HI-AWARE Working Paper 12

The Teesta Basin

Enough water for power and agriculture for all?

Consortium members

About HI-AWARE Working Papers

This series is based on the work of the Himalayan Adaptation, Water and Resilience (HI-AWARE) consortium under the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) with financial support from the UK Government's Department for International Development and the International Development Research Centre, Ottawa, Canada. CARIAA aims to build the resilience of vulnerable populations and their livelihoods in three climate change hot spots in Africa and Asia. The programme supports collaborative research to inform adaptation policy and practice.

HI-AWARE aims to enhance the adaptive capacities and climate resilience of the poor and vulnerable women, men, and children living in the mountains and flood plains of the Indus, Ganges, and Brahmaputra river basins. It seeks to do this through the development of robust evidence to inform people-centred and gender-inclusive climate change adaptation policies and practices for improving livelihoods.

The HI-AWARE consortium is led by the International Centre for Integrated Mountain Development (ICIMOD). The other consortium members are the Bangladesh Centre for Advanced Studies (BCAS), The Energy and Resources Institute (TERI), the Climate Change, Alternative Energy, and Water Resources Institute of the Pakistan Agricultural Research Council (CAEWRI-PARC) and Wageningen Environmental Research (Alterra). For more details see www.hi-aware.org.

Titles in this series are intended to share initial findings and lessons from research studies commissioned by HI-AWARE. Papers are intended to foster exchange and dialogue within science and policy circles concerned with climate change adaptation in vulnerability hotspots. As an interim output of the HI-AWARE consortium, they have only undergone an internal review process.

Feedback is welcomed as a means to strengthen these works: some may later be revised for peer-reviewed publication.

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The Teesta Basin

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Authors

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In Sikkim, extensive meetings and discussions have happened with the communities, State Authorities including the Dzumsa. We would like to thank all of them for their time and inputs provided to help build the report.

Executive Summary

This working paper summarizes the situational analysis of upstream, mid-stream and downstream areas of Teesta sub-basin of greater Brahmaputra basin. The situational analysis contains the condition of the people and ecosystems of the Teesta basin, including a summary of historical trends and stresses and identification of major issues that require attention through regional policies cooperation and action.

Teesta river is 414 km long with a total catchment area of 12,159 km2. Teesta basin is home to around 30 million people, 2% in Sikkim, 27% in West Bengal; and 71% in northwest Bangladesh of which 78% are rural and 22% urban. Sikkim is mountainous with very low population density, whereas West Bengal has a mix of low hills and plains, and in Bangladesh the terrain is almost flat. There are two large barrages on Teesta that diverts water for mainly irrigation purpose: one at Gajoldobha in India and the other at Duani in Bangladesh.

The method used in developing this working paper includes a review of available literature, and fieldwork in selected villages in three different elevation levels in Teesta basin. The fieldwork was limited to mainly expert observations, focus group discussions with the community, and key informant interviews with local leaders, representatives of administrative bodies, government and non-government organizations to gather information on the local physical conditions and the impact of climate change and variability on people's lives and livelihoods. For the analysis, the basin was divided into three areas defined by elevation: upstream (>1,500 m above sea level-masl); mid-stream (500 - 1,500 masl); and downstream plains or floodplains (<500 masl).

The hydrological regime may be summarized as: (i) the climate is dominated by Indian summer monsoon system; (ii) there are 398 glaciers with ice reserves of 41 km3 as of 2005; (iii) 10% of annual runoff comes from glacier melt contribution; (iv) mean annual discharge at Gajoldobha barrage decreased from 700 m3/s 1993 to below 300 m3/s 2010; and (v) upstream areas depend mainly on the surface water while downstream areas depend on both surface and groundwater, however, groundwater table drops below 7.5 m below the surface (below this level hand tubewells normally dry up) during dry season in some places downstream of Gajoldobha barrage in India and in Rangpur, Kurigram and Gaibandha of Bangladesh which creates crisis of safe drinking water availability.

The socio-economic regime may be summarized as the high elevation villages are inhabited by Nepali-speaking disadvantaged indigenous groups, mid-hills by equally mixed with Nepali ethnic community, other scheduled tribes, and migrants from Assam, Bhutan and Nepal, while the downstream floodplains are inhabited by mainly Bengalese in West Bengal and Bangladesh. The studied high elevation village of Lachen in North Sikkim is home of 380 households of tribal community of Lachenpas and Dokpas while the mid-hill study villages are Pendam in East Sikkim, Hee Gaon in West Sikkim, and Melli-Dara, Possyor and Chibo in South Sikkim. The majority of population depend on natural resources for their livelihoods, and living standard is generally low to lower-middle. However, proportion of people below poverty level went down from 31% in 2004-5 to 8% in 2011-12 in the mid-hill region. In downstream Indian part, Jalpaiguri and Siliguri are the largest townships; however, subsistence agriculture is the main economic activity in the rural parts where average size of landholdings is 1.3 ha. In Bangladesh part, 54% of 14 million people is involved in subsistence agriculture where people in chars (sand bars) are the most vulnerable in the area.

The high mountains of the basin are characterized by sub-zero temperature in winter to 20°C in peak summer. Local people in both upstream and midstream areas opined on increasing summer and winter temperature and drier winter and wetter monsoon. For example, in Thangu and Gurudongmar, people reported that even 10 years ago, every winter it was normal to have snow of 1.5 m deep while now this is reduced to just a couple of feet or less. In the mid-hills local people reported increasing warm days in summer and decreased rainy months but increased erratic rainfall. In the downstream areas in India, meteorological data shows that the degree of warming has increased over last 30 years (1979-2008) and rainfall is becoming higher intensity but less frequent.

The data and field analysis showed that the communities in the Teesta basin are affected by both climatic and non-climatic stressors. Changes of climatic variables affect people's lives and livelihoods especially in water availability, water-related disaster risks, agricultural opportunities, and energy availability and requirement. The local people have observed changes in temperature and rainfall that had severely affected their local water sources, cropping calendars, patterns of cultivation, and livelihoods and exposed them to vulnerable conditions. These impacts are compounded by a variety of factors like access to resources, social structures, and cultural norms and believes, that add to the environmental challenges and aggravate communities' vulnerability. Rising temperature and spatio-temporal precipitation variability are affecting natural water balance, therefore, availability of water for drinking, household use, agriculture, fisheries and other uses. Upstream areas are facing problems of mainly drying up of springs therefore shortage of water during dry season and melting glaciers therefore glacial lake outburst floods during monsoon while 80% of Sikkim population depends on springs and streams for their water demand of household and irrigation. The mid-hills area in Sikkim experienced shifting and disappearance of springs due to landslides and recent earthquake. The downstream floodplains of Teesta in Bangladesh suffer from too much water in monsoon and too little water during dry season. Both the quality and quantity of water resources due to high abstraction of groundwater and therefore, decline and contamination by arsenic and other heavy metals in groundwater occur. Flash floods during monsoons cause enormous riverbank erosion and shoal island/san bar formation within the river bed. These make the river braided and wider while navigability lost because of siltation. This again reduce water carrying capacity of the river which gives rise overtopping and flood during monsoon period. Recurrent floods in Teesta plain damage crops and infrastructure making and leaving people homeless and jobless.

The adaptation activities in the upper Teesta basin seem more planned than in the floodplains. The traditional institution of Dzumsa in Lachen has developed strong coping and adaptive strategies for high altitude agro-pastoralism in the trans-Himalayan zone, which include determining the timing of farming and diversification of agricultural crops, rotational grazing, sharing and time of use of grazing lands, number and seasonal movement of animals, and fodder production for the lean season. In the mid hills area, cardamom growers have started cultivating the high yielding and short-rotation seremna cultivar. A new technology called root-stocking has been introduced for orange cultivation; it helps plants develop a better root structure thereby improving the quality and quantity of the fruit. The local communities are also engaging in additional sectors such as poultry farming, tourism, working in the nearby pharmaceutical factories, and service in the army, to diversify away from agriculture and gain assured income. In the Jalpaiguri floodplains, the Department of Fisheries of Government of West Bengal has supported development of a chain of small ponds on private lands ranging from 0.25 to 1.25 ha. In Bangladesh, government departments are playing an active role in facilitating the uptake of adaptation strategies e.g., Department of Agricultural Extension has set up climate schools and other means of agro-technology transfer to educate farmers about crops that can adapt to floods and droughts. Besides, high yielding, hybrid, short rotation, drought and inundation tolerant varieties are introduced and supported with seeds and other materials in the area.

The adaptation options undertaken by communities in the Teesta basin have been successful in many ways, as they were supported in some cases by government policies, and reflect people's will to change. National, regional, and international interventions with regard to existing policies, strategies, and action plans have benefited the communities in India, especially in Sikkim. In West Bengal and Bangladesh, much more adaptations need to be done as vulnerability is very high because of elevation difference and variable water availability and scarcity. Hence, higher level research for innovation in the area of adaptation options, new tools and technologies, and improvement and promotion of tested practices/options by sector and ecosystem are necessary. Moreover, in the interest of the communities across borders, transboundary issues need to be resolved through basin level management plans or programs.

1. Introduction

The Teesta river basin extends from Sikkim in India in the eastern Himalayas, through West Bengal (Darjeeling, Jalpaiguri, Cooch Behar, Uttar Dinajpur, Dakshin Dinajpur, and Malda districts), to the northern Rangpur division in Bangladesh (Lalmonirhat, Nilphamari, Rangpur, Kurigram, and Gaibandha districts), where the river joins the Brahmaputra before it flows into the Bay of Bengal after meeting with the Ganges and the Meghna (Figure 1). The river rises in the Teesta Khangse glacier in North Sikkim and is then joined by several tributaries including the Lachung chu, Rangyong (Talung) Chu, Rangit, Rangphu, Mahananda, Balason, and Jaldhaka. It enters Bangladesh at Dimla in Nilphamari district and is then joined by the Buri-teesta and Trimohini before it flows into the Brahmaputra (Jamuna) at Chilmari upazila in Kurigram district (left bank) and Sundarganj upazila in Gaibandha district (right bank) at an elevation of 23 masl. Historically, the Teesta was part of the Ganges river system and flowed south from Jalpaiguri in West Bengal as three separate rivers, the Karatoya, Purnabhaba, and Atrai, or Trisrota, until it changed its course after a flood in 1787 and shifted southeast to join the Brahmaputra (Prasai and Surie, 2013).

