rotberg	Climate and Development	Social networks and adaptation in rural Bangladesh	2010

Sultana and Thompson	Environmental Hazards	Local institutions for floodplain management in Bangladesh and the influence of the flood action plan	2010
Sultana	Environmental Hazards	Living in hazardous waterscapes: Gendered vulnerabilities and experiences of floods and disasters	2010
Ahiduzzaman and Islam	Renewable and Sustainable Energy Reviews	Greenhouse gas emission and renewable energy sources for sustainable development in Bangladesh	2011
Ahsan et al.	Environmental Justice	Climate migration and urban planning system: A study of Bangladesh	2011
Al-Amin et al.	Asian Journal of Animal and Veterinary Advances	An analysis of animal health and veterinary facilities in coping the climate change in Bangladesh: What education system can offer for benefit	2011
Hasan and Akhter	European Journal of Social Sciences	Determinants of public awareness and attitudes on climate change in urban Bangladesh: Dhaka as a case	2011
Hashizume et al.	Environmental Health Perspectives	The Indian ocean dipole and cholera incidence in Bangladesh: A time-series analysis	2011
Irfanullah and Motaleb	Indian Journal of Traditional Knowledge	Reading nature's mind: Disaster management by indigenous peoples of Bangladesh	2011
Islam	Int. J. Sustainable Society	Decision support system for ex ante cost-benefit assessment of new agro-technology in the context of climate change	2011
Lisa et al.	Functional Plant Biology	Physiology and gene expression of the rice landrace Horkuch under salt stress	2011
Miah et al.	Environmentalist	Major climate-change issues covered by the daily newspapers of Bangladesh	2011
Mourshed	Applied Energy	The impact of the projected changes in temperature on heating and cooling requirements in buildings in Dhaka, Bangladesh	2011
Zaman	Regional Development Dialogue	Current issues on climate change and poverty in Bangladesh	2011
Ahammad	Environment and Urbanization	Constraints of pro-poor climate change adaptation on Chittagong city	2011
Banks et al.	Environment and Urbanization	Neglecting the urban poor in Bangladesh: research, policy and action in the context of climate change	2011
Huq and Rubbani	Journal of Bangladesh Studies	Climate change and Bangladesh: Policy and institutional development to reduce vulnerability	2011
Kartiki	Gender and Development	Climate change and migration: A case study from rural Bangladesh	2011
Khan et al.	Environmental Health Perspectives	Drinking water salinity and maternal health in coastal Bangladesh: Implications of climate change	2011
Rawlani and Sovacool	Mitigation and Adaptation Strategies for Global Change	Building responsiveness to climate change through community based adaptation in Bangladesh	2011
Shahid	Theoratical and Applied Climatology	Trends in extreme rainfall events of Bangladesh	2011
Shahid	Climatic Change	Impact of climate change on irrigation water demand of dry season Boro rice in north west Bangladesh	2011
Akter et al.	Disaster	Exploring the feasibility of private micro flood insurance provision in Bangladesh	2011
Alam et al.	IDS Bulletin	The political economy of climate resilienent development planning in Bangladesh	2011
Ayers	Global Environmental Politics	Resolving the adaptation paradox: Exploring the potential for deliberative adaptation policy-making in Bangladesh	2011
Barua and Ast	Water Policy	Towards interactive flood management in Dhaka, Bangladesh	2011

Braun and Aßheuer	Natural Hazards	Floods in megacity environments: vulnerability and coping strategies of slum dwellers in Dhaka/Bangladesh	2011
Burkart et al.	Environmental Pollution	The effect of atmospheric thermal conditions and urban thermal pollution on all-cause and cardiovascular mortality in Bangladesh	2011
Dasgupta et al.	Journal of Environment and Development	Climate proofing infrastructure in Bangladesh: The incremental cost of limiting future flood damage	2011
Gain et al.	Hydrology and Earth System Science	Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flow based on discharge-weighted ensamble modelling	2011
Huq	Bulletin of the Atomic Scientists	Lessons of climate change, stories of solutions	2011
Khan et al.	Environment: Science and Policy for Sustainable Development	Climate change, sea-level rise, and health impacts in Bangladesh	2011
Mallik et al.	Mitigation and Adaptation Strategies for Global Change	Coastal livelihood and physical infrastructure in Bangladesh after cyclone Aila	2011
Paul and Routray	Natural Hazards	Household response to cyclone and induced surge in coastal Bangladesh: Coping strategies and explanatory variables	2011
Ahmed et al.	International Journal of Global Warming	Climate change issues: Challenges for natural resource management in Bangladesh – A way forward	2012
Akter	Journal of Environment and Development	The role of microinsurance as a safety net against environmental risks in Bangladesh	2012
Alam et al.	Global Health Action	The association of weather and mortality in Bangladesh from 1983 2009	2012
Ali et al.	Water Resource Management	Sustainability of groundwater resources in the north-eastern region of Bangladesh	2012
Bhuiyan and Dutta	Estuarine, Coastal and Shelf Science	Assessing impacts of sea level rise on river salinity in the Gorai river network, Bangladesh	2012
Bhuiyan and Dutta	Natural Hazards	Analysis of flood vulnerability and assessment of the impacts in coastal zones of Bangladesh due to potential sea-level rise	2012
Gain et al.	Water	Water resources systems in developing countries: A climate change adaptation and vulnerability assessment of generalized framework and a feasibility study in Bangladesh	2012
Haque et al.	Environment and Urbanization	Participatory integrated assessment of flood protection measures for climate adaptation in Dhaka	2012
Haque et al.	Environmental Health	Households' perception of climate change and human health risks: A community perspective	2012
Haque et al.	Bull World Health Organ	Reduced death rates from cyclones in Bangladesh: what more needs to be done?	2012
Karim et al.	Agronomy for Sustainable Development	Climate change model predicts 33 % rice yield decrease in 2100 in Bangladesh	2012
Karim et al.	Italian Journal of Agronomy	Modeling of seasonal water balance for crop production in Bangladesh with implications for future projection	2012
Penning-Rowsell et al.	Environmental Science and Policy	The 'last resort'? Population movement in response to climate-related hazards in Bangladesh	2012
Rahman et al.	Journal of Earth System Science	Rainfall and temperature scenarios for Bangladesh for the middle of 21st century using RegCM	2012
Rahman et al.	International Journal of Climate Change Strategies and Management	Rainfall and temperature scenario for Bangladesh using 20 km mesh AGCM	2012
Rajib and Rahman	Atmosphere	A comprehensive modeling study on regional climate model (RCM) application — Regional warming projections in monthly resolutions under IPCC A1B scenario	2012

