

# Building resilience to environmental stress in coastal Bangladesh: An integrated social, environmental, and engineering perspective

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## Abstract

Environmental vulnerability in Bangladesh—especially vulnerability to climate change—is too often treated in isolation from the social, economic, and political contexts in which communities and their inhabitants make their livelihood. We propose that resilience and vulnerability to environmental stress are best understood in terms of a modification of Ostrom’s socioecological systems paradigm that we call “multiple dynamic equilibria:” livelihoods in vulnerable regions are shaped by multiple overlapping patterns of interaction between the physical environment in which people live and the social, economic, and political environments in which they interact, within their communities, with other communities, and external actors. Translating policy goals into effective action requires understanding these interactions at multiple levels.

We report on a new transdisciplinary project that draws geoscientists, engineers, and social scientists together to investigate the interactions between communities and the environment in the southwestern coastal region of Bangladesh and understand the dynamics of vulnerability and resilience.

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## Introduction

Global climate change represents an enormous threat to vulnerable populations.. It also poses tremendous challenges for the physical and social scientists who study its dynamics. Moreover, the dynamics among the social and environmental factors are complex, rendering many endeavors to study climate change actually efforts to simplify our conceptualizations of the dynamics. For example, the approach of the International Commission on Climate Change has been to disaggregate the study of climate change by discipline. It summarizes the state of the literature by discipline, focusing on the physical science (climate change), engineering (mitigation), and social sciences (vulnerability) dimensions. In fact there are some benefits to such approaches. Specifically, from the observation of the impacts of climate change on populations and their environments in their particulars, general patterns such as the relatively higher vulnerability of people in low lying coastal areas emerge. However, community level impacts are a function of both macro-level dynamics like rising concentrations of greenhouse gases in the atmosphere and global labor markets *and community level (or meso-level) dynamics*. While the broad strokes enable us to see the scale of the problem, they are less useful in policy design because they eclipse the community-level dynamics.

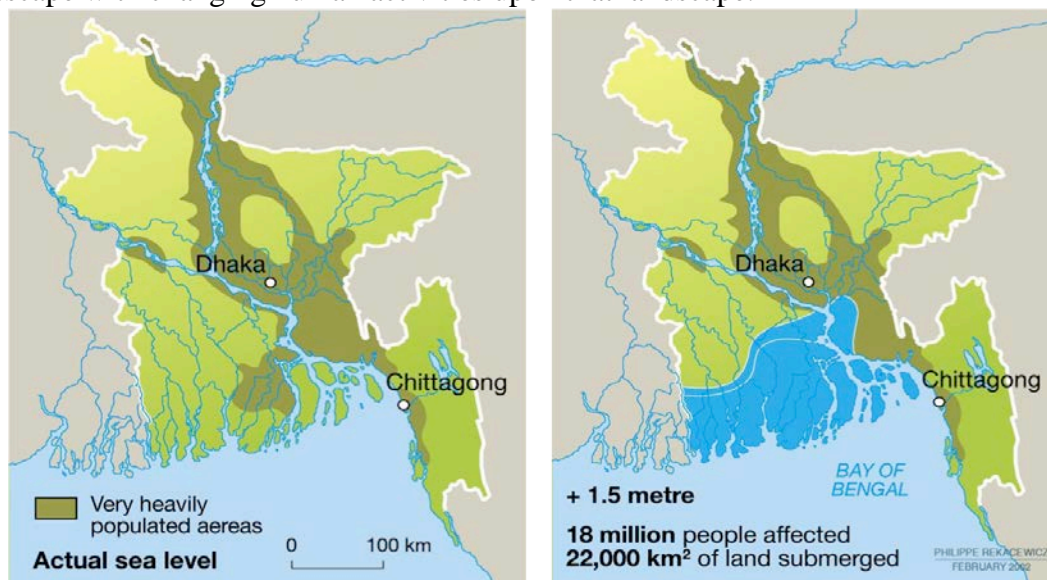
In Bangladesh, these meso-level dynamics include local political economies of foreign aid, the development of the shrimp aquaculture, the availability of wage work in agriculture for seasonal migrants, the development of low wage labor in the export industries of ready-made garments and shrimp, and the shift from subsistence based sources for family solvency to wage-based sources. They also include how the impacts of familiar cyclones and floods affect communities with these changing political economies. These dynamics are essential to understanding the processes of climate change and cannot be observed in macro-level patterns.