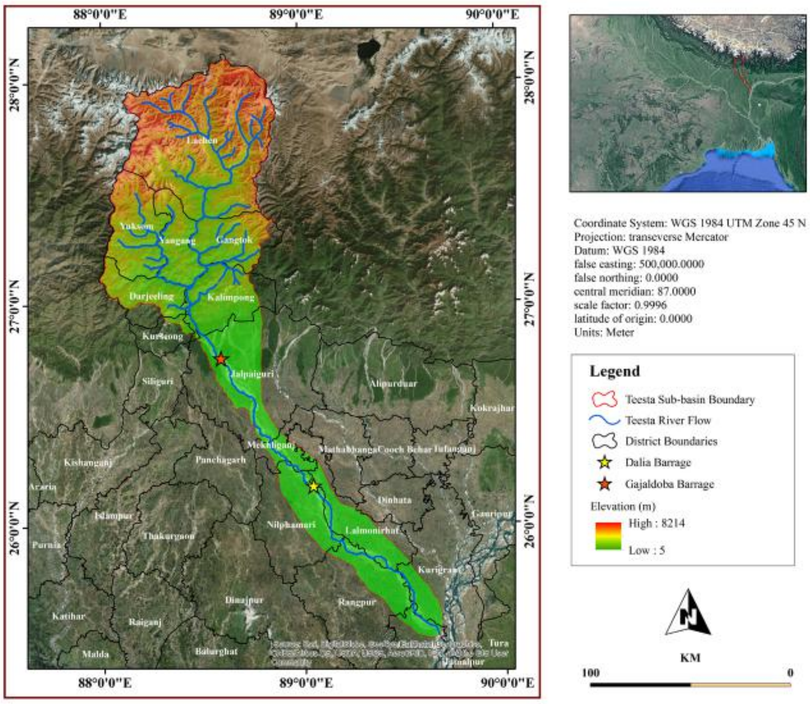


Figure 1: Teesta basin map, credit: BCAS

The river is 414 km long with the greater part in India (151 km in Sikkim, 19 km along the border between Sikkim and West Bengal, 29 km in West Bengal), 94 km along the Indo-Bangladesh border, and the final 121 km in Bangladesh. The total catchment area is 12,159 km^2 distributed between mountains and hills (8,051 km^2, with 6,930 km^2 in Sikkim and 1,121 km^2 in West Bengal) and plains (4,108 km^2, with 2,104 km^2 in West Bengal and 2,004 km^2 in Bangladesh.

The basin is home to around 30 million people, 2% in Sikkim, 27% in West Bengal; and 71% in northwest Bangladesh (Waslekar et al., 2013). Sikkim is mountainous with a very low population density, whereas West Bengal has a mix of low hills and plains, and in Bangladesh the terrain is almost flat. There is a barrage at Gajoldobha in India which diverts water into a canal system for drinking and irrigation purposes. The lower floodplain areas of West Bengal and Bangladesh are known as the Teesta Development Area and contain the Bogra irrigation canals through the Barind tract and Rangpur irrigation canals in the floodplain within the Bangladesh Teesta irrigation command area. The flow of the river is too low to supply water to these canals in the dry season. Other rivers in this area in Bangladesh (the Jamuneswary, Ghagot, Kharkhariya, Ichamati, Tulsiganga, Harabati, and Nagar) generate reasonable flows in the monsoon but are almost dry otherwise.

This working paper presents the results of a situational analysis into the condition of the people and ecosystems of the Teesta basin, including a summary of historical trends and stresses and identification of major issues that require attention through policies and action. The report also seeks to identify and analyse the role of key stakeholders – groups of people and institutions with a right, mandate, and/or interest in resources and their management in the geographic area of the project.

2. Methodology

For the analysis, the basin was divided into three areas defined by elevation: upstream, areas more than 1,500 metres above sea level (masl); mid-hills (mid-stream), areas at elevations between 500 and 1,500 masl; and downstream plains or floodplains, areas below 500 masl. The research included a review of primary and secondary literature, and fieldwork in selected villages in the three areas (Table 1). The fieldwork used expert observations, focus group discussions, and key informant interviews to gather information on the local physical conditions and the impact of climate change and variability on people's lives and livelihoods. Interviews and discussions were held with local leaders and representatives of administrative bodies, heads of women's groups, non-government organizations (NGOs), government officials from different sectors and departments, health workers, farmers, and others, using a gender disaggregated approach.

Table 1: **Location of the study sites**

Basin section	Elevation	Country	State/ district	Study village/area
Upstream (high elevation)	>1,500 masl	India	North Sikkim	Thangu, Munguthang, Gurudongmar, Lachen (2,500 masl)
			West Sikkim	Gumbadara, Uttarey (2,000 masl)
Mid-hills (mid-stream)	500–1,500 masl	India	West Sikkim	Hee-Gaon
			East Sikkim	Pendam
			South Sikkim	Melli-Dara (Sadam)
			Kalimpong sub-division, Darjeeling, West Bengal	Possyor and Chibo Teesta Valley
Downstream (plains)	<500 masl	India	Jalpaiguri, West Bengal	Patkata GP and Kariya-II GP in Jalpaiguri Sadar Block, Domohinit-I GP in Maynaguri Block, and Chapadanga GP in Mal Block
		Bangladesh	Rangpur	Kaunia
			Nilphamari	Dimla
			Lalmonirhat	Patgram and Hatibandha

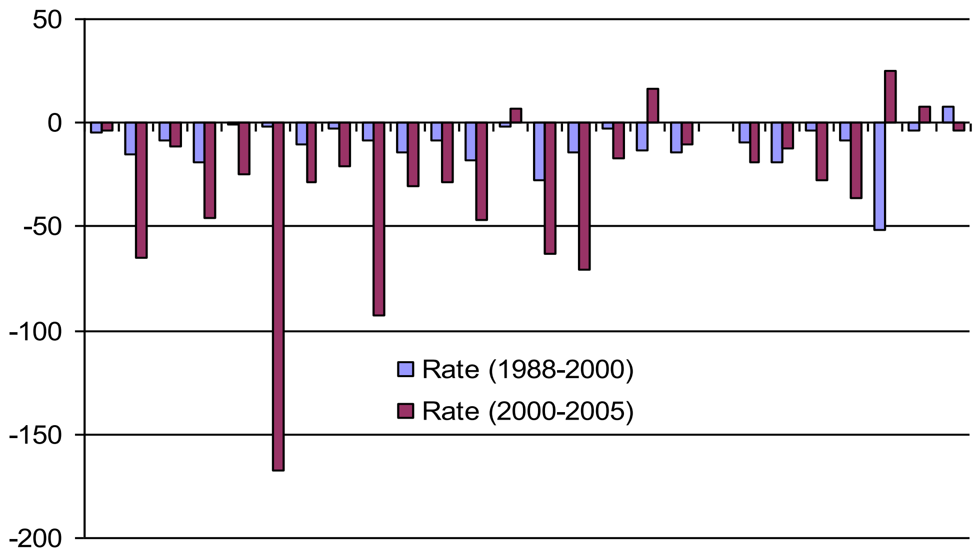
3. Major basin characteristics

3.1 Hydrology

The climate of the basin is dominated by the Indian summer monsoon system; in the North Bengal plains about 90% of total annual rainfall falls in the summer months (Mukherjee and Saha, 2016). During this season, heavy rainfall commonly leads to water-related disasters such as flash floods and landslides in the mid to higher elevation areas and riverine floods and riverbank erosion in the plains. As of 2005, the upstream catchments had 398 glaciers with a total area of 453 km^2 and an estimated 40.5 km^3 of ice reserves (Bajracharya and Shrestha, 2011). Glacier melt is thought to contribute around 10% of average annual runoff in the eastern Himalayan rivers (Sharma, 1993) but the contribution fluctuates seasonally with the largest amount in the summer season but the highest proportion in pre monsoon. Figure 3 shows the river system in the upper basin (Sikkim).

Glaciers in the Teesta basin are in a general state of retreat; more than 90% of 26 glaciers studied were found to have retreated between 1988 and 2005, with the greatest recession after 2000 (Figure 4) (Raina, 2009). The East Rathong glacier, which is the source of the Rangit river, the most important tributary of the Teesta river, is reported to have lost 20% of its ice volume between 1962 and 2011 (Agrawal and Tayal, 2013). Although there was no climate prediction studies found so far in Teesta basin, prediction by

Figure 2: Rate of retreat (metres/year) of 26 selected glaciers in the Teesta basin between 1988 and 2005; adapted from data in Table 9 of Raina (2009)



Immerzeel et al.(2013) shows that in the high mountains of Langtang river basin (some 250 km west of high mountains in Teesta), the glacier area shrinkage averaged over 2021-2050 is 9% for RCP-4.5 and 14% for RCP-8.5 scenarios whereas for 2071-2100 the glacier retreat is 37% and 54% respectively.

3.2 Socioeconomic Parameters

A number of dams and diversions have been constructed along the Teesta river. The largest is the Teesta barrage project at Gajoldobha in Jalpaiguri district of West Bengal in India (TBPI). The project aimed to use the potential of the Teesta River for irrigation, hydropower generation, flood mitigation, communication, construction, and recreation and tourism development (Mukherjee and Saha, 2016) and also supplies drinking water to Siliguri. The overall plan comprises: (1) construction of a barrage across the river Teesta at Gajoldobha; (2) two pick-up barrages, one across the Mahananda river at Fulbari in Jalpaiguri district and the other across the river Dauk at Chopra in Uttar Dinajpur district; (3) construction of five canals with a total length of 211 km; and 4) construction of approximately 2,400 km of distributaries, minors, sub-minors and water courses (IWD-GOWB, 2016). The TBPI is highly ambitious project, construction work started in 1976/77 but several components are still under construction including, as of 2016, the last 20% of the main canal and about half of the distribution system. The reported benefits include a maximum of 104,000 ha of agricultural area irrigated annually, 50 million litres of drinking supplied daily (mainly to Siliguri Municipality), around 106 million units of hydropower generated annually (67.5 MW installed) and inspection paths of 226 km constructed which improve the communication system in adjoining areas (IWD-GOWB, 2016).

There is a second Teesta barrage project 100 km downstream from the Indian project at Duani in Hatibandha upazila in Lalmonirhat District in Bangladesh which is further referred to as TBPB. TBPB is the largest surface water irrigation along with flood control and drainage project in Bangladesh (IUCN, 2012). Construction started in 1979 and partially it started its operation in 1997/98. The command area is 154,250 ha, with 111,406 ha net irrigable area. The scheme has helped increase agricultural production, contributed to fisheries development through the canal systems, and contributed to increased recreation and communication. The barrages have helped increase cropping intensity and flood control as well as creating potential employment opportunities in the surrounding areas. The Government of Bangladesh is now trying to increase the project to irrigate an additional 386,000 hectares of land.

