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**IMPACTS OF HYDROPOWER DEVELOPMENT ALONG THE
BRAHMAPUTRA RIVER IN NORTHEAST INDIA ON THE RESILIENCE
OF DOWNSTREAM COMMUNITIES TO CLIMATE CHANGE IMPACTS**

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ENVIRONMENTAL STUDIES

by

Costanza Rampini

December 2016

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ABSTRACT

Costanza Rampini

Impacts of hydropower development along the Brahmaputra river in Northeast India on the resilience of downstream communities to climate change impacts.

This project explores how large-scale hydropower development along the Brahmaputra river in Northeast India's shapes the resilience of downstream populations to the impacts of climate change on water resources.

Northeast India is highly vulnerable to the impacts of climate change on the Brahmaputra river. The region is predominantly rural and a majority of the population is engaged in natural resource-based activities. The abundant flows of the Brahmaputra and its tributaries are essential to the local economy and especially the livelihoods of over 30 million rural dwellers in the region. By shrinking Himalayan glaciers and altering the patterns of the Indian monsoon, anthropogenic climate change threatens to reduce river flows and increase flow variability in the long-term, with important implications for communities living in the river basin. Additionally, destructive summer floods along the Brahmaputra and its tributaries are a major challenge for people living in Northeast India and climate change impacts are expected to further intensify the rivers' flood regime.

At the same time as climate change is altering the flows of the Brahmaputra, a multitude of new dams are under construction along its stretches, in an effort to meet India's growing energy demands. The impacts of large-scale hydropower development on the Brahmaputra river basin will influence the vulnerability and adaptive capacity of downstream communities to climate change impacts on water

resources. This research has three main components: First, I explore how, by modifying river flows, dam-building efforts affect downstream communities' exposure to variations in river flows as a result of climate change (Chapter 1). Second, I more specifically interrogate how, by altering the river's flood regimes, hydropower development efforts shape the adaptive capacity of downstream communities to summer floods that are becoming increasingly severe as a result of climate change (Chapter 2). Third, I examine the impacts of dam-based development on the livelihood resilience of downstream rural households to climate change impacts (Chapter 3). This project relies on a case study dam and data from semi-structured household-level interviews, archival research of dam planning documents, and key informant interviews. This research employs theoretical frameworks and concepts from political ecology, hazards and vulnerability studies, climate change adaptation, sustainable livelihoods and resilience theory.

Overall, this project shows that dam-based development along the Brahmaputra is eroding the resilience of downstream communities and their livelihoods to the impacts of climate change on river flows. This research helps us understand how two interacting stressors – climate change and hydropower development – are transforming the riparian landscapes of Northeast India with important implications for local communities and the future of the region. This work also highlights the risks of pursuing renewable energy development and climate change mitigation without taking into consideration local climate change adaptation needs.

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CHAPTER 1

THE 'DOUBLE-EXPOSURE' OF RIVERINE COMMUNITIES IN NORTHEAST INDIA TO DAMS AND CLIMATE CHANGE.

Abstract:

Northeast India is especially vulnerable to the impacts of climate change on the flows of the Brahmaputra river. At the same time, aggressive hydropower development efforts along the Brahmaputra are modifying its flows and the region's riparian landscapes. Using a case study, this paper assesses the vulnerability of riverine communities in Northeast India to climate change impacts on the Brahmaputra River, in the context of dam-building efforts. Data from key informant interviews with local officials and semi-structured interviews with households living downstream of the Ranganadi Hydroelectric Project is used to argue that hydropower development enhances local communities' vulnerability to variations in river flows as a result of climate change. Results showed that, by focusing on hydroelectricity generation over flood control and environmental flows, dams along the Brahmaputra are worsening floods, reducing winter season flows and increasing overall flow variability, hence compounding the impacts of climate change on river flows. This research helps us understand how interacting stressors are changing the riparian landscapes of Northeast India with important implications for local communities and the future of the region.

Keywords: climate change, vulnerability, Himalayas, Northeast India, Brahmaputra, hydropower, multiple stressors, double-exposure.

1. Introduction

Starting in the seventies, as the devastating social and ecological impacts of large dams became increasingly difficult to ignore, dams fell out of favor as an instrument of resource management and development, reversing the course of four decades of modernist development practices (Scudder 2001). The 1990s saw a lull in dam-building efforts worldwide, partly in response to successful anti-dam movements that forced funders to reconsider their involvement in several projects (International Rivers 2005). After a decade hiatus, however, the climate change crisis and sustainable development initiatives, such as the Clean Development Mechanisms, facilitated the resurgence of hydropower development, particularly in middle-income countries such as China and India (Ahlers et al. 2015). Combining responses to anthropogenic climate change with sustainable development goals has meant a return to viewing large dams as a ‘win-win’ solution for meeting energy demands. Several hundred new dams are planned along the stretches of Himalayan rivers in China, India, Pakistan, Nepal, Bhutan, Myanmar, and Laos (Bakker 1999, Grumbine and Pandit 2013). The growing energy needs of the countries’ economies, worries about a looming water crisis as a result of climate change, and international and domestic pressures to reduce carbon emissions have created the catalysts for damming the steepest stretches of these rivers. Approximately one third of these new dams are planned along the Brahmaputra river and its tributaries in Northeast India (MDONER 2012).

Many have argued that the recent revival of dam building efforts as a solution to the climate change crisis is an example of ‘green developmentalism,’ which favors

technological fixes and neoliberal approaches to resource management issues and environmental problems (Boyd 2009, McAfee 1999). While dams are depicted as politically neutral, expert-driven, techno-economic artifacts, they further the expansion of markets, private property rights, and private capital into new waterscapes and rural areas for the purpose of optimal resource allocation and private profits (Bakker 1999, D'Souza 2008). Indeed, the harnessing of the Brahmaputra river basin hydropower potential was largely made possible by the gradual liberalization of India's hydropower sector starting in the 1980s, which increased private sector involvement (Vagholikar and Das 2010). This critique of hydropower development questions the capacity of dam-based development to deliver sustainable development outcomes and highlights the ways in which it reproduces the pitfalls of conventional development strategies, by enclosing common natural resources that are key to local livelihoods and local economies (D'Souza 2008, Escobar 1996, McAfee 1999).

Within this critique of dams as a win-win solution to the climate change crisis, fewer have examined the ways in which dams influence the vulnerability of downstream communities to climate change impacts on water resources. Himalayan rivers such as the Brahmaputra are experiencing changes to their flows as a result of climate change impacts on glaciers and the India summer monsoon. In the short-term, changing monsoon patterns and melting glaciers intensify the Brahmaputra's flood regime, while in the long-term they threaten to reduce river runoffs, particularly during the winter season (Hijioka et al. 2014, Immerzeel et al. 2010, Jiménez Cisneros et al. 2014). Changes to the Brahmaputra flood regime and winter flows

will have significant impacts on water availability and the wellbeing of downstream populations (Xu et al. 2009). The development of the Brahmaputra river basin for its hydropower potential in a time of great climatic uncertainty will influence the vulnerability of local communities to these changes. The crucial question is whether the regulation of river flows through a cascade of dams will magnify or mitigate the impacts of fluctuating river flows on downstream populations. Through, household-level interviews in 51 villages downstream of a dam project in Arunachal Pradesh, this work shows that hydropower development is enhancing local communities' vulnerability to the impacts of climate change on river flows. This research applies the "double-exposure" framework developed by Leichenko and O'Brien (2008) to understand how two large-scale processes of change – climatic and socio-technical – act as compounding stressors for riverine communities in Northeast India. This work argues that, by replicating and aggravating the impacts of climate change on river flows, the damming of the Brahmaputra river basin creates a 'lose-lose' scenario for local communities and the long-term sustainable development of Northeast India.

In the next section, I briefly discuss the concept of vulnerability and the double-exposure framework to build a conceptual foundation for my argument that dams are increasing downstream communities' vulnerability to climate change impacts. In section 3, I summarize the impacts of climate change on the Brahmaputra River. Section 4 describes the ongoing efforts to build a cascade of dams along the Brahmaputra and its major tributaries. In section 5, I introduce the case study dam and the methods used to gather and analyze the data. In section 6, I present evidence that dams in Northeast India are altering river flows in much the same way as climate

change. I conclude by outlining the synergies between climate change and dams in making the waterscapes of Northeast India increasingly uninhabitable and unproductive for riparian communities.

2. Vulnerability to climate change impacts in the Himalayas

In climate change research, vulnerability is commonly defined as the susceptibility of a person or a group to be harmed by the impacts of climate (Adger 2006). It is theorized as depending on a system's degree of exposure, sensitivity, and adaptive capacity to climate change impacts (Eaking and Luers 2006). With roots in natural hazard studies and the entitlements and capabilities approach, vulnerability research sheds light into human-environment interactions and challenges conventional thinking about environmental hazards, by showing that they are the result of both natural and social processes (Hewitt 1983, Robbins 2004, Sen 1981, White et al. 2001). Within vulnerability and risk studies, this project draws on political ecology approaches that trace vulnerability to underlying political, economic, and institutional factors (Adger 1999, Blaikie et al. 1994, Watts and Bohle 1993). Political ecology and human geography have shown how these factors systematically give rise to specific relations between people and their environment, so that different places and people are made to be differentially vulnerable to the impacts of environmental change (Cutter et al. 2003, Leichenko and Silva 2014, Liverman 1994, Lynch 2012, Pelling 1999, Van der Land and Hummel 2013). Specifically, this research contributes to research that looks at vulnerability to climate change in the context of multiple stressors. Climate change impacts take place in the context of

other social, cultural, economic, political, and technological transformations occurring at multiple spatial and temporal scales that can affect the vulnerability of people to climate change by acting as added stressors (Adger et al. 2008, Bennett et al. 2015, Eakin 2005, Turner et al. 2003, Leichenko et al. 2010). Through an examination of hydropower development in Northeast India, this work expands upon efforts to understand how other types of ongoing changes within the broader political economy aggravate the effects of climate change on local communities.

The concept of “double-exposure” developed by Leichenko and O’Brien (2008) provides an approach for analyzing the interactions between global environmental change and other global changes and identifying the ‘winners’ and ‘losers’ created by these interacting processes. In their work, Leichenko and O’Brien (2008) use the double-exposure framework to examine how climate change and economic globalization not only have overlapping negative outcomes for certain regions and groups of people, but also influence exposure and vulnerability to one another, and accelerate rates of change. Several others have used this conceptual framework to look at the linkages and feedbacks between the outcomes of climatic changes and other large-scale processes of change (Belliveau et al. 2006, Birk 2014, Bunce et al. 2010, McCubbin et al. 2015, Prno et al. 2011, Silva et al. 2010, Tschakert 2007). This research uses the double-exposure framework to understand in which ways the transformation of the Brahmaputra river basin into India’s new powerhouse will amplify or mitigate climatic risks for downstream communities.

In Northeast India, climate change and regional hydropower power development will interact over the next decades to transform the Brahmaputra river

flows with important consequences for local communities. Northeast India is already highly vulnerable to climate change impacts due to its low levels of economic development, relative political and economic marginalization, and the fact that local economies and livelihoods depend closely on the Brahmaputra river and riparian ecosystems. Given plans to build 140 new dams in the river basin, there is an urgent need to understand how their impacts will affect the vulnerability of local communities to changing water resources as a result of climate change. Research on the impacts of hydraulic interventions has shown that engineered structures meant to protect people from environment hazards, such as levees and dams, can actually increase people's vulnerability to floods (Dhawan 1993, D'Souza 2006, Kates et al. 2006, Tobin 1995, White 1945). But little is know about the influence of large-scale hydraulic interventions such as dams on people's vulnerability to climate change impacts on water resources. This research aims to fill this gap by extending previous ideas about engineered vulnerability, multiple stressors and double-exposure to examining the outcomes of dam-based development in Northeast India in light of climate change impacts. This paper provides empirical evidence of the experience of double-exposure amongst local communities in Northeast India, by documenting how large dams along the Brahmaputra act as an added stressor for downstream households faced that are highly vulnerable to the impacts of climate change on river flows.

3. Climate change impacts along the Brahmaputra river basin in Northeast India

The Brahmaputra is one of China and India's largest rivers in terms of discharge, sediment load and length (Shi et al. 2011). Its flows depend on summer monsoon rains and the melting of Himalayan snow and ice (Goswami 1985). The river originates in Tibet, and flows through China, Northeast India and Bangladesh, before reaching the Bay of Bengal. In Northeast India, the Brahmaputra traverses the states of Arunachal Pradesh and Assam, and its flows are key to local livelihoods and the local economy. Both Arunachal Pradesh and Assam have primarily agrarian economies and a majority of the states' population is engaged in agricultural and allied activities (Government of Arunachal Pradesh 2001, Government of Assam 2016). Throughout the year, Assamese and Arunachali people use the river system for fishing, water for irrigation, drinking water for people and livestock, and as a space for recreational and religious activities. At the same time, during the summer monsoon season, destructive floods punctuate the lives of people living in the river basin, causing tremendous damage to houses, fields, public utilities and infrastructure, drinking water sources, and leading to the spread of disease and the loss of livestock and human lives. Floods along the Brahmaputra river basin are a chronic problem for Arunachali and especially Assamese people, and one of the biggest resource management challenges for the governments of both states.

Climate change impacts on Himalayan glaciers and the Indian summer monsoon are altering the flows of the Brahmaputra river with cascading negative consequences for downstream populations (Xu et al. 2009). Temperatures in the region are expected to rise by 2-2.5 °C between 2021 and 2050, and increasing

surface temperatures are causing Himalayan glaciers and snowpacks to retreat at rates similar to glaciers and ice sheets around the world (Immerzeel 2013). According to the IPCC Fifth Assessment Report, under the more conservative climate change scenario RCP4.5, the Himalayas will experience glacier mass losses between 15 and 78% by 2100 (Jiménez Cisneros et al. 2014). The shrinking of Himalayan glaciers, in turn, is altering the flow of Himalayan rivers such as the Brahmaputra, particularly during the dry winter season when the relative contribution of snow and glacial melt to river flows is most important (Baraer et al. 2012, Cruz et al. 2007). As glaciers retreat due to warming temperatures, glacier-fed rivers first experience an increase in runoff, followed by a long-term decrease in runoff as glaciers move past a critical mass threshold (Baraer et al. 2012). The Himalayan region is expected to reach this threshold around 2050, and the Brahmaputra may experience a nearly 20% decrease in mean upstream water supply over the period 2046 to 2065 (Immerzeel et al. 2010, Immerzeel et al. 2013).

Additionally, the flows of the Brahmaputra are heavily dependent on monsoon rains during the summer season (Thayyen and Gergan 2009). The effects of climate change on the Indian summer monsoon remain the largest source of uncertainty in determining the future runoff of the Brahmaputra River in the context of climate change (Cruz et al. 2007, Immerzeel et al. 2013). A warmer atmosphere increases atmospheric moisture, resulting in an increase in total rainfall and the lengthening of the monsoon season (Christensen et al. 2013). Climate models also project an increase in both mean and extreme monsoon precipitations (Christensen et al. 2013). In other words, during the summer monsoon season, the frequency of heavy

precipitation events is increasing, while the number of light rain events is decreasing (Hijioka et al. 2014). As intensities of precipitation and floods increase, so will erosion and river sedimentation (Dharmadhikary 2008). Monsoon patterns are also becoming increasingly variable from year to year (Hijioka et al. 2014).

Overall, in the short term, an increase in glacial melt and heavy precipitation events during the summer exacerbates the challenge of living with floods for communities in the Brahmaputra river basin (Apurv et al. 2015). In the long-term, climate change impacts will decrease river flows, especially during the dry winter season, and also increase overall runoff variability. The impacts of climate change on the Brahmaputra river basin threaten agricultural production, food security, water security and the livelihoods of local communities in Northeast India (Eriksson et al. 2009, Xu et al. 2009). At the same time, climate change also has implications for the large-scale dam-building efforts that are taking place in the region, since hydropower development outcomes depend on river flows that are being altered by climate change, and dams further modify river flows that are already changing as a result of climate change.

4. Damming the Brahmaputra river basin

India is the third largest emitter of climate change-inducing greenhouse gases (Olivier et al. 2015). Presently, coal is India's primary source of energy while hydropower is the second largest domestic source of electricity (EIA 2016). To meet the country's growing energy needs while contributing to international efforts to mitigate anthropogenic climate change, India has recently placed a stronger emphasis

on the harnessing of domestic and renewable energy sources, including the hydropower potential of the Brahmaputra river basin (EIA 2012). The volume and the course of the Brahmaputra River give it the largest hydropower potential of all rivers in India, with nearly 40% of the total assessed hydropower potential of the country, 87% of which remains unexploited (MDONER 2012, CEA 2014). The hydropower potential of the river basin is concentrated in the state of Arunachal Pradesh, where the main stem of the river and its north-bank tributaries flow across steep slopes as they go from the Tibetan Plateau to the plains of Assam. As of 2012, the government of Arunachal Pradesh had allotted 140 new dam projects in the Brahmaputra river basin for a total installed capacity of 41,500 MW (MDONER 2012). Most of these new dams are large projects above 25 MW in capacity or mega-dams above 100 MW in capacity (ibid).

Plans to dam the Brahmaputra were etched in the early 1980s by the Brahmaputra Board. The main task of the Board was to devise a series of infrastructure projects in the Brahmaputra river basin that would help to control floods, harness its hydropower potential, and encourage the overall economic development of the region by attracting new industries and increase energy supply (Baruah 2012, Brahmaputra Board n.d.). In the mid-70s, the National Hydroelectric Power Company (NHPC) and the North Eastern Electric Power Corporation (NEEPCO) were established as public sector undertakings to further the development of hydropower in Northeast India and other regions. But it was the gradual privatization of India's energy sector and hydropower sector starting in the 1980s that facilitated the large-scale development of hydropower in the Brahmaputra river basin

(Vagholikar and Das 2010). Changing policies introduced mechanisms that make it easier for private companies to make profits from hydropower projects leading to a large number of new players, many without any previous experience in the hydropower sector, signing contracts for building dam projects (Dharmadhikary 2008). While NEEPCO and NHPC remain important energy developers in the Brahmaputra river basin, with a few large dam projects as the Lower Subansiri Hydroelectric Project (HEP) and the Pare HEP under construction, most new dams are now being developed by private players (Vagholikar and Das 2010).

The entrance of private players in Northeast India's hydropower sector led to a shift from multipurpose dams to run-of-the-river projects, which have small reservoirs and no flood cushioning capacity, but maximize hydroelectricity production. In other words, "concern for irrigation provision and flood mitigation appear to have been overshadowed, if not completely replaced, by a single-minded focus on the generation of electricity" (Crow & Singh 2009). Small reservoirs also minimize conflicts over land submergence with constitutionally-protected tribes in Arunachal Pradesh (Baruah 2012). The shift to run-of-the-river projects has important implications for downstream communities, who would benefit from flood control during the summer season particularly in light of climate change impacts. Additionally, rural downstream communities will reap few advantages from the generation of hydroelectricity in the Brahmaputra river basin, since a majority will be exported to urban centers and other regions (Baruah 2012). Unsurprisingly, downstream communities have been largely excluded from public hearings about dam projects. India's environmental clearance procedures put enormous discretion in the

hands of authorities allowing them to do away with public hearings. They also restrict the right of participation in public hearings to the most immediate villages in Arunachal Pradesh, thus excluding affected communities further downstream and in Assam (Dharmadhikary 2008). Public hearings about dam projects along the Brahmaputra have also been fraught with controversy: The meetings are often held in Hindi or English, highly technical and poorly publicized so that the participation of local villagers becomes largely symbolic. In some cases, in a blatant abuse of authority, public hearings were held after the dam projects had already begun construction (Vagholikar et al. 2005).