In this paper we review these dynamics and propose an integrated research model that enables their study. By studying the dynamics of environmental change at a level where we can study the processes of interaction among physical and social variables, we are better able to understand the processes of social change – including those related to migration which have been of such policy interest – and therefore be better able to predict them.

## Climate change dynamics

Industrial activities by the wealthiest and most industrialized nations of the world are creating a global environmental threat whose brunt will be borne primarily by the poorest and least industrialized nations.(Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007) As Sir Nicholas Stern observed in his landmark study of the economic impacts of climate change, “The poorest will be hit earliest and most severely.”(Stern, 2007, p. 99) Bangladesh is characterized both by high population density and environmental vulnerability due to its flat topography, which exposes it to river flooding, sea-level rise, and tropical cyclones. It has thus become the exemplar of vulnerability to climate change.(Ahsan et al., 2011; Alam, Rahman, Huq, & Kabir, 2000; A. Ali, 1999; Dasgupta et al., 2011; Friedman, 2009; Hussain, 2011; Shamsuddoha,

Chowdhury, & Trust, 2007) However, discussion of the impacts of climate change too often oversimplifies and treats natural and human systems as passive or static, when in fact, both the physical and human landscapes of Bangladesh are highly dynamic and have surprising abilities to respond to stresses. Many depictions of climate-induced displacement in Bangladesh, such as Figure 1, simply assume that as sea-level rises, the topography of the landscape will not change, so one meter of sea level rise will inundate all land currently less than one meter above sea-level and only the people living in the inundated region are considered displaced or affected. This map represented a useful heuristic tool for illustrating the scale on which sea-level rise *could potentially* affect the nation, but it has subsequently taken on a life of its own and is too often presented by others as a prediction of the *actual* impacts of future sea-level rise. More sophisticated treatments must account for the impacts of erosion and deposition of sediment carried to the coast by the Ganges-Brahmaputra river system and the interactions of the changing landscape with changing human activities upon that landscape.



**Figure 1. Simple description of impact of sea-level rise: Coastline is considered static and without benefit of widespread sediment deposition, and only people living on submerged land are assumed to be affected.(Rekacewicz, 2002)**

As a recent report by Humanitywatch observes, “People are always migrating from one place to another since the very beginning of human history as the earth's climate has never been stable,” and “Climate change, on its own, does not directly displace people or cause them to move but it produces environmental effects and exacerbates current vulnerabilities that make it difficult for people to survive where they are.”(Mehedi, 2010) The International Organization for Migration similarly observes that “Migration is a multi-causal phenomenon: even in cases where the environment is a predominant driver of migration it is usually compounded by social, economic, political and other factors. ... [And] just as the environment is only one among many factors that drive migration, migration is also only one among many possible responses to environmental change.”(Walsham, 2010)