Ghosh (2014) analysed the mean annual outflow discharge at the Gajoldobha barrage (total input water flow minus the water diversion to the Teesta-Mahananda Link Canal) over the period 1993 to 2010, i.e. before and after the barrage regulation. The mean annual outflow discharge from the barrage towards the downstream gradually decreased from above 700 m3/s to below 300 m3/s, a decline of more than 50%. This supports the view that the low discharge downstream during the dry season is not only the result of lower rainfall but is closely linked to interventions in the upstream areas including large dams and diversion from the main flow. The downstream areas depend on both surface and groundwater. During the dry season, the shallow aquifers situated near and beneath the floodplains of the Teesta and its tributaries are the only sources of base flow to the Teesta River, which has a direct impact on groundwater availability (Wahid et al., 2007).

India and Bangladesh constructed major irrigation projects on the Teesta River with the objective of reducing poverty and securing food security. Along with this, a measure of boosted agriculture production was to provide a social safety net for the river basin community. These projects triggered the demand for water in the region. The command area of Indian and Bangladeshi projects are 1,214,000 ha and 750,000 ha respectively, where developed irrigable area are 922,000 ha and 540,000 ha for the same. In order to provide the irrigation facility in the entire command area of India and Bangladesh, a total of 93,523 cusec water is required in all the cropping seasons. Whereas, the virgin flow of the Teesta river are recorded 6,984, 51,966 and 27,987 cusec in dry, wet and lean season correspondingly. In order to meet the water demand in the irrigable area, approximately 43,905 cusecs and 25,714 cusecs of water are required in India and Bangladesh from the Teesta. Based on the water availability, currently 540,000 and 111,406 hectares areas of the barrages are receiving irrigation facility in India and Bangladesh. It is found that India has already brought about 58% of its total irrigable area under irrigation. Whereas, Bangladesh has only been able to provide irrigation for 20% of its total irrigable area (BWDB-GOB, 2015)

4. Key climate trends

Overall in the basin there is a trend towards rising temperatures and increased variability in precipitation, but the specific trends are slightly different in the different areas from the mountains to the plains.

The upper part of the basin is characterized by sub-zero temperature in winter rising to around 20°C during the peak summer season. Climate studies carried out in the higher elevations show an increase in average temperature, early onset of summer, delayed monsoons, and shorter winters (Ingty and Bawa, 2012). Local people in both the upstream and midstream areas considered that summer temperatures were rising and winters were also warmer and drier. In Thangu and Gurudongmar, the Lachenpas and Dokpas reported that even ten years ago it was normal to have snow 1.5 m deep, but now this has reduced to "just a couple of feet or even less"; more precipitation falls as rain and the glaciers are receding. In Gumbadara, the people reported that changes in climate can be felt in terms of increased temperature during the summer and decreased precipitation in seasons other than the monsoon.

In the mid-hills (Pendam and Melli-Dara in Sikkim, and Possyor and Teesta Valley in Darjeeling), local people reported that warm days are increasing. Rainy months have decreased, whilst rainfall intensity has increased, and rainfall has become more erratic with heavy downpours leading to more frequent landslides and mudslides in places previously not affected. In Melli-Dara, people mentioned that the winter rains were becoming a rare phenomenon with winters becoming progressively drier and warmer. The dry conditions are intensified by the location in the rain shadow area of the Darjeeling hills, so annual rainfall is relatively low (1,370 mm in 2011) (Tambe et al., 2012). The winter of 2008/09 was one of the driest winters ever experienced in Sikkim (GOS, 2011). There had also been an increase in the number of hailstorms in March and April, which caused damage to both food and fodder crops. In Pendam, people have been facing erratic rainfall over the past few years. They observed that the winters were shorter and warm clothes were only needed from December to mid-January, suggesting that the number of cold days had reduced to half the number experienced 15–20 years before.

In the downstream area, rainfall is crucial as the river and its tributaries are mostly rainfed. The changing climate is affecting the water availability in the river. The temperature trends over north Bengal vary with location; there is a decreasing trend in the mean maximum temperature in Malda in all seasons; in Jalpaiguri in all seasons except post-monsoon; in Cooch Behar in the winter and pre-monsoon seasons; and in Balurghat only in the post-monsoon season (PRASARI, 2011). The mean minimum temperature is increasing in Jalpaiguri in the winter, pre-monsoon, and post-monsoon seasons, and overall. The degree of warming is more pronounced in the two most rapidly developing towns of Jalpaiguri and Malda, which may be attributed to the rapid urbanization and infrastructure development. There is a decreasing trend in the annual cumulative rainfall over north Bengal, and in the seasonal cumulative rainfall in all seasons except winter and pre-monsoon, while there is a decreasing trend in the mean frequency of rainy days in all seasons except winter. Overall the findings indicate that the degree of warming in the region has increased over the last 30 years (1979–2008) and that rainfall is becoming of higher intensity but less frequent (Raha et al., 2014).

The Bangladesh section of the lower Teesta is a drought-prone area. The Barind tract in the northwest of the region is the most drought prone area in Bangladesh, and includes a portion of the flood free area of the Teesta basin. In this area, local observations were consistent with the findings by (Reeve et al., 2012; Stiller-Reeve et al. (2015)); Syed and Al Amin (2016); and (Waslekar et al., 2013) that there is a trend towards fewer rainy days with the same or more total rainfall, in other words an increase in short intense rainfall events. The overall decadal average rainfall has shown an increasing trend of 57 mm per decade between the 1960s and 1980s, when the highest average rainfall was 2,607 mm (BCAS, 2016). A time series analysis of seasonal rainfall in Rangpur using Bangladesh Meteorological Department's daily data showed an increasing trend in the pre-monsoon (March–May), monsoon (June–September), and post-monsoon (October–November) seasons, with no significant trend in winter (December–

February). The decadal mean maximum temperature increased over the last four decades with temperatures of 28.8, 29.4, 29.6, and 29.6°C in the1970s, 1980s, 1990s, and 2000s, respectively. The decadal mean minimum temperature also gradually increased from the 1960s to 2000s, except in the 1970s (BCAS, 2016), which is consistent with the perception of local communities that cold and heat waves had increased.

5. Climate change risks, vulnerabilities and impacts

The changes in climate variables are affecting people's lives and livelihoods in a number of ways, especially in water availability, water-related disaster risks, agricultural opportunities, and energy availability and requirement, as well as health and environmental factors.

5.1 Water

Both the rising temperature and changes in the spatio-temporal patterns of precipitation are affecting the natural water balance, replenishment of water resources, and availability of water for agriculture, fisheries, household use and drinking. The increased temperatures can lead to higher evaporation from surface water bodies, reduced soil moisture, and higher transpiration by vegetation, all of which can potentially reduce water availability, while the increase in intense rainfall, with fewer rainy days, can lead to flash floods. More rainfall, rather than snowfall, at higher altitudes can lead to reduced glacier accumulation and accelerated melting, with an increased discharge in the short term but reduced in the long term, which can affect both the seasonal pattern and annual availability of river water. UN-WWAP (2015) predicted that water quality might be affected by the changes in temperature and rainfall patterns. The changes in climate may also lead to an increase in the risk of water-related disasters, such as landslides, floods, and glacial lake outbursts. The water related risks and vulnerabilities vary across the basin.

The upstream areas are facing problems of drying up of springs, melting of glaciers, damming of rivers, and construction of tunnels to divert water. Torrential rainfall during the monsoon frequently triggers landslides which also disrupt the water sources, contributing to dry season water scarcity. People in the upper and mid-Teesta basin are entirely dependent upon springs and streams (kuwa, khola, kholsa) to meet their water demand for agriculture and consumption. Around 80% of the rural population in Sikkim depend on natural springs, as in this area the steep terrain largely supports the system (Tambe et al., 2009). The springs and streams are dependent on rainfall, but most rainfall occurs during the monsoon season and it has a high spatial and temporal variation from north to south and east to west, due to the highly variable terrain. In the Lachen area, the quality of water from glacial springs and rivers was reported to be good throughout the year, but the change in climate has resulted in less snowfall in the sub-alpine zones which has indirectly reduced the quantity of water, especially during winter. A study of high elevation areas like Deythang Gram Panchayat Unit (GPU) in Kaluk Block in West Sikkim (1,600 masl) revealed drying of springs and lakes due to reduced discharge influenced by changing climate patterns (Gurung, undated). In almost all the high elevation villages, water was mainly supplied through private pipelines laid down by the villagers direct from the source. The communities also maintain the spring catchments and carry out conservation measures, such as plantation. A few households carry water from distant sources when the springs nearby dry up during January to April. The very few pipelines of the government water supply schemes which also use springs as the main source are repaired by local fitters employed by the villagers; however, many of the taps remain dry. In Gumbadara ward, the majority of households depend on the government water supply from distant spring sources. In Uttarey, water sources (locally called dhara, kuwa, simsar, simdhap, muhan, anko-tsetey) are considered as sacred or devithan (place of the goddess) by the traditional communities and are therefore protected and conserved (Sharma et al., 2012). Although there are no acute water shortages as yet, the local people in Uttarey have observed that the wetlands, water bodies, and springs are shrinking or drying up leading to low discharge from springs and low water availability during the dry season (December-May).

The upstream areas are also threatened by major hazards like earthquakes, landslides during the monsoon, unpredictable snowfall events, hailstorms, and strong winds and wind gusts, all of which cause damage to human life and property. Further, there is a threat from glacial lake outburst floods, which result when there is a sudden failure in the moraine dam confining a lake and subsequent discharge of large volumes of water and debris (Ives et al., 2010). The number and size of such lakes is increasing with climate change, which increases the threat (GOS, 2011).

The mid-hills area in Sikkim has experienced shifting and disappearance of springs, partly as a result of the Government of India programme Pradhan Mantri Gram Sadak Yojana (PMGSY) to establish road connectivity to every village in Sikkim. These projects lack environmental impact assessments and environmental sustainability measures, which has had an impact on water sources and led to acute water shortages in several locations. An extensive field survey was carried out in the mid hills of south-central Sikkim in 2012 to monitor the important springs and streams, and the possibilities for spring revival (Tambe and Arrawatia, 2012; Tambe et al., 2012; Tambe et al., 2013). The annual average discharge of all sources was 29 l/min with one spring serving an average of 35 households. The average discharge of the springs in the drought prone areas varied from 51 l/min during the post-monsoon months to 8 l/min at the lowest point in the dry season. The average lean period discharge of springs in villages located on hill crests was less than half that in the valley (18 l/min compared to 40 l/min). There were also fewer sources within the villages near the crest so that the per capita water availability in the lean season (62 litres per day) was only one-third of that in the valley (186 litres per day). The lean period discharge had declined by nearly 50% in drought-prone areas and by 35% in other areas over the previous decade. In Darjeeling in West Bengal, water is supplied from two reservoirs located in Senchal forest; South Lake with a capacity of 60,000 m3 built in 1910, and North Lake with a capacity of 90,000 m3 built in 1932. The sources of these lakes are 26 perennial springs with their catchments located in different parts of Senchal Wildlife Sanctuary (Ghatani, 2015). However, the status of the springs, which provide water to more than 95% of the people in Possyor in Kalimpong and in Darjeeling, have yet to be documented. Drying up of springs and associated water crises in urban areas has also been attributed to deforestation in the area.

