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Livelihood exposure to climatic stresses in the north-eastern floodplains of Bangladesh

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ABSTRACT

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

1. Introduction

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

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

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double exposure (McDowell and Hess, 2012; Leichenko and O'Brien, 2002, 2008).

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

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

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

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

2. Conceptual framework

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

2.1. Temporal properties and climatic stresses

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

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

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

Climatic extremes may not be perceived as a stress unless it directly affects livelihood productivity. More generally, all extreme events may not be stresses to livelihoods, although all the stresses may appear as a consequence of extreme events, if other conditions (e.g., bio-physical properties, land use practices etc.) are constant. Confirming Proposition

1 has the potential to inform longer term adaptation actions (Birkmann and von Teichman, 2010). Moreover, this proposition has particular relevance to the study area because adaptation actions are taken based on the temporal occurrence of perceived stress events. For example, temporary flood protection embankments are built and renovated every year in the area to protect winter crops (i.e., mostly paddy) from flash-flood events that mostly appear immediately before and during the crop harvesting period (MPHA, 2012). However, such temporally-specific adaptation actions may involve both cross-sectoral uncertainties and opportunities (Haque et al., 2017). Therefore, by differentiating stresses from extreme climatic events, this proposition may help us to better understand the level of effectiveness of existing adaptation actions in the study areas.

2.2. Local geographic and environmental properties and livelihood practices

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

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

2.3. Determining stress from the perspectives of rural smallholders

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

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

3. Study setting: north-eastern floodplain of Bangladesh

This research was conducted in the north-eastern floodplain communities of Bangladesh, an area considered one of the most climate-vulnerable and under-studied regions in the country (Rahman et al., 2018a). This area is dominated by wetland ecosystems (Deb et al., 2016; Rahaman et al., 2016), and subjected to regular seasonal flood and extreme rainfall events. Beyond these stresses, flash-floods and drought are the two most destructive climatic stresses on livelihood sustainability in the area (Nowreen et al., 2015).

The north-eastern floodplain of Bangladesh falls under the upper Meghna tributary, which is one of the three major river basins in Bangladesh (Mirza, 2011). This part of the country is boarded by Indian states including Meghalaya in the north, Tripura in the south, and Assam in the east. The floodplain comprises several wetland systems locally known as *haors*, which are defined as bowl-shaped depressions, seasonally flooded by monsoon water and river flow from the Indian uplands. During dry seasons, the *haors* dry up and only a few permanent shallow lakes remain inundated, locally known as *beels*. Small rivers also pass through the *haors*, which serve as water inflow and outflow channels (MPHA, 2012). *Haors* are considered to be very important ecosystems because of their rich biodiversity and natural resources (Muzaffar and Ahmed, 2007). Local smallholders largely depend on these floodplain systems for their livelihood opportunities (Rahman et al., 2018b). Agriculture is a common practice during the dry season while fishing is practiced throughout the year (Rahman et al., 2015; Salam et al., 1994). In this area, government policies and management systems limit open water fishing practices (Rahman et al., 2012). Among the several wetland systems distributed across the north-eastern floodplain, Hakaluki and Tanguar are considered to be the two most important because of their geographic location, the availability of exploitable resources, the number of dependent households and the abundance of biodiversity (see also Rahman et al., 2018b) (Fig. 1).

3.1. Hakaluki haor

Hakaluki *haor* is the largest freshwater natural wetland in Bangladesh, which lies between 24°35′N to 24°44′N and 92°00′ E to 92°08′ E. It has an area of 41,614 ha (Khan and Haque, 2010) with a permanent inundation area of 4,635 ha (Choudhury and Nishat, 2005). The permanent inundation area comprises *beels* which are the natural habitats of fisheries. The Department of Environment (DoE) of the Government of Bangladesh declared this wetland to be an Ecologically Critical Area in 1999 (DoE, 2015) under the Bangladesh Environment Conservation Act (1995) for the conservation of the natural environment and sustainable use of resources. This *haor* falls under the jurisdictions of 5 sub-districts in Sylhet (Goalpganj and Fenchuganj sub-districts) and Maulavibazar (Kulaura, Juri and Borolekha sub-districts) districts. The villages are distributed in 11 unions (the lowest administrative unit of the Bangladesh Government) including: Dakshin Badepasha and Gilachara under Fenchugaj sub-district; Sharifganj under Golapgonj; Vatera, Sosharkandi under Kulaura; Poschim Juri, Jafar