5. Case Study and methods

This research used a case study approach to understand how hydropower development magnifies or mitigates the impacts of fluctuating river flows on downstream populations. The Ranganadi HEP was chosen because it is the first mega-dam built along the Brahmaputra river basin, and shortly after its completion downstream communities began complaining about dam-induced flashfloods (Dharmadhikary 2008, The Telegraph 2008). The Ranganadi HEP is a diversion dam built by NEEPCO in the Lower Subansiri District of Arunachal Pradesh connecting the Ranganadi basin with the adjoining Dikrong basin. The 68 meters tall and 345 meters long dam is located on the Ranganadi River, fifty kilometers north of the town of Kimin and the border with Assam. At the dam site, a ten kilometer long tunnel with a capacity diverts water from the Ranganadi to the Dikrong River, where the powerhouse is located near the town of Doimukh. The Ranganadi HEP has an

installed capacity of 405 Megawatts and has been operational since 2002. Due to its design as a diversion dam and its close proximity to the Arunachal-Assam border, the ecological and social impacts of the hydropower project are felt along both the Ranganadi and the Dikrong rivers in Arunachal Pradesh and Assam.

This research used archival research and qualitative interviews to understand how dam projects in Northeast India affect downstream, communities' vulnerability to climate change impacts on water resources. Archival research was conducted at the headquarters of the Brahmaputra Board in Guwahati, Assam, to obtain historical hydrological data and details about the Ranganadi HEP design. The master plan for the Ranganadi River, compiled by the Brahmaputra Board in the early 1990s, contains the baseline hydrological data used to design the Ranganadi HEP, as well as design recommendations for the building of the hydropower project. Hydrological data and design recommendations extracted from the Ranganadi River master plan alongside information made available by NEEPCO highlighting the salient features of the Ranganadi HEP were used to understand to what extent the project was designed to buffer against floods, and whether future climate projections were considered in the planning stages.

Semi-structured interviews were conducted with 74 households in fifty-one villages downstream of the Ranganadi HEP along the Ranganadi and Dikrong rivers in Arunachal Pradesh and Assam. Household interviews took place between January and September 2014. Villages were selected that were located less than 2 kilometers from the Ranganadi and Dikrong riverbanks, because they had directly experienced the impacts of the hydropower project on river flows. Due to the lack of formal

village maps and lists of population, convenience sampling was used to select households to be interviewed in each village. Forty-four interviews were conducted along the Ranganadi River and thirty took place along the banks of the Dikrong River. Fifty-one interviews were conducted in the Lakhimpur District of Assam in three revenue circles: Lakhimpur Revenue Circle (n=22), Nowboicha Revenue Circle (n=11), and Bihpuria Revenue Circle (n=18). Due to government-imposed limits on non-residents visiting Arunachal Pradesh and the state's low population density, only twenty-three interviews were conducted in the state near the towns of Doimukh (n=12) and Kimin (n=11) in the Lower Subansiri District. Interviews were conducted and recorded in Assamese and Hindi, and then transcribed into English. Interviews focused on households' perceptions of the impacts of the Ranganadi HEP on river flows and particularly flooding events, and their perceived vulnerability to these changes. Descriptive statistics were generated and ethnographic details were selected to help illustrate the ways in which hydropower development acts as a stressor for downstream communities, enhancing their vulnerability to climatic changes. This project relies largely on qualitative interview data, because its objective is not to quantify vulnerability but rather to understand the nature of vulnerability based on institutional arrangements and the lived experiences of riverine communities living downstream of large dams and highly dependent on the Brahmaputra river system.

6. Findings: Impacts of Ranganadi HEP on river flows and downstream vulnerability

On one hand, an analysis of the Ranganadi Master plan and NEEPCO documents showed that the Ranganadi HEP is not designed to buffer downstream communities against floods. On the other hand, interviews with downstream households revealed that the release of water from the Ranganadi dam floodgates is actually exacerbating their experience of flood events. Additionally, respondents also described reduced winter river levels and daily flow fluctuations since the construction of the Ranganadi HEP. Overall, findings suggest that the hydropower project is affecting river flows in ways that are similar to the predicted impacts of climate change in the river basin.

6.1. Ranganadi HEP flood design

An analysis of the Ranganadi Master plan and NEEPCO documents for the Ranganadi HEP showed that the hydropower project can provide minimal flood control along the Ranganadi River at the beginning of the monsoon season, but it cannot buffer against heavy floods. The reservoir is small in size and storage capacity, when full it covers a surface area of 1.6 square kilometers and holds 0.008 km³ of water. In comparison, when full, Hoover dam's reservoir along the Colorado River covers 642 km² and contains 35.7 km³ of water, while the Three Gorges dam reservoir along the Yangtze River has a total surface area of 1,045 km² and holds 39.3 km³ of water (Bureau of Reclamation 2015, CTGC 2002). In addition to being small in size and storage capacity, the Ranganadi HEP reservoir has no exclusive flood

storage capacity. Because the full reservoir level and the maximum water level were set at the same height of 567 meters, there is no space in the reservoir that is kept empty and reserved for the purpose of regulating flood inflows. As a result of its size, overall water storage capacity, and lack of flood storage capacity, the Ranganadi HEP reservoir can only provide buffer against weak flood events along the Ranganadi river at the beginning of monsoon rains before the reservoir is filled, but it cannot absorb heavy flood waves particularly in the later part of the summer season.

Similarly, the diversion of water from the Ranganadi to the Dikrong River at a maximum rate of 160 cubic meters per second (cumecs) does little to reduce heavy floods along the Ranganadi River. According to the Ranganadi master plan, the most severe flood observed at the dam site before the construction of the project occurred on September 14th, 1984 and had a recorded discharge of 2,268 cumecs (see Table 1), in other words a volumetric flow rate 14 times larger than the capacity of the Ranganadi HEP tunnel water diversion. While the diversion of water from the Ranganadi to the Dikrong river cannot alleviate heavy floods along the Ranganadi, it can further exacerbate flooding events along the Dikrong river through the addition of more water from the Ranganadi.

A comparison of the Brahmaputra Board Ranganadi River master plan and the NEEPCO documents highlighting the salient features of the Ranganadi HEP reveals that NEEPCO followed all the recommendations of the Board in designing the hydropower project, except for the spillway capacity and number of floodgates. NEEPCO reduced the spillway capacity of the Ranganadi dam from 13,241 cumecs to 9,175 cumecs. Reducing spillway capacity translates into an increase in the risk of

heavy floods overtopping or breaching the Ranganadi dam. Additionally, the hydrologic data used by the Brahmaputra Board to make recommendations for designing the Ranganadi HEP does not include any consideration or modeling of future flows in light of climate change impacts in the region.

Year	Maximum Discharge		Minimum discharge	
	Discharge (cumecs)	Date	Discharge (cumecs)	Date
1956	453.3	May 16	29.7	December 7
1957	584.2	July 18	19.2	January 24
1958	363.4	August 3	13.6	April 29
1959	528.7	September 22	12.5	April 10
1960	611.7	August 31	9.9	April 30
1961	822.2	June 1	15.6	January 7
1962 to 1971 - Data Not Available ¹				
1972	1528.6	July 27	26.1	January 2
1973	1307.2	June 16	24.0	October 24
1974	1128.6	July 7	33.2	December 29
1975	999.6	July 21	28.3	February 11
1976	651.6	July 14	30.4	March 7
1977	1138.0	June 1	55.9	January 20
1978	724.4	June 26	24.3	March 12
1979	1506.2	July 2	25.7	May 9
1980	485.5	July 18	15.6	October 31
1981	619.3	July 15	33.3	February 1
1982	803.6	June 20	30.1	May 28
1983	1451.3	September 13	36.4	December 21
1984	2267.6	September 14	33.3	March 2
1985	2159.9	July 6	35.2	January 25
1986	535.4	July 19	68.9	March 24
1987	661.0	August 12	38.7	December 31
1988	418.5	June 8	36.3	February 1
1898	784.0	July 28	32.2	May 20
1990	1006.45	June 22	18.19	January 17

Table 1: Maximum and minimum discharge of the Ranganadi river at the Ranganadi HEP dam site from 1956-62 and 1972-1990. Source: Brahmaputra River Board, Ranganadi River Master Plan. ¹ During that period of time, Northeast India was the stage for both the Sino-Indian war of 1962 and the Indo-Pakistani war of 1971.

6.2. Perceived changes in floods since the commissioning of the Ranganadi HEP

Household interview data confirmed that the Ranganadi HEP has not provided any flood relief to downstream communities. On the contrary, respondents complained that the opening of the spillway gates to release floodwaters and the diversion of water to the Dikrong River have exacerbated both rivers' flood regimes (see Table 22). A majority of surveyed households (80%) have noticed faster and stronger floods along the Ranganadi and Dikrong rivers since the building of the Ranganadi HEP. Many remarked that, with the added force of the water released from the Ranganadi dam spillway gates, floods are now more likely to destroy homes or breach the embankments than in the past (see Figure 2, a-b). As one respondent explained:

We can no longer depend on the flood season to help agriculture, now the flood comes abruptly as the dam releases water, and it destroys agriculture. Now it is a threat to our lives. The natural flood regime was much more beneficial. Before the dam we knew the flood regime.

Many households (47%) also described floods as occurring more suddenly than in the past. Respondents explained that both the volume and timing of floods are less predictable than before, because they are now dictated by how much water is released from the NEEPCO dam:

How much water comes with the floods depends on how much they open the flood gates. The more water they release the more sand it carries.

A majority of interviewed households (64%), especially in Assam, described floods as carrying and depositing more sand since the commissioning of the dam. Many complained of sand covering their rice fields and challenging their capacity to sustain

their agricultural livelihoods (see Figure 2c). Several interviewed households (32%) said floods have also been causing more erosion along the riverbanks, particularly in Arunachal Pradesh and along the Dikrong River. Households also described an increase in river braiding (26%), especially in Assam and along the Dikrong River. River braiding is a natural occurring process in the Brahmaputra river basin by which floods deposit sediments that form sandbars and small river islands, causing river flows to shift course and create new channels. The shifting of the river course can have severe negative consequences for households that find themselves in the new path of the river, while also creating novel, albeit temporary, opportunities for households willing to settle on newly formed river islands. Some households (18%) described changes in the depth and width of the riverbed, especially in Assam. Others complained of an increase in the sediment load of the river (13.5%), particularly along the Dikrong River and in Arunachal Pradesh. As one respondent described:

The water released from the dam is very dirty, and muddier than before. It creates a problem for feeding livestock. They get sick grazing and there is not as much forage, because it is covered in mud.

Overall, while the Ranganadi reservoir is not designed to buffer downstream communities against floods, the release of water from the Ranganadi HEP spillway gates and the water diversion scheme are exacerbating the impacts of floods downstream of its infrastructure.

Perceived change in floods	Percentage of households				
	ASS (n=51)	ARU (n=23)	RANG (n=44)	DIKR (n=30)	TOTAL (N=74)
Increase flood speed & intensity	82	73	84	73	80
More sandcasting	77	30	59	67	64
More abrupt floods	43	56	52	40	47
More erosion	20	61	20	50	32
Increased river braiding	31	13	18	37	26
Wider & shallower river bed	22	9	16	20	18
More sediments & boulders	10	22	9	20	13.5

Table 2: Perceived impacts of Ranganadi HEP on the flood regime of the Ranganadi (RANG) & Dikrong (DIKR) rivers in Assam (ASS) and Arunachal Pradesh (ARU).



Figure 1: Flood impacts downstream of the Ranganadi HEP in Possim Kharkati, Assam. (a.) On the right, the Ranganadi river flows along its main stem. In the middle, bamboo and sandbags protect what is left of the embankment after it breached on August 14th, 2014. On the left, stagnant floodwaters and sand submerge rice fields and a large communal fishpond. (b.) An Assamese woman looks at her house destroyed by floodwaters after the embankment breached. (c.) Large amounts of sand cover rice fields after the flood.

6.3. Changes to winter season flows and hydropeaking

Household interviews revealed that the commissioning of the Ranganadi HEP has modified the Ranganadi and Dikrong flood regimes during the summer season, when river levels are at their highest as a result of monsoon rains and glacial melt from the Himalayas. At the same time, respondents also described changes to the rivers' winter season flows. Throughout the Brahmaputra river basin, the winter season is characterized by dry weather and reduced river runoffs. Interviews with

downstream households indicate that the impoundment of water behind the Ranganadi dam and its diversion to the powerhouse on the Dikrong River at the maximum rate of 160 cumecs are further reducing the Ranganadi winter season flows. Hydrological data from the Brahmaputra Board shows that, during the winter season, the Ranganadi river reaches minimum levels much lower than the volumetric capacity of the diversion tunnel (see Table 1). The prioritization of hydropower generation over other uses of the Ranganadi river by downstream communities and ecosystems has meant a further reduction in winter river levels. Nearly all the households surveyed along the Ranganadi River (93%) complained about this problem, and many told stories of the river drying up completely during the winter months. As one respondent described:

During the lean season now there is no water. Before the dam there was some water and we could use it for agriculture. [...] Banana trees used to grow well, now they won't grow anymore.

Interviewed households also linked reduced lean season flows to an increase in riverbank erosion during the summer, as riverbank vegetation dried up during the winter weakening the riverbanks before the arrival of the floods. As one respondent explained:

During the dry season, water is kept behind the dam. The land became dry and the vegetation on the hills dried up. Then when the summer rains came there were massive landslides that cut off communication.

The diversion of water from the Ranganadi to the Dikrong River should in theory have increased the Dikrong River winter flows. However, in 2010 NEEPCO

began construction of the Pare HEP dam, 5 kilometers downstream of the Ranganadi HEP powerhouse. The impoundment of water behind the Pare dam has further altered the Dikrong flows. Indeed, because household interviews were conducted in 2014, a majority of households interviewed along the Dikrong (81%) also complained of a decrease in river runoff during the winter, despite the Ranganadi HEP diversion scheme.

In addition to reduced river levels, many of the households interviewed along the Dikrong river (60%) noticed daily fluctuations in river levels since the commissioning of the Ranganadi HEP as a result of hydropeaking. Hydropeaking is the practice of withholding water behind a dam during hours of the day when electricity demand is low, and releasing it during peak demand hours to generate hydroelectricity. Hydropeaking causes unnatural fluctuations in the daily and hourly flow of rivers with significant impacts on riparian ecosystems and communities (Vagholikar 2011). According to respondents, the turbines of the Ranganadi HEP powerhouse are opened and water is released into the Dikrong river channel primarily during the evening hours to meet peak demand. Respondents told stories of going to the Dikrong riverbanks to fish, swim or have a picnic and being caught by surprise by the sudden increase in river levels.

7. Discussion

The dam-induced changes in river flows that are being felt by communities downstream of the Ranganadi HEP mimic the predicted impacts of climate change on the Brahmaputra river and its tributaries. The Ranganadi dam reservoir and diversion tunnel cannot provide flood protection during heavy floods. Electricity needs and

revenue from the sale of hydroelectricity require a full reservoir, while flood moderation for the benefit of rural populations require an empty reservoir that can accommodate higher river flows (Dixit 2003). In addition, the ways in which the dam infrastructure mediates floods is enhancing their destructiveness and the amount of sand and sediment they carry, while increasing uncertainty about the timing and amount of flooding. Similarly, climate change impacts on Himalayan glaciers and monsoon patterns are increasing the frequency of severe floods and the overall stochasticity of the Brahmaputra flood regime, while also leading to higher erosion and increasing river sedimentation (Dharmadhikary 2008, Hijioka et al. 2014). The Ranganadi HEP has also reduced winter river levels and led to unnatural daily fluctuations as a result of hydropeaking. While the dam increases the variability of daily flows, the impacts of climate change on the Indian monsoon are increasing the annual variability in river flows (Hijioka et al. 2014). Retreating Himalayan glaciers also threaten to cause a long-term reduction in river flows, especially during the winter season (Jiménez Cisneros et al. 2014, Immerzeel et al. 2010, Immerzeel et al. 2013). The interactions between climatic impacts and hydropower impacts on winter river flows, flow variability and floods will pose important challenges to downstream populations (see Figure 2). Yet the impacts of climate change on river flows were not taken into account in the planning and designing of the Ranganadi HEP. On the contrary, NEEPCO reduced the dam spillway capacity, increasing the risk of dam overtopping or failure in the event of very heavy floods.

The large-scale development of the hydropower potential of the Brahmaputra river basin is a unique opportunity for local officials to manage the river basin

resources in ways that reduce the vulnerability of downstream communities to climate change. But the liberalization of the Indian hydropower sector has led to the prioritization of hydroelectricity production over the vulnerability of riparian communities to changing water resources. By facilitating the entrance of private companies in the hydropower sector, the central and local government devolved responsibility for flood risk management to private players, who in turn transferred hydrological risks to the public (Dharmadhikary 2008). As a result, this research argues, dam-building efforts in Northeast India and climate change impacts on Himalayan rivers are creating a situation of ‘double-exposure.’ These two large-scale processes of change have overlapping negative outcomes for riverine communities in Northeast India, as both worsen floods, decrease lean season flows, and increase flow variability. They also influence exposure and vulnerability to one another, and accelerate rates of change as they are perceived by communities living downstream of hydropower projects. The sudden opening of the Ranganadi HEP spillway gates increases downstream communities’ vulnerability to floods that are becoming more severe as a result of climate change. Similarly, the impoundment and diversion of river flows, and hydropeaking will become more problematic for downstream communities that rely on the river system, as climate change gradually reduces winter flows. Research on the impacts of the Lower Subansiri HEP, another mega-dam project under construction in the Brahmaputra river basin, shows similar impacts on river flows, raising concern about the cumulative impacts of 140 dams in the region in light of climate change impacts (Baruah 2012).

In part, this work echoes much of the critique of large dams that is summarized in the report of the World Commission on Dams. The report suggests that the terrestrial, aquatic and riparian impacts of large dams can have serious consequences for people, including increasing their vulnerability to floods, and that these consequences are exacerbated by poor management, such as in the operation of reservoirs and floodgates (WCD 2000). What has remained largely absent from this critique and what this project helps elucidate is how, by transforming river flows, dams influence the vulnerability of local communities to the impacts of climate change on water resources. Government and hydropower officials promote hydropower development in Northeast India as a ‘win-win’ solution to increasing energy needs. However, by compounding the impacts of climate change on river flows, the damming of the Brahmaputra river basin creates a ‘lose-lose’ scenario for local communities that have to face changes in river flows as a consequence of these two parallel but interacting processes. Also, hydropower generation depends on river flows that are fluctuating as a result of climate change impacts, raising question about the soundness of investing in the large-scale hydropower development of Himalayan rivers at this time of climatic uncertainty. This research reinforces calls for skepticism regarding the capacity of dam-based development to foster sustainable development goals in light of climate change.