In the lower part of the basin in Jalpaiguri, West Bengal, the river has dried up extensively due to construction of dams upstream. The river is characterized by chars, the local name for the islands or sand bars that form due to erosion and accretion processes during the monsoon floods, with rich fertile soils, good for agriculture. These chars are becoming prone to flooding during the monsoon, which is affecting settlements and agriculture on these lands. The low volume of water has affected fishing, a major livelihood activity in the region, especially during the summer (pre-monsoon) breeding season, although the monsoon is still good for fishing activities. Downstream from the Gajoldobha barrage, which supplies irrigation water through canals, the stream is completely dry except for minor leakages that allow farmers close by to grow more than one crop. The groundwater is at a depth of 9–11 m and is pumped up with diesel pumps for irrigation. The barrage also diverts river water to cater to the drinking water needs of Siliguri town.

The Bangladesh section of the Teesta faces problems due to its transboundary nature. The withdrawal of water by India in the upstream areas limits water availability for irrigation in the Bangladesh Teesta barrage area. Low flow in the Teesta river causes damage to the floodplains due to siltation of the riverbed and sand casting of the paddy fields. The shallow aquifers underlying the floodplain are the only sources of freshwater during the dry season for the local communities. The relationship between the surface and groundwater resources of the floodplain suggests that changes in the Teesta water flow directly affect groundwater availability for the local communities (BCAS, 2016), who buy water from the owners of diesel operated irrigation machines. Farmers, especially poor farmers, become more vulnerable as they cannot afford the high cost for irrigation. The groundwater table shows seasonal fluctuation, from 2 m deep in the monsoon to 7 m in the dry season. The water table is also dropping, especially in Rangpur, Kurigram, and Gaibandha, where the water table drops to more than 7.5 m below the surface in the dry season – beyond the suction limit of traditional hand tubewells (BCAS, 2016). The drop in the water table means that households in the southwestern part of Gaibandha district lack safe drinking water. This area is close to the Barind tract, where there is extensive groundwater abstraction for irrigation schemes under the Barind Multipurpose Development Authority (BMDA) of the Government of Bangladesh, and communities also suffer from contamination of water by arsenic and other heavy metals (WHO, 2011). The river has dried up so much that it is now characterized by large numbers of shoal islands and has braided enormously; it can easily be crossed on foot in the dry season. Permanent lowering of the water table has been observed in some urban areas, where natural groundwater recharge is obstructed due to concrete structures like footpaths and buildings.

In the plains in Bangladesh, flash floods during the monsoons cause enormous riverbank erosion and damage infrastructure such as settlements, schools, colleges, madrassas, union parishad offices (lowest level of local government administration), and rural markets, leaving people homeless and jobless, and children out of school. To cope, entire households, or more often male household members, migrate temporarily to a different village or nearby city in search of work. This can make the family left behind more vulnerable, having to face disasters with no one to support them. If the whole family migrates, they are likely to have to live under detrimental conditions, and it also poses pressure on the urban infrastructure. Those who migrate temporarily for work, generally return to their village at harvest time to work as agricultural labourers. Poor families are the worst victims of migration as they migrate under compulsion, and women and the old become vulnerable to unfavourable conditions in the cities.

5.2 Agriculture and other livelihoods

Agriculture in the high elevation areas is characterized by a mixed farming system with crops, horticulture, and livestock rearing. The main crop rotation systems are cardamom-potato-maize; maize-soybean seed, and potato-pea-soybean-temperate fruits like mandarin oranges (GOS, 2011). The traditional communities from Lachen (2,500 masl) and Thangu (4,300 masl) grow crops in the summer after the snow melts, with wheat, barley, and seasonal vegetables such as beans, potato, cabbage, cauliflower, and radish widely grown on cultivable lands at different places. They also cultivate medicinal and aromatic plants in the Dambochey area above Thangu. Apple is the main fruit grown in Lachen, but the area under cultivation has gone down drastically due to construction of houses (field observations and interactions). In winter, people migrate to lower areas to pursue livelihoods like tourism (for example running homestays), or move further uphill for free grazing on the slopes in the trans-Himalayan areas where the snow is blown off by the strong winds during winter. However, climate extremes have increased the vulnerability of the herdsmen; yak and sheep populations have reduced in recent years due to inadequate grazing lands in the trans Himalayan zones as well as climatic hazards such as heavy snowfall causing deaths of yak, sheep, and goats. The Sikkim Institute of Cottage Industry (SICI) has established a centre in Lachen which provides additional sources of income for women like carpet weaving and making tents, caps, gloves, shoes, and other souvenirs using yak wool and bone. In Uttarey, farmers grow peas, potato, maize, and millet as the main food crops, with large cardamom, orange, turmeric, ginger, and broom grass cultivated as cash crops; these provide a considerable income to most cultivators (large cardamom USD 30 per kg, ginger USD 1 per kg, broom grass USD 1 per kg). The farmers have divided up their farmland for growing vegetables, cereals, and cash crops. Livestock and poultry farming (cows, buffaloes, pigs, chicken, and sheep/goats) are an integral part of farming and both provide manure and supplement household income. However, the changing climate is also impacting agriculture. In Uttarey, crop failure due to the variable climate and pest attacks has become very common and is affecting household income. While in Lachen, the market supply of apples to Chungthang, Mangan, and Gangtok has gone down drastically due to weak farm management, incidences of pests and diseases, and low productivity caused by the changing climate.

In the mid-hills, agriculture is the main source of livelihood. It is the main class of land cover, followed by forestry, with a large part used for tea plantations. Around 90% of cultivated land is rainfed, except for rice, which is cultivated on terraced slopes through irrigation. The traditional farming system is a mix of floriculture, crops, horticulture, livestock rearing, and agroforestry, with rice, wheat, maize, mustard, millet, ginger, soybean, oranges, legumes, peas, potatoes, and cardamom seed as the most common crops. Livestock rearing is very important within the farm economy, especially dairy production. Oxen are still kept for ploughing, but their population is rapidly declining due to shortages of both farm labour and feed (Sharma et al., 2009). Mid-hills agriculture is highly sensitive to changes in the climatic conditions. Agricultural activities that previously flourished have become vulnerable to frequent hailstorms during March and April every year which are affecting the cultivation of maize, and damaging fruit, vegetables, and especially large cardamom (GOS, 2011). Oranges are no longer being cultivated in West Pendam, Possyor, and the Teesta Valley although they were previously well-suited to the climatic conditions. Those who continue to grow oranges incur losses due to low productivity attributed to the rise in temperature, erratic and untimely rain, and pest attacks, which are also related to the change in climate. In all areas, extreme rainfall events during the monsoon are affecting crop productivity. Agriculture has become less profitable in the region leading to unemployment and migration, which in turn has created a shortage of agricultural labour, with additional labour often brought in from the plains. Outmigration of men in Possyor and Teesta Valley has left women and older people more stressed as they have to manage agricultural activities as well as the home.

In the floodplains of Jalpaiguri, farming is limited as the river doesn't provide irrigation water, except where there are leakages from the canal, and chars are becoming less ideal locations for agriculture. Water tables are declining and farmers depend on diesel pumps for irrigation. In general, farmers grow three crops – groundnuts (March to May), paddy or seasonal vegetables (June to September), and potatoes (October to December).

Just over half (54%) of households in the Teesta floodplains in Bangladesh are primarily engaged in farming, of these 84% are marginal farmers with less than 1 ha of cultivable land (BBS-GOB, 2010). Apart from rice, other important crops grown are wheat, jute, sugarcane, maize, potato, tobacco, onion, garlic, pepper, mustard, and vegetables. Rice is the most important crop, especially in Rangpur region, and the area is seen as one of the country's food baskets with surplus amounts of rice produced each year. The soil is sandy due to deposition. The amount of water available for irrigation has gone down and as a result, farmers have started to cultivate maize, and in some cases pumpkin, in preference to mustard and wheat (which they cultivated about 10 years back). The TBPB provides irrigation facilities to 91,226 hectares of agricultural land during the monsoon as supplementary irrigation. The cropping intensity in the project area has increased from 180% to a formidable rate of 233% during the last 15 years, which is also reflected in increased crop production (BWDB-GOB, 2015). Use of groundwater for irrigation through shallow and deep tube-wells has also increased. The average cropping intensity over the whole Teesta floodplains in Bangladesh is 200%, compared to 169% for all India (IANS, 2015), which indicates a high land use efficiency (Baas and Ramasamy, 2008; BBS-GOB, 2012). Production of paddy, wheat, other cereals, and vegetables have increased because of the change in practice from a single rainfed local crop to two or even three new high yield variety crops per year. This has contributed significantly to poverty reduction among the households in the project area. However, frequent heat waves are now affecting paddy production, and the extreme foggy conditions in winter are affecting maize, while discussions with local people indicated that recently erratic rainfall has drastically hampered potato production.

5.3 Energy

In the high-altitude areas of the Teesta basin, the major source of household energy for cooking and heating is fuel-wood, either from agroforestry plots established by the communities on their own land (as in Uttarey) or from the nearby forests (in some areas of Lachen). Wood is collected mostly by men and women and sometimes children, and is stored near the homestead or in the basement. A pilot study in Sikkim indicated an average consumption of approximately 20 kg per household per day, or close to 7,500 kg per year (GOS, 2015). Uttarey's consumption of fuel-wood is very high as it is also used for preparation of fodder for the cattle. In the trans-Himalayas, the herders also collect roots of Juniperus spp. and Rhododendron spp. for cooking and heating, while women collect yak dung which they sun dry and pile up near the camp sites. Use of liquefied petroleum gas (LPG) for cooking, kerosene and electric heaters, and rice cookers is also common in some households. To protect the forests, the Government of Sikkim is promoting alternative energy use by distributing LPG cylinders to households in different villages (GOS, 2011).