Reiner et al.	PNAS	Highly localized sensitivity to climate forcing drives endemic cholera in a megacity	2012
Salauddin and Ashikuzzaman	International Journal of Climate Change Strategies and Management	Nature and extent of population displacement due to climate change-triggered disasters in the south-western coastal region of Bangladesh	2012
Saroar and Routray	Regional Environmental Change	Impacts of climatic disasters in coastal Bangladesh: why does private adaptive capacity differ?	2012
Shahid et al.	Atmospheric Research	Changes in diurnal temperature range in Bangladesh during the time period 1961–2008	2012
Shahid	Regional Environmental Change	Vulnerability of the power sector of Bangladesh to climate change and extreme weather events	2012
Anik and Khan	Adaptation and Mitigation Strategies for Global Change	Climate change adaptation through local knowledge in the north eastern region of Bangladesh	2012
Gray and Mueller	PNAS	Natural disasters and population mobility in Bangladesh	2012
Hassani-Mahmoddei and Parries	Environment and Development Economics	Climate change and internal migration patterns in Bangladesh: An agent-based model	2012
Sarker et al.	Agricultural Systems	Exploring the relationship between climate change and rice yield in Bangladesh: an analysis of time series data	2012
Thurlow et al.	Review of Development Economics	A stochastic simulation approach to estimating the economic impacts of climate change in Bangladesh	2012
Ahammad et al.	Journal of Coastal Conservation	Unlocking ecosystem based adaptation opportunities in coastal Bangladesh	2013
Ahmed et al.	Marine Policy	The impact of climate change on prawn post larvae fishing in coastal Bangladesh: Socioeconomic and ecological perspectives	2013
Ahmed	Ocean and Coastal Management	Linking prawn and shrimp farming towards a green economy in Bangladesh: Confronting climate change	2013
Al-Amin et al.	International Journal of Global Warming	Global warming and climate change: prospects and challenges toward long-term policies in Bangladesh	2013
Ali et al.	Journal of Health, Population and Nutrition	Time series analysis of cholera in Matlab, Bangladesh, during 1988-2001	2013
Bala and Hossain	Environmental Modelling and Assessment	Modeling of ecological footprint and climate change impacts on food security of the hill tracts of Chittagong in Bangladesh	2013
Haque et al.	BMC Public Health	Health coping strategies of the people vulnerable to climate change in a resource-poor rural setting in Bangladesh	2013
Hashizume et al.	PlosOne	A differential effect of Indian ocean dipole and El Nin˜o on cholera dynamics in Bangladesh	2013
Hossain et al.	Pertanika Journal of Science and Technology	Climate change resilience assessment using livelihood assets of coastal fishing community in Nijhum Dwip, Bangladesh	2013
Hossain et al.	AoB Plants	Wheat production in Bangladesh: Its future in the light of global warming	2013
Hossain et al.	Mitigation and Adaptation Strategies for Global Change	Integrating ecosystem services and climate change responses in coastal wetlands development plans for Bangladesh	2013
Huda	Natural Hazards	Understanding indigenous people's perception on climate change and climatic hazards: A case study of Chakma indigenous communities in Rangamati Sadar Upazila of Rangamati District, Bangladesh	2013

Miah et al.	Forest Science and Technology	Socio-economic and environmental impacts of casuarina shelterbelt in the Chittagong coast of Bangladesh	2013
Minar et al.	Middle-East Journal of Scientific Research	Climate change and coastal Zone of Bangladesh: Vulnerability, resilience and adaptability	2013
Naser	Nordic Journal of International Law	Climate-induced displacement in Bangladesh: Recognition and protection under international law	2013
Parvin and Ahsan	Management of Environmental Quality: An International Journal	Impacts of climate change on food security of rural poor women in Bangladesh	2013
Rabbani et al.	International Journal of Global Warming	Salinity-induced loss and damage to farming households in coastal Bangladesh	2013
Rabbani et al.	Sustainability	Impacts of climatic hazards on the small wetland ecosystems (ponds): Evidence from some selected areas of coastal Bangladesh	2013
Roy et al.	Environment and Urbanization	Contrasting adaptation responses by squatters and low-income tenants in Khulna, Bangladesh	2013
Ruane et al.	Global Environmental Change	Multi-factor impact analysis of agricultural production in Bangladesh with climate change	2013
Sarker et al.	International Journal of Climate Change Strategies and Management	Assessing the determinants of rice farmers' adaptation strategies to climate change in Bangladesh	2013
Wadud and Khan	Environmental Science and Technology	Air quality and climate impacts due to CNG conversion of motor vehicles in Dhaka, Bangladesh	2013
Younus and Harvey	Journal of Environmental Assessment Policy and Management	Community -based flood vulnerability and adaptation assessment: A case study from Bangladesh	2013
Ahamad et al.	Adaptation and Mitigation Strategies for Global Change	Seasonal food insecurity in Bangladesh: Evidences from northern areas	2013
Coirolo et al.	Development Policy Review	Climate change and social protection in Bangladesh: are existing programmes able to address the impacts of climate change	2013
Gain and Hoque	Journal of Flood Risk Management	Flood risk assessment and its application in the eastern part of Dhaka city, Bangladesh	2013
Gain et al.	Climatic Change	Thresholds of hydrologic flow regime of a river and investigation of climate change impact-the case of lower Brahmaputra river basin	2013
Haque et al.	BMC Public Health	Health coping strategies of the people vulnerable to climate change in a resource poor rural setting in Bangladesh	2013
Khan et al.	Energy Policy	The global climate change and its effect on power generation in Bangladesh	2013
Lee	Journal of Geophysical Research: Ocean	Estimation of extreme sea levels along the Bangladesh coast due to storm surge and sea level rise using EEMD and EVA	2013
Mottaleb et al.	Agricultural Systems	The effects of natural disasters on farm household income and expenditures: A study on rice farmers in Bangladesh	2013
Rahman et al.	Natural Hazards	Summer monsoon rainfall scenario over Bangladesh using a high-resolution AGCM	2013
Rotberg	Journal of International Development	Social networks, brokers and climate change adaptation: A Bangladeshi case	2013
Sarwar and Woodroffe	Journal of Coastal Conservation	Rates of shoreline change along the coast of Bangladesh	2013