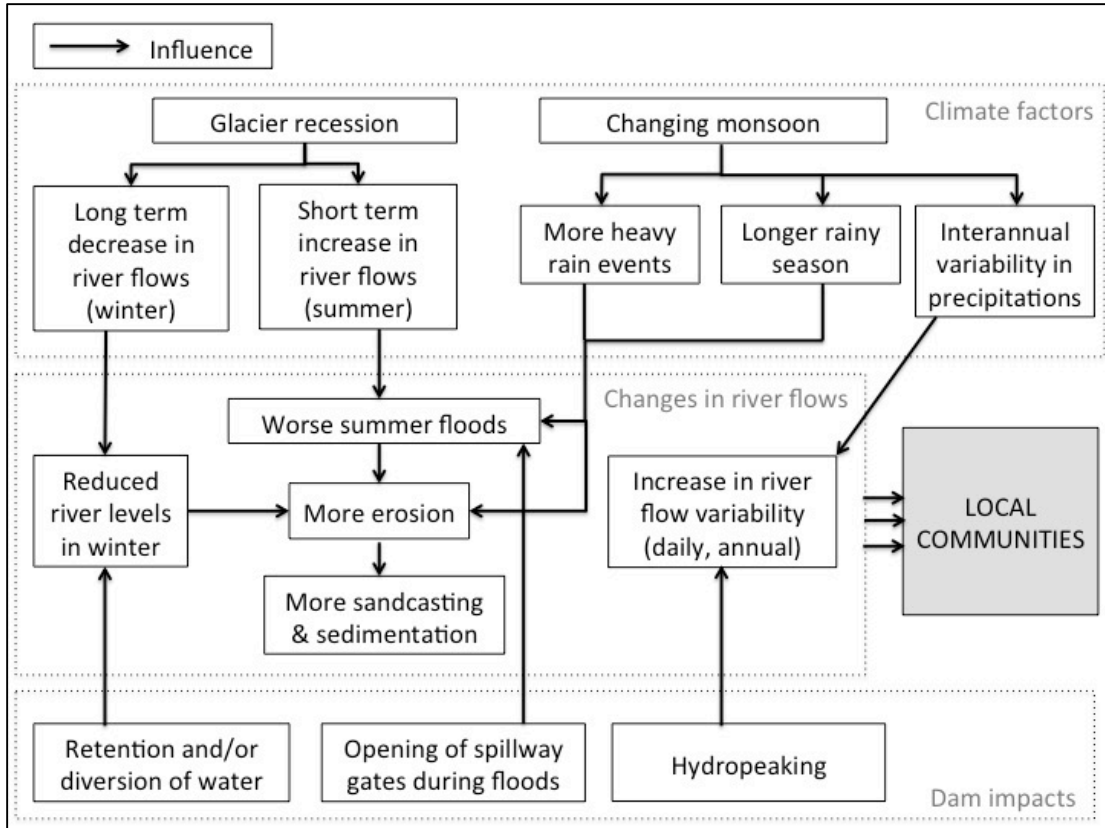


Figure 2: Interactions between the climate change and hydropower development impacts on river flows and local communities in Assam & Arunachal Pradesh.

9. Conclusion

The Himalayas are the source of all of Asia's main rivers, as such they are often referred to as 'Asia's Water Towers.' Himalayan rivers are at the center of Asia's water supply, economies and livelihoods. They are also at the center of two large-scale processes of change that are transforming the region – climate change and hydropower development. More than 400 hydroelectric schemes are planned along Himalayan rivers (Walker 2013), and a third of these dams are planned in the Brahmaputra river basin in Northeast India. Dams in the Himalayas are designed based on historical data of river flows and without taking into consideration climate

change impacts, yet climatic changes have consequences for dam performance, safety and impacts (Dharmadhikary 2008). This research has shown the role of dams as an added stressor for riverine communities in Northeast India in light of climate change. As climate change and hydropower development both modify river flows, they interact in threatening the long-term sustainable development of the region. The uncoordinated building of 140 dams in Arunachal Pradesh is short-sighted and unwise in light of climate change impacts on the Brahmaputra river basin. Rather than enrolling the flows of the Brahmaputra in the production of hydroelectricity for distant urban communities, the sustainable development of the river basin and other Himalayan rivers must take into account the impacts of climate change on these river systems, and prioritize reducing the vulnerability of local riverine communities to these impacts. Further research is needed to understand how the transformation of Asia's water towers at the hands of climate change and hydropower development will affect downstream populations and economies throughout the Asian continent.

References

- Adger, W.N. (1999). Social vulnerability to climate change and extremes in coastal Vietnam. *World Development*, 27(2), 249-269.
- Adger, W.N. (2006). Vulnerability. *Global Environmental Change*, 16, 268-281.
- Adger, W.N., Eakin, H., & Winkels, A. (2008). Nested and teleconnected vulnerabilities to environmental change. *Front. Ecol. Environ.*, 6. doi:10.1890/070148
- Ahlers, R., Budds, J., Joshi, D., Merme, V., & Zwarteveen, M. (2015). Framing hydropower as green energy: Assessing drivers, risks and tensions in the Eastern Himalayas R. *Earth Syst. Dynam.*, 6, 195–204.
- Apurv, T., Mehrotra, R., Sharma, A., Goyal, M.K., & Dutta, S. (2015). Impact of

- climate change on floods in the Brahmaputra basin using CMIP5 decadal predictions. *Journal of Hydrology*, 527, 281-291.
- Bakker, K. (1999). The politics of hydropower: Developing the Mekong. *Political Geography*, 18, 209-232.
- Baraer, M., Mark, B.G., McKenzie, J.M., Condom, T., Bury, J., Huh, K., Portocarrero, C., Gomez, J., & Rathay, S. (2012). Glacier recession and water resources in Peru's Cordillera Blanca. *Journal of Glaciology*, 58(207),134-150.
- Baruah, S. (2012). Whose river is it anyway? Political economy of hydropower in the Eastern Himalayas. *Economic & Political Weekly*, XLVII(29), 41- 52.
- Belliveau, S., Smit, B., & Bradshaw, B. (2006). Multiple exposures and dynamic vulnerability: Evidence from the grape industry in the Okanagan Valley, Canada. *Global Environmental Change*, 16, 364-378.
- Bennett, N.J., Dearden, P., & Peredo, A.M. (2015). Vulnerability to multiple stressors in coastal communities: a study of the Andaman coast of Thailand. *Climate and Development*, 7:2, 124-141. DOI: 10.1080/17565529.2014.886993
- Birk, T. (2014). Assessing vulnerability to climate change and socioeconomic stressors in the Reef Islands group, Solomon Islands. *Danish Journal of Geography* 114, 59–75. DOI: 10.1080/00167223.2013.878228
- Blaikie P., Cannon T., Davis, I., & Wisner, B. (1994). *At Risk: Natural hazards, people's vulnerability and disasters*. London: Routledge.
- Boyd, E. (2009). Governing the Clean Development Mechanism: Global rhetoric versus local realities in carbon sequestration projects. *Environment and Planning A*, 4, 2380-2395.
- Brahmaputra Board. (n.d.). Functions of the Brahmaputra Board. Ministry of Water Resources, Government of India. Guwahati, India. Retrieved from <http://www.brahmaputraboard.gov.in/NER/Functions/functions.html>
- Bunce, M., Brown, K., & Rosendo, S. (2010). Policy misfits, climate change and cross-scale vulnerability in coastal Africa: How development projects undermine resilience. *Environmental Science & Policy*, 13, 485–497.
- Bureau of Reclamation. (2015). Hoover Dam: Frequently asked questions and answers, Lake Mead. U.S. Department of the Interior. Retrieved from <https://www.usbr.gov/lc/hooverdam/faqs/lakefaqs.html>

- [CEA] Central Electric Authority. (2014). Review of Performance of Hydropower Stations 2014-15. Government of India. Ministry of Power. Retrieved from http://www.cea.nic.in/reports/annual/hydroreview/hydro_review-2014.pdf
- Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P., & Zhou, T. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Crow, B., & Singh, N. (2009). The management of international rivers as demands grow and supplies tighten: India, China, Nepal, Pakistan, Bangladesh. *India Review*, 8(3), 306- 339.
- Cruz, R.V., Harasawa, H., Lal, M., Wu, S., Anokhin, Y., Punsalmaa, B., Honda, Y., Jafari, M., Li, C., & Huu Ninh, N. (2007). Asia. Climate Change 2007: impacts, adaptation and vulnerability. Pages 469-506 in Parry, M.L., O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson, editors. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K. Retrieved from <http://www.ipcc.ch/pdf/assessment-report/ar4/wg2/ar4-wg2-chapter10.pdf>
- Dharmadhikary, S. (2008). Mountains of concrete: Dam building in the Himalayas. Berkeley: International Rivers.
- Dixit, A. (2003). Floods and vulnerability: Need to rethink flood management. *Natural Hazards*, 28(1), 155-179.
- Dhawan, B.D. (1993). Coping with floods in Himalayan rivers. *Economic and Political Weekly*, (28)18, 849-853.
- D'Souza, R. (2006). *Downed and dammed: Colonial capitalism and flood control in eastern India*. New Delhi: Oxford University Press.
- D'Souza, R. (2008). Framing India's hydraulic crises: The politics of the modern large dam. *Monthly Review*, 60(3). Retrieved from <http://monthlyreview.org/2008/07/01/framing-indias-hydraulic-crisis-the-politics-of-the-modern-large-dam/>

- [CTGC] China Three Gorges Corporation. (2002). Three Gorges Project. Brief Introduction. Retrieved from <http://www.ctgpc.com/>
- Cutter, S.L., Boruff, B.J., & Shirley, W. L. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly*, 84(2), 242-261.
- Eakin, H. (2005). Institutional change, climate risk, and rural vulnerability: Cases from Central Mexico. *World Development*, 33(11), 1923–1938.
- Eakin, H., & Luers, A.L. (2006). Assessing the vulnerability of social-environmental systems. *Annu. Rev. Environ. Resour.*, 31, 365-94.
- [EIA] Energy Information Administration. (2016). India Overview. EIA Beta. U.S. Department of Energy. Retrieved from <https://www.eia.gov/beta/international/analysis.cfm?iso=IND>
- Eriksson, M., Jianchu, X., Shrestha, A.B., Vaidya, R.A., Nepal, S., & Sanstrom, K. (2009). The changing Himalayas: impact of climate change on water resources and livelihoods in the Greater Himalayas. International Centre for Integrated Mountain Development (ICIMOD). Kathmandu, Nepal. Retrieved from <http://lib.icimod.org/record/26471>
- Escobar, A. (1996). Construction nature: Elements for post-structuralist political ecology. *Futures*, 28(4), 325-343.
- Goswami, D.C. (1985). Brahmaputra River, Assam, India: physiography, basin denudation, and channel aggradation. *Water Resources Research*, 21(7), 959-978.
- Government of Assam. (2016). Gracious Assam: Socio-economic profile. Department of Industries and Commerce. Retrieved from http://www.investinassam.com/socio_economic_profile.php
- Government of Arunachal Pradesh. (2001). New Agricultural Policy. Status of Agriculture in Arunachal Pradesh (Base Year 1999-2000). Department of Agriculture. Itanagar, Arunachal Pradesh. Retrieved from <http://arunachalpradesh.gov.in/departement.htm>
- Grumbine, R.E., & Pandit, M. K. (2013). Threats from India's Himalaya dams. *Science*, 339, 36-37.
- Hewitt, K. (1983). *Interpretations of calamity from the viewpoint of human ecology*. Boston: Allen & Unwin Inc.
- Hijioka, Y., Lin, E., Pereira, J.J., Corlett, R.T., Cui, X., Insarov, G.E., Lasco, R.D., Lindgren, E., & Surjan, A. (2014). Asia. In: *Climate Change 2014: Impacts,*

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

Immerzeel, W.W., van Beek, L.P.H., & Bierkens, M.F.P. (2010). Climate change will affect the Asian water towers. *Science*, 328, 1382.

Immerzeel, W.W., Pellicciotti, F., & Bierkens, M.F.P. (2013). Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. *Nature Geoscience*, 6, 742-645.

International Rivers. (2005). The World Bank and Dams. Part 1: Lessons Not Learned. Berkeley, CA. Retrieved from https://www.internationalrivers.org/sites/default/files/attached-files/world_bank_and_dams_fact_sheet_web.pdf

Jiménez Cisneros, B.E., Oki, T., Arnell, N.W., Benito, G., Cogley, J.G., Döll, P., Jiang, T., & Mwakalila, S. S. (2014). Freshwater resources. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 229-269.

Kates, R.W., Colten, C.E., Laska, S., & Leatherman, S. P. (2006). Reconstruction of New Orleans after Hurricane Katrina: A research perspective. *PNAS*, 103(40), 14653-14660.

Leichenko, R.M., & O'Brien, K. L. (2008). *Double exposure: Global environmental change in an era of globalization*. Oxford University Press, Oxford, U.K.

Leichenko, R.M., O'Brien, K.L., & Solecki, W.D. (2010). Climate change and the global financial crisis: A case of double exposure. *Annals of the Association of American Geographers*, 100(4), 963-972. DOI: 10.1080/00045608.2010.497340

Leichenko, R., & Silva, S. J. (2014). Climate change and poverty: vulnerability, impacts and alleviation strategies. *WIREs Clim. Change*, 5, 539-556.

Liverman D. (1994). Vulnerability to global environmental change. In *Environmental*

- Risks and Hazards*, ed. S.L. Cutter, pp. 326–42. Englewood Cliffs, NJ: Prentice Hall.
- Lynch, B.L. (2012). Vulnerabilities, competition and rights in a context of climate change toward equitable water governance in Peru's Rio Santa Valley. *Global Environmental Change*, 22, 364–373.
- McAfee, K. (1999). Selling nature to save it? Biodiversity and green developmentalism. *Environment and Planning D: Society and Space*, 17, 133-154.
- McCubbin, S., Smit, B., & Pearce, T. (2015). Where does climate fit? Vulnerability to climate change in the context of multiple stressors in Funafuti, Tuvalu. *Global Environmental Change*, 30, 43–5.
- [MDONER] Ministry of Development of Northeast Region. (2012). Hydropower projects. Government of India. Retrieved from <http://mdoner.gov.in/node/1307>
- O'Brien, K.L., Leichenko, R.M., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H. Javed, A., Bhadwal, S., Barg, S., Nygaard, L., & West, J. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, 14, 303–313.
- Olivier, J.G.J., Janssens-Maenhout, G., Muntean, M., & Peters, J.A.H.W. (2015). Trends in global CO2 emissions: 2015 Report. PBL Netherlands Environmental Assessment Agency, The Hague, Netherlands. Retrieved from: http://edgar.jrc.ec.europa.eu/news_docs/jrc-2015-trends-in-global-co2-emissions-2015-report-98184.pdf
- Pelling, P. (1999). The political ecology of food hazard in urban Guyana. *Geoforum*, 30, 249-261.
- Prno, J., Bradshaw, B., Wandel, J., Pearce, T., Smit, B., & Tozer, L. (2011). Community vulnerability to climate change in the context of other exposure-sensitivities in Kugluktuk, Nunavut. *Polar Res.*, 30, 1–21.
- Robbins, P. (2004). *Political ecology: A critical introduction*. Malden, MA: Blackwell Publishing.
- Scudder, T. (2001). The World Commission on Dams and the need for a new development paradigm. *International Journal of Water Resources Development*, 17:3, 329-341. DOI: 10.1080/07900620120065110
- Sen, A. (1981). Ingredients of famine analysis: Availability and entitlements. *The Quarterly Journal of Economics*, 96(3), 433–463.

- Shi, Y., Gao, X., Zhang, D., & Giorgi, F. (2011). Climate change over the Yarlung Zangbo Brahmaputra River Basin in the 21st century as simulated by a high resolution regional climate model. *Quaternary International*, 244(2), 159-168.
- Silva, J.A., Eriksen, S., & Ombe, Z.A. (2010). Double exposure in Mozambique's Limpopo River basin. *Geographical Journal*, 176(1), 6–24.
- Thayyen, R.J., & Gergan, J.T. (2009). Role of glaciers in watershed hydrology: a preliminary study of a “Himalayan catchment.” *The Cryosphere*, 4, 115-128.
- The Telegraph. (2008, June 20). Neepeco rejects demand. The Telegraph. Retrieved from http://www.telegraphindia.com/1080620/jsp/northeast/story_9435220.jsp
- Tobin, G.A. (1995). The levee love affair: a stormy relationship. *American Water Resources Association Water Resources Bulletin*, 31, 359-367.
- Tschakert, P. (2007). Views from the vulnerable: Understanding climatic and other stressors in the Sahel. *Global Environmental Change*, 17, 381–396.
- Turner II, B.L., Kaspersonb, R. E., Matsone, P. A., McCarthy, J. J., Corellg, R.W., Christensene, L., Eckleyg, N., Kaspersonb, J.X., Luerse, A., Martellog, M.L., Polskya, C., Pulsiphera, A., & Schillerb, A. (2003). A framework for vulnerability analysis in sustainability science. *PNAS*, 100 (14), 8074-8079.
- Vagholikar, N. (2011). Are big dams leaving India high and dry? Sanctuary Asia. Mumbai, India. Retrieved from <http://www.sanctuaryasia.com/magazines/conservation/5289-are-big-dams-leaving-india-high-and-dry-by-neeraj-vagholikar.html>
- Vagholikar, N., & Das, P.J. (2010). Damming Northeast India: Juggernaut of hydropower projects threatens social and environmental security of the region. *Kalpavriksh, Aaranyak and ActionAid India*. Retrieved from <http://chimalaya.org/wp-content/uploads/2010/12/damming-northeast-india-final.pdf>
- Vagholikar, N., Choudhury, A., & Ahmed, F. (2005). “Environmental Impact Assessment Report of Lower Subansiri Hydroelectric Project: substandard on Many Fronts.” in *Large Dams for Hydropower in Northeast India: A Dossier*. Menon, M. and K. Kohli, Eds. New Delhi: Kalpavriksh and South Asia Network on Dams, Rivers and People. Pp. 43-47.
- Van der Land, V., & Hummel, D. (2013). Vulnerability and the role of education in environmentally induced migration in Mali and Senegal. *Ecology and Society*, 18(4), 14. <http://dx.doi.org/10.5751/ES-05830-180414>

- Walker, B. (2013). China-India deal on water: why we should be sceptical. Chinadialogue. Retrieved from <https://www.chinadialogue.net/blog/6451-China-India-deal-on-water-why-we-should-be-sceptical/en>
- Watts, M. J., & Bohle, H.G. (1993). The space of vulnerability: The causal structure of hunger and famine. *Progress in Human Geography*, 17: 43–67.
- [WCD] World Commission on Dams. (2000). Dams and development: a new framework for decision-making. Earthscan Publications Ltd, London, U.K. Retrieved from http://www.internationalrivers.org/files/attached-files/world_commission_on_dams_final_report.pdf
- White, G. F. (1945). *Human adjustment to floods: A geographical approach to the flood problem in the United States*. Chicago: University of Chicago Press.
- White, G.F., Kate, R.W., & Burton, I. (2001). Knowing better and losing even more: the use of knowledge in hazards management. *Environmental Hazards*, 3, 81–92.
- Xu, J., Grumbine, R.E., & Shrestha, A. (2009). The melting Himalayas: cascading effects of climate change on water, biodiversity, and livelihoods. *Conservation Biology*, 23(3), 520-30.

CHAPTER 2

HYDROPOWER DEVELOPMENT ALONG THE BRAHMAPUTRA RIVER: TESTING DOWNSTREAM COMMUNITIES' CAPACITY TO LIVE WITH FLOODS AND ADAPT TO CLIMATE CHANGE.

Abstract: Summer floods along the Brahmaputra and its tributaries have always been a major challenge for people living in Northeast India. Riverine communities in the region rely upon a variety of adaptation strategies to live with recurrent floods, but climate change impacts are straining their adaptive capacity by increasing the frequency of severe flooding events. At the same time, a multitude of new dams are under construction in the Brahmaputra river basin, in an effort to meet India's growing energy demands. Using a case study dam in Arunachal Pradesh and household-level interview data, this research examines how large-scale hydropower development efforts along the Brahmaputra shape the adaptive capacity of downstream communities to floods. Results showed that, by changing the flood regime and undermining current adaptive strategies, large dams along the Brahmaputra are testing the capacity of downstream communities to live with summer floods, at a time when climate change impacts are exacerbating the flood problem.