Fuel-wood is also the major source of energy for households in the mid hills area of the Teesta basin in Sikkim. About 20,000 tons of fuel-wood is used annually just to dry the harvested crop of large cardamom (Roy et al., 2013), with more fuel-wood used for cooking, boiling milk, cheese making, heating water, and domestic heating (TMI-India, 2010). In West Pendam, Melli-Dara, Possyor, and Teesta Valley, households have started using LPG cylinders for cooking in place of fuel-wood. However, several households reported that they were using their monthly subsidy of LPG sparingly keeping it for emergency situations and relying more on fuel-wood and kerosene for heating and lighting. The supply of electricity in some parts of the mid-basin is inconsistent. Studies have indicated that higher temperatures and increasing frequency of extreme rains can affect the transmission and distribution of electricity; while the melting of glaciers may affect hydropower generation (GOWB, 2012).

In the Jalpaiguri section of the basin in India, rural communities collect fuel-wood or logs brought down by the river as driftwood. In winter, they travel considerable distances (1–4 km) to the nearby forests to bring fuel-wood; while many use dung as fuel. Although 70% of households have access to liquid petroleum gas (LPG) with an easy refilling mechanism, many households prefer to use fuel-wood as it is freely available. Agricultural residues, leaves, tree branches, cow dung, and others are also used to provide energy for cooking in both India and Bangladesh. There has been a rapid increase in hydropower development along the Teesta River and in its major tributaries both in Sikkim and in Darjeeling in West Bengal. But even so, more than 40% of the population of the lower basin still lacks direct access to electricity; either because of lack of supply or due to the high price, which makes it unaffordable for the poor.

In the Bangladesh plains, Chars are hard to reach area for grid power and thus most of Teesta char population rely on conventional kerosene for lighting or agricultural residues for cooking. , kerosene is used primarily for heating and lighting, due to lack of access to gas and thus stoves as well. There is limited or no access to electricity, for households or agriculture. At the household level, women are exposed to health hazards from smoke, but only limited numbers use solar home system for evening lighting only and very few reported using improved stoves, bioenergy, or organic fertilizer.

5.4 Health

In the high and mid-hills, an increased incidence of diabetes and heart disease has been reported across all age groups over the years. Recently, there has been an increase in cases of malaria in the lower parts of Pendam, and dengue in Budang and Central Pendam, attributed to the rise in temperature. Hypertension, gastric problems, diabetes, tuberculosis, and chronic skin diseases are common in both sections of the basin; while waterborne diseases are reported every year from Darjeeling district. Cases of enteric fever are becoming virulent; the rates doubled between 2008 and 2010. Discussions with local people confirmed that increasing pollution and contamination of water sources is the key factor in the increase in diarrhoeal disease, gastric problems, and kidney stones. In Lachen, the increase in the number of cancer cases was thought to be a possible outcome of consuming smoked meat. Several people had experienced skin-related diseases like ringworm, measles, and prickly heat, which they attributed to the hotter climate as they were not-recorded 5–10 years previously (Chaudhary et al., 2011). Respiratory diseases have also been reported from rural areas arising from the inhalation of pollutants from burning of fossil fuels (kerosene, coal), cow dung, and fuel-wood (GOWB, 2012). In the higher attitude areas, the health centre in Lachen is sufficient for treating common ailments such as fever, diarrhoea, coughs, and colds; for other health concerns, people go to Mangan district hospital or Gangtok. In Uttarey, a dispensary caters to people for minor ailments, but for more serious complaints, people go to the district hospital at Gyalsing or Jorethang. There are no doctors at the hospital owned by a tea-estate company in Teesta Valley, so people must go to Kalimpong, Darjeeling, or Siliguri for proper treatment. The nearest dispensary for the communities in Possyor village is in Kalimpong, around 8 km away.

In the lower part of the basin, the primary health problems are associated with climate extremes and water pollution with skin diseases, pneumonia, and viral fever common during both cold waves and droughts. There are also high rates of malnutrition due to shortage of food. Poor sanitation also causes illness, with the main victims being children under five, as well as women and the elderly (Brody et al., 2008). Water contamination has been responsible for increasing cases of kidney stones in the floodplains of Jalpaiguri, while in Bangladesh, where latrines are damaged during floods, degraded water sources have increased the prevalence of cholera, diarrhoea, and dysentery. The use of dried leaves and twigs for cooking in Bangladesh produces toxic fumes that affect particularly women's health, making them vulnerable to respiratory diseases and eye problems. Health facilities are available from community clinics at union health care centres and the upazila health complex, but the quality of treatment is poor and lack of medicines leave especially women and children at risk.

5.5 Land use and urban impacts

The basin is characterized by marked changes in land use, with development proceeding at a rapid pace. Changes in housing, transportation systems, forests, and others are visible in all parts. In Lachen, at high elevation, around 80% of the traditional houses have been replaced by concrete houses constructed for hotels and lodges for tourism, leaving only small areas of farmland for agriculture. With loss of forests, human-animal conflicts have increased. Local people in Lachen reported that black bears have been encroaching human habitations every year, while wild boars are a menace to potatoes. Feral dogs pose a menace to livestock (yak calves, sheep, goats, and even wild animals) in the Lachen-Gurudongmar area. As grazing lands are also being encroached, herders are threatened. The land is unstable and prone to landslides, especially during the rainy season, a problem compounded by earthquakes; deforestation worsens the situation leading to more frequent landslides, which destroy roads and other basic infrastructure. In the both the upper and mid basin, deforestation for urban expansion and terrace farming have become rampant, as, for example, in Gangtok and Pendam, where communities reported that the forest cover has decreased due to construction of electricity towers for hydropower projects.

The extremely uneven distribution of population in Sikkim poses pressure on planners to accelerate the growth of towns in the south and west districts; population migration to the east, where the main economic activities are concentrated, has led to the formation of slums which reduces the ability of planners to ensure provision of basic services (GOS, 2013). There is a limit to the level of urbanization that can be achieved in the high and mid-altitude areas of the basin due to the remoteness and problems of accessibility. Nevertheless, the annual flow of tourists to the higher elevations has been increasing over the years, posing a demand for tourist amenities and other infrastructure like hotels and lodges. The heavy inflow of traffic also affects air quality, leading to health problems and damaging the delicate ecology, with new roads an additional cause of frequent landslides in the area. These areas are also grappling with the problem of waste, despite the promotion of eco-tourism. In Darjeeling city, the built-up area has increased over the decades to cater to tourism, but the infrastructure is not yet able to cope with the rising demand, while the water and air quality has also been compromised by the increase in congestion.

In the floodplains of Jalpaiguri, large-scale deforestation has increased human-animal conflicts, and efforts have been undertaken to counter them. Moreover, several animal species are threatened by illegal poaching (Manoj et al., 2013). The land use pattern has undergone repeated change due to the shifting courses of the rivers that drain the area. Some areas in the northeastern part of the district are threatened by water pollution due to illegal dolomite mining in Bhutan, while groundwater in the areas around the tea

gardens is affected by the use of chemicals (Banerjee et al., 2009).

6. Factors co-determining impacts and vulnerability

The data and field analysis showed that the communities in the Teesta basin are affected by both climatic and non-climatic stressors. The local people have observed changes in temperature and rainfall that had severely affected their local water sources, cropping calendars, patterns of cultivation, and livelihoods and exposed them to vulnerable conditions. These impacts are compounded by a variety of factors that add to the environmental challenges and aggravate communities' vulnerability.

In the upper elevation areas, the problems of changing rainfall patterns are compounded by the uncertainty in river flow due to the increasing number of hydropower projects, which is also affecting the communities downstream. In Dzongu (900 to 6,000 masl) in North Sikkim where the hydropower projects are located, the reduced soil stability has led to frequent landslides and soil erosion, which disrupt water pipelines, change the orientation of springs, and reduce groundwater recharge (EPD-GOS, 2013). The Lepcha community, who live in this area, have protested against Phase-V of the hydropower project as it will alter their customs and traditional common property rights on water bodies, forests, and others and greatly affect the land use. Moreover, the gas released during blasting is thought to be responsible for the reduced production of cardamom – by up to 50% (Purkayastha, 2013). Water is becoming a precious commodity during the lean periods and its use is restricted to drinking and cooking. Even so, the burden for women of fetching water increases markedly during the dry season as they have to walk longer distances, although men do participate in the task. Women complain of joint pains resulting from the daily routine of fetching water. Reduction in grazing lands is also increasing the problems for herders. In Uttarey, the yak and sheep population has gone down in recent years, due to the lack of adequate grazing lands in the trans-Himalayan area, while climatic hazards are also affecting animal health, with yaks being affected by foot and mouth disease, and sheep by respiratory diseases (Sharma and Rai, 2012). Further stress co-factors noted by the communities include uncontrolled waste production in in the high-altitude areas such as Lachen (2800 m), Thangu (4200 m), Gurudongmar (5200 m), and Tsho Lhamu (5000 m), and air pollution due to the large number of tourist taxis. Further, the hydropower projects and pharmaceutical industries established in more than 15 locations in Sikkim have attracted labour migration from other Indian states in the plains which is placing stress on the infrastructure and leading to an increase in cases of HIV/AIDS in North Sikkim. The construction activities for hydropower, and issues of air and water pollution and waste management, have had direct and indirect impacts upon human health and ecosystem integrity.

The mid-hills area is also being affected by the low water flows in the river, in addition to issues of air and water pollution and waste management. In some places, households only receive water once every two to three days, and then only for a few hours, which affects personal hygiene and sanitation and exposure to water-borne diseases. Although some families have installed rainwater harvesting structures, there is hardly any water to harvest. The emergence of new fungal diseases (chirkey and phurkey) is affecting the rhizome of the cardamom plant. Local varieties (ramsai, bharlange, and sawney) were being cultivated by farmers in Hee Gaon in West Sikkim until a few years ago, but most have changed to the new variety seremna as it is large and particularly suitable for this mid elevation region. In West Pendam, farmers reported a new type of earthworm, which hardens the soil in the fields so that it forms bigger and drier clods which make the land difficult to cultivate. Ginger productivity is also on the decline in West Pendam and Melli-Dara due to soil-borne disease and rhizome rot, which force farmers to harvest immature ginger and sell at a very low price in the markets. Storage and preservation of seeds is also becoming difficult due to pest attacks. To add to these problems, forest fires are damaging agricultural crops in adjacent fields; flash floods are eroding top soil, which affects soil fertility; and landslides are creating rills and gullies and affecting soil nutrition and productivity.

In Jalpaiguri, the living and working conditions of farmers on the chars are becoming extremely harsh, as they are under constant threat of erosion and flooding. Nevertheless, a significant number of people have created opportunities for human settlement and agricultural activities in this area. No rights are reserved on the chars, and those displaced during floods must work as wage labourers in the cities. Construction of the canal system from the Gajoldobha Barrage is incomplete, and the area under irrigation is less than promised. The west bank canal has sufficient water for irrigation but is poorly maintained. In addition, the high levels of siltation from upstream limits access to water during the dry season and, despite promises, no provision has been made for releasing water into the canals to manage the problem.