Sarker et al.	Journal of Agronomy and Crop Sciences	How does the variability in Aus rice yield respond to climate variables in Bangladesh?	2013
Ahsan and Warner	International Journal of Disaster Risk Reduction	The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks– A case study in the south-western coastal Bangladesh	2014
Alam and Mullick	International Journal of Climate Change Strategies and Management	Climate change effects upon massive land and housing development Case of Dhaka, Bangladesh	2014
Alauddin and Sarker	Ecological Economics	Climate change and farm-level adaptation decisions and strategies in drought-prone and groundwater-depleted areas of Bangladesh: an empirical investigation	2014
Alston et al.	Women's Studies International Forum	Are climate challenges reinforcing child and forced marriage and dowry as adaptation strategies in the context of Bangladesh?	2014
Ayers et al.	Climate and Development	Mainstreaming climate change adaptation into development in Bangladesh	2014
Bala et al.	Strategic Planning for Energy and the Environment	Energy Perspective of Climate Change: The Case of Bangladesh	2014
Cash et al.	PlosOne	Cholera and shigellosis: Different epidemiology but similar responses to climate variability	2014
Coirolo and Rahman	Climate and Development	Power and differential climate change vulnerability among extremely poor people in Northwest Bangladesh: Lessons for mainstreaming	2014
Collins	Australian Geographer	A rising tide in Bangladesh: Livelihood adaptation to climate stress	2014
Fakhruddin and Rahman	International Journal of Disaster Risk Reduction	Coping with coastal risk and vulnerabilities in Bangladesh	2014
Hasan et al.	Journal of Engineering Science and Technology	Analysis of the statistical behavior of daily maximum and monthly average rainfall along with rainy days variation in Sylhet, Bangladesh	2014
Hatsuzuka et al.	Monthly Weather Review	Characteristics of low pressure systems associated with intraseasonal oscillation of rainfall over Bangladesh during Boreal Summer	2014
Hoque et al.	Procedia Engineering	Evaluation of energy payback and CO2 emission of solar home systems in Bangladesh	2014
Islam et al.	Regional Environmental Change	Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: Insights from coastal Bangladesh	2014
Jilani et al.	Mitigation and Adaptation Strategies for Global Change	The future role of agriculture and land use change for climate change mitigation in Bangladesh	2014
Mahmood et al.	Facilities	The state of multi-purpose cyclone shelters in Bangladesh	2014
Mainuddin et al.	Irrigation Science	Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh	2014
Molla et al.	Environmental Development	Multidisciplinary household environmental factors: Influence on DALYs lost in climate refugees community	2014
Molla et al.	Urban Climate	Quantifying disease burden among climate refugees using multidisciplinary approach: A case of Dhaka, Bangladesh	2014
Mortuza et al.	Arabian Journal of Geosciences	Evaluation of temporal and spatial trends in relative humidity and dew point temperature in Bangladesh	2014
Pavel et al.	International Journal of Environmental Studies	Economic evaluation of floating gardening as a means of adapting to climate change in Bangladesh	2014
Rai et al.	Development in Practice	Climate resilient planning in Bangladesh: A review of progress and early experiences of moving from planning to implementation	2014