Keywords: hydropower development, Brahmaputra river, floods, adaptive capacity, climate change

1. Introduction

Summer floods along the Brahmaputra and its tributaries have always been a major challenge for people living in Northeast India, causing severe damages to fields and infrastructure, direct and indirect loss of lives, and harming local livelihoods and the local economy. These destructive floods are the result of the unique topography of the Brahmaputra River and the Indian monsoon, which is characterized by heavy rains between June and September. Local communities rely upon a variety of adaptation strategies that help them live with recurrent summer floods, including stilted houses, embankments and temporary relocation. However, climate change impacts are expected to strain their current adaptive capacity to floods. Warmer temperatures are melting Himalayan glaciers that contribute to the Brahmaputra river flows and altering the Indian monsoon, leading to an increase in the frequency of severe floods (Gosh and Dutta 2012).

At the same time, 140 new dams are planned along the Brahmaputra and its tributaries in Northeast India in an effort to meet India's growing energy demands, while curbing greenhouse gas emissions from energy production (Government of Arunachal Pradesh Department of Power 2008, MDONER 2012). Large-scale efforts to harness the hydropower potential of the Brahmaputra river basin, which has remained largely undammed, will significantly alter river flows and riparian ecosystems and have cascading impacts on downstream communities (Vagholikar and Das 2010). Notably, dams will affect the capacity of people in the Brahmaputra river basin to continue living with floods. The reconfiguration of the Brahmaputra flows and riparian landscapes by hydropower development provides an occasion to

scrutinize how large-scale natural resource development reshapes the adaptive capacity of rural communities to climate change impacts. This research poses the question: Will dam-building efforts in Northeast India make it manageable for downstream communities to live with floods that are becoming increasingly severe as a result of anthropogenic climate change?

Flood forecasting techniques in the region are largely missing or inadequate, and flood management has been treated mostly as a question of relief after the event rather than disaster preparedness (Dixit 2003). The cascade of dams planned in the river basin creates an opportunity for local state officials and resource managers to control floods and implement new flood adaptation strategies throughout the river basin, such as flood-warning systems. These strategies could prove crucial in helping downstream communities adapt to an intensification in the flood regime. Yet, contrarily to expectations, this research reveals that dam-building efforts along the Brahmaputra are eroding the adaptive capacity of downstream rural households to summer floods. Using a case study dam in Arunachal Pradesh and household-level interview data, this project describes how downstream households' current strategies against floods have become less effective as a result of dam-induced floods, and highlights the inadequacy of the new flood early warning system that was set up in the aftermath of the dam.

In the next section, I briefly explain the concept of adaptive capacity and the many synergies between climate change adaptation and development efforts. In section 3, I describe the unique characteristics of the Brahmaputra river basin that lead to recurrent and destructive summer floods, as well as recent efforts to dam the

river and its main tributaries. In section 4 and 5, I introduce the case study dam and the methods that were used for this project. In section 6, I present the results of the analysis showing that dams in Northeast India are decreasing the adaptive capacity of downstream communities to floods. In the remainder of the paper, I explain the implication of these findings in light of climate change impacts on the Brahmaputra flood regime. I conclude by reflecting upon the risks of pursuing renewable energy development and climate change mitigation efforts without considering the impact of these actions on the adaptive capacity of local populations to climate change impacts.

2. Key concepts and framework

Adaptation refers to actions taken to adjust to the impacts of environmental change and hazards (Gallopín 2006). The issue of climate change adaptation is gaining increased attention given evidence that, despite current efforts to reduce greenhouse gas emissions, we will experience at minimum a 2-degree Celsius increase in average surface temperatures and a myriad of related impacts, from sea level rise to an increase in extreme events (Hansen 2005, Pielke et al. 2007). Efforts to facilitate climate change adaptation are complicated by the fact that adaptive capacity exists at different organizational levels and takes place within hierarchical structures (Adger et al. 2005, Yaro et al. 2015). Individuals and households often develop methods for adapting to environmental change and hazards, such as planting new crop varieties, but they also rely on and are constrained by broader institutional processes and system-level adaptive capacities, such as access to improved seeds and credit. Furthermore, building adaptive capacity entails not only implementing

specific strategies, but also avoiding making decisions that reduce flexibility and narrow adaptation options in light of possible future scenarios, leading to what is called a rigidity trap (Allison and Hobbs 2004). This work sheds light on this latter issue by describing how the development of the Brahmaputra river basin for its hydroelectricity generation potential is narrowing downstream communities' options for adaptation to future flood scenarios.

In recent years, many have recognized the links between development and climate change adaptation and called for a better integration of those two fields, especially in areas that are most vulnerable to climate change and have low levels of economic development such as Northeast India (Brown 2011, Cannon and Muller-Mahn 2010, Conway and Schipper 2011, Eakin et al. 2014, Klein 2011, Lemos et al. 2007). On one hand, climate change impacts exacerbate existing development challenges by threatening food production, causing the spread of vector-borne diseases and triggering human migration, so that development outcomes depend in part on the capacity of countries and people to adapt to climate change (Bauer & Scholz 2010, Chevallier 2010). In Northeast India, amongst other things, low-income rural communities will need to wrestle with more ferocious summer floods as a result of climate change. On the other hand, economic, political, social, and technological factors also determine a system's or a group's need and capacity for adaptation to climate change (Adger et al. 2009, Eakin and Luers 2006, Eriksen and Lind 2009). Structural underdevelopment severely limits people's capacity for adaptation and results in the unequal distribution of adaptive capacity between countries and people (Pelling & Manuel-Navarrete 2011, Tschakert and Dietrich 2010). But development

interventions that do not take into consideration climate change impacts can also erode people's capacity to adapt to climate change (Brooks et al. 2009). This research provides one such example, by documenting the negative impacts of large-scale hydropower development in the Brahmaputra river basin on the capacity of downstream rural households to live with recurrent floods.

Development efforts and climate change adaptation efforts should work in tandem to reduce poverty, social inequality, and vulnerability to climate change (Eriksen and O'Brien 2007). Vulnerability refers to the degree to which a system is susceptible to the impacts of climate change and it is inversely related to adaptive capacity (Adger 2006). Development interventions that increase adaptive capacity to climate change, and vulnerability reduction measures that lessen economic and political marginalization promote both sustainable development and climate change adaptation objectives (Eriksen and O'Brien 2007). Hydropower development along the Brahmaputra in Northeast India is promoted by hydropower and government officials as a form of sustainable development, given its combined energy generation and climate change mitigation benefits. Within sustainable development and climate change action, adaptation efforts have consistently received less institutional attention and funding than mitigation efforts, in part because adaptation is seen as having local benefits while mitigation brings global benefits (Pielke et al. 2007). Through household-level interviews with riverine communities in the Brahmaputra river basin, this research provides new insights about the risks of pursuing climate change mitigation and sustainable development without taking into consideration how these efforts influence the capacity of local communities to adapt to climate change. As

climate change intensifies the Brahmaputra's flood regime, the prioritization of national development and climate change mitigation goals over the adaptation needs of rural communities in Northeast India compromises the sustainable development of one of India's poorest and most climate-vulnerable region. This research illustrates the continuing tension between development, mitigation and adaptation efforts at various scales, and echoes calls for a better integration of development and climate change adaptation efforts.

3. The Brahmaputra River

3.1. Summer floods

The Brahmaputra is one of the world's largest river systems. It originates in the glaciers of Tibet, and flows through Northeast India and Bangladesh before discharging into the Bay of Bengal. In Northeast India, the Brahmaputra river basin lies primarily in the states of Arunachal Pradesh and Assam. The Brahmaputra is the backbone of the states' resource-based economies and is often referred to as "the lifeline of Northeast India" (Vagholikar and Das 2010). At the same time, the river system is the source of recurrent destructive floods that cause significant damage and losses to the region's economies and local livelihoods. Eighty percent of the Brahmaputra's annual flow is concentrated during the summer season from mid-May to mid-October (Bora 2004). During these months, heavy monsoon rains and meltwater from Himalayan glaciers combine to swell the river and its tributaries, causing destructive floods in Northeast India and particularly in Assam, where forty

percent of the land surface is vulnerable to floods (ASDMA n.d.). Annually, the area of land affected by floods in Assam ranges from 1 to nearly 4 million hectares compared to 9 million hectares for India as a whole (The World Bank 2007).

Floods along the Brahmaputra cause both direct damages and losses due to the force of the floodwaters, and indirect ones as a result of river braiding, riverbank erosion and sandcasting. Because the river and its north-bank tributaries traverse very steep, highly seismic, and easily erodible slopes, they carry enormous amounts of sediment, particularly during flooding events (Bora 2004, Pahuja and Goswami 2006). As floods deposit large amounts of silt throughout the river channel, they cause the formation of bars and small river islands, locally called *chars*, which force the river to braid into new channels and send floodwaters in new and unpredictable directions. Heavy floods also lead to severe riverbank erosion across vast areas of both Assam and Arunachal Pradesh during the summer season (Bora 2004, The World Bank 2007). Additionally, floodwaters often deposit sand along the riverbanks and onto nearby farmland (Aaranyak 2009). The various effects of floods compromise both the habitability and productivity of the rural landscapes of Northeast India and present a major challenge for local communities and officials.

3.2. Large-scale hydropower development

The Brahmaputra flows from the highest mountain chain in the world to sea level in approximately three thousand kilometers (Goswami 1985). As the river traverses steep slopes from the Tibetan Plateau to the Bay of Bengal, its flows garner enormous hydroelectricity generation potential. Indeed, the Brahmaputra river basin

holds 40% of India's total assessed hydropower potential, all of it concentrated in the northeastern state of Arunachal Pradesh, and most of it remained undammed until recently (MDONER 2012, CEA 2014).

Plans to harness the hydropower potential of the Brahmaputra began in the 1980s, when India's central government created the Brahmaputra River Board for the purpose of developing the basin's water resources. The Board collected hydrological data and identified potential sites for dam projects throughout the river basin. Dams proposed by the Board were envisaged primarily as multipurpose dams that included flood control and irrigation components, in accordance with the national water policy (J. Barman, personal communication, December 4, 2012, Kalita et al. 2010). With the gradual liberalization of India's hydropower sector beginning in the 1980s and accelerating in the 2000s, the involvement of private capital in the hydropower development of the Brahmaputra river basin grew, and projects originally conceived by the Brahmaputra River Board were handed over to private companies (Water for Welfare Secretariat 2008).

Between 2006 and 2012, the government of Arunachal Pradesh allotted contracts for the building of 140 new dams along the Brahmaputra and its north-bank tributaries (MDONER 2012). Most of these new projects involve private companies and their designs have been modified from multipurpose projects to run-of-the-river projects (J. Barman, personal communication, December 4, Vagholikar and Das 2010). Unlike storage dams with large reservoirs that can buffer floods, run-of-the-river projects have small reservoirs and little flood cushioning capacity (Vagholikar and Das 2010). Run-of-the-river projects maximize hydroelectricity production while

minimizing the amount of land submerged by the reservoir. However, this shift comes to the detriment of the people living downstream of the dams, especially those living in the floodplains of Assam, who would instead benefit from flood control during the summer season. Unsurprisingly, downstream communities have been largely excluded from public hearings about dam projects. The right of participation in public hearings is restricted to the most nearby villages in Arunachal Pradesh, thus excluding affected communities further downstream and in Assam (Dharmadhikary 2008). Additionally, the presence of local villagers at public hearings is mostly symbolic, as they have little capacity to intervene in these highly technical conversations that are held in Hindi or English, and hearings are sometimes held after construction of the project has already begun (Vagholikar et al. 2005).

4. Case Study: The Ranganadi Hydroelectric Project

This research employs a case study approach to investigate the impacts of dams in the Brahmaputra river basin on the adaptive capacity of riverine communities' to floods and climate change. The Ranganadi Hydroelectric Project (HEP) is the first mega-dam to be completed in the Brahmaputra river basin and was selected as an illustrative hydropower project foreshadowing the impacts of other dams yet to be completed. Local protests, heavy summer floods, and the geophysical challenges of the region have delayed the completion of several other large dams, as in the case of the Lower Subansiri HEP and the Lower Siang HEP.

The Ranganadi Hydroelectric Project (HEP), was completed in 2002 by the North Eastern Electric Power Corporation (NEEPCO) in the Lower Subansiri District

of Arunachal Pradesh (see Figure 1). The project consists of a run-of-the-river dam located on the Ranganadi River and a ten-kilometer-long tunnel, which diverts water from the Ranganadi to the Dikrong River, at a maximum rate of 160 cubic meters per seconds. The dam is located on the Ranganadi river fifty kilometers north of the border between Arunachal Pradesh and Assam. The project's powerhouse is located along the Dikrong river near the town of Doimukh and has an installed capacity of 405 Megawatts.

The impacts of the Ranganadi HEP affect downstream communities in both Arunachal Pradesh and Assam. In particular, the hydropower project has modified the flood regimes of the Ranganadi and Dikrong rivers and intensified the negative impacts of floods (Rampini 2017). The dam reservoir and diversion tunnel can mitigate weaker floods but do not provide significant flood buffer during heavier floods. At the same time, the sudden release of waters from the dam floodgates and the diversion of flows from the Ranganadi to the Dikrong during flooding events are worsening flood impacts along both rivers (Dharmadhikary 2008). Households downstream of the Ranganadi HEP have described the floods as faster and stronger, occurring more suddenly than in the past, carrying more sediments and sand, and causing more damage than before the construction of the Ranganadi HEP (Rampini 2017). Overall, the hydropower project has exacerbated the negative impacts of floods, and increased uncertainty about the timing and amount of flooding along both rivers. Despite various protests and public demands, NEEPCO has largely ignored the requests of downstream communities to share information regarding the dam's expected impacts (Das and Ahmed 2005).



Figure 1: The Ranganadi Hydroelectric Project (405 MW) dam near Kimin, Arunachal Pradesh.

5. Methods

This research relies on qualitative semi-structured interview data with households in flood-affected villages downstream of the Ranganadi HEP to understand how their adaptive capacity to floods has been influenced by the project. This method was chosen because it allows us to understand how households' experiences of living with floods are changing from the perspectives of those most affected. Qualitative semi-structured interviews also enable the voices of rural flood-

affected households, which are largely sidelined in the process of approving dam projects along the Brahmaputra, to be heard on their own terms (Bernard 2016, Edwards and Holland 2013).

Interviews were conducted downstream of the Ranganadi HEP dam and powerhouse along the Ranganadi and Dikrong rivers between January and September 2014. Villages within 2 kilometers from the Ranganadi and Dikrong riverbanks were identified and selected based on their exposure to riparian floods. Officials at the Assam State Disaster Management Authority (ASDMA) office in North Lakhimpur were instrumental in helping the author identify flood-affected villages in Assam to be included in the sample. Given the lack of formal village maps and lists of population, convenience sampling was used to select the households to be interviewed within each village. Overall, 74 households were interviewed representing approximately 465 people in 51 rural villages. Forty-four interviews were conducted along the Ranganadi river and 30 took place along the Dikrong river. Fifty-one interviews were conducted in the Lakhimpur District in Assam¹. Due its status as a Restricted Area, which places limitations on non-residents visiting the state, only 23 interviews were conducted in Arunachal Pradesh in the Lower Subansiri District.

Interviews were conducted in Assamese, Hindi and English. Interviews were recorded and interviewers took notes, which were then transcribed in English. Analysis focused on the impacts of floods on households, on the adaptation methods that riverine communities use to cope with recurrent summer floods, and on the

¹ Interviews were conducted in three-divisions: the Lakhimpur Revenue Circle, the Nowboicha Revenue Circle, and the Bihpuria Revenue Circle.

perceived changes to their capacity to adapt to floods since the construction of the Ranganadi HEP began in 1998. For the analysis, adaptation strategies were subdivided into “soft” methods, which comprise behavior changes, policy actions and institutional arrangements such as flood insurance, and “hard” approaches that use specific technologies or tangible assets, including infrastructure such as levees (Jones et al. 2012). This categorization allows us to understand whether hydropower development efforts affect social networks and governance structures that facilitate adaptation differently than measures that involve capital-intensive technology and infrastructure.

Multiple key informant interviews were also conducted with a high-ranking official at the Assam State Disaster Management Authority (ASDMA) office in Lakhimpur, Assam. Starting in 2008, ASDMA collaborated with NEEPCO to set up a flood early warning system along the Ranganadi River. Key informant interviews were used alongside household interviews to gather information about the effectiveness of this early warning system.

6. Findings

All of the sampled households described being affected by floods. The various impacts of floods as perceived by interviewed households are summarized in Figure 2. A majority of households described the devastating effect of floods on their livelihoods (88%) and food security (65%) as floods eroded paddy fields, lowered their productivity and destroyed household food reserved. Households also

experienced a variety of different debilitating damages and losses, including the death of family members and neighbors.

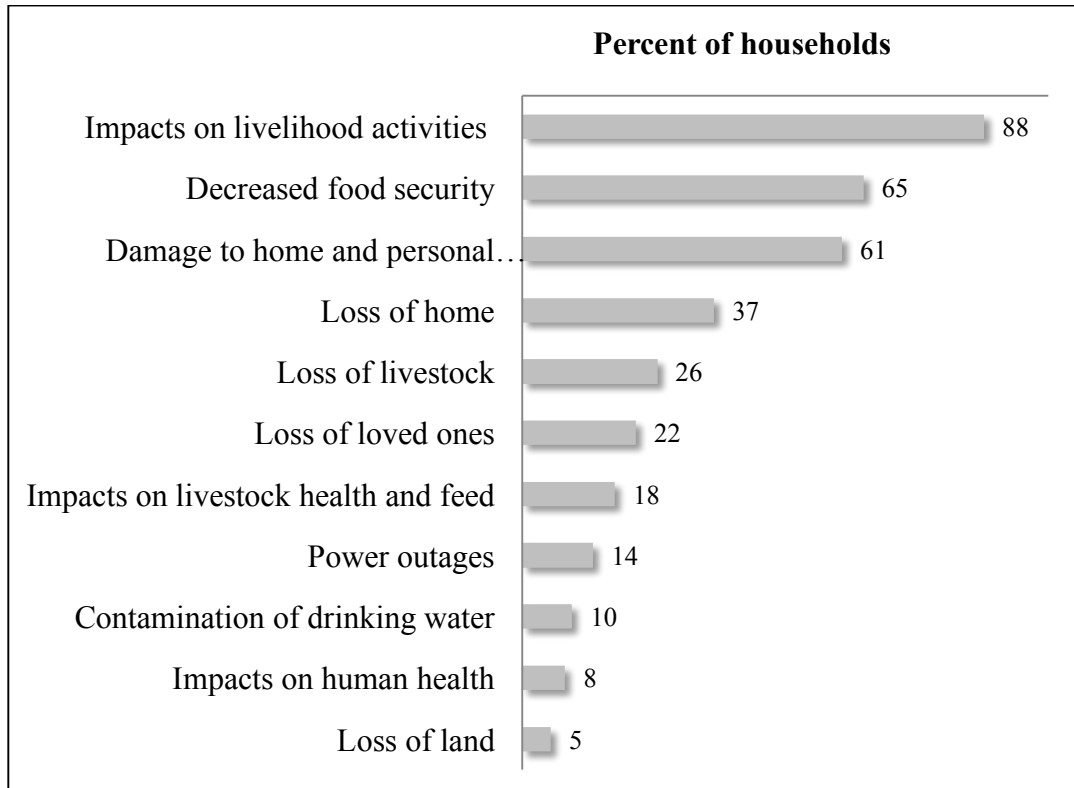


Figure 2: Perceived impacts of floods on interviewed households living along the Ranganadi and Dikrong rivers.