In the plains area in Bangladesh, multiple factors add to people's vulnerability. Political problems have contributed towards the drying up of the channel. The transboundary conflict over the waters of the Teesta have escalated as the waters are either being or are planned to be diverted through several canals into secondary streams like the Mahananda, Dauk, and Nagar to serve the drinking water needs of Jalpaiguri and Siliguri. People from the Gajoldobha Barrage region considered that the water stopped flowing downstream after the new Chief Minister of West Bengal in India took over. Further, in the field interactions, a government official noted that the Government of West Bengal has refused to share 50% of stored water with Bangladesh on the grounds that Bangladesh receives runoff from a 20 km stretch after the barrage. Over the years, construction of various dams upstream has affected the river ecology. The channel has narrowed due to heavy siltation and braiding, and there is very limited water in the river compared to the past. Low environmental flow is likely to enhance the discharge of groundwater as base flow at the end of the dry season (April to June) leading to groundwater depletion, which affects agricultural production and the availability of drinking water from shallow tubewells. The local communities reported a shortage of freshwater for drinking in the dry season due to declining water tables and contamination during the monsoon. During floods, most of the tubewells go under water and become unusable. The poor become more vulnerable as installation of shallow or deep tube-wells to access water for drinking or irrigation is expensive and they are compelled to consume water from unhygienic sources which has implications for health. Floods have been a blessing to local farmers in the past as they provided silt which improved soil fertility. But with the changes in flow, floods are becoming more of a bane, as huge amounts of sand are now flushed down, covering the fertile soils and cropland and reducing the water holding capacity of the stream and floodplains. Riverbank erosion is also destroying agricultural production as it washes away croplands. Risks of poor yield in main staple crops affect smallholders' household food security, because of the subsistence nature of agriculture. This situation deters farmers from pursuing agricultural activities making them vulnerable and in extreme need of other sources of income.

7. Local adaptation practices and responses

The adaptation activities in the upper Teesta basin seem more planned than in the floodplains. The traditional institution of Dzumsa in Lachen has developed strong coping and adaptive strategies for high altitude agro-pastoralism in the trans-Himalayan zone, which include determining the timing of farming and diversification of agricultural crops, rotational grazing, sharing and time of use of grazing lands, number and seasonal movement of animals, and fodder production for the lean season. Dzumsa specifies the dates of movement to new locations as per the Tibetan Calendar, the number of days of grazing at a given location, and the amount of extraction of resources, among others. Any herder disobeying Dzumsa is fined. In Lachen, local people are also adapting to change by moving to lower altitudes and running homesteads and other tourism related activities during the winter. The nomadic Dokpas and some Lachenpa herders move to the higher Gurudongmar and Tsho-Lhamu areas to wide mountain slopes to graze yaks. Herders have also started to produce grass fodder on their farms during the summer season to feed the animals during winter and ensure that the fallow period is sufficient for natural regeneration allowing the grazing land to develop enough biomass. This indigenous conservation and management practice by the nomadic herders is contributing to sustainable management of the grazing pastures. The Lachen Dzumsa has also banned sheep slaughter to increase numbers following the drastic decline in the sheep population (Ingty and Bawa, 2012). To cope with the declining population of cows, the Animal Husbandry Department of the Government of Sikkim has started breeding siri cows, a valuable adaptation option which has the capacity to effectively contribute to human nutrition, soil improvement, organic farming, and environmental improvement. To adapt to increasing problems of waste, the Lachen Dzumsa has banned the use of bottled mineral water to reduce waste production. In Gumbadara in Uttarey, water is only diverted for irrigation during the night when domestic water demands are least, in effect implementing water rationing.

In the mid hills area, cardamom growers have started cultivating the seremna cultivar developed by the Limbus in Hee-Gaon to adapt to disease attacks, and characterized by a shorter growing period. This cultivar commands a higher price in the market due to its high productivity, inspiring some innovative farmers to cultivate cardamom in their home gardens using manure and irrigation to increase the productivity. In Hee-Gaon in west Sikkim, the villagers had responded to the problem of crop diseases and pest attacks by shifting from traditional crops like millet and potatoes to cardamom, which is easily grown, less labour intensive, and more profitable. Cardamom farmers were growing bharlangey and sawney varieties at higher elevations (1700–2000 masl) and the seremna variety at slightly lower elevations (1300–1800 masl). The entire Hee-Gaon area (1500 m) had cultivated the sawney variety up until 15–20 years ago, but this has disappeared completely due to chirkey and furkey viral disease. Farmers have also started cultivating broom grass as a way of adapting to water scarcity. This is not only a cash crop but also a source of fodder. The Government of Sikkim has provided poly houses for cultivation, but they are not very popular with farmers, who argue that the quality of soil in them is poor, and completely dead after three years, which affects the taste of the vegetables grown. The vegetables are also highly perishable and efficient transportation is a challenge. In Pendam, water sources like springs and river water have been classified and their use regulated according to the level of cleanliness, with spring water for domestic use (springs) and river and stream water for agriculture. This helps reduce the incidence of water-borne diseases. Implementation of rainwater harvesting during the monsoon has been useful in providing water for agriculture and livestock during the subsequent lean season, while a spring shed development programme has helped to revive several dying springs in the Melli-Dara area and address water insecurity. A new technology called root-stocking has been introduced for orange cultivation; it helps plants develop a better root structure thereby improving the quality and quantity of the fruit. The local communities are also engaging in additional sectors such as poultry farming, tourism, working in the nearby pharmaceutical factories, and service in the army, to diversify away from agriculture and gain assured income.

In the Jalpaiguri floodplains, the Department of Fisheries of Government of West Bengal has supported development of a chain of small ponds on private lands ranging from 0.25 to 1.25 ha (1–5 bigha). The income per 0.25 ha is USD 150–300 annually, but fishermen have to get fish spawn from Maldah and sell the produce in Siliguri market. At the same time, with barely enough water to cultivate lands, many people are migrating to other states in India, especially Kerala, where the agricultural wages are higher. Young men migrate in groups and some have even migrated to Dubai. Some people work temporarily in Siliguri town as masons, rickshaw drivers, and so on, or engage as labour under the NREGS (National Rural Employment Generation Scheme).

In the Bangladesh flood plains area, the National Adaptation Programme of Action (NAPA) has acknowledged the interplay between socioeconomic development, demographic changes, and natural disasters (floods, riverbank erosion, and water scarcity/drought) in the Teesta basin (MOEF-GOB, 2005). Government departments have played an active role in facilitating the uptake of adaptation strategies. The Department of Agricultural Extension has set up climate schools and other means of agro-technology transfer to educate farmers about crops that can adapt to floods and droughts, which has led to changes in cropping patterns as a way of adapting to the lack of sufficient water for irrigation. In areas where canal water is not sufficient to fulfil the irrigation demands, some farmers, particularly the growers of traditional Aus paddy, are adapting to water stress by employing drip irrigation using an electric motor or diesel engine, cultivating different crops in the same field, and using high yielding variety (HYV) seeds to maximize yield. Flood and heat tolerant species and short rotation varieties are being cultivated in areas that are prone to flash floods and heat waves. Despite the variability of the climate, the cultivation of winter vegetables is satisfactory and farmers have shown an interest in expanding their cultivation. In some areas, farmers are growing maize, sesame, mustard, groundnuts, pumpkin, and lentils instead of paddy, as paddy cultivation is threatened by the higher levels of inundation and sand deposition and has a lower economic value. Women have found a means of adapting to the drought and flood related food insecurity and malnutrition by undertaking home-based farming – growing vegetables and fruit to meet the household food needs – and keeping livestock (cows, goats, sheep, and poultry) for family nutrition as well as income generation. Discussions with the villagers revealed efforts to protect drinking water sources by covering tube-wells with plastic sheets, to store food and fuel for cooking, and to protect latrines from damage by flood water. People are also taking the initiative to construct improved latrines to protect themselves from waterborne diseases during floods. There is also a move towards use of improved stoves to conserve fuel, and use of biogas wherever available. Local organizations also sometimes raise community awareness of early warning systems and hazard management.

8. Policies and institutions

In the high elevation areas of the Teesta basin in North Sikkim, there is a unique system of local governance called Dzumsa, literally gathering place (dzum: meeting, sa: place) introduced sometime in the early 17th century. Dzumsa is still legally recognized by the Government of Sikkim (India) as the local self-government body. Field studies in Lachen reported that Dzumsa has a strong control over the distribution of funds and materials from government schemes and takes a pivotal role in benefit sharing among the villagers. The Dzumsa has functioned successfully for centuries, adapting to changing situations and circumstances. People's loyalty towards the system works in their favour and helps them adapt more easily to some of the vagaries of climate change that have affected the area. Many other organizations are also helping to address climate change issues and support adaptation in the higher elevation areas. In Uttarey, a local self-help group, Samjhana, has undertaken plantation work at different schools and repair work on footpaths and water pipes. Income generating activities are undertaken through plantation and agricultural work and the group rotates money and helps with social work in the villages. The Social Service Bureau is another important organization which conducts awareness programmes in schools and primary health centres and helps with funding for community development activities such as construction of community halls and water tanks when requested. The NGO Himali Vikas Sanstha works in the areas of health, environment, agriculture, livelihood opportunities, and women's empowerment. This organization currently has 35 members, including 10 women, helping to address women's issues. The Agriculture Department of the Government of Sikkim has provided greenhouses (poly-house) for growing chilli, tomatoes, and offseason vegetables (although their success is queried, see previous section), and communities have also started growing orchids and cut flowers in them. Other programmes from the Government of Sikkim include Forest Development Agency activities, an integrated watershed management programme, the Hariyali project (the Integrated Wastelands Development Programme (IWDP) and the National Watershed Development Project for Rainfed Areas (NWDPRA)), and projects promoting alternative energy use such as LPG for reducing the pressure on forests (GOS, 2011). The Northeast Rural Livelihood Project (NERLP), under the Government of India Ministry of Development of Northeast Region (DoNER), works actively in the high elevation rural areas with the aim of improving rural livelihoods, especially for women, unemployed youth, and the most disadvantaged. The NERLP is playing an active role in women's empowerment and encouraging the formation of self-help groups by providing grants and training to women in rural areas. In Uttarey, an active fishing cooperative society has begun cultivation of trout on a small scale as a government cooperative society. The cooperative provides subsidized eggs to 22 households, thereby creating income opportunities. The fish are bought directly by the government, which provides easy marketing. In another scheme, a Kisan credit card is being provided to farmers on the basis of property to enable loans of up to USD 500. Many irrigation schemes for the construction of minor irrigation canals are being initiated using funding from the Accelerated Irrigation Benefits Programme (AIBP) and Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) to support the production of special varieties of rice, which have medicinal properties and are well suited to the local agro-ecological conditions. Villagers in Gumbadara reported that wage-employment was being generated under the MGNREGA scheme with at least 100 days in a year. In Lachen, the Rajiv Gandhi Shilpi Swasthya Bima Yojna provided employment for one year to handicraft artisans with three dependent family members.