Sarker et al.	Economic Analysis and Policy	Assessing the effects of climate change on rice yields: An econometric investigation using Bangladeshi panel data	2014
Shabib and Khan	Climate and Development	Gender-sensitive adaptation policy-making in Bangladesh: Status and ways forward for improved mainstreaming	2014
Shameem et al.	Ocean and Coastal Management	Vulnerability of rural livelihoods to multiple stressors: A case study from the southwest coastal region of Bangladesh	2014
Siddik and Rahman	Theoretical and Applied Climatology	Trend analysis of maximum, minimum, and average temperatures in Bangladesh: 1961–2008	2014
Toufique and Islam	International Journal of Disaster Risk Reduction	Assessing risks from climate variability and change for disaster-prone zones in Bangladesh	2014
WU et al.	Epidemiology and Infection	Association of climate variability and childhood diarrhoeal disease in rural Bangladesh, 2000–2006	2014
Younus and Harvey	Local Economy	Economic consequences of failed autonomous adaptation to extreme floods: A survey case study from Bangladesh	2014
Younus and Sharna	Journal of Environmental Assessment Policy and Management	Combination of community-based vulnerability and adaptation to storme surges in coastal regions of Bangladesh	2014
Younus	Journal of Environmental Assessment Policy and Management	Flood vulnerability and adaptation to climate change in Bangladesh: A review	2014
Ahammad et al.	Journal of Forestry Research	Governance of forest conservation and co-benefits for Bangladesh under climate change	2014
Ahammad et al.	Atmospheric Research	Variability of annual daily maximum rainfall of Dhaka, Bangladesh	2014
Ahamed et al.	Reviews in Aquaculture	Community-based climate change adaptation strategies for integrated prawn-fish-rice farming in Bangladesh to promote social-ecological resilience	2014
Ali et al.	PlosOne	Will climate change affect outbreak patterns of Planthoppers in Bangladesh	2014
Anwar and Takewaka	Journal of Coastal Conservation	Analyses on phenological and morphological variations of mangrove forests along the southwest coast of Bangladesh	2014
Ayres et al.	WIREs Climate Change	Mainstreaming climate change adaptation into development: a case study of Bangladesh	2014
Banu et al.	Environment International	Projecting the impact of climate change on dengue transmission in Dhaka, Bangladesh	2014
Burkert et al.	International Journal of Biometeorology	An analysis of heat effects in different subpopulations of Bangladesh	2014
Dasgupta et al.	Climate and Development	Cyclones in a changing climate: the case of Bangladesh	2014
Etzold et al.	Climate and Development	Clouds gather in the sky, but no rain falls. Vulnerability to rainfall variability and food insecrity in Northern Bangladesh and its effects on migration	2014
Gain and Wada	Water Resource Management	Assessment of future water scarcity at different spatial and temporal scales of the Bramhaputra river basin	2014
Habiba	Natural Hazards	Farmers' adaptive practices for drought risk reduction in the northwest region of Bangladesh	2014
Haque et al.	Environment and Urbanization	Individual, communal and institutional responses to climate change by low-income households in Khulna, Bangladesh	2014
Haque et al.	BMC Public Health	Use of traditional medicines to cope with climate-sensitive diseases in a resource poor setting in Bangladesh	2014

Islam et al.	Climatic Change	Migrating to tackle climate variability and change? Insights from coastal fishing communities in Bangladesh	2014
Islam et al.	Marine Policy	Limits and barriers to adaptation to climate variability and change in Bangladeshi coastal fishing communities	2014
Khan et al.	Natural Hazards	Is area affected by flood or stagnant water independently associated with poorer health outcomes in urban slums of Dhaka and adjecent rural area	2014
Kumar et al.	International Journal of Climatology	Impact of climate change on rainfall in Northwestern Bangladesh using multi-GCM ensembles	2014
Martin et al.	Population and Environment	Climate-related migration in rural Bangladesh: A behavioural model	2014
Nahar et al.	BMC Public Health	Increasing the provision of mental health care for vulnerable, disaster-affected people in Bangladesh	2014
Nowreen et al.	Water Policy	Historical analysis of rationalizing South West coastal polders of Bangladesh	2014
Prasanna et al.	Meteorological Applications	Development of daily gridded rainfall dataset over the Ganga, Brahmaputra and Meghna river Basin	2014
Rasheed et al.	BMC Public Health	How much salt do adults consume in climate vulnerable coastal Bangladesh	2014
Rouillard et al.	International Journal of Water Resource Development	Evaluating IWRM implementation success: are water policies in Bangladesh enhancing adaptive capacity to climate change impacts?	2014
Sala and Bocchi	Climate and Development	Green revolution impacts in Bangladesh: exploring adaptation pathways for enhancing national food security	2014
Nowreen et al.	Theoratical and Applied Climatology	Changes of rainfall extremes around the haor basin areas of Bangladesh using multi-member ensemble RCM	2014
Abedin and Shaw	International Journal of Disaster Risk Reduction	The role of university networks in disaster risk reduction: Perspective from coastal Bangladesh	2015
Ahmed and Diana	Aquaculture Reports	Coastal to inland: Expansion of prawn farming for adaptation to climate change in Bangladesh	2015
Ahmed and Diana	Ocean and Coastal Management	Threatening“white gold”: Impacts of climate change on shrimp farming in coastal Bangladesh	2015
Alam	Agricultural Water Management	Farmers’ adaptation to water scarcity in drought-prone environments: A case study of Rajshahi District, Bangladesh	2015
Alamgir et al.	Applied Geography	Modelling spatial distribution of critically endangered Asian elephant and Hoolock gibbon in Bangladesh forest ecosystems under a changing climate	2015
Amin et al.	Sustainability	Effects of Climate Change on the Yield and Cropping Area of Major Food Crops: A Case of Bangladesh	2015
Basak et al.	Weather and Climate Extremes	Impacts of floods on forest trees and their coping strategies in Bangladesh	2015
Beier et al.	Glob Health Action	Indirect consequences of extreme weather and climate events and their associations with physical health in coastal Bangladesh: a cross-sectional study	2015
Bhuiyan	South Asia Research	Adaptation to climate change in Bangladesh: Good governance barriers	2015
Caesar et al.	Environmental Science Processes and Impacts	Temperature and precipitation projections over Bangladesh and the upstream Ganges, Brahmaputra and Meghna systems	2015
Clarke et al.	Environmental Science Processes and Impacts	Projections of on-farm salinity in coastal Bangladesh	2015
Dasgupta et al.	Ambio	Climate change and soil salinity: The case of coastal Bangladesh	2015
Dastagir	Weather and Climate Extremes	Modeling recent climate change induced extreme events in Bangladesh: A review	2015