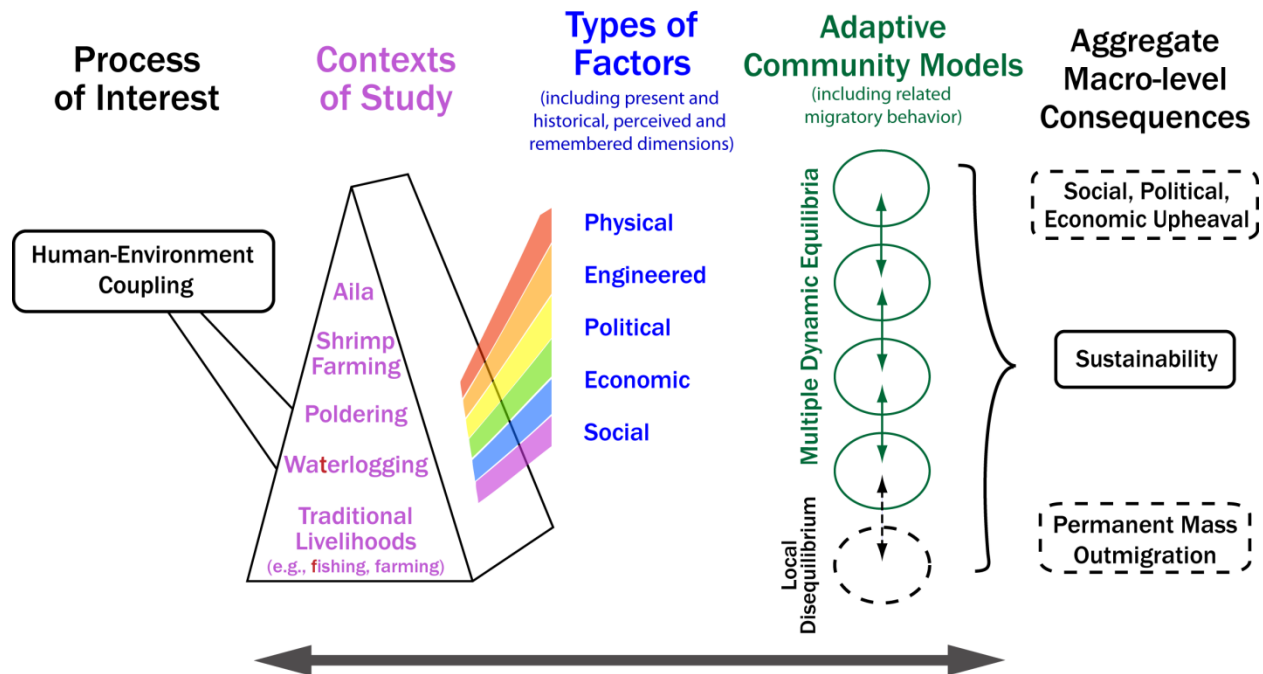
To understand the impacts of climate change, or more generally the impacts of environmental stress, due both to natural hazards and to global and local degradation caused by human activities, we must study how those stresses interact with other stresses produced by the social, political, and economic context in which vulnerable populations reside and make their livelihood. Failure to understand the interactions between the physical environment and the lives

of the people who interact with it can lead to flawed policies as well as flawed implementations of even well-chosen policies. Effective policy selection and policy implementation require understanding the dynamics of the coupled human-environmental system. In this paper, we present a new transdisciplinary research direction for capturing these dynamics in a novel theoretical framework and report some preliminary results.

## **Research Design and Model**

This project focuses on improving our understanding of coupled human-environmental interactions and their role in shaping both vulnerability and resilience to natural and anthropogenic environmental stresses. One of the principle patterns emerging from existing literature on the impacts of environmental change is the variability in vulnerability (big cite). However, the tendency has been to treat that vulnerability as a monolithic “variability in vulnerability.” In this study we develop a research design that enables us to study the dynamics of vulnerability and the meso-level *and* then to model the impacts of these dynamics across diversity of contexts.

We start by observing that both the people and the landscape of Bangladesh have a long history of resilience. Over the past 10,000 years of the Holocene epoch, the Bengal delta has kept pace with more than 100 meters of sea level rise, often at rates comparable to the worst-case climate change scenarios. Environmental change on the delta was minimal during these times due to the immense river sediment load that helps offset rising sea level by building land surface elevation.(Goodbred Jr & Kuehl, 2000) The people of the delta have demonstrated similar resilience, allowing the most densely populated region of earth to achieve self-sufficiency in rice production despite annual monsoon flooding and severe tropical cyclones that strike the coast an average of once every three years.(Lewis, 2011) We focus on southwest Bangladesh because this region has a diverse physical environment, a great deal of variation in the ways communities provide for themselves and interact with one another, and vulnerability to a broad range of natural and anthropogenic environmental stresses. In addition, this location is always cited by those enumerating the populations and regions of the world that are most vulnerable to climate change impacts. Within this varied human and physical landscape, we look for patterns of resilience and adaptation to environmental challenges and examine the role of migration, both as a strategy to enhance resilience and as a response to failures of resilience. By developing a model for studying the complexity of environmental, social, and political dynamics in this setting, we are developing a model relevant to one of the “hardest cases” of climate change. (Ackerly, forthcoming).