Many of the areas at mid-elevation in Sikkim have taken up the Dhara Vikas Yojna or Spring Shed Development Programme, an initiative under MGNREGA to recharge groundwater and revive drying springs. This intervention has had a positive impact in areas like Deythang GPU in Kaluk block (1,600 masl), where within a year, the quantity of spring water discharge increased from critically low levels even during the lean season (Gurung, undated). A climate change vulnerability assessment has also been initiated at gram panchayat level by the Rural Management and Development Department, Government of Sikkim, and 50 springs and 4 lakes in 20 GPUs have been successfully revived (GOS, 2014). The Rural Management and Development Department (RM&DD) has promoted the plantation of fast growing indigenous tree species like Terminalia myriocarpa (panisaj) and Alnus nepalensis (utis) on steep land in water scarce regions with funding sourced from MGNREGA. Activities undertaken under MGNREGA have provided a supplementary climate resilient income of around USD 150 per annum for approximately 65%

of the rural households in the state (Tambe and Arrawatia, 2012). These tree species provide a good income to farmers and help conserve soil and water. The Sikkim Organic Mission, initiated in 2003, has resulted in successful adoption of organic farming in Pendam, Melli-Dara, and Hee-Gaon. As an incentive, the registered farmers were provided with vermin-compost pits to increase on-farm manure (organic) production, while educated unemployed youths have been trained and employed as field officers to develop an internal control system (ICS) for organic certification. Another endeavour in this direction is the Food Security and Agriculture Development Department initiative to encourage farmers to cultivate buckwheat organically as it can tolerate moisture stress. As an incentive, seeds and manure have been provided and the Department has 'tied up the minimum support price from Sikkim State Cooperative Supply and Marketing Federation Ltd. (SIMFED)' to support marketing of the produce (Sharma and Rai, 2012). This has resulted in good returns for farmers, preserved soil moisture, prevented the growth of weeds, and provided fodder. In Pendam, the Agriculture Department has focused on providing farmers with seed at subsidized rates of USD 0.07 (INR 5) per kg for maize, millets, soybean, turmeric, and others. The government is also promoting sericulture in Pendam and coffee plantation in Melli-Dara to provide alternative livelihood options to the communities. The Department of Animal Husbandry, Livestock, Fisheries and Veterinary Services has encouraged the adoption of poultry farming in drought prone villages in South Sikkim like Melli-Dara, where the highest production of poultry in South Sikkim now takes place. Water harvesting tanks have been provided to several households to conserve water for these activities. Eco-tourism is also being promoted as part of the Sikkim Government's Tourism Mission 2015, with a focus on pilgrimage, culture, tradition, heritage, adventure, eco-tourism, and wellness. The tourism sector is expected to provide employment to 75,000 people, with trained manpower of about 17,000 (GOS, 2015). The local anganwadi integrated child development programmes (ICDP) have been effective in generating awareness about diseases and the National Health Mission in providing para-health services to the communities, which has helped to address health issues.

The institutional response in the floodplains of Jalpaiguri has been minimal, with some support from the Fisheries Department and wage labour through NREGS. In the plains area in Bangladesh, the National Adaptation Programme of Action, 2005 (NAPA) has identified urgent and immediate actions for adaptation to climate change, which includes 15 projects for capacity building and reducing risks and vulnerability (MOEF-GOB, 2005). Bangladesh also formulated a Climate Change Strategy and Action Plan (BCCSAP) in 2009 (MOEF-GOB, 2009), which aims to promote climate resilient development and a low carbon economy in support of the Bali Action plan of the UNFCCC (2008). Six key thematic areas for interventions have been identified: food security and social protection; disaster preparedness; protection of resources and infrastructure from climate change; knowledge generation and capacity building; low carbon sustainable development; and institutional strengthening and integration. Unfortunately, the conventional adaptation practices which have worked in the past are not effective in the Teesta basin, which is more vulnerable to climate extremes. As a result, more effective institutional responses are necessary to reduce the risks. The Government of Bangladesh initiated adaptation practices identified during the fieldwork in the area include building concrete blocks to control river erosion in Hatibandha upazila, a riverbank protection initiative for the Saniajahan river, and supplying sandbags to local communities to protect earthen roads and embankments from breaching during floods. Local development agencies can play a crucial role in building awareness about climate change, carrying out participatory vulnerability assessments, and supporting adaptation by internalising climate change adaptation and mitigation in their policies and practices when designing projects.

9. Conclusions and recommendation

The Teesta river originates in the Teesta Khangste glacier in the high altitude area of Sikkim in India, flows through the northern parts of West Bengal, and then enters Bangladesh where it flows through the northern Rangpur division before meeting the Brahmaputra. The situational analysis identified climate-related hazards such as floods, droughts, unpredictable snowfall, hailstorms, strong winds, cold and heat waves, extreme precipitation events, and landslides, as well as the non-climatic hazard of earthquakes, as major factors in the vulnerability of the people in the region. The seasonal and annual Teesta river flow can be affected by the melting of glaciers at higher altitudes, which can affect water availability in the nearby downstream during the dry season. Rainfall was found to be crucial in the Teesta downstream area, as the river and its tributaries are mostly rain fed. Climatic variability across the basin has several implications for people's lives and livelihoods.

In the upper and mid-Teesta basin, communities depend on springs and streams for water for agriculture and drinking, but these are being affected by the warmer climate and frequent landslides. In some areas of Sikkim, efforts linked to government interventions to revive springs have been successful. Mixed farming systems of agriculture, horticulture, and livestock rearing are common in the high elevation study areas, but are increasingly affected by problems of reduced rainfall in the dry season, higher temperatures leading to an increase in pest attacks, and a reduction in the number of cattle and yak due to diseases. Apple and cardamom cultivation have been affected most; although new cultivars of cardamom have been identified which are fetching good returns in the market, apple production has declined drastically. At the same time, the changing climate has enabled cultivation of vegetables at higher altitudes where snowfall has gone down. Government initiatives have supported organic cultivation of buckwheat in Sikkim, and seeds have been distributed to farmers for other crops at subsidized rates as an incentive. Various other means of income generation have been developed such as tourism – with the government promoting eco-tourism – to help maintain the ecological balance and mitigate climate change impact. However, increasing congestion in the hill towns of Darjeeling and Gangtok manifest in air and water pollution and issues of waste management. New industries have attracted people from the plains to work in Sikkim. Even farm labour, in many cases, is being brought in from the plains to support agriculture and the younger generation are shifting to other sources of income.

The problems in the lower-basin are largely due to its transboundary nature; unilateral withdrawal of water from the Teesta in India, limits the availability of irrigation water in the Teesta Barrage area in Bangladesh. This further reduces the flow of the river in the floodplains and groundwater availability for drinking and irrigation. The short but intense rainfall period brings down sand and alters soil characteristics and prevents groundwater recharge, all affecting cultivation. During the dry season, the river flow is so limited that it leads to groundwater depletion. In Bangladesh, the northwest region is drought-prone. But it is affected by flash floods during the monsoon, which bring large quantities of sand, covering the fertile soil, and preventing the cultivation of traditional crops like paddy. Flash floods also affect access to fresh drinking water, as hand pumps are unusable and sanitation facilities damaged. Due to the Gajoldobha Barrage in Jalpaiguri, farmers on the west bank of the Teesta in India receive enough water. But the irrigation efficiency is low because the canals are poorly maintained. Lack of water and subsistence farming practices are likely to generate food security issues in this part of the basin. Drinking water shortages are also likely to aggravate the conflict with India, as there are more plans for diversion of Teesta water to the Mahananda and Dauk rivers to cater for the domestic water demand of Siliguri and Jalpaiguri, and India is also refusing to share 50% of the water from the Teesta Barrage.

Fuel-wood is the preferred source of energy for cooking and heating in all parts of the Teesta basin, obtained either from agroforestry plots established by the communities on their own land (as in Uttarey), from nearby forests (in some areas of Lachen and Bangladesh), or from drift wood logs (in Bangladesh). In the upper and mid-basin areas, fuel-wood is used for cooking, boiling milk, cheese preparation, heating water, drying cardamom, and heating. To prevent deforestation in the higher elevation areas, the Sikkim government is trying to promote the use of solar energy and is also providing LPG to households. In Darjeeling, at least 70% of the households have LPG with the facility for refill. In Bangladesh, kerosene is used for lighting, as electricity is not available. Farmers also lack electrification for agriculture and are dependent on diesel for pumping. Pumps can only be hired by those who can afford them and hence subsistence-farmer households tend to become food insecure. Diseases like malaria and dengue are now prevalent in the upper and mid-hills due to rising temperatures. Further, rising air pollution in the urban areas, water contamination, and problems of sanitation and waste management directly affect human and ecosystem health. Cases of respiratory disease, diarrhoea, gastric problems, and kidney stones are on the rise, with limited medical facilities at the local level. Pneumonia due to cold waves, viral fever as a result of heat waves, and malnutrition due to food shortages are prevalent in the floodplains, as are waterborne diseases and incidences of kidney stones.

The adaptation options undertaken by communities in the Teesta basin have been successful in many ways, as they were supported in some cases by government policies, and reflect people's will to change. National, regional, and international interventions with regard to existing policies, strategies, and action plans have benefited the communities in India, especially in Sikkim. In West Bengal and Bangladesh, much more adaptations need to be done as vulnerability is still very high. The implementation of the various policies adopted in Bangladesh is not very satisfactory as integration among different sectors is lacking. Adoption of the community-based adaptation to climate change (CBACC) approach has priority over other initiatives. Hence, higher level research for innovation in the area of adaptation options, new tools and technologies, and improvement and promotion of tested practices/options by sector and ecosystem are necessary. Moreover, in the interest of the communities across borders, transboundary issues need to be resolved.

References

Agrawal, A., Tayal, S., 2013. Assessment of volume change in East Rathong glacier, eastern Himalaya. International Journal of Geoinformatics, 9(1): 73-82.

Baas, S., Ramasamy, S., 2008. Community based adaptation in action: A case study from Bangladesh - Project summary report (phase I): Improved adaptive capacity to climate change for sustainable livelihoods in the agriculture sector. Food and Agriculture Organization of the United Nations, Rome and Department of Agricultural Extension, Government of Bangladesh, Dhaka, Bangladesh, pp. 64.