Gain and Giupponi	Ecological Indicators	A dynamic assessment of water scarcity risk in the Lower Brahmaputra River Basin: An integrated approach	2015
Gusyev et al.	Proceedings of International Association of Hydrological Sciences	Effectiveness of water infrastructure for river flood management – Part 1: Flood hazard assessment using hydrological models in Bangladesh	2015
HANIF et al.	Research on Crops	Potentiality of carbon sequestration by agroforestry species in Bangladesh	2015
Huq et al.	Sustainability	Climate change impacts in agricultural communities in rural areas of coastal Bangladesh: A tale of many stories	2015
Islam et al.	Journal of Indian Society of Remote Sensing	Assessment of coastal vulnerability due to sea level change at Bhola island, Bangladesh: Using geospatial techniques	2015
Islam et al.	International Journal of Remote Sensing	Pattern analysis of trace gases over Bangladesh using satellite remote sensing	2015
Jabeen and Guy	Habitat International	Fluid engagements: Responding to the co-evolution of poverty and climate change in Dhaka, Bangladesh	2015
Jabeen	International Journal of Urban Sustainable Development	Adapting the assets of urban low-income households with climate extremes: Experience from Dhaka	2015
Jordan	Climate and Development	Swimming alone? The role of social capital in enhancing local resilience to climate stress: A case study from Bangladesh	2015
Kabir et al.	PlosOne	Child centred approach to climate change and health adaptation through schools in Bangladesh: A cluster randomised intervention trial	2015
Karim et al.	Resources, Conservation and Recycling	Reliability and economic analysis of urban rainwater harvesting in a megacity in Bangladesh	2015
Kay et al.	Environmental Sciences: Processes Impacts	Modelling the increased frequency of extreme sea levels in the Ganges–Brahmaputra–Meghna delta due to sea level rise and other effects of climate change	2015
Khan and Ali	International Social Work	Do non-governmental organisations' socio-economic and training programmes improve disaster prevention capacity of their beneficiaries?	2015
L´ az´ ar et al.	Environmental Sciences: Processes Impacts	Agricultural livelihoods in coastal Bangladesh under climate and environmental change–a model framework	2015
Lu et al.	Sustainability	Residence and job location change choice behavior under flooding and cyclone impacts in Bangladesh	2015
Maniruzzaman et al.	Agricultural Water Management	Validation of the AquaCrop model for irrigated rice production under varied water regimes in Bangladesh	2015
Masood et al.	Hydrology and Earth System Sciences	Model study of the impacts of future climate change on the hydrology of Ganges–Brahmaputra–Meghna basin	2015
Mechler and Bouwer	Climatic Change	Understanding trends and projections of disaster losses and climate change: is vulnerability the missing link?	2015
Mojid et al.	International Journal of Climatology	Climate change impacts on reference crop evapotranspiration in North-West hydrological region of Bangladesh	2015
Mondal et al.	Environmental Science: Processes Impacts	Simulating yield response of rice to salinity stress with the AquaCrop model	2015
Moniruzzaman	Ecological Economics	Crop choice as climate change adaptation: Evidence from Bangladesh	2015
Mukhopadhyay et al.	Environmental Science Processes and Impacts	Changes in mangrove species assemblages and future prediction of the Bangladesh Sundarbans using Markov chain model and cellular automata	2015

agura et al.	Journal of Climate	The role of temperature inversions in the generation of seasonal and interannual SST variability in the far Northern Bay of Bengal	2015
Aser	Asian Journal of Law and Society	Climate change and migration: Law and policy perspectives in Bangladesh	2015
Nath et al.	Small-scale Forestry	Contribution of homestead forests to rural economy and climate change mitigation: A study from the ecologically critical area of Cox's Bazar— Teknaf peninsula, Bangladesh	2015
Rahman and Rahman	Weather and Climate Extremes	Climate extremes and challenges to infrastructure development in coastal cities in Bangladesh	2015
Rahman and Rahman	Weather and Climate Extremes	Natural and traditional defense mechanisms to reduce climate risks in coastal zones of Bangladesh	2015
Rahman et al.	Climate and Development	Coping with flood and riverbank erosion caused by climate change using livelihood resources: A case study of Bangladesh	2015
Rahman et al.	Global Ecology and Conservation	High carbon stocks in roadside plantations under participatory management in Bangladesh	2015
Rahman	Agriculture, Ecosystems and Environment	Agroecological, climatic, land elevation and socio-economic determinants of pesticide use at the farm level in Bangladesh	2015
Routledge	Antipode	Engendering Gramsci: Gender, the Philosophy of Praxis, and Spaces of Encounter in the Climate Caravan, Bangladesh	2015
Shameem et al.	Climatic Change	Local perceptions of and adaptation to climate variability and change: the case of shrimp farming communities in the coastal region of Bangladesh	2015
Sharmin et al.	Plos Integrated Tropical Diseases	Interaction of Mean Temperature and Daily Fluctuation Influences Dengue Incidence in Dhaka, Bangladesh	2015
Sikder et al.	Journal of Urban and Regional Analysis	Stakeholders participation for urban climate resilience: A case of informal settlements regulation in Khulna city, Bangladesh	2015
Sohel et al.	Land Use Policy	Carbon storage in a bamboo (*Bambusa vulgaris*) plantation in the degraded tropical forests: Implications for policy development	2015
Thiele-Eich et al.	International Journal of Environmental Research Public Health	Trends in water level and flooding in Dhaka, Bangladesh and their impact on mortality	2015
Xenarios and Polatidis	Environment Development and Sustainability	Alleviating climate change impacts in rural Bangladesh: A PROMETHEE outranking-based approach for prioritizing agricultural interventions	2015
Younus	Environmental Hazards	Crop adaptation processes to extreme floods in Bangladesh: A case study	2015
Ahmed and Diana	Reg Environ Change	Does climate change matter for freshwater aquaculture in Bangladesh?	2016
Ahmed and Glaser	Ocean and Coastal Management	Can "Integrated Multi-Trophic Aquaculture (IMTA)" adapt to climate change in coastal Bangladesh?	2016
Akter et al.	Global Environmental Change	The influence of gender and product design on farmers' preferences for weather-indexed crop insurance	2016
Alamgir et al.	Jurnal Teknologi	Predictors and their domain for statistical downscaling of climate in Bangladesh	2016
Ara et al.	Agriculture and Food Security	Spatio-temporal analysis of the impact of climate, cropping intensity and means of irrigation: an assessment on rice yield determinants in Bangladesh	2016
Araos et al.	Journal of Environmental Policy and Planning	Climate change adaptation planning for global south megacities: the case of Dhaka	2016
Brammer	International Journal of Environmental Studies	Floods, cyclones, drought and climate change in Bangladesh: A reality check	2016