At the same time, communities living along the Dikrong and Ranganadi rivers rely on several household-level and system-level adaptation methods against floods. Our interviews revealed 17 different adaptation methods used by flood-affected households, and nearly all of the interviewed households (93%) described relying on at least one of these methods. However, by altering the rivers' flood regimes, the Ranganadi HEP is reducing the efficacy of many of these adaptation methods and the

new flood early warning system, set up by the hydropower company, is largely inadequate.

6.1. Soft adaptation strategies against floods

6.1.a. Current strategies

Amongst the numerous soft adaptation strategies identified during our interviews, most interviewed households (72%) described local informal social networks as key for dealing with floods. These include extended family members, neighbors and in some cases other nearby villages that provide food, drinking water and temporary shelter in the aftermath of floods. In two of the sampled villages, residents had formed a local organization, known as a *sangha*, that helped members organize important yearly events such as weddings, and also provided assistance and relief during floods. Surveyed households (69%) also relied on system-level networks such as local government institutions, and to a lesser extent (23%) non-governmental organizations including student groups and church missions, to bring flood relief in the form of food, water, medical supplies and transportation. This is consistent with other research that has highlighted the importance of social networks, both formal and informal, for adapting to environmental hazards and change (Adger 2003, Rotberg 2010, Pelling and High 2005, Wisner et al. 1994). Local social networks are important partly because they are a source of accumulated experiential knowledge about the disturbance regime, and ways to respond and re-organize in its aftermath (Folke et al. 2005).

Most households (65%) also temporarily relocated to higher grounds during floods, by taking shelter on nearby embankments or roads. Interviewed households described living on embankments from a few days to several months, as they waited for floodwaters to recede and they rebuilt their homes. Many households (45%) also moved their animals to the embankment or to elevated granaries during floods. Several families (24%) also said they stacked and hung valuables inside their homes, by creating a tower of bed mattresses for example, to protect them from floodwaters. Finally, others (15%) permanently relocated further away from the riverbanks or uphill, while still remaining within two kilometers from the riverbanks. Our sample could not capture households that migrated further away to protect against floods.

A minority of households (4%) shifted primary livelihood strategies from rice agriculture to casual labor after losing their fields as a result of floods. In India, casual laborers are people, who work in public works or other manual, unskilled or low-skilled jobs in exchange for a daily wage. Casual labor is carried out temporarily and depending upon demand; it includes activities such as loading, unloading, helping a mason or a carpenter, doing earthwork for a contractor, working for others doing households chores, or sometimes owners of vehicles who utilize their spare capacity to earn extra money occasionally (MOSPI 2012). All of the interviewed households whose members shifted to casual labor due to floods were located in Assam, where the percentage of rural workers employed in casual labor is already significantly higher (18%) than in Arunachal Pradesh (6%) (MOSPI 2014).

6.1.b. Newly implemented Ranganadi HEP flood early warning system

Several interviewed households (27%) mentioned being notified of the arrival of floods by the new flood early warning system that NEEPCO established downstream of the Ranganadi HEP starting in 2008. The 2008 summer monsoon season caused particularly devastating floods across Northeast India. The District of Lakhimpur in Assam was heavily hit, and excess water released from the Ranganadi HEP floodgates worsened the situation claiming several lives. While NEEPCO denied responsibility, the company agreed to install a warning system for communities downstream of the Ranganadi HEP dam in Assam. Based on this agreement, NEEPCO should notify the Assam State Disaster Management Authority (ASDMA) three hours before opening the dam floodgates. Upon receiving the notification, ASDMA activates a network of government workers, volunteers, village defense parties, and village headmen to spread the news by boat, motorbike or foot to households located along the Ranganadi River in Assam. ASDMA officials claim that this system reaches approximately 100 villages in the Lakhimpur District though, upon request, they could only produce a tentative list of 46 villages. Additionally, ASDMA officials complained that NEEPCO usually notifies them in the middle of the night and only 30 minutes before opening the spillway gates, making it difficult to communicate the warning to flood-affected villages with sufficient advance (R.D. Chowdury, personal communication, January 24, 2014).

Beginning in January 2014, NEEPCO set up a similar warning system downstream of the Ranganadi dam in Arunachal Pradesh. With the help of local villagers, the company installed sirens in two villages, Lichi and Hawa Camp. Upon

receiving a call from NEEPCO officials, appointed villagers must activate the sirens using a switch located in their household. Since public telecommunications infrastructure and power stations often experience damages and failures in times of floods, the villagers have also been equipped with a manual siren (see Figure 3).



Figure 3: Ranganadi water release notification system in Lichi village, Arunachal Pradesh. Electric switch activating sirens (left) and manually operated siren (right).

This new early warning system has the potential to increase the adaptive capacity of local riverine communities to floods through timely alerts of the release of floodwaters behind the dam. However, in practice, it has proven to be inadequate and unable to reach a significant portion of the flood-affected households downstream of the hydropower project. On one hand, the early warning system only reaches villages along the Ranganadi river. No notification system has been set up downstream of the Ranganadi HEP powerhouse along the Dikrong river, even though diversion of water

from the Ranganadi to the Dikrong during flooding events can exacerbate floods along the latter. At the same time, even along the Ranganadi river, 51% of surveyed households said they had never received a flood warning and 5% had been notified only once since 2008. Amongst the households along the Ranganadi river that had been notified at least once (49%), the median amount of time between the notification and the arrival of floodwaters was 30 minutes. Many complained that the early warning did not allow them sufficient time to prepare for the arrival of the floodwaters. Several households even described receiving the notification after the floodwaters had already reached their village.

In the summer of 2014, a heavy monsoon season exacerbated by the water release from the Ranganadi HEP floodgates brought more severe floods in the Lakhimpur District of Assam. On August 14th at night, NEEPCO officials opened the Ranganadi dam spillway gates only thirty minutes after notifying ASDMA. The strength of the floodwaters breached the embankment near West Kharkati in Assam destroying nearly fifty homes and a large communal fishpond before anyone could be notified.

6.2. Hard adaptation strategies against floods

Amongst the hard adaptation strategies, a majority of households (53%) used banana rafts, locally known as *vhur*. These rafts are built by tying together the trunks of three or four banana trees and they are commonly used in many areas of Northeast India and Bangladesh in times of floods. They allow flood-affected households to navigate the floodwaters and check on their rice paddies, move livestock, or reach

their flooded homes to retrieve belongings. Most interviewed households built banana rafts using trees from their gardens, while others bought the trees from their neighbors. Interviewed households also relied on bamboo bridges (16%) and wooden boats (8%), as methods of transportation and communication in times of floods.

Many of the interviewed households (43%) lived in raised homes to minimize flood damage, but the type of raised home varied amongst different tribes and castes. Surveyed households belonging to the Mising tribal community (7%) all lived in stilted bamboo houses called *chang-gars* that are raised six to seven feet above the ground. The floor of a *chang-gar* is adjustable so that it can be raised during floods. The Misings originally migrated from the hills of Arunachal Pradesh to the floodplains of Assam, where they are now the second largest tribe (Sarma and Choudhury 2015). Today, Mising tribes are found in the most flood-prone areas of the Brahmaputra river basin, and their traditional stilt-houses are evidence of their adaptation to recurrent summer floods (ibid). Instead, interviewed households belonging to the Assamese general caste or to other tribes raised their homes using mud or cement. Many respondent households (30%) also built raised livestock sheds to keep their animals safe from rising floodwaters.

Several of the respondent households (38%) lived behind river embankments built by the government under various flood control programs. In Assam, 4500 kilometers of riverbanks along the Brahmaputra river and its tributaries have been armored with embankments (Goyari 2005). Embankments protect people and their property from floodwaters, and they are also used as shelter to relocate to higher ground during flood events. For households living in the Brahmaputra river basin,

embankments are a symbol of safety but also a source of vulnerability (Das et al. 2009). Embankments and levees can give people a false sense of safety and increase flood damages when they fail, this phenomenon is known as the ‘levee effect’ (White et al. 2001). In the Brahmaputra river basin, embankments are made of mud and sand and breaches are common. Indeed, some of the interviewed households (7%) indicated that the embankment near their home had failed at least once during recent floods. To protect against flood-induced erosion and reduce the risk of embankments breaching, some households (19%) built floodwalls along the riverbank, while others (14%) used wood and bamboo to reinforce them.

6.3. Impacts of Ranganadi HEP on adaptation strategies

By altering the Dikrong and Ranganadi flood regimes, the Ranganadi HEP is reducing the efficacy of many flood adaptation methods upon which downstream riverine communities rely (see Figure 4). Many households (30%) said that, by mediating floods through the release of water behind the floodgates, the Ranganadi HEP had eroded their traditional knowledge of floods and overwhelmed their capacity to adapt to them. As one respondent commented:

We never know when water will be released. [...] The water is released at nighttime so the flood happens at night so we have less time to prepare and shift. Before the dam, floods occurred when there was heavy rainfall, now we never know.

More abrupt floods due to the release of floodwaters from behind the dam are making it hard for downstream households to rely on soft adaptation strategies. As floods

have become less predictable, households now have less time to move their livestock and relocate to higher grounds. As another interviewee explained:

The water released from the dam causes floodwater to be much much faster. We barely have time to run away from our fields. Floods used to rise slowly, now the flood comes with much more force because it gets stored and released.

These changes in the flood regime have also eroded people's capacity to rely on informal social networks for help during times of flood. As one interviewee answered, when asked whether their household had received help from his family or neighbors during the last flood season:

Yes, but all are facing the same situation. This year the embankment broke at 12am, who will help at that time?

Similarly, the impacts of the Ranganadi HEP on the strength and speed of floodwaters are rendering hard adaptation strategies less effective. According to our interviews, stronger floods are triggering more frequent embankment failures. An interviewed household along the Ranganadi river in Kolaguri, Assam, told us that the embankment protecting their home had breached for three consecutive summers since 2012. Interviewed households also told us that faster floodwater currents are making banana rafts less safe to use during floods. Others noted that, by holding river flows behind the dam during the rainless winter months, the Ranganadi HEP decreased river levels, causing their banana trees to die and making it harder for them to build rafts during the summer flood season.

On one hand, the impacts of Ranganadi HEP on the Ranganadi and Dikrong rivers' flood regimes have undermined many of the soft and hard adaptive strategies that downstream households rely upon during floods. On the other hand, NEEPCO has done little to boost their adaptive capacity through the implementation of new flood adaptation strategies. As previously seen, the flood early warning system they implemented is largely inadequate: It doesn't reach many flood-affected households, it relies on telecommunication and transportation infrastructure that tends to fail during heavy rains, and, when it does reach flood-affected households, it gives them too little time to prepare for the arrival of the floodwaters. The only other improvement that respondents credited to NEEPCO was the provision of funds for floodwalls. Interviewed households in four different villages in Arunachal Pradesh reported that their village had received funds from the hydropower company to build floodwalls along the riverbanks. These included Manibasti and Parbotibur villages downstream of the powerhouse along the Dikrong River, and the neighboring Lichi and Hawa Camp villages downstream of the dam along the Ranganadi River.

Adaptation Methods	% Respondents	Impacts of dam on adaptive capacity
Soft adaptation methods:		
Local coping networks	72	Less able to help each other
Government disaster relief & compensation	69	-
Temporary relocation	65	Less time to relocate
Relocate livestock	45	Less time to move animals
Flood early warning system	27	Set up in 2008-14
Stack/hang valuables inside home	24	Less time to prepare
Civil society disaster relief	23	-
Permanent relocation ¹	15	-
Primary livelihood shift	4	-
Hard adaptation methods:		
Banana raft	53	Less safe to use
Raised house	43	-
Government-built embankment	38	More frequent breaches
Raised animal shed/granary	30	-
Floodwall	19	Provision of funds to build floodwalls
Bamboo bridge	16	-
Other erosion control methods ²	14	-
Wooden boat	8	-



Figure 4: Adaptation methods against floods and impact of Ranganadi HEP on those methods. Top left to bottom right, column-wise: Flood-affected households relocated temporarily on the road after the 2014 summer floods, a stilted house in a Mishing village, an embankment reinforced with bamboo and wood, a man building a bamboo bridge, a banana raft, a floodwall, a raised Assamese house.

¹ Remained within 2km of riverbank ² Not including floodwalls

7. Discussion and conclusions

Floods along the reaches of the Brahmaputra are an age-old problem causing significant damages and loss of life across Northeast India every summer. As a result of climate change, the Brahmaputra's flood regime is intensifying and future flood scenarios for the region are increasingly grim. Warmer surface temperatures are causing Himalayan glaciers and snowpacks to melt faster during the summer months, causing them to shrink over time (Bolch et al. 2012). This suggests that glacier-fed rivers such as the Brahmaputra will experience an increase in summer season discharge in the short-term (Baraer et al. 2012). The Brahmaputra's flood regime is also heavily influenced by monsoon rains during the summer season (Thayyen and Gergan 2009), which coincide in timing with the melting of Himalayan glaciers. Latest reports suggest that climate change is increasing the frequency of heavy precipitation events and decreasing the frequency of light precipitation events during the Indian monsoon season, while also lengthening the overall rainy season (Christensen et al. 2013; Hijjoka et al. 2014). Together, a short-term increase in glacial melt from the Himalayas combined with an increase in extreme precipitation events during the monsoon season will exacerbate the challenge of summer floods for people living in the Brahmaputra river basin in Northeast India.

Riverine communities living in the river basin rely on a variety of adaptation strategies against floods that help them cope with the hazardous summer season. The question is whether these existing strategies will be sufficient in light of increasingly severe floods as a result of climate change. Additionally, climate change impacts occur in the context of other social, cultural, economic, political, and technological

transformations that affect the adaptive capacity of people to climate change impacts (Adger et al. 2005; Leichenko & O'Brien 2008). In Northeast India, the cascade of dams under construction along the Brahmaputra and its tributaries could increase the capacity of downstream rural communities to adapt to an intensification of the flood regime. Large-scale coordinated hydropower development efforts can help regulate flows throughout the river basin and provide the catalyst for the deployment of other adaptive measures, such as early flood warning system. Hydropower development along the Brahmaputra could also help improve flood forecasting techniques and shift flood management approach away from relief and towards anticipatory preparedness. Yet this research suggests that dam building efforts in Northeast India will likely erode the current adaptive capacity of riverine communities against floods by reducing their options for adaptation.

This case study indicates that, as India rushes to dam the Brahmaputra river basin in Northeast India to meet growing energy demands through the development of domestic renewable energy sources, it could be undermining the long-term sustainable development of one of its poorest and most climate-vulnerable regions. The effects of the Ranganadi HEP on river floods are overwhelming many of the soft and hard adaptation strategies upon which downstream communities rely, and the hydropower company has not mitigated for those impacts by implementing new and more effective adaptation solutions. By decreasing the adaptive capacity of downstream households to floods, dam-building efforts in Northeast India increase their vulnerability to future climate and flood scenarios. Further research is needed to understand whether, by narrowing adaptation options and rendering strategies such as

informal social networks less effective, hydropower development may be pushing rural households to rely increasingly on government relief, livelihood shifts and migration as adaptation strategies against intensifying floods. This is crucial given that some adaptation strategies can increase people's vulnerability to environmental hazards and further impede sustainable development and poverty alleviation efforts. Emergency relief after flood events aims to restore the situation to what it was before the disaster without helping those repeatedly affected by disasters to reduce their vulnerability (Dixit 2003). Migration can increase social inequalities, push people to settle in hazardous locations and lead to the breakdown of livelihood networks (Black et al. 2011, Wrathall 2012). This analysis of the impacts dam-building efforts highlights the risks of pursuing renewable energy development and climate change mitigation without taking into consideration local climate change adaptation needs.

References

- Aaranyak. (2009). "Adjusting to floods on the Brahmaputra plains, Assam, India." in *Local Responses to Too Much and Too Little Water in the Greater Himalayan Region*. International Centre for Integrated Mountain Development, Kathmandu, Nepal. Retrieved from <http://lib.icimod.org/record/8021>
- Adger, W.N. (2003). Social capital, collective action and adaptation to climate change. *Economic Geography*, 79, 387-404.
- Adger, W.N. (2006). Vulnerability. *Global Environmental Change*, 16, 268-281.
- Adger, W.N., Arnell, N.W., & Tompkins, E.L. (2005). Successful adaptation to climate change across scales. *Global Environmental Change*, 15, 77-86.
- Adger, W.N., Dessai, S., Gouldem, M., Hulme, M., Lorenzoni, I., Nelson, D.R., Naess, L.O., Wold, J., & Wreford, A. (2009). Are there social limits to adaptation to climate change? *Climatic Change*, 93, 335-354.

- Allison, H. E., & Hobbs, R. J. (2004). Resilience, adaptive capacity, and the “Lock-in Trap” of the Western Australian agricultural region. *Ecology and Society*, 9(1), 3.
- [ASDMA] Assam State Disaster Management Authority. (n.d.). Flood Early Warning System. Retrieved from http://www.asdma.gov.in/project_flood_warning.html
- Bauer, S., & Scholz, I. (2010). Adaptation to climate change in Southern Africa: New boundaries for sustainable development? *Climate and Development*, 2(2), 83-93. doi:10.3763/cdev.2010.0040
- Baraer, M., Mark, B.G., McKenzie, J.M., Condom, T., Bury, J., Huh, K., Portocarrero, C., Gomez, J., & Rathay, S. (2012). Glacier recession and water resources in Peru’s Cordillera Blanca. *Journal of Glaciology*, 58(207), 134-150.
- Baruah, S. (2012). Whose river is it anyway? Political economy of hydropower in the Eastern Himalayas. *Economic & Political Weekly*, XLVII(29), 41- 52.
- Bernard, H. R. (2006). *Research methods in anthropology: Qualitative and quantitative approaches*. Lanham, MD: Altamira Press.
- Black, R., Bennett, S.R.G., Thomas, S.M., & Beddington, J.R. (2011). Migration as adaptation. *Nature* 478, 447-449.
- Bora, A.K. (2004). “Fluvial geomorphology” in V.P. Singh et al. (eds.), *The Brahmaputra Basin Water Resources*, pp. 88-112. Netherlands: Kluwer Academic Publishers.
- Brooks, N., Brown, K., & Grist, N. (2009). Development futures in the context of climate change: challenging the present and learning from the past. *Development Policy Review*, 27(6), 741–765.
- Bolch, T., Kulkarni, A., Käab, A., Huggel, C., Paul, F., Cogley, J. G., Frey, H., Kargel, J. S., Fujita, K., Scheel, M., Bajracharya, S., & Stoffel, M. (2012). The state and fate of Himalayan Glaciers. *Science*, 336, 310-314.
- Brown, K. (2011). Sustainable adaptation: An oxymoron? *Climate and Development*, 3:1, 21-31. DOI: 10.3763/cdev.2010.0062
- Cannon, T., & Muller-Mahn, D. (2010). Vulnerability, resilience and development discourses in context of climate change. *Natural Hazards*, 55, 621–635. doi: 10.1007/s11069-010-9499-4.