**Figure 2. Integrated Social, Environmental, and Engineering (ISEE) model.**

Our overall research design is based on an Integrated Social, Environmental, and Engineering (ISEE) model, shown in Figure 2. Our model is an adaptation and development of the SES model developed by Elinor Ostrom and others through years of collaborative research on complex environmental and social systems. (Dietz, Ostrom, & Stern, 2003; Ostrom, 2007) Ostrom's original SES model focuses on locally managed common-pool resources in which the relevant stresses are due to endogenous factors. We adapt this model in two principle ways. First, we site the model not in the concept of "common pool resource" but rather in a political concept of "community." Second, our model can include significant and seemingly distant exogenous factors, such as global climate change and global economic forces. By modeling these dynamics in their complexity, we expand the scope of the SES model beyond what can be studied in specific communities using detailed ethnographic techniques. Our ISEE model enables us to generate hypotheses about the relationships among social, environmental, and engineering factors and to inform these hypotheses by analysis of data from the study of human-environment coupling.

The ISEE research is not bound to a common pool resource, though it could be sited around a common pool resource. Rather the ISEE model can take be sited in any of a number of research contexts (shown in purple), each of which defines a unique perspective on the coupled human-environmental system. The study context acts as a prism through which we identify and measure a number of factors (shown in blue) that describe aspects of the human-environmental interactions relevant to the study context. We analyze interactions among these factors to identify patterns of actions by means of which the populace makes its livelihood. We analyze these patterns to identify *dynamic equilibria* (shown in green) by means of which communities are able not only to provide for themselves under ordinary conditions, but which are sufficiently flexible and stable to adapt to changing stresses in the physical and human environments. A major underlying hypothesis of this conceptual framework is that a community whose livelihood comprises many diverse dynamic equilibria will be more resilient because it can adapt to the collapse of any single equilibrium by shifting its constellation of activities and establishing

another equilibrium. This collection of equilibria and the dynamics that enable them to be sustaining in the face of constant destabilizing pressures characterizes the community's ability to adapt to new and changing stress. The dynamics of the model do not rely on simplifying assumptions about

## **STUDY CONTEXT**

To organize the many variables we measure and the connections among them, we select a context of study (depicted in purple in Figure 2). This context serves as a frame that defines the perspective of the study and highlights certain kinds of connections among the observations and measurements.

**Waterlogging** is one possible context of study: Waterlogging occurs when land is saturated with water--- from rain, river floods, storm surges, or other causes---that does not drain after the source of the water abates.(Emergency Capacity Building Project, 2011) Embankments constructed to protect land from tides or river floods can cause waterlogging by preventing water on the inland side from draining into rivers. Land use, such as conversion of rice fields to shrimp ponds, can also produce waterlogging. When land is waterlogged with saline water, as happens with cyclonic storm surges and with shrimp farming, salt contamination may persist for several years after the land is drained.

Adopting a waterlogging context results in organizing research around the different factors that cause or contribute to waterlogging, the impacts of waterlogging both on the land and on people's livelihoods in a waterlogged environment, and on the measures that might ameliorate waterlogging itself or its impacts on people's livelihoods.

**Tropical cyclones**, such as Cyclone Aila, which struck the region in 2009, can form a context of study in which waterlogging moves out of the focus of study to become just one of many impacts the cyclone has on the people and the landscape.(Dasgupta et al., 2011; Kumar, Baten, Al Masud, Osman, & Rahman, 2010; Mehedi, 2010; United Nations, 2010) In choosing cyclones as a context of study, other causes of waterlogging move to the periphery while other consequences of cyclones that would not loom large in a waterlogging study now grow in significance.