Chattopadhyay et al.	The Electricity Journal	Building climate resilience into power systems plans: Reflections on potential ways forward for Bangladesh	2016
Chowdhury et al.	Trees	Cambial dormancy induced growth rings in *Heritiera fomes Buch.- Ham.*: A proxy for exploring the dynamics of Sundarbans, Bangladesh	2016
Chowdhury et al.	PlosOne	Climatic Signals in Tree Rings of *Heritiera fomes Buch.-Ham.* in the Sundarbans, Bangladesh	2016
Deb et al.	Wetlands	Freshwater swamp forest trees of Bangladesh face extinction risk from climate change	2016
Delaporte and Maurel	Climate Policy	Adaptation to climate change in Bangladesh	2016
Fernandes et al.	ICES Journal of Marine Science	Projecting marine fish production and catch potential in Bangladesh in the 21st century under long-term environmental change and management scenarios	2016
Haque et al.	Journal of Sustainability Science and Management	The importance of community based approach to reduce sea level rise vulnerability and enhance resilience capacity in the coastal areas of Bangladesh: A review	2016
Haque et al.	Climate Risk Management	A critical assessment of knowledge quality for climate adaptation in Sylhet Division, Bangladesh	2016
Hossain and Rahman	Environ Dev Sustain	Adaptation to climate change as resilience for urban extreme poor: Lessons learned from targeted asset transfers programmes in Dhaka city of Bangladesh	2016
Hossain et al.	Natural Hazards	Farmer-level adaptation to climate change and agricultural drought: empirical evidences from the Barind region of Bangladesh	2016
Huq	Bulletin of the Atomic Scientists	Climate change, technological innovation	2016
Islam and Hasan	Nat Hazards	Climate-induced human displacement: a case study of Cyclone Aila in the south-west coastal region of Bangladesh	2016
Islam et al.	Ocean and Coastal Management	Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh: A geospatial approach	2016
Islam et al.	Field Crops Research	Assessment of adaptability of recently released salt tolerant rice varieties in coastal regions of South Bangladesh	2016
Kabir et al.	BMC Public Health	Knowledge and perception about climate change and human health: Findings from a baseline survey among vulnerable communities in Bangladesh	2016
Kabir et al.	Global Health Action	Climate change and health in Bangladesh: a baseline cross-sectional survey	2016
Kabir et al.	Journal of Environmental and Public Health	Climate Change Impact: The Experience of the Coastal Areas of Bangladesh Affected by Cyclones Sidr and Aila	2016
Kamruzzaman et al.	Environ Dev Sustain	Spatio-temporal analysis of climatic variables in the western part of Bangladesh	2016
Kamruzzaman et al.	Environ Dev Sustain	Modeling of agricultural drought risk pattern using Markov chain and GIS in the western part of Bangladesh	2016
Ayeb-Karlsson et al.	Sustainability Sciences	A people-centred perspective on climate change, environmental stress, and livelihood resilience in Bangladesh	2016
Kirby et al.	Climatic Change	The impact of climate change on regional water balances in Bangladesh	2016
Lopa and Ahmed	Development in Practice	Participation of CSOs/NGOs in Bangladeshi climate change policy formulation: Co-operation or cooptation?	2016
Lu et al.	Climatic Change	Detecting climate adaptation with mobile network data in Bangladesh: Anomalies in communication, mobility and consumption patterns during cyclone Mahasen	2016

Lu et al.	Climatic Change	Job and residential location changes responding to floods and cyclones: An analysis based on a cross-nested logit model	2016
Lu et al.	Global Environmental Change	Unveiling hidden migration and mobility patterns in climate stressed regions: A longitudinal study of six million anonymous mobile phone users in Bangladesh	2016
Masood and Takeuchi	Futures	Climate change impacts and its implications on future water resource management in the Meghna Basin	2016
Misra	Climate and Development	Smallholder agriculture and climate change adaptation in Bangladesh: Questioning the technological optimism	2016
Mostafa et al.	Bulletin of the Atomic Scientists	Climate adaptation funding: Getting the money to those who need it	2016
Nurunnabi	Environment Development and Sustainability	Who cares about climate change reporting in developing countries? The market response to, and corporate accountability for, climate change in Bangladesh	2016
Ortolano et al.	Climate and Development	Strategy for adapting to climate change and conserving biodiversity in the Bangladesh Sundarbans	2016
Perez-Saez et al.	Advances in Water Resources	Climate-driven endemic cholerais modulated by human mobility in a megacity	2016
Rahman and Giessen	Climate Policy	The power of public bureaucracies: forest-related climate change policies in Bangladesh (1992–2014)	2016
Rahman and Lateh	Environ Earth Sci	Meteorological drought in Bangladesh: assessing, analysing and hazard mapping using SPI, GIS and monthly rainfall data	2016
Rhaman	South Asia Research	Climate justice framing in Bangladeshi newspapers, 2007–2011	2016
Rahman	Land Use Policy	Impacts of climate change, agroecology and socio-economic factors on agricultural land use diversity in Bangladesh (1948–2008)	2016
Rasheed et al.	PlosOne	Salt intake and health risk in climate change vulnerable coastal Bangladesh: What role do beliefs and practices play?	2016
Ray-Bennett et al.	Development in Practice	Everyday health security practices as disaster resilience in rural Bangladesh	2016
Shourav et al.	Jurnal Teknologi	Historical trends and future projection of climate at Dhaka city of Bangladesh	2016
Shahid et al.	Regional Environmental Change	Climate variability and changes in the major cities of Bangladesh: Observations, possible impacts and adaptation	2016
Shams and Shohel	Environment and Urbanization	Food security and livelihood in coastal area under increased salinity and frequent tidal surge	2016
Szabo et al.	Sustainability	Inequalities in human well-being in the urban Ganges Brahmaputra Meghna delta	2016
Szabo et al.	Sustainability Sciences	Soil salinity, household wealth and food insecurity in tropical deltas: Evidence from south-west coast of Bangladesh	2016
Talukder et al.	Environmental Pollution	The effect of drinking water salinity on blood pressure in young adults of coastal Bangladesh	2016
Wu et al.	Environ Sciences and Technology	Influence of climate extremes and land use on fecal contamination of shallow tubewells in Bangladesh	2016
Xenarios et al.	Water Resources and Rural Development	Assessing vulnerability to climate change: Are communities in flood-prone areas in Bangladesh more vulnerable than those in drought-prone areas?	2016
Zafor et al.	ARPN Journal of Engineering and Applied Sciences	Analysis of rainfall trends and variability at Sylhet region in Bangladesh	2016
Zaman et al.	Climate Services	Impacts on river systems under 2C warming: Bangladesh Case Study	2016
Acharjee et al.	Agricultural Water Management	Declining trends of water requirements of dry season Boro rice in the north-west Bangladesh	2017