Bajracharya, S.R., Shrestha, B., 2011. The status of glaciers in the Hindu Kush-Himalayan region. International Centre for Integrated Mountain Development, Kathmandu, pp. 140.

Banerjee, S.S., Poddar, B.C., Chakraborty, S., Saha, M., 2009. Environmental hazard of tea garden belt in Jalpaiguri district, West Bengal, Geospatial World.

BBS-GOB, 2010. Census of agriculture 2008: National series, volume 1 - Structure of agricultural holdings & livestock population. Bangaladesh Bureau of Statistics, Ministry of Planning, Government of Bangladesh, Dhaka, pp. 711.

BBS-GOB, 2012. Household Income and Expenditure Survey (HIES) 2010. Bangladesh Bureau of Statistics, Ministry of Planning, Government of Bangladesh, Dhaka, pp. 611.

BCAS, 2016. Situational analysis in HI-AWARE study basins: Teesta river floodplains (unpublished report), Bangladesh Centre for Advanced Studies, Dhaka.

Brody, A., Demetriades, J., Esplen, E., 2008. Gender and climate change: Mapping the linkages - A scoping study on knowledge and gaps. BRIDGE, Institute of Development Studies, University of Sussex, Brighton, UK, pp. 27.

BWDB-GOB, 2015. Teesta barrage project annual report 2014–15, Bangladesh Water Development Board, Ministry of Water Resources, Government of Bangladesh, Rangpur.

Chaudhary, P. et al., 2011. Consistency of local perceptions of climate change in the Kangchenjunga Himalaya landscape. Current Science: 504-513.

Debnath, B., 2014. Status of development in different blocks of Jalpaiguri district. The Journal of Population Research, 1(1): 4-18.

EPD-GOS, 2013. Energy and power sector–vision 2015, Energy and Power Department, Government of Sikkim, Gangtok, India.

Ghatani, S., 2015. Sustainable urban water management in Darjeeling, Sikkim University, Gangtok, 126 pp.

Ghosh, K., 2014. Planform pattern of the lower Teesta river after the Gazaldoba barrage. Indian Journal of Geography and Environment, 13: 127-137.

GOS, 2011. The Sikkim action plan on climate change (2012-2030). Government of Sikkim, Gangtok, India, pp. 167.

GOS, 2013. Sikkim urban dynamics, Urban Development and Housing Department, Government of Sikkim, Gangtok, India.

GOS, 2014. Sikkim revives Himalayan springs. Government of Sikkim.

GOS, 2015. Sikkim human development report 2014: Expanding opportunities, promoting sustainability. Government of Sikkim by Routledge, New Delhi, Oxon, New York, pp. 135.

GOWB, 2012. West Bengal state action plan on climate change. Government of West Bengal, Government of India, Kolkata, India, pp. 333.

Gurung, R., undated. Impact of climate change on spring water of eastern Himalayas. The State Institute of Rural Development, Sikkim (SIRD), pp. 9.

IANS, 2015. Small dams, drought–resistant crops could resolve Teesta imbroglio (Comment: Special to IANS), Business Standard - Indo-Asian News Service.

Immerzeel, W.W., Pellicciotti, F., Bierkens, M.F.P., 2013. Rising river flows throughout the twenty-first century in two Himalayan glacierized watersheds. Nature Geosci, 6(9): 742-745. DOI:10.1038/ngeo1896 http://www.nature.com/ngeo/journal/v6/n9/abs/ngeo1896.html#supplementary-information

Ingty, T., Bawa, K.S., 2012. Climate change and indigenous people. In: Arrawatia, M.L., Tambe, S. (Eds.), Climate change in Sikkim - Patterns, impacts and initiatives. Information and Public Relations Department, Government of Sikkim, Gangtok, pp. 275-290.

IUCN, 2012. Ecosystems for life project team visits northern Bangladesh to understand water management issues. International Union for Conservation of Nature.

Ives, J.D., Shrestha, R.B., Mool, P.K., 2010. Formation of glacial lakes in the Hindu Kush-Himalayas and GLOF risk assessment. International Centre for Integrated Mountain Development, Kathmandu, Nepal, pp. 66.

IWD-GOWB, 2016. Present status of Teesta barrage project. Irrigation and Waterways Department, Government of West Bengal, Kolkata, India.

Manoj, K., Bhattacharyya, R., Padhy, P.K., 2013. Forest and wildlife scenarios of Northern West Bengal, India: A review. International Research Journal of Biological Sciences, 2(7): 70-79.

MOEF-GOB, 2005. National Adaptation Programme of Action. Ministry of Environment and Forest, Government of Bangladesh, Dhaka, pp. 46.

MOEF-GOB, 2009. Bangladesh climate change strategy and action plan 2009. Ministry of Environment and Forest, Government of Bangladesh, Dhaka, pp. 98.

Mukherjee, B., Saha, U.D., 2016. Teesta barrage project - A brief review of unattained goals and associated changes. International Journal of Science and Research (IJSR), 5: 2027-2032.

Prasai, S., Surie, M.D., 2013. Political economy analysis of the Teesta river basin. The Asia Foundation, New Delhi, pp. 45.

PRASARI, 2011. Livelihood zones analysis in West Bengal: A tool for planning agricultural water management investments in West Bengal. Food and Agriculture Organization of the United Nations, FAOWATER, AGWater Solutions, and Rajarhat PRASARI, Rome, Italy, pp. 31.

Purkayastha, S., 2013. Hydro power development and the Lepchas: A case study of the Dzongu in Sikkim, India. International Research Journal of Social Sciences, 2(8): 19-24. DOI:10.18844/gjs.v5i1.79

Raha, G.N., Bhattacharjee, K., Das, M., Dutta, M., Bandyopadhyay, S., 2014. Statistical study of surface temperature and rainfall over four stations in north Bengal. MAUSAM, 65(2): 179-184.

Raina, V.K., 2009. Himalayan glaciers: A state-of-art review of glacial studies, glacial retreat and climate change. Ministry of Environment and Forest, Government of India, New Delhi, pp. 60.

Reeve, M.A., Syed, M.A., Hossain, P.R., Maainuddin, G., Mamnun, N., 2012. Community level perceptions of the monsoon onset, withdrawal and climatic trends in Bangladesh. Extended Abstract, International conference on 'Opportunities and Challenges in Monsoon Prediction in a Changing Climate' (OCHAMP-2012), Pune, India, 21-25 February 2012, pp. 2.

Roy, A.K., Prdhan, B.B., Ray, A., Jaswal, V., 2013. Study on the alternative energy technologies implementation for promoting the sustainable of technologies in Sikkim. International Journal of Emerging Technology and Advanced Engineering, 3(Special issue 3): 560-565.

Sharma, G., Rai, L.K., 2012. Climate change and sustainability of agrodiversity in traditional farming of the Sikkim Himalaya In: Arrawatia, M.L., Tambe, S. (Eds.), Climate change in Sikkim: Patterns, impacts and initiatives. Information and Public Relations Department, Government of Sikkim, Gangtok, India, pp. 193-217.

Sharma, G., Sharma, D.P., Dahal, D.R., 2012. Adaptive approaches for reviving the dying springs in Sikkim, The Mountain Institute, India, Gangtok, India.

Sharma, G., Sharma, R., Sharma, E., 2009. Traditional knowledge systems in large cardamom farming: biophysical and management diversity in Indian mountainous regions. Indian Journal of Traditional Knowledge, 8(1): 17-22.

Sharma, K.P., 1993. Role of meltwater in major river systems of Nepal. Snow and Glacier Hydrology, IAHS Publ. no. 218(Procecdings of the Kathmandu Symposium, November 1992): 113–122.

Stiller-Reeve, M.A., Syed, M.A., Spengler, T., Spinney, J.A., Hossain, R., 2015. Complementing scientific monsoon definitions with social perception in Bangladesh. Bulletin of the American Meteorological Society, 96(1): 49-57. DOI:10.1175/bams-d-13-00144.1

Syed, M., Al Amin, M., 2016. Geospatial Modeling for Investigating Spatial Pattern and Change Trend of Temperature and Rainfall. Climate, 4(2): 21.

Tambe, S., Arrawatia, M.L., 2012. Climate change initiatives in Sikkim. In: Arrawatia, M.L., Tambe, S. (Eds.), Climate change in Sikkim: Patterns, impacts and initiatives. Information and Public Relations Department, Government of Sikkim, Gangtok, India, pp. 369–412.

Tambe, S., Arrawatia, M.L., Kumar, R., Bharti, H., Shrestha, P., 2009. Conceptualizing strategies to enhance rural water security in Sikkim, Eastern Himalaya, India, Workshop on integrated water resource management. Central Ground Water Board, Eastern Region, Ministry of Water Resources, Government of India, Kolkata, India.

Tambe, S. et al., 2012. Reviving dying springs: Climate change adaptation experiments from the Sikkim Himalaya. Mountain Research and Development, 32(1): 62-72. DOI:10.1659/MRD-JOURNAL-D-11-00079.1

Tambe, S., Kharel, G., Subba, S., Arrawatia, M., 2013. Rural water security in the Sikkim Himalaya: Status, initiatives and future strategy. India Mountain Initiative, Summit in Kohima, Nagaland.

TMI-India, 2010. Non-invasive monitoring to support local stewardship of snow leopards and their prey, Final project report submitted to Critical Environment Partnership Fund of Ashoka Trust for Research in Ecology and Environment by The Mountain Institute, India, Gangtok, Sikkim.

UN-WWAP, 2015. The United Nations world water development report 2015: Water for a sustainable world. UNESCO for United Nations World Water Assessment Programme, Paris, pp. 139.

UNDP, 2014. Human development report 2014: Sustaining human progress: Reducing vulnerabilities and building resilience. United Nations Development Programme, New York, USA, pp. 239.

UNFCCC, 2008. Report of the conference of the parties on its thirteenth session, held in Bali from 3 to 15 December 2007: Addendum-Part two: Action taken by the conference of the parties at its thirteenth session. United Nations Framework Convention on Climate Change.

Wahid, S.M., Babel, M.S., Gupta, A.D., Clemente, R.S., 2007. Spatial assessment of groundwater use potential for irrigation in Teesta Barrage Project in Bangladesh. Hydrogeology Journal, 15(2): 365-382. DOI:10.1007/s10040-006-0143-z

Waslekar, S. et al., 2013. Rivers of peace: Restructuring India Bangladesh relationships. Strategic Foresight Group, Mumbai, India, pp. 96.

WHO, 2011. Guidelines for drinking-water quality, fourth edition. World Health Organization, Geneva, pp. 564.

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