**Poldering** is the practice of reclaiming intertidal lands---land along tidal channels that is submerged twice a day by high tides---with embankments, following a model of the Netherlands. In the 1950s and 1960s, a massive program of poldering was introduced under the auspices of the East Pakistan Water and Power Development Authority (WAPDA) and continued after independence by the Bangladesh Water Development Board (BWDB).(M. L. Ali, 2002; Thompson & Sultana, 1996) Poldering changes the dynamics of tides in the rivers and tidal channels and changes the transport, deposition, and erosion of sediment. In the natural landscape, the twice-daily inundation by tides constantly deposits fresh sediment and builds the land up as sea level rises or the underlying land subsides. With embankments, this minor inundation is prevented, but without the constant supply of sediment the landscape cannot adjust to subsidence or rising seas and may thus end up more vulnerable to catastrophic flooding. As Gilbert White observed, embankments can also have a deleterious social effect by giving people a false sense of security and enticing them to move toward danger rather than away from it.(Burton, Kates, & White, 1968; White, 1945)

At the same time that it produces hazards, poldering also produces opportunities to expand agricultural production to land that could not otherwise be cultivated. It produces conflict over both control of and responsibility for maintaining and managing embankments and sluice gates that control the flow of water into and out of the interior. In a poldering context, cyclonic storm surges are one of many factors that threaten the integrity of the embankments and waterlogging is one of many hazards that the embankments can both exacerbate and ameliorate, depending on the way they are designed and used. By altering the physical landscape, embankments also alter the social, economic, and political landscapes by defining the spaces in which people will live, travel, farm, and fish, by delineating boundaries between communities, and by creating economic and political power relationships surrounding the construction, maintenance, and control of the embankment. Actors with money to perform necessary repairs can exact concessions from a vulnerable population, as we describe below.

**Shrimp aquaculture** provides an opportunity to generate considerable wealth, but at the cost of potentially damaging the environment, disrupting social and political structures, increasing economic inequality, and reducing employment opportunities for agricultural day laborers. (Béné, 2005; Chowdhury, Khairun, Salequzzaman, & Rahman, 2011; Datta, Roy, & Hassan, 2010; Deb, 1998; Gammage, Swanberg, et al., 2006; Gammage, Swanburg, et al., 2006; Guhathakurta, 2008; Haque, Bhatta, Hoque, Rony, & Rahman, 2008; McLachlan, 2003; B. G. Paul & Vogl, 2010; Rahman; Stonich & Vandergeest, 2001)

Shrimp aquaculture has grown rapidly in coastal Bangladesh, and now constitutes the second largest export, after garments. Shrimp farming can have devastating effects on a community, killing livestock that drink the brackish water from the shrimp ponds, degrading soil fertility through increased salinity and acidification, and disrupting the political and economic integrity of a community by reducing employment opportunities, increasing economic inequality, and bringing political corruption as wealthy farmers manipulate the political and legal system to the detriment of poor and vulnerable individuals. (Béné, 2005; Chowdhury et al., 2011; Datta et al., 2010; Deb, 1998; Gammage, Swanberg, et al., 2006; Gammage, Swanburg, et al., 2006; Guhathakurta, 2008; Haque et al., 2008; McLachlan, 2003; B. G. Paul & Vogl, 2010; Rahman; Stonich & Vandergeest, 2001) These consequences have led some authors to portray shrimp aquaculture as a terrible and destructive force, but the impacts of shrimp aquaculture are different in different communities. Some appear to manage it to benefit the community as a whole, whereas in others it has been destructive. Careful observation of the impacts of shrimp farming in the context of different communities, and in the context of the full range of dynamical processes, is necessary to arrive at a suitably nuanced and accurate picture.

## **FACTORS**

After selecting a context of study, we identify specific factors that are important to that context. In a poldering context, relevant physical factors include the topography of the embankments and the land within, the water in the river outside the embankment (temperature, salinity, depth, etc.), the transport of sediment by the river, the stratigraphy of the land within the embankment, and the hydrography of ground and surface water within the embankment, including the salinity, acidity, arsenic content, sulfur content, and oxidation/reduction state. Engineering factors include the design and construction of the embankments, including roads built atop them and sluice gates and drains that penetrate them; and infrastructure, including roads, cyclone shelters, and water sources (pond sand filters, tube wells, and desalination facilities). Political factors include the

local (union parishad) government, the regional (upazila parishad) government, and the national government as well as more informal political actors and relationships. Economic factors comprise an assessment of the activities and economic relationships by which people provide for their material needs (food, shelter, medical care, etc.). Economic activities include rice farming, shrimp aquaculture, fishing, migrant labor (both seasonal and day labor), commerce, and harvesting wood and honey from the Sundarbans. Social factors comprise relationships among individuals, households, and groups (ethnic, religious, etc.) both within a single community and among different communities.