Adri and Simon	Climate and Development	A tale of two groups: Focusing on the differential vulnerability of "climate-induced" and "nonclimate-induced" migrants in Dhaka City	2017
Ahmed and Cokinos	Environmental Hazards	How does ecological modernization explain agriculture adaptation in coastal Bangladesh? A critical discussion	2017
Alam et al.	Ecological Indicators	Vulnerability to climatic change in riparian char and river-bank households in Bangladesh: Implication for policy, livelihoods and social development	2017
Alam	Environmental Management	Livelihood cycle and vulnerability of rural households to climate change and hazards in Bangladesh	2017
Chowdhury and Moore	Journal of Cleaner Production	Floating agriculture: a potential cleaner production technique for climate change adaptation and sustainable community development in Bangladesh	2017
Fenton et al.	World Development	The role of microfinance in household livelihood adaptation in Satkhira district, Southwest Bangladesh	2017
Haq and Ahmed	Natatural Hazards	Does the perception of climate change vary with the socio-demographic dimensions? A study on vulnerable populations in Bangladesh	2017
Hatsuzuka and Fujinami	Journal of Climate	Effects of the South Asian monsoon intraseasonal modes on genesis of low pressure systems over Bangladesh	2017
Hossain et al.	Science of the Total Environment	Operationalizing safe operating space for regional social-ecological systems	2017
Islam and Walkerden	International Journal of Disaster Risk Reduction	Social networks and challenges in government disaster policies: A case study from Bangladesh	2017
Islam et al.	Advances in Meteorology	Drought hazard evaluation in Boro paddy cultivated areas of Western Bangladesh at current and future climate change conditions	2017
Islam	Science of the Total Environment	Greenhouse gas footprint and the carbon flow associated with different solid waste management strategy for urban metabolism in Bangladesh	2017
Islam	Social Indicators Research	Climate change, natural disasters and socioeconomic livelihood vulnerabilities: Migration decision among the char land people in Bangladesh	2017
Jahan et al.	Environment, Development and Sustainability	Fishers' local knowledge on impact of climate change and anthropogenic interferences on Hilsa fishery in South Asia: Evidence from Bangladesh	2017
Kabir et al.	Land Use Policy	Farm-level adaptation to climate change in Western Bangladesh: An analysis of adaptation dynamics, profitability and risks	2017
Lu et al.	Nat Hazards	The interrelationship between travel behavior and life choices in adapting to flood disasters	2017
Nury et al.	Journal of King Saud University – Science	Comparative study of wavelet-ARIMA and wavelet-ANN models for temperature time series data in northeastern Bangladesh	2017
Paprocki & Huq	Climate and Development	Shrimp and coastal adaptation: on the politics of climate justice	2017
Quader et al.	Ocean and Coastal Management	Multi-decadal land cover evolution in the Sundarban, the largest mangrove forest in the world	2017
Rahman and Lateh	Theoretical and Applied Climatology	Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model	2017
Rahman et al.	Acta Oecologica	Long-term growth decline inToona ciliatain a moist tropical forest in Bangladesh: Impact of global warming	2017
Sohel et al.	iForest	Predicting impacts of climate change on forest tree species of Bangladesh: Evidence from threatened *Dysoxylum binectariferum (Roxb.) Hook.f. ex Bedd. (Meliaceae)*	2017
Younus	Environmental Hazards	Adapting to climate change in the coastal regions of Bangladesh: Proposal for the formation of community-based adaptation committees	2017

Appendix 3.1

Correlation coefficients of Hakaluki *haor* drought variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_drou	int_drou	loss_drou	surv_drou
liv_div	1								
main_prof	-0.121*	1							
crop_div	0.0405	0.155**	1						
rot_crop	-0.092**	-0.144*	0.250	1					
lan_cul	-0.016	-0.023	0.523***	0.358***	1				
dur_drou	0.113	0.079	-0.018	-0.084	0.001	1			
int_drou	-0.066*	0.093	-0.057	-0.038	-0.112**	-0.167	1		
loss_drou	-0.005	0.236**	0.119*	-0.043*	0.132	0.298*	-0.029	1	
surv_drou	0.069	-0.035	-0.269	-0.121	-0.242	-0.098	0.126*	-0.150	1