- [CEA] Central Electric Authority. (2014). Status of hydroelectric potential development basin wide. Government of India. Ministry of Power. Retrieved from http://www.cea.nic.in/reports/hydro/he_potentialstatus_basin.pdf
- Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P., & Zhou, T. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Chevallier, R. (2010). Integrating adaptation into development strategies: The Southern African perspective. *Climate and Development*, 2(2), 191-200.
- Conway, D., & Schipper, E.L.F. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *Global Environmental Change* 21, 227–237. doi:10.1016/j.gloenvcha.2010.07.013
- Das, P.J., Chutiya, D., & Hazarika, N. (2009). Adjusting to Floods on the Brahmaputra Plains, Assam, India. Kathmandu: ICIMOD & Aaranyak.
- Dharmadhikary, S. (2008). Mountains of concrete: Dam building in the Himalayas. Berkeley: International Rivers.
- Dixit, A. (2003). Floods and vulnerability: Need to rethink flood management. *Natural Hazards*, 28(1), 155-179.
- Eakin, H., & Luers, A.L. (2006). Assessing the vulnerability of social-environmental systems. *Annu. Rev. Environ. Resour*, 31, 365-94.
- Eakin, H.C., Lemos, M.C., & Nelson, D.R. (2014). Differentiating capacities as a means to sustainable climate change adaptation. *Global Environmental Change*, 27, 1-8.
- Edwards, R., & Holland, J. (2003). *What is qualitative interviewing?* London: Bloomsbury Publishing Plc.
- Eriksen, S. H., & O'Brien, K. (2007). Vulnerability, poverty and the need for sustainable adaptation measures. *Climate Policy*, 7(4), 337-352.

- Eriksen, S., & Lind, J. (2009). Adaptation as a political process: Adjusting to drought and conflict in Kenya's drylands. *Environmental management*, 43(5), 817–835.
- Eriksen, S., Aldunce, P., Bahinipati, C.S., Martins, R.D., Molefe, J.I., Nhemachena, C., O'Brien, K., Olorunfemi, F., Park, J., Sygna, L., & Ulsrud, K. (2011). When not every response to climate change is a good one: Identifying principles for sustainable adaptation. *Climate and Development*, (3)1, 7-20.
- Folke, C., Hahn, T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annu. Rev. Environ. Resour.*, 30, 441-473.
- Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society*, 15:4, 20.
- Gallopín, G.C. (2006). Linkages between vulnerability, resilience, and adaptive capacity. *Global Environmental Change*, 16, 293-303.
- Gosh, S., & Dutta, S. (2012). Impact of climate change on flood characteristics in Brahmaputra basin using a macro-scale distributed hydrological model. *J. Earth Syst. Sci.*, 121(3), 637–657.
- Goswami, D.C. (1985). Brahmaputra River, Assam, India: physiography, basin denudation, and channel aggradation. *Water Resources Research*, 21(7), 959-978.
- Government of Arunachal Pradesh, Department of Power. (2008). Hydro Power Policy – 2008. The Arunachal Pradesh Gazette. Extraordinary. Retrieved from http://powermin.nic.in/whats_new/pdf/new_hydro_policy.pdf
- Hansen, J.E. (2005). A slippery slope: how much global warming constitutes “dangerous anthropogenic interference”? *Climatic Change*, 68, 269-279. doi:10.1007/s10584-005-4135-0
- Hijioka, Y., Lin, E., Pereira, J.J., Corlett, R.T., Cui, X., Insarov, G.E., Lasco, R.D., Lindgren, E., & Surjan, A. (2014). Asia. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327-1370.

- Immerzeel, W.W., Pellicciotti, F., & Bierkens, M.F.P. (2013). Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. *Nature Geoscience*, 6, 742-645.
- Jones, H.P., Hole, D.G., & Zavaleta, E. S. (2012). Harnessing nature to help people adapt to climate change. *Nature Climate Change*, 2, 504-509.
- Kalita, J., Bhagawati, A.K., Kalita, S., Duarah, B.P., Sarma, A.K., Mahanta, C., Biswas, S.P., & Sarma, J.N. (2010). Downstream Impact Study of the ongoing Subansiri Lower Hydroelectric Power Project at Gerukamukh of National Hydroelectric Power Corporation Limited. Guwahati & Dibrugarh: Gauhati University, IIT Guwahati and Dibrugarh University.
- Klein, R.J.T. (2011). Adaptation to climate change: More than technology. In Linkov, I. and T.S. Bridges (eds.), *Climate: Global Change and Local Adaptation*, pp. 157-168. NATO Science for Peace and Security Series C: Environmental Security. DOI 10.1007/978-94-007-1770-1_9.
- Leichenko, R., & O'Brien, K. (2008). *Double exposure: Global environmental change in an era of globalization*. Oxford: Oxford UP.
- Lemos, M.C., Boyd, E., Tompkins, E.L., Osbahr, H., & Liverman, D. (2007). Developing adaptation and adapting development. *Ecology and Society*, 12(2), 26.
- [MDONER] Ministry of Development of Northeast Region. (2012). Hydropower projects. Government of India. Retrieved from <http://mdoner.gov.in/node/1307>
- [MOSPI] Ministry of Statistics and Programme Implementation. Central Statistics Office. (2012). Manual on labor statistics (I)-2012. Government of India. New Delhi. Retrieved from http://mospi.nic.in/mospi_new/upload/Manual_Labour_Statistics-I_3oct12.pdf
- [MOSPI] Ministry of Statistics and Programme Implementation. Central Statistics Office. (2014). "Ch. 4: Participation in the economy" in Women and Men in India – 2014. Government of India. New Delhi. Retrieved from http://mospi.nic.in/mospi_new/upload/man_and_women/women_men_in_india_2014.htm
- Pahuja, S., & Goswami, D. (2006). A fluvial geomorphology perspective on the knowledge base of the Brahmaputra. Background Paper #3 for The World Bank Strategy Report "Development and Growth in Northeast India: The Natural Resources, Water, and Environment Nexus". Retrieved from http://web.worldbank.org/archive/website01062/WEB/0_CO-62.HTM

- Pelling, M., & High, C. (2005). Understanding adaptation: What can social capital offer assessments of adaptive capacity? *Global Environmental Change*, 15, 308–319.
- Pelling, M., & Manuel-Navarrete, D. (2011). From resilience to transformation: the adaptive cycle in two Mexican urban centers. *Ecology and Society*, 16(2), 11.
- Rampini, C. (2017). Impacts of hydropower development in Northeast India on the flows of the Brahmaputra and the resilience of downstream communities to climate change impacts on water resources. (Unpublished doctoral dissertation). University of California, Santa Cruz, USA.
- Rotberg, F.J.Y. (2010). Social networks and adaptation in rural Bangladesh. *Climate and Development*, 2(1), 65-72. doi:10.3763/cdev.2010.0031
- Sarma, M., & Choudhury, B. (2015). Continuity and change of certain culturally coded survival strategies of the Misings of Brahmaputra River Valley of Assam. *J. Hum. Ecol.*, 49(1-2), 129-137.
- Thayyen, R.J., & Gergan, J. T. (2009). Role of glaciers in watershed hydrology: A preliminary study of a “Himalayan catchment.” *The Cryosphere*, 4, 115-128.
- The World Bank. (2007). Development and growth in Northeast India: The natural resources, water, and environment nexus. Strategy Report. Roots Advertising Services Pvt Ltd., New Delhi, India. Retrieved from <http://web.worldbank.org/archive/website01062/WEB/IMAGES/NORTHEAS.PDF>
- Tschakert, P., & Dietrich, K. A. (2010). Anticipatory learning for climate change adaptation and resilience. *Ecology and Society*, 15(2), 11.
- Vagholikar, N., & Das, P. J. (2010). Damming Northeast India: juggernaut of hydropower projects threatens social and environmental security of the region. Kalpavriksh, Pune, India and Aaranyak/ActionAid India, Guwahati, India. Retrieved from http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Damming_Northeast_India_Kalpavriksh_Aaranyak_ActionAid_India_2010.pdf
- Water for Welfare Secretariat. (2008). Hydropower policies and guidelines. Indian Institute of technology. Roorkee, India. Retrieved from <http://www.ahec.org.in/links/water4welfare/HYDRO%20POWER%20POLICIES%20AND%20GUIDELINES.pdf>

- White, G.F., Kate, R.W., & Burton, I. 2001. Knowing better and losing even more: the use of knowledge in hazards management. *Environmental Hazards*, 3, 81–92.
- Wisner, B., Blaikie, P., Cannon, T., & Davis, I. (1994). *At Risk*. Second Edition. New York: Routledge
- Wrathall, D.J. (2012). Migration amidst social-ecological regime shift: The search for stability in Garífuna villages of northern Honduras. *Human Ecology*, 40, 583–596.
- Yaro, J.A., Teye, J., & Bawakyillenuo, S. (2015). Local institutions and adaptive capacity to climate change/variability in the northern savannah of Ghana. *Climate and Development*, 7(3), 235-245. DOI: 10.1080/17565529.2014.951018

CHAPTER 3

HYDROPOWER DEVELOPMENT ALONG THE BRAHMAPUTRA RIVER ERODES RURAL LIVELIHOODS' RESILIENCE TO CLIMATE CHANGE.

Abstract:

India's Northeastern region is highly vulnerable to the impacts of climate change on the Brahmaputra, Barak and Teesta rivers. The region is predominantly rural and a majority of the population is engaged in natural resource-based activities. The abundant flows of the rivers are essential to the local economies and especially the livelihoods of over 30 million rural dwellers in the region. Changes to river flows as a result of climate change impacts on Himalayan glaciers and monsoon rains threaten the rural economies and livelihoods of Northeast India. Additionally, a cascade of new dams are being built along the Brahmaputra and the Teesta rivers, rapidly modifying water flows and riparian ecosystems. This paper uses the concept of 'livelihood resilience' to critically examine the impacts of dam-based development along the Brahmaputra on rural livelihoods. In light of climate change impacts, local development efforts and policies should prioritize enhancing the resilience of rural livelihoods while facilitating diversification and opportunistic migration. However, findings from household interviews conducted in Arunachal Pradesh and Assam between January and October 2014 suggest that dam-based development along the Brahmaputra is eroding rural livelihood resilience to climate change. Hydropower development does not facilitate livelihood diversification into new sectors, but threatens ecosystem services that rural households rely on for their current livelihood portfolios. In the context of climate change impacts on Northeast India's rivers, the

damming of these key water resources decreases rural household's capacity to sustain their livelihoods, and sets the stage for distress migration and forced livelihood shifts towards casual wage labor.

Keywords: hydropower development, rural livelihoods, resilience, climate change, Northeast India, Brahmaputra

1. Introduction

India's Northeastern region is predominantly rural and a majority of the population is engaged in natural resource-based activities. Year-round, the abundant flows of the Brahmaputra, Barak and Teesta rivers are key to supporting a broad range of local ecosystems and the rural livelihoods of over 30 million people. At the same time, the river systems also bring destructive floods during the summer monsoon season, causing significant damages and losses to the region. Unlike the rest of country, there is little evidence of growth in Northeast India's industrial and service sectors, suggesting that agriculture and allied activities will remain the backbone of the local economy (The World Bank 2007). This poses an important challenge for local officials and resource managers given the climatic changes taking place in the region. Anthropogenic climate change is expected to increase temperatures in Northeast India by 2-2.5 °C between 2021 and 2050 (Eriksson et al. 2009). Warmer temperatures will bring increasingly harsher floods during the summer, lower river levels and drought conditions during the winter season, and increasingly variable rainfall patterns and river flows (Christensen et al. 2013,

Immerzeel et al. 2013). Northeast India's rural economies and livelihoods are highly vulnerable to the impacts of climate change on river flows, and local development efforts and policies must prioritize enhancing the resilience of local livelihoods while facilitating diversification and opportunistic migration in light of climate change impacts.

Currently, one of most important development processes taking place in Northeast India is the building of a cascade of dams along its rivers, particularly the Brahmaputra. Over one hundred new dams are planned in the river basin and their impacts will transform river flows and riparian ecosystems. The dams cannot provide significant flood control during the summer season, since most are run-of-the-river projects with small reservoirs (Vagholikar and Das 2010, Rampini 2017). However, officials claim hydropower development along the Brahmaputra river will bring local benefits and employment by increasing energy supplies and attracting new industries to Northeast India (The World Bank 2007). Yet little evidence exists to justify the claim that dam-based development benefits local rural economies and livelihoods (WCD 2000). Given the impacts of climate change and the reliance of rural livelihoods on the region's water resources, it is especially important to critically assess the livelihood impacts of hydropower development along the Brahmaputra.

By adopting an analytical framework that integrates sustainable livelihoods and resilience approaches, this paper examines the impact of dams on the livelihood resilience of downstream rural communities to climatic changes. If dam-based development facilitates industrialization in Northeast India, diversification into new industries can increase the resilience of local livelihoods to climate change (Zhang

2011). At the same time, this research shows that skill and education constraints can limit the ability of rural households to take advantage of employment opportunities in new sectors. Hence, maintaining access to key water resources and riparian ecosystems remains essential for the livelihoods of rural households in Northeast India. Moreover, in rural areas, many non-agricultural activities such as house construction are also dependent on natural-resources linked to the river system, so access to these resources is critical to rural livelihoods even when they are not based primarily on agriculture. Drawing on a case-study dam and household-level interviews, this study examines the impacts of hydropower development on rural livelihoods to understand whether dams are building or eroding their resilience to climate change.

In the next section, I define key terms and explain how an integrative livelihood resilience framework helps us examine the reconfiguration of rural livelihood systems by hydropower development in light of climate change impacts on water resources. In section 3, I focus on the key role that the Brahmaputra river plays in supporting local livelihoods in Northeast India, and I describe current efforts to dam the main stem of the river and its tributaries. In section 4 and 5, I introduce the case study dam and the methods that were used for this project. In section 6, I discuss my findings showing that, by limiting access to key ecosystem services, the hydroelectric project is reducing the capacity of downstream families to maintain diverse rural livelihoods, without at the same time creating new opportunities for livelihood diversification and transformation. In the remainder of the paper, I reflect on future scenarios for the millions of rural dwellers who must adapt to climatic

changes at the same time as large-scale hydropower development erodes the resilience of their rural livelihoods.

2. Resilient rural livelihoods

This paper integrates sustainable livelihoods and resilience approaches to critically examine the impacts of dam-based development along the Brahmaputra on rural livelihoods downstream. The next paragraphs review key insights from both frameworks. Afterwards, I describe the ways in which the integrative concept of ‘livelihood resilience’ helps us understand the impacts of hydropower development in Northeast India on rural livelihoods, within the broader context of anthropogenic climate change.

A livelihood is the ensemble of capabilities, assets and activities required to support a given standard of living (Chambers and Conway 1992). It encompasses various forms of income, as well as the social relations and institutions that allow people to access assets and pursue particular livelihood activities (Ellis 1998). Beginning in the early 1990s, the concept of ‘sustainable livelihoods’ became popular amongst development agencies and researchers concerned with rural poverty alleviation (Scoones 2009). A livelihood is defined as sustainable when it can recover from stresses and shocks, sustain or improve standards of living, and contribute benefits to other livelihoods at the local and global level in the short and long term (Chambers and Conway 1992). Unlike previous approaches to poverty alleviation that focused on single economic sectors like agriculture, the sustainable livelihoods approach argues that eliminating poverty requires understanding the

complex web of activities and interactions through which rural dwellers make a living (Enns and Bersaglio 2015, Scoones 2009).

The sustainable livelihoods approach contributes two important aspects to our understanding of rural economies. First, it portrays rural livelihoods as a diverse portfolio of activities that include farm income, both cash and in-kind, and non-farm income such as wage employment and remittances. The capacity of rural households to maintain a diverse set of livelihood activities is influenced by a variety of constraints and opportunities in the local and broader economy and society (Ellis 1998, Paavola 2008). Livelihood diversification is considered key to the sustainability of rural livelihoods coping with shocks and changes, such as climate change, because it helps spread risks ex-ante and speeds up recovery in the aftermath of a shock (Paavola 2008, Vincent et al. 2013). Secondly, the sustainable livelihoods framework argues that access to natural resources is crucial to rural households, whether they are engaged primarily in agriculture or not, because it increases options for livelihood diversification. As such, social, political, economic and natural resource management regimes that inhibit access to natural resources also constrain rural livelihood sustainability (Ellis and Allison 2004). The sustainable livelihoods framework is a useful lens for understanding the impacts of hydropower development in Northeast India, since dams transform river flows and ecosystems upon which local rural households rely for their livelihood portfolios.

In the last decade, the sustainable livelihood approach has become less prominent. In part, this is because it has failed to engage with the power dynamics that drive agrarian change and to tackle broader long-term trends, such as historical

processes of proletarianization and de-agrarianisation (O’Laughlin 2002, Scoones 2009). Some scholars are now attempting to re-energize livelihood perspectives by integrating the sustainable livelihoods approach with resilience theories from ecology. Resilience theory warns that ecosystems can flip to entirely new states, for example from grassland to shrubland, as a result of a shock. In this context, resilience is defined as the amount of change a system can endure before it flips to a different state (Gunderson 2000). More specifically, it is the ability of a system to absorb a disturbance while maintaining the same set of essential functions, structures and relationships between its components (Berkes 2007, Holling 1973). The use of resilience theory has extended beyond ecology to examine how societies recover from stresses and shocks, and to understand the feedbacks between social and ecological systems (Turner et al. 2003, Walker and Meyers 2004). The resilience framework both echoes and complements sustainable livelihoods perspectives in helping us understand how rural households and their livelihoods adapt to stresses and shocks. Both approaches acknowledge the close link between human and natural systems and are concerned with “sustaining ‘life support systems’, and the capacity of natural systems to provide for livelihoods into the future” (Scoones 2009, p. 190). Both perspectives also emphasize the importance of diversity in helping systems recover from disturbances. Livelihood diversification and the preservation of a variety of social networks are considered key to building resilient social systems (Berkes 2007, Folke et al. 2005, Turner et al. 2003). At the same time, resilience theory takes one step further by highlighting the importance of transformability. Transformability is the capacity of the actors in a system to make use of a disturbance as an opportunity

to initiate transformative change into a more desired state (Folke et al 2005, Walker et al. 2004).

The concept of livelihood resilience draws from both the resilience and sustainable livelihoods theories and it refers to the capacity of livelihood strategies to absorb the impacts of disturbances without causing major declines in production and wellbeing, or causing a shift to entirely new livelihood configurations (Marschke and Berkes 2006, Speranza et al. 2014). Within this emerging literature, researchers have begun to empirically document livelihood strategies that build resilience to environmental change and factors that erode it (Agrawal and Perrin 2008, Cooper and Wheeler 2015, Osbahr et al. 2008, Sallu et al. 2010). Livelihood resilience research focuses on people as the main actors and considers human agency, empowerment, freedoms and entitlements to assets as fundamental to helping households navigate processes of change while sustaining their livelihoods (Tanner et al. 2015). Importantly, the concept of livelihood resilience also addresses the transformational aspects of disturbances and calls for development programs that help people deal with environmental change by considering novel livelihood opportunities and trajectories (Speranza et al. 2014, Enns and Bersaglio 2015). At the same time, livelihood resilience prioritizes the right of people to determine their own livelihoods and advocates for “reformulations of livelihood systems that enable the most vulnerable people to navigate potentially destabilizing global changes on their own terms” (Tanner et al. 2015, p. 25).

The notion of climate-resilient livelihoods is gaining traction within development organizations such as the United Nations and the World Bank, but

scholarly research on livelihood resilience is still nascent. On one hand, this paper answers calls for more research on the resilience of the livelihood systems of poor people to climatic change (Tanner et al. 2015). On the other hand, it advances the livelihood resilience literature by shedding light on broader processes, in this case dam-based development, that shape the ability of households to build climate-resilient livelihoods. A livelihood resilience approach also gives us a new perspective into the effects of dams on rural households, because it emphasizes the importance of sustaining rural livelihoods, maintaining access to key natural resources, and preventing forced livelihood shifts in light of uncertain climatic futures.