### **ADAPTIVE COMMUNITY MODELS**

The core of our theoretical framework and our methods is the hypothesis that communities are resilient because of multiple dynamic equilibria. A dynamical equilibrium is a metaphor adopted from physics, where a system that is unstable at rest becomes stable in motion. Analyses of vulnerability to natural hazards in Bangladesh has gone astray when they consider only a static snapshot rather than the dynamics of people's livelihoods.

The Flood Action Plan proposed in 1989, is such a case. The flood action plan observed that the severe monsoon flooding in 1987 and again in 1988 were devastating and proposed a massive engineering project to control and contain monsoon waters to prevent future flooding.(Boyce, 1990) But by focusing only on specific moments of time in which exceptional floods were harming people, the planners failed to see how their project would disrupt the normal cycle of flooding.(N. Islam, 1990; B. K. Paul, 1995; Rasid, 1993; Rasid & Haider, 2003; Rasid & Mallik, 1993) The people of Bangladesh have adapted to annual monsoon flooding, where the normal range of floods acts as a resource that maintains the fertility of farmland and provides opportunities to harvest and raise fish—an important source of protein. The seasonal rhythms of livelihood, accommodating and exploiting the annual monsoon cycle, is an example of a dynamic equilibrium, and the public's rejection of the Flood Action Plan illustrates the importance of understanding dynamics when designing and analyzing policy for natural hazards.

One question our project is investigating is whether the Coastal Embankment Project's construction of massive polders during the 1950s and 60s suffered from a similar failure to appreciate dynamics. The polders produce a lot of good by creating dry land for farming and habitation on what were previously intertidal lands, but they also create new hazards and experts on the tidal river systems have suggested that the benefits of polders could have been realized with less collateral damages and dangers if they had used Tidal River Management (TRM) instead.(M. R. Islam, 2006; Kibria, 2011) TRM is adapted from a traditional practice in which smaller embankments were constructed each year during the dry season to keep salty water off the land, and torn down during the wet season to allow sweet rain-fed monsoon water to wash over the land, depositing fresh sediment and washing away contaminants.

TRM is a controversial topic and this controversy erupted into political violence this summer in Jessore.(The Daily Sun, 2012) This violence illustrates that it is necessary to understand not only the science, but also the social, political, and economic context and consequences of engineering projects.

While dynamics can enhance the stability of a pattern of livelihood, exceptional circumstances can disrupt even a dynamic equilibrium, just as the 1987 and 88 floods disrupted the adaptation to the normal monsoon cycle. We hypothesize that communities whose livelihood involves multiple dynamic equilibria will be more resilient because when one dynamic equilibrium is disrupted, others can provide support. These multiple dynamic equilibria may



involve not just activities within a single community, but interactions between multiple communities. In the community we studied, people engaged in rice farming locally but also engaged in seasonal migrant work on rice farms in a distant part of the country. When Cyclone Aila rendered local farmland unusable for several years, the established pattern of migrant farmwork and the network that had developed to facilitate it served to provide livelihoods for people who might otherwise have had few options.

To study multiple dynamic equilibria, we look for patterns in the relationships between the factors relevant to our context of study.

An active question in our research is to determine at which scales multiple dynamic equilibria are a sign of resilience and health and at which scales they are signs of stress and desperation. It appears to be healthy for a community to have a diverse collection of activities by which its members make their livelihoods. This diversity protects the community from events that render one livelihood activity dysfunctional. However, we have anecdotal observations, as well as theoretical reasons to believe that at the individual level, diversity of livelihood activities may be a sign of desperation rather than resilience. Having to switch from one activity to another to another over the course of the year to make a living can prevent people from doing any one activity intensively enough to develop expertise, and may take them away from the activities they do best. In a truly resilient state, people who have exceptional ability as a farmer would farm all the time, whereas if they become desperate they may have to engage in many activities, such as fishing and aquaculture, to which they are not well suited. As the saying goes, they risk becoming “a jack of all trades and master of none.” Assessing these competing effects of diversification and specialization remains a priority as our project moves forward.