**p < 0.1, **p < 0.05, ***p < 0.001*

Appendix 3.2

Correlation coefficients of Hakaluki *haor* flash-flood variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_ff	int_ff	loss_ff	surv_ff
liv_div	1								
main_prof	-0.294**	1							
crop_div	0.129	0.158	1						
rot_crop	0.044	-0.022***	0.225	1					
lan_cul	0.194*	-0.022	0.500*	0.130*	1				
dur_ff	-0.068	0.173	0.052	-0.262	0.041	1			
int_ff	-0.025**	-0.13*	-0.180**	0.071	-0.04	-0.155	1		
loss_ff	-0.112	0.285	0.192	-0.392**	0.024*	0.777**	-0.248	1	
surv_ff	-0.021	-0.240**	-0.232	0.215	-0.082	-0.377	0.320	-0.506*	1

**p < 0.1, **p < 0.05, ***p < 0.001*

Appendix 3.3

Correlation coefficients of Hakaluki *haor* over rainfall variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_or	int_or	loss_or	surv_or
liv_div	1								
main_prof	-0.294*	1							
crop_div	0.129	0.158**	1						
rot_crop	0.044	-0.022	0.225**	1					
lan_cul	0.194**	-0.022	0.500*	0.130	1				
dur_or	0.017	0.034	-0.078	-0.034	0.004	1			
int_or	-0.213	0.016	-0.103	0.028	-0.152*	0.024	1		
loss_or	-0.078*	0.094	0.058	0.072	0.076	0.140	-0.151	1	
surv_or	-0.051	-0.156*	-0.247	-0.099	-0.013	0.263***	0.071	-0.384*	1

*$p < 0.1$, **$p < 0.05$, ***$p < 0.001$

Appendix 3.4

Correlation coefficients of Hakaluki *haor* regular flood variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_rf	int_rf	loss_rf	surv_rf
liv_div	1								
main_prof	-0.294*	1							
crop_div	0.129	0.158	1						
rot_crop	0.044	-0.022	0.225	1					
lan_cul	0.194	-0.022	0.500***	0.130	1				
dur_rf	0.104	0.076	-0.130	0.346	-0.102	1			
int_rf	-0.166**	0.068	-0.08	0.131	-0.157	0.106	1		
loss_rf	0.091	0.005	0.27	0.665	0.142	0.427**	-0.031	1	
surv_rf	-0.225	0.028	-0.367	-0.423*	-0.231	-0.162	0.330	-0.620	1

$*p < 0.1$, $**p < 0.05$, $***p < 0.001$

Appendix 3.5

Correlation coefficients of Tanguar *haor* drought variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_drou	int_drou	loss_drou	surv_drou
liv_div	1								
main_prof	0.273	1							
crop_div	-0.028*	0.222	1						
rot_crop	-0.164	-0.522**	0.333	1					
lan_cul	-0.086	-0.130	0.408***	0.549***	1				
dur_drou	0.081	0.197	-0.069	-0.092	0.057	1			
int_drou	-0.027	0.015*	0.079	0.117	0.154	0.159	1		
loss_drou	0.021*	0.181	-0.264	-0.249**	-0.145	0.356	0.275	1	
surv_drou	-0.193	-0.198	0.213	0.227	0.139	-0.411**	-0.019	-0.524*	1

$^*p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.001$

Appendix 3.6

Correlation coefficients of Tanguar *haor* flash-flood variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_ff	int_ff	loss_ff	surv_ff
liv_div	1								
main_prof	0.273	1							
crop_div	-0.028	0.222	1						
rot_crop	-0.164*	-0.522**	0.333	1					
lan_cul	-0.086	-0.130	0.408*	0.549	1				
dur_ff	0.075	0.052	0.031	0.123	-0.032	1			
int_ff	0.074	-0.170	-0.104	-0.022**	-0.215	0.027	1		
loss_ff	0.282	0.435*	-0.126	-0.574	-0.298	0.062	0.028	1	
surv_ff	-0.340**	-0.445*	0.099	0.446	0.314	-0.0001*	-0.068	-0.672	1

**p < 0.1, **p < 0.05, ***p < 0.001*

Appendix 3.7

Correlation coefficients of Tanguar *haor* over rainfall variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_or	int_or	loss_or	surv_or
liv_div	1								
main_prof	0.273*	1							
crop_div	-0.028	0.222	1						
rot_crop	-0.164*	-0.522***	0.333	1					
lan_cul	-0.086	-0.13	0.408**	0.549***	1				
dur_or	0.046	0.028	0.007*	-0.103	0.025	1			
int_or	0.059	-0.028	-0.207	-0.076	-0.113	0.075	1		
loss_or	0.142	0.081	-0.05	-0.276	-0.255	0.067	-0.087	1	
surv_or	-0.211**	-0.371	0.156	0.606*	0.312*	-0.035*	0.012	-0.430	1

**p* < 0.1, ***p* < 0.05, ****p* < 0.001

Appendix 3.8

Correlation coefficients of Tanguar *haor* regular flood variables

	liv_div	main_prof	crop_div	rot_crop	lan_cul	dur_rf	int_rf	loss_rf	surv_rf
liv_div	1								
main_prof	0.273	1							
crop_div	-0.028**	0.222	1						
rot_crop	-0.164	-0.522*	0.333	1					
lan_cul	-0.086	-0.130	0.408**	0.549	1				
dur_rf	0.025	0.084	0.397	0.414*	0.405	1			
int_rf	0.156	-0.104	0.003*	0.048	-0.013	0.04	1		
loss_rf	-0.009**	0.05***	0.562*	0.557*	0.609*	0.63	0.019	1	
surv_rf	0.017	0.206	-0.288	-0.555	-0.502	-0.455	-0.105	-0.673*	1

$p < 0.1$, $**p < 0.05$, $***p < 0.001$