3. The Brahmaputra river basin

3.1. Livelihood support and summer floods

Originating in the glaciers of Tibet and flowing through China, Northeast India and Bangladesh, the Brahmaputra river is one of the world's largest river systems. In Northeast India, the Brahmaputra river is the backbone of the region's agrarian economies, especially in the states of Assam and Arunachal Pradesh, where a majority of the river basin lies. The river system provides countless resources to the region, including water for irrigation, fish for food, groundwater recharge, transportation, and cultural services such as recreation and religious activities (see Figure 1).

Both Arunachal Pradesh and Assam have primarily natural resource-based economies and a large majority of the population is engaged in agricultural activities.

In Arunachal Pradesh, about half of the cultivated area is under *jhum* (shifting) cultivation, while the other half is under permanent cultivation (Government of Arunachal Pradesh 2001). Rice is the most widely grown crop, and other major crops include maize, millet, legumes, fruits, oilseeds, leafy vegetables, tubers and ginger. Crop cultivation is often supplemented by a number of activities including hunting, fishing, and the collection of forest products (Government of Arunachal Pradesh 2006). In Assam, agriculture, fisheries and silk farming make up the state's primary economic sectors (Government of Assam 2016). A vast majority of Assamese farmers harvest a single rice crop at the end of the monsoon season, after which the fields remain idle for the rest of the year. Other crops commonly grown by Assamese farmers include rapeseed and mustard, turmeric, chilies, cabbage, cauliflower, potato, banana, papaya, areca nut, orange, pineapple and jute. Assam is well known for its sericulture and especially for the rearing of the muga silkworm, which produces a golden thread only found in Assam. Assam also produces more than half of the tea grown in India and accounts for about 14% of the world's tea output (Government of Assam n.d.).

A large majority of farmers in Assam are smallholders practicing subsistence agriculture in holdings that average 1.55 hectares in size (Government of Assam n.d.). In Arunachal Pradesh, the average size of land holdings is 3.55 hectares, but nearly 40% of farmers cultivate on less than two hectares of land despite low population densities (Government of Arunachal Pradesh 2006). The level of mechanization, fertilizer usage and irrigation in both Assam and Arunachal Pradesh are very low. Assamese and Arunachali farmers depend mostly on monsoon rains and light flood

events, which occur primarily between June and October, for irrigation. Less than 17% of Assam's cropland and 21% of Arunachal Pradesh' cropped area is irrigated using canals, irrigation tanks or groundwater from tube wells (Department of Irrigation, Assam, n.d.). Fertilizer use in both Assam and Arunachal Pradesh is low, with 63 kg and 3 kg of fertilizer used per hectare respectively compared to the national average of 135.3 kg per hectare (ICC 2013). Farmers are also hampered by low levels of mechanization and very low access to credit (Government of Assam n.d., Verghese and Iyer 1993).

While the Brahmaputra river system provides natural resources that are key to rural livelihoods, the river also floods yearly during the summer season, posing a tremendous challenge for the region's inhabitants and local officials. Summer floods cause tremendous damage to houses, fields, cattle, public utilities, infrastructure, drinking water sources, and lead to the spread of disease and the loss of human lives.



Figure 1: Children fishing in the Dikrong river, a tributary of the Brahmaputra, in Assam.

3.2. Hydropower development

In the last decade, the Brahmaputra river has been at the center of India's efforts to increase its large-scale hydroelectric generation capacity, which currently accounts for 14% of India's total installed capacity (EIA 2016). The push for hydropower in India mainly comes from the need to meet the increasing power demands of a rapidly growing economy and population. Additionally, India is affected by power and energy shortages and over 20% of India's population still does not have access to electricity (Dharmadhikari 2008, EIA 2016). The Brahmaputra has the highest hydropower generation potential of any river in India, representing approximately 40% of India's total hydropower potential (MDONER 2012). This potential is concentrated in the state of Arunachal Pradesh, where the river and its north-bank tributaries traverse steep slopes as they flow from the Himalayan

mountains to the floodplains of Assam. Plans to dam the Brahmaputra began in the 1980s, after India's central government created the Brahmaputra River Board to help develop the basin's water resources. Dam building efforts accelerated in the early 2000s due to the entry of many private companies in the hydropower sector (Water for Welfare Secretariat 2008). New policies in India, which made it easier for private companies to profit from hydroelectricity sales, led to a large number of private players signing contracts to build hydropower projects, many without any previous experience in the sector (Dharmadhikari 2008). The acceleration of dam building efforts in Northeast India mirrors the efforts of many Asian countries to dam Himalayan rivers: Several hundred new dams are planned or under construction in China, Pakistan, Nepal, Bhutan, Myanmar, and Laos (Bakker 1999, Grumbine and Pandit 2013). More broadly, the damming of the Himalayas is part of a global resurgence in hydropower development efforts in the 21st century (Ahlers et al. 2015, Briscoe 2010).

Between 2006 and 2012, the government of Arunachal Pradesh allotted contracts for 140 new dams along the Brahmaputra for a total installed capacity of 41,000 MW (MDONER 2012, Vaghlikar and Das 2010). All of these new hydropower projects entail large or mega-dams, above 25 MW and 100 MW in generation capacity respectively, and most are run-of-the-river projects that maximize hydroelectricity production while minimizing reservoir size (Vaghlikar and Das 2010). Downstream communities, particularly those in Assam, have been largely excluded from public hearings about dam projects, and public consultation procedures have been fraught with controversy calling into question the legitimacy of

those hearings (Dharmadhikary 2008, Vaghlikar et al. 2005). Furthermore, even though Northeast India struggles with energy poverty, most of the hydroelectricity generated in Northeast India will benefit regions and urban centers further away. A strategy report by the World Bank (2007) on the economic development of Northeast India states that “until large-scale industrial expansion takes place in the region, most of the generated power will need to be transmitted to the other regions of the country” (p. 62). The central Indian government has begun investing in large-scale transmission infrastructure to export hydroelectricity from the Brahmaputra river basin in Northeast India to regions further away that have higher energy demands (MDONER 2014) (see Figure 2).

Indeed, though Northeast India has abundant energy sources – moderate coal and natural gas reserves, large petroleum reserves and immense and untapped hydropower potential – local energy demand is fairly low. Arunachal Pradesh and Assam have a per capita consumption of electricity that is nearly 4 times lower than the national Indian average (Arunachal Pradesh Human Development Report 2006, Verghese 2006). Both states struggle with low levels of operational efficiency, low voltage operations, high operation costs to remote villages, irregular power supply in transmission lines, and de-electrification as a result of floods and theft, which result in low electrification rates particularly in rural areas (Assam Human Development Report 2003, Arunachal Pradesh Human Development Report 2006).



Figure 2: Transmission lines in Mipubasti, Arunachal Pradesh, exporting hydroelectricity from the Ranganadi HEP.

4. Case Study: The Ranganadi Hydroelectric Project

This research uses a case study dam to investigate the impacts of hydropower development in the Brahmaputra river basin on the livelihood resilience of downstream communities. The Ranganadi Hydroelectric Project (HEP) was built by the North Eastern Electric Power Corporation (NEEPCO) in the Lower Subansiri District of Arunachal Pradesh. The Ranganadi HEP went online in 2002 and is the first mega-dam to be completed along the Brahmaputra river in Northeast India. This hydroelectric project was selected to exemplify the impacts of many other similar projects in the region.

The Ranganadi HEP, like most other projects along the Brahmaputra and its tributaries, is a run-of-the-river project. The 68-meter tall and 345-meter long dam on the Ranganadi river diverts water from the Ranganadi to the Dikrong river, where the

powerhouse is located, at a maximum rate of 160 cubic meters per seconds. The Ranganadi HEP has an installed capacity of 405 Megawatts. Before its commissioning, the total installed power generation capacity of Arunachal Pradesh was only 59MW (Arunachal Pradesh Human Development Report 2006). Assam receives 43% of the hydroelectricity generated by the Ranganadi HEP annually, while Arunachal Pradesh receives 12% of the generated hydropower for free in accordance with the state hydroelectric power policy (Government of Assam 2006). Both the dam and the powerhouse are located in the Lower Subansiri district of Arunachal Pradesh, near the state border with Assam. Due to its proximity to the Assamese border and the diversion of water from the Ranganadi to the Dikrong, the Ranganadi HEP affects river flows, riparian ecosystems, downstream communities and their livelihoods along both rivers in Assam and Arunachal Pradesh.

In particular, research shows that the impacts of the Ranganadi HEP on the flows of the Ranganadi and Dikrong rivers mimic the predicted impacts of climate change on the Brahmaputra river basin – more destructive floods, reduced lean season flows and increased flow variability – hence acting as an added stressor for downstream communities as they move towards uncertain water futures (Rampini 2017). This paper focuses specifically on whether the Ranganadi HEP, through its impacts on key ecosystem services and local rural economies, is making the rural livelihoods of downstream households more or less resilient to climate change impacts.

5. Methods

This research uses qualitative interview data with rural households living downstream of the Ranganadi HEP to get an in-depth understanding of the perceived livelihood impacts of the hydropower project. Most research on livelihoods takes the household as the unit for empirical investigation, though the role of non-resident members is often explicitly recognized (Ellis 1998). This project focuses on impacts on downstream livelihoods because the Ranganadi HEP has a small reservoir, which according to NEEPCO required the assisted resettlement of only 297 families. Downstream impacts of the dam along the Dikrong and Ranganadi river in both Assam and Arunachal Pradesh will affect a much larger number of households.

Overall, seventy-four semi-structured household-level interviews were conducted in 51 rural villages along both rivers in both states encompassing a total of 465 people (see Table 1). The interviews took place between January and September 2014 in villages located less than 2 kilometers from the riverbank. Villages close to the riverbanks were selected because they tend to rely closely on riparian resources and have experienced first-hand changes in river flows and riparian ecosystems since the construction of the Ranganadi HEP. At the same time, given their proximity and dependence on the river system, they are also especially vulnerable to the impacts of climate change on river flows. Given the lack of formal village maps and lists of population, convenience sampling was used to select the households to be interviewed within each village. Due to Arunachal Pradesh's status as a Restricted Area, which places limits on non-residents visiting the state, less interviews were conducted in Arunachal Pradesh than in Assam.

Interviews were conducted in Assamese, Hindi and English. Interviews were recorded and then transcribed into English. Analysis focused on the impacts of the Ranganadi HEP on key ecosystem services and households' livelihood activities, and on the perceived benefits from the Ranganadi HEP in terms of livelihood diversification. For the analysis, descriptive and analytical statistics were used to summarize trends in the data, while ethnographic details were used to enrich our understanding of households' livelihood resilience. This project relies on qualitative interview data because this method allows rural households to identify what characteristics are most important to their own livelihoods, and self-assess how dam-based development has affected their livelihood resilience. This bottom-up approach is in line with the livelihood resilience approach, which aims to put people's perspectives and livelihood priorities at the center of the analysis (Tanner et al. 2015).

	Assam	Arunachal Pradesh	Total
Number of interviewed households	51	23	74
Sample population	283	182	465
Number of villages in sample	38	13	51
Interviews along Ranganadi River	33	11	44
Interviews along Dikrong river	18	12	30

Table 1: Overview of households' interviews sample.

6. Impacts of Ranganadi HEP on livelihood resilience of downstream communities

Interviews revealed that rural households downstream of the Ranganadi HEP have diverse livelihood portfolios that depend in part on the various ecosystem services provided by the river. Secondly, respondents described how, by modifying river flows, the Ranganadi HEP is limiting their access to key natural resources and reducing their capacity for livelihood diversification. At the same time, respondents did not perceive any new opportunities for livelihood transformations and diversification since the completion of the project. Overall, findings suggest that dam-based development is eroding the livelihood resilience of downstream households.

6.1. Diverse rural livelihoods

The Brahmaputra river basin is the backbone of the Arunachali and Assamese natural resource-based economies. During the summer season, monsoon rains and river floods throughout the basin irrigate and deposit nutrient-rich sediment on rice fields, recharge the groundwater table, and form wetlands that act as nurseries for fish. During the dry winter season, waters from the river basin are used for irrigating winter crops, providing water for livestock, and for recreational and religious activities. Because of the fundamental role of the river system in supporting rural livelihoods and the local economy, Arunachali and Assamese people often refer to the Brahmaputra as the ‘lifeline of the region’ (Vagholikar and Das 2010). The

households sampled reflected the predominantly agrarian nature of the local economy (see Table 2).

Livelihood types	Number of households
Agriculture and livestock	42
Business	12
Casual labor	9
Professional	7
Pension and remittances	3
Other ¹	1

Table 2: Summary of households' primary livelihood activities.

¹ Security officer at NEEPCO housing colony in Doimukh

A majority of the interviewed household (57%) practiced agriculture and livestock-rearing as their primary livelihood activity, including some households (5%) that worked as share-croppers and one household whose members worked on a tea plantation for a daily wage. Amongst the rest of the households whose primary livelihood was agriculture, nearly all of them (92%) cultivated crops for household consumption, but many (41%) also sold a share of their harvested crops and animals for income. A large majority of farming households (88%) grew rice as their main crop, and most households (67%) also grew winter crops, known locally as *rabi* crops, including potatoes, mustard, onions, garlic, ginger, turmeric, chili, peas and other vegetables. Many also cultivated fruit orchards (60%), primarily bananas, oranges, pineapples and betel nut trees. During the dry winter season, these secondary crops are an important economic buffer for households whose primary livelihood is rainfed rice agriculture.

A majority of farming households (57%) also indicated hunting or fishing as part of their livelihood activities, and many (33%) had female household members engaged in weaving of traditional Assamese or Arunachali garments. Amongst the agricultural households that engaged in hunting, fishing or weaving as part of their livelihood portfolio, nearly half (48%) sold a share their harvest or products. These results show that rural farming households already diversify their agricultural livelihoods by engaging in a variety of natural-resource based activities and selling a share of their products for income generation. At the same time, many farming households also engaged in non-farm activities as part of their livelihood portfolio. Nearly one fourth (22%) ran a family business, including a river-crossing boat business, a small timber operation and a shop to recharge mobile phone card, while another fourth of the farming households had members engaged in casual wage labor. A smaller percentage relied on remittances (12%), and even fewer (7%) had a household member that worked as a salaried employee. Overall, this variety of farm and non-farm activities allows farming households to be adaptable to seasonal cycles and fluctuations in resource abundance, since the region receives 80% of its rain between mid-June and mid-September.

At the same time, even amongst the interviewed households whose primary income came from non-farming activities (43%), nearly all of them (94%) engaged in natural-resource based activities as part of their livelihood portfolio. Most of them (78%) raised livestock, and nearly half of them (47%) cultivated fruit orchards. Interestingly, many (44%) also engaged in rainfed rice agriculture, and an equal number cultivated winter crops during the dry winter season. Finally, numerous non-

farming households listed fishing or hunting (44%) and weaving (16%) amongst their livelihood activities.

6.2. Riparian ecosystem services and hydropower impacts

Rural households in the Brahmaputra river basin rely on various ecosystem services provided by the river to support their livelihood portfolio, even when their primary livelihood is not agriculture. Ecosystem services are benefits that people obtain from ecosystems and they include provisioning services, such as food and water, cultural services that provide recreational, aesthetic, or spiritual benefits, supporting services such as wetland formation and nutrient cycling, and regulating services such as climate and disease control (Millennium Ecosystem Assessment 2005). A vast majority of the interviewed households (84%) identified at least one riparian ecosystem service upon which they relied. All together, interviewed households listed 10 key ecosystem services provided by the Ranganadi and Dikrong rivers (see Table 3). Households relied on a median of 2 ecosystem services, though some respondents listed as many as 7 different ecosystem services as being key to their household activities. An independent-samples t-test was conducted to compare the average number of ecosystem services that farming and non-farming households relied upon. There was a significant difference in the number of ecosystem services used by farming households ($M=3.14$, $SD= 0.32$) and non-farming households ($M= 2.06$, $SD= 0.31$); $t(71)= 2.41$, $p = 0.019$. These results suggest that, while all rural households rely on riparian ecosystem services provided by the river system,

households whose primary livelihood activity is agriculture relied on more ecosystem services.

Ecosystem service (ES)	Type of ES	Percent of households
Fishing	Provisioning, consumptive	53
Freshwater for laundry	Provisioning, non-consumptive	43
Space for outdoor recreation	Cultural, recreation	39
Freshwater for bathing	Provisioning, non-consumptive	37
Freshwater for livestock	Provisioning, consumptive	35
Space for religious activities	Cultural, spiritual	22
Formation of wetlands and fishponds	Supporting, habitat formation	20
Freshwater for irrigation	Provisioning, consumptive	10
Sand and boulders for construction	Provisioning, raw materials	5
Freshwater for drinking	Provisioning, consumptive	4

Table 3: Key riparian ecosystem services identified by rural households.

The majority of respondents (53%) mentioned fishing as the most important ecosystem service, and several others (20%) also recognized the important supporting service provided by the rivers as they form and replenish wetland habitats. Throughout the year, but especially during the flood season, Assamese and Arunachali rural dwellers use the river basin and its wetlands for fishing and restocking their fishponds with juvenile fish. In both states, fish is a key component of the local diet and fishing is an important subsidiary livelihood activity for many rural households. Indeed, research has shown that fishing strengthens livelihood resilience, because it is a highly monetized activity that provides households with

cash that they can use for other livelihood objectives (Ellis and Allison 2004).

Many households described relying on the river for freshwater for their cattle (35%), for laundry (43%), and for bathing (37%). Several respondents emphasized the importance of the river for recreation (39%) and religious activities (22%). The Brahmaputra river and its tributaries are at the center of many religious activities, including funeral rites and religious holidays such as the Bohag Bihu, Assam's main holiday. It was less common, on the other hand, for interviewed households to use the river for irrigation or drinking water, largely because of the high levels of sediment-load and iron concentration (Mahanta and Subramanian 2004). Instead, households that engaged in farming activities relied mostly on summer monsoon rains for irrigation, or groundwater during the lean season. For potable water, most interviewed households used their private tube well (71%), while the remainder (25%) obtained drinking water from a communal well, spring water storage facilities, or through a residential water supply plumbing system. Overall, interviews revealed the importance of ecosystem services in allowing households to sustain a variety of livelihood and other activities.

During our interviews, respondents also noted that, by modifying the Ranganadi and Dikrong river flows, the Ranganadi HEP has changed the extent to which they can rely on the river system to provide key ecosystem services. Most interviewed households (60%) noticed a decline in the quantity and quality of riparian ecosystem services and a reduction in access to these services, since the project began construction in 1998. In particular, respondents emphasized the negative impacts of the Ranganadi HEP on fish and winter season flows. A majority of the surveyed

households (63%) noticed that fish have decreased in size and abundance. In the winter, when river levels are low, the impoundment and diversion of water by the dam for hydroelectricity generation further reduces river flows (Rampini 2017). Interviewed households complained that reduced winter flows have made it harder to rely on the river for rabi crop irrigation. Others had to resort to using water from their tube wells for their cattle. Respondents also said their orchards had experienced water-stress and noted a decrease in the amount of grass along the riverbanks for animals to graze. Overall, by modifying ecosystems and reducing the capacity of downstream rural household to access key natural resources, the Ranganadi HEP challenges their capacity to sustain a diverse livelihood portfolio.