## **Choice of Context and Site Selection:**

We chose to focus our research on Khulna and Satkhira districts in Southwest Bangladesh because in these districts there is great variation in the different adaptive community models, even among communities located close together. These districts also face a variety of environmental stresses, including salinity of the soil and groundwater, relative sea-level rise, and flooding by cyclonic storm surges, as well as political and economic stresses associated with conflict between shrimp aquaculture and rice cultivation and the interaction between these activities and the physical environment. Several upazilas in these districts were identified as especially vulnerable along several different dimensions of environmental vulnerability and were subsequently devastated by Cyclone Aila in 2009.(Uddin & Kaudstaal, 2003)

## **Research Methods:**

We gathered data in each of the five categories identified as factors (blue) in Figure 2: physical, engineered, political, economic, and social. The variables were identified in a thorough literature review and preliminary fieldwork in September 2011 and March 2012.

We studied the physical environment using traditional earth sciences methods: surveying and mapping the landscape, taking water samples from wells and ponds for chemical analysis, taking soil cores for stratigraphy, and monitoring the water level, temperature, and salinity of tidal channels. In addition, remote-sensing images were used to assess the change of the landscape

and land cover in the area over the previous several decades. We investigated the social, political, and economic factors with a combination of participatory rapid appraisal (PRA), focus-group discussions, and individual interviews with key informants. A key aspect of our research approach was integrating the physical science and social science teams, with members of each team observing the other team's work and with the teams debriefing regularly with each other to ensure close coordination and awareness of phenomena that cross disciplinary boundaries. Preliminary insights from social data about changes in land-use were checked against physical data. Findings from physical data that was inconclusive were checked against social data.

To compensate for the danger of preconceptions biasing the research, we employed a grounded-theory approach to research design, allowing our research protocols to adapt as we learned from newly acquired data.

## Discussion and Conclusions

Too often, disaster assistance offered with the best intentions is ineffective when it is insufficiently informed about the details of local conditions. Much the same can be said about many larger scale, longer-term aid efforts, for example the unanticipated consequences of widespread poldering in the region. Ignorance can be about technical issues, such as one NGO recommending that drinking water shortages after Cyclone Aila should be remedied by a massive program to build tube wells, apparently not realizing that almost all of the groundwater in the region is saline and concentrations of arsenic and magnesium are widespread. Moreover, we observe that vast numbers of pond sand filters are built, but quickly become useless because no process was established to maintain it after it was installed; similarly, large sluice gates are frequently installed in embankments with little transparency or community engagement in decision-making. These represent foregone opportunities to connect the human and environmental sides of the picture and the costs to livelihood are being born unevenly within communities.

While our research is still in its early stages, our conceptual framework has enabled us to propose hypotheses that run counter to contemporary political narratives.

For example, while the region is vulnerable to cyclones, transformations in land-use and not cyclonic events are forcing changes in political economy and migration. Sea-level rise is not forcing massive outmigration, but rather meso-level transformations in the political economy are destabilizing sources of livelihood and making some families engage in migration. The population is not miserable and looking to migrate; they like their land, their shade trees, the taste of the fish, the view of the Sundarbans.

By triangulating across social, engineering, and physical methods, our research has destabilized these arguments that have been politically salient in national and international debates. While more research is necessary to understand what will happen in this destabilized region, it is clear that the political narratives are not supported by the data.

As we develop alternative hypotheses, the ISEE model enables us to identify the most important vulnerabilities and the most important opportunities to build and enhance resilience in the face of environmental stress from both natural and human causes *and to model the ways that these interact over time*. Moreover, awareness of the connections between changes in the physical environment and changes in social, political, and economic conditions has the potential to inform decision-making, both at the policy-making level of choosing which measures to pursue and also at the level of effectively implementing those measures.

Studying physical environmental stresses in isolation can lead to policy failure, as can studying political, social, and economic stresses without considering the impact of human action on the environment and the impact of environmental change on political, community, and economic institutions and relations. Moreover, studying these data alongside each other has enabled triangulation across the disciplines and increased our confidence in our interpretation of preliminary data. Bringing physical scientists and social scientists together to jointly study the dynamics of interactions between coupled human and natural systems offers a more complete perspective that we hope will contribute to better informed decision-making and more effective action to build resilience and avoid disaster.

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