6.3. Impacts of the Ranganadi HEP on downstream household livelihood diversification

Both Assam and Arunachal Pradesh have low levels of economic development when evaluated using conventional indicators. Per capita income levels are below the national average, and more than a third of Assamese people and nearly one quarter of Arunachali households are below the poverty line (Government of Assam 2003, Government of Arunachal Pradesh 2006). Hydropower enthusiasts argue that dam-building in Northeast India promotes local economic development and employment by generating cheap energy that will attract new industries to the region, while creating roads and infrastructure that facilitate market connectivity and employment opportunities (Brahmaputra River Board 1983, Verghese 2006). Increased industrialization and diversification into new sectors is one pathway to

increase income levels, alleviate poverty, and reduce vulnerability to environmental change (Zhang 2011). Our findings show that, in the context of Northeast India, these claims are problematic in two ways.

First, there is little evidence that dam-based development creates employment for local communities beyond a short-lived pulse during the project construction stages. Even then, migrant workers are often hired instead, sometimes leading to conflicts with local communities (WCD 2000). The 74 families interviewed for this project comprised a total of 465 people and 274 working-age adults (aged 15-65). Amongst the working-age adults in our sample, only 2 individuals had been employed by NEEPCO in low-skilled jobs, since the construction of the dam began in 1998. One individual had been temporarily employed to build culverts near the dam site, while the other had worked as a security officer at the Doimukh housing colony for 6 years at the time of our interview. Many respondents had hoped for employment opportunities through NEEPCO and a few applied unsuccessfully. One respondent – the son of the NEEPCO security officer – submitted a job application to the hydropower company in 2012, but never received a reply despite holding a master's degree in Commerce. A few respondents cited local corruption and preference for migrant workers, who do not have ties with local communities, as the reasons for why downstream rural household had seen so little benefits in terms of employment opportunities.

Secondly, skill and education constraints limit the ability of local rural households to take advantage of employment opportunities in new industries. In both Assam and Arunachal Pradesh, literacy rates are lower than the national rate and the

absence of adequate school facilities leads to high drop out rates (Government of Assam 2003, Government of Arunachal Pradesh 2006, Indian Census 2011). Amongst interviewed households, the average literacy rate was 81% – 86% for men and 72% for women – but high school graduation rates were much lower, especially amongst women (see Table 4). Independent-samples t-tests were conducted to compare educational attainments between farming and non-farming households. Average educational attainments were lower amongst non-farming households across categories, but the differences between the two groups were not statistically significant. The average college graduation rate for all interviewed households was only 8%, not counting members who had migrated. This suggests that both farming and non-farming households are constrained by educational attainments in their capacity to diversify into new sectors.

Educational attainments (means)	Farming households (1)	Non-farming households (2)	Total	P-value (1) = (2)
Literacy rate	.77 (.25)	.85 (.18)	.81 (.23)	.14
Men	.84 (.24)	.90 (.22)	.86 (.23)	.28
Women	.69 (.36)	.77 (.29)	.72 (.33)	.36
High school graduation rate	.19 (.24)	.27 (.35)	.22 (.29)	.24
Men	.22 (.31)	.33 (.43)	.27 (.37)	.25
Women	.15 (.25)	.20 (.36)	.17 (.30)	.45

Table 4: Comparison of educational attainments between farming and non-farming households.

While interviewed households did not perceive livelihood diversification benefits as a result of the Ranganadi HEP, a few respondents said that changes in river flows and floods as a result of the project forced their household to abandon farming as a livelihood activity. Three families in Assam abandoned farming as their primary activity and transitioned fully to casual wage labor, while two other families ceased farming as a secondary livelihood activity. Casual wage labor entails manual, unskilled or low-skilled labor that is carried out temporarily in exchange for a daily wage. All five families had also permanently relocated as a result of dam-induced floods. Two of these families had resettled illegally on government-owned land and voiced concern about possible future evictions. One of these families described relocating alongside 35 other households from their village after they lost their paddy fields and communal fishpond to a dam-induced flood.

7. Discussion and conclusion

Natural-resource based economies and livelihoods are facing unique pressures as a result of climate change impacts on temperatures, water availability, and extreme events. Northeast India's rural livelihoods are highly vulnerable to the impacts of climate change on the Brahmaputra, Barak and Teesta rivers. Warmer temperatures are shrinking Himalayan glaciers, changing monsoon patterns, and altering the flows of these rivers (Eriksson et al. 2009, Immerzeel et al. 2013). On one hand, summer floods are becoming more frequent and severe, on the other hand river flows are decreasing during the dry winter season and over the long-term (Christensen et al. 2013, Immerzeel et al. 2013). Climate change is also increasing the interannual

variability of river flows (Hijioka et al. 2014). Climate change impacts on the Brahmaputra river system will have significant negative consequences for millions of people in the region, who rely on the river for their livelihoods.

At the same time, the riparian landscapes of Northeast India are undergoing large-scale transformations as a series of dams are built along the Brahmaputra and Teesta rivers. While hydropower development is cast as a path towards the sustainable development of the region, this research argues that dam-based development in Northeast India erodes the livelihood resilience of rural households and sets the stage for distress migration and forced livelihood shifts towards casual wage labor. Several important insights emerged from interviews with rural households downstream of the Ranganadi HEP. First of all, rural households are resilient to seasonal fluctuations in river flows because they have diverse livelihood portfolios made up of farming and non-farming activities. Secondly, access to a variety of riparian ecosystem services is fundamental to the capacity of rural households, especially farming households, to sustain an assortment of livelihood activities. Interviews also revealed that, by reducing the capacity of downstream rural household to access key ecosystem services such as fish, the Ranganadi HEP is constraining livelihood diversification via natural resource-based activities. At the same time, the project has not created new employment opportunities, and educational constraints limit the capacity of households to take advantage of them.

While Northeast India possesses abundant energy and natural resources, dam-based development risks repeating the historical experience of oil exploitation and tea plantations, which siphoned off resources from the region without contributing to its

overall well-being (Vagholikar and Das 2010). Large-scale dam-building efforts that are taking place in the Brahmaputra river basin threaten the river's capacity to deliver important ecosystem services and support rural livelihoods, at the same time as climate change alters river flows. Hydropower development efforts in the region are proceeding in the absence of a plan to optimize regional and local benefits (Crow and Singh 2009), which has led to prioritizing hydroelectricity generation for distant urban centers over the long-term sustainability of the region, its rural economies and livelihoods. In light of climate change impacts on key water resources, development efforts in Northeast India should prioritize enhancing the resilience of rural households and their livelihoods. This entails sustaining key ecosystem services that currently support rural livelihood activities, while adapting agricultural systems through improvements in irrigation and mechanization, access to credit, the introduction of new crop varieties, and insurance schemes. It also requires institutional support in the form of training and education to help rural households reconfigure their livelihood portfolios and consider new livelihood trajectories on their own terms. In other words, the development of Northeast India's rivers should aim to help rural households adapt to climatic changes, and prevent processes of forced proletarianization, migration and impoverishment that can increase vulnerability to environmental change in the long-term.

References

Agrawal, A., & Perrin, N. (2008). Climate adaptation, local institutions, and rural livelihoods. *IFRI Working Paper # W08I-6*. School of Natural Resources and Environment University of Michigan.

- Ahlers, R., Budds, J., Joshi, D., Merme, V., & Zwarteveen, M. (2015). Framing hydropower as green energy: Assessing drivers, risks and tensions in the Eastern Himalayas. *Earth Syst. Dynam.*, 6, 195–204.
- Bakker, K. (1999). The politics of hydropower: Developing the Mekong. *Political Geography*, 18, 209-232.
- Berkes, F. (2007). Understanding uncertainty and reducing vulnerability: Lessons from resilience thinking. *Nat. Hazards*, 41, 283-295.
- Brahmaputra River Board. (1983). Project Report on Subansiri Dam Project. Guwahati, Assam.
- Briscoe, J. (2010). Overreach and response: The politics of the WCD and its aftermath. *Water Alternatives*, 3(2), 399-415.
- Chambers, R., & Conway, G. (1992). Sustainable rural livelihoods: practical concepts for the 21st century. IDS discussion paper, 296. Brighton: IDS.
- Christensen, J.H., Krishna Kumar, K., Aldrian, E., An, S.-I., Cavalcanti, I.F.A., de Castro, M., Dong, W., Goswami, P., Hall, A., Kanyanga, J.K., Kitoh, A., Kossin, J., Lau, N.-C., Renwick, J., Stephenson, D.B., Xie, S.-P., & Zhou, T. (2013). Climate Phenomena and their Relevance for Future Regional Climate Change. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.
- Cooper, S.J., & Wheeler, T. (2015). Adaptive governance: Livelihood innovation for climate resilience in Uganda. *Geoforum*, 65, 96–107
- Crow, B., & Singh, N. (2009). The management of international rivers as demands grow and supplies tighten: India, China, Nepal, Pakistan, Bangladesh. *India Review*, 8(3), 306- 339.
- Das, P.J., & Ahmed, F. (2005). “Downstream impacts of the Ranganadi dam with special emphasis on the hydrological impact of the flow diversion plan.” in *Large Dams for Hydropower in Northeast India: A Dossier*. Menon, M. and K. Kohli, Eds. New Delhi: Kalpavriksh and South Asia Network on Dams, Rivers and People. Pp. 57-63.

- Datta, B., & Singh, V. P. (2004). "Hydrology" in V.P. Singh et al. (eds), *The Brahmaputra Basin Water Resources*, pp. 139-195. Kluwer Academic Publishers.
- Department of Irrigation, Assam. (n.d.). Website. Retrieved from <http://irrigassam.nic.in/>
- Dharmadhikary, S. (2008). Mountains of concrete: Dam building in the Himalayas. Berkeley: International Rivers.
- [EIA] Energy Information Administration. (2016). India Overview. EIA Beta. U.S. Department of Energy. Retrieved from <https://www.eia.gov/beta/international/analysis.cfm?iso=IND>
- Ellis, F. (1998). Household strategies and rural livelihood diversification, *The Journal of Development Studies*, 35(1), 1-38, DOI: 10.1080/00220389808422553
- Ellis, F., & Allison, E. (2004). Livelihood diversification and natural resource access. FAO, LSP WP 9. Access to Natural Resources Sub-Programme, Livelihood Diversification and Enterprise Development Sub-Programme.
- Enns, B., & Bersaglio, C. (2015). Exploring the implications of oil and gas development for livelihood resilience in Turkana, Kenya. Technical Report. London: Overseas Development Institute. DOI: 10.13140/RG.2.1.2339.5681
- Eriksson, M., Jianchu, X., Shrestha, A.B., Vaidya, R.A., Nepal, S., & Sanstrom, K. (2009). The changing Himalayas: impact of climate change on water resources and livelihoods in the Greater Himalayas. International Centre for Integrated Mountain Development (ICIMOD). Kathmandu, Nepal. Retrieved from <http://lib.icimod.org/record/26471>
- Folke, C., Hahn T., Olsson, P., & Norberg, J. (2005). Adaptive governance of social-ecological systems. *Annual Review of Environment and Resources*, 30, 441-473.
- Goswami, D.C. (1985). Brahmaputra River, Assam, India: physiography, basin denudation, and channel aggradation. *Water Resources Research*, 21(7), 959-978.
- Government of Assam. (n.d.). Agriculture and irrigation in Assam. Retrieved from <http://online.assam.gov.in/web/guest/agricultureandirrigation>
- Government of Assam. (2003). Assam human development report 2003. Planning & Development Department. Guwahati, Assam.

- Government of Assam. (2006). Rural electrification plan Assam. Power Department. Retrieved from <http://assam.gov.in/web/power-department/rural-electrification>
- Government of Assam. (2016). Gracious Assam: Socio-economic profile. Department of Industries and Commerce. Retrieved from http://www.investinassam.com/socio_economic_profile.php
- Government of Arunachal Pradesh. (2001). New Agricultural Policy. Status of Agriculture in Arunachal Pradesh (Base Year 1999-2000). Department of Agriculture. Itanagar, Arunachal Pradesh. Retrieved from <http://arunachalpradesh.gov.in/department.htm>
- Government of Arunachal Pradesh. (2006). Arunachal Pradesh human development report 2005. Department of Planning. Itanagar, Arunachal Pradesh.
- Government of Arunachal Pradesh. 2008. Department of Power Hydro Power Policy – 2008. The Arunachal Pradesh Gazette. Extraordinary. Available from <http://www.indiaenvironmentportal.org.in/files/State%20Mega%20Hydro%20Electric%20Power%20Policy%202008.pdf>
- Gunderson, L.H. (2000). Ecological resilience: In theory and application. *Annual Review of Ecology and Systematics*, 31, 425-439.
- Grumbine, R.E., & Pandit, M. K. (2013). Threats from India's Himalaya dams. *Science*, 339, 36-3.
- Hijioka, Y., Lin, E., Pereira, J.J., Corlett, R.T., Cui, X., Insarov, G.E., Lasco, R.D., Lindgren, E., & Surjan, A. (2014). Asia. In: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1327-1370.
- Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4, 1-23.
- [ICC] Indian Chamber of Commerce. (2013). India's North-East: Diversifying growth opportunities. PricewaterhouseCoopers Pvt Ltd., India. Retrieved from https://www.pwc.in/en_IN/in/assets/pdfs/publications/2013/north-east_summit-2013.pdf

- Immerzeel, W.W., Pellicciotti, F., & Bierkens, M.F.P. (2013). Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. *Nature Geoscience*, 6, 742-645.
- Mahanta, C., & Subramanian, V. (2004). "Water quality, mineral transport and sediment biogeochemistry." in *V.P. Singh et al. (eds.), The Brahmaputra Basin Water Resources*, pp. 376-400. Netherlands: Kluwer Academic Publishers.
- Marschke, M. J., & Berkes, F. (2006). Exploring strategies that build livelihood resilience: a case from Cambodia. *Ecology and Society*, 11(1), 42.
- [MDONER] Ministry of Development of Northeast Region. (2012). Hydropower projects. Government of India. Retrieved from <http://mdoner.gov.in/node/1307>
- [MDONER] Ministry of Development of North Eastern Region. (2014). Transmission projects: transmission system of POWERGRID in North Eastern Region. Government of India. Retrieved from from <http://mdoner.gov.in/content/transmission-projects>
- Millennium Ecosystem Assessment. (2005). *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.
- O'Laughlin, B. (2002). Proletarianisation, agency and changing rural livelihoods: Forced labour and resistance in colonial Mozambique. *Journal of Southern African Studies*, 28(3), 511-530. DOI: 10.1080/0305707022000006495
- Osbahr, H., Twyman, C., Adger, W. N., & Thomas, D.S.G. (2008). Effective livelihood adaptation to climate change disturbance: Scale dimensions of practice in Mozambique. *Geoforum*, 39, 1951–1964.
- Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. *Environmental Science & Policy*, 11, 642-654.
- Pahuja, S., & Goswami, D. (2006). A fluvial geomorphology perspective on the knowledge base of the Brahmaputra. Background Paper #3 for The World Bank Strategy Report "Development and Growth in Northeast India: The Natural Resources, Water, and Environment Nexus". Retrieved from http://web.worldbank.org/archive/website01062/WEB/0_CO-62.HTM
- Rampini, C. (2017). Impacts of hydropower development in Northeast India on the flows of the Brahmaputra and the resilience of downstream communities to climate change impacts on water resources. (Unpublished doctoral dissertation). University of California, Santa Cruz, USA.

- Sallu, S. M., Twyman, C., & Stringer, L. C. (2010). Resilient or vulnerable livelihoods? Assessing livelihood dynamics and trajectories in rural Botswana. *Ecology and Society*, 15(4), 3.
- Scoones, I. (2009). Livelihoods perspectives and rural development. *The Journal of Peasant Studies*, 36(1), 171-196. DOI: 10.1080/03066150902820503
- Speranza, C.I., Wiesmann, U., & Rist, S. (2014). An indicator framework for assessing livelihood resilience in the context of social–ecological dynamics. *Global Environmental Change*, 28, 109-119.
- Tanner, T., Lewis, D., Wrathall, D., Bronen, R., Cradock-Henry, N., Huq, S., Lawless, C., Nawrotzki, R., Prasad, V., Rahman, M.A., Alaniz, R., King, K., McNamara, K., Nadiruzzaman, M., Henly-Shepard, S., & Thomalla, F. (2015). Livelihood resilience in the face of climate change. *Nature Climate Change*, 1, 23-26.
- The World Bank. (2007). Development and growth in Northeast India: The natural resources, water, and environment nexus. Strategy Report. Roots Advertising Services Pvt Ltd., New Delhi, India. Retrieved from <http://web.worldbank.org/archive/website01062/WEB/IMAGES/NORTHEAS.PDF>
- Tse-ring, K., Sharma, E., Chettri, N., & Shrestha, A., editors. (2010). Climate change vulnerability of mountain ecosystems in the Eastern Himalayas. Climate change impact and vulnerability in the Eastern Himalayas – Synthesis report. International Centre for Integrated Mountain Development (ICIMOD). Kathmandu, Nepal. Retrieved from <http://lib.icimod.org/record/8051>
- Turner II, B.L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polasky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *PNAS*, 100 (14), 8074–8079.
- Vagholikar, N., Choudhury, A., & Ahmed, F. (2005). “Environmental Impact Assessment Report of Lower Subansiri Hydroelectric Project: substandard on Many Fronts.” in *Large Dams for Hydropower in Northeast India: A Dossier*. Menon, M. and K. Kohli, Eds. New Delhi: Kalpavriksh and South Asia Network on Dams, Rivers and People. Pp. 43-47.
- Vagholikar, N., & Das, P. J. (2010). Damming Northeast India: juggernaut of hydropower projects threatens social and environmental security of the region. Kalpavriksh, Pune, India and Aaranyak/ActionAid India, Guwahati, India. Retrieved from http://www.indiawaterportal.org/sites/indiawaterportal.org/files/Damming_Northeast_India_Kalpavriksh_Aaranyak_ActionAid_India_2010.pdf

- Verghese, B.G. (2006). Water resources in the Northeast: Development options in a cooperative framework. Background Paper No. 1 as input to the World Bank Strategy Report “*Development and Growth in Northeast India: The Natural Resources, Water, and Environment Nexus.*” Retrieved from http://web.worldbank.org/archive/website01062/WEB/0_CO-62.HTM
- Verghese, B.G. & Iyer, R. R. (1993). *Harnessing the Eastern Himalayan rivers*. Delhi: Konark Publishers Pvt. Ltd.
- Vincent , K., Cull , T., Chanika , D., Hamazakaza , P., Joubert , A., Macome, E., & Mutonhodza-Davies, C. (2013). Farmers' responses to climate variability and change in southern Africa – is it coping or adaptation? *Climate and Development*, 5(3), 194-205. DOI: 10.1080/17565529.2013.821052
- Walker, B., Holling C.S., Carpenter S.R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2), 5.
- Walker, B., & Meyers, J. A. (2004). Thresholds in ecological and social–ecological systems: A developing database. *Ecology and Society*, 9(2), 3.
- Water for Welfare Secretariat. (2008). Hydropower policies and guidelines. Indian Institute of technology. Roorkee, India. Retrieved from <http://www.ahec.org.in/links/water4welfare/HYDRO%20POWER%20POLICIES%20AND%20GUIDELINES.pdf>
- [WCD] World Commission on Dams. (2000). Dams and development: a new framework for decision-making. Earthscan Publications Ltd, London, U.K. Retrieved from [http://www.internationalrivers.org/files/attached-files/world commission on dams final report.pdf](http://www.internationalrivers.org/files/attached-files/world%20commission%20on%20dams%20final%20report.pdf)
- Zhang, L. (2011). Is industrialization still a viable development strategy for developing countries under climate change? *Climate Policy*, 11(4), 1159-1176. DOI:10.1080/14693062.2011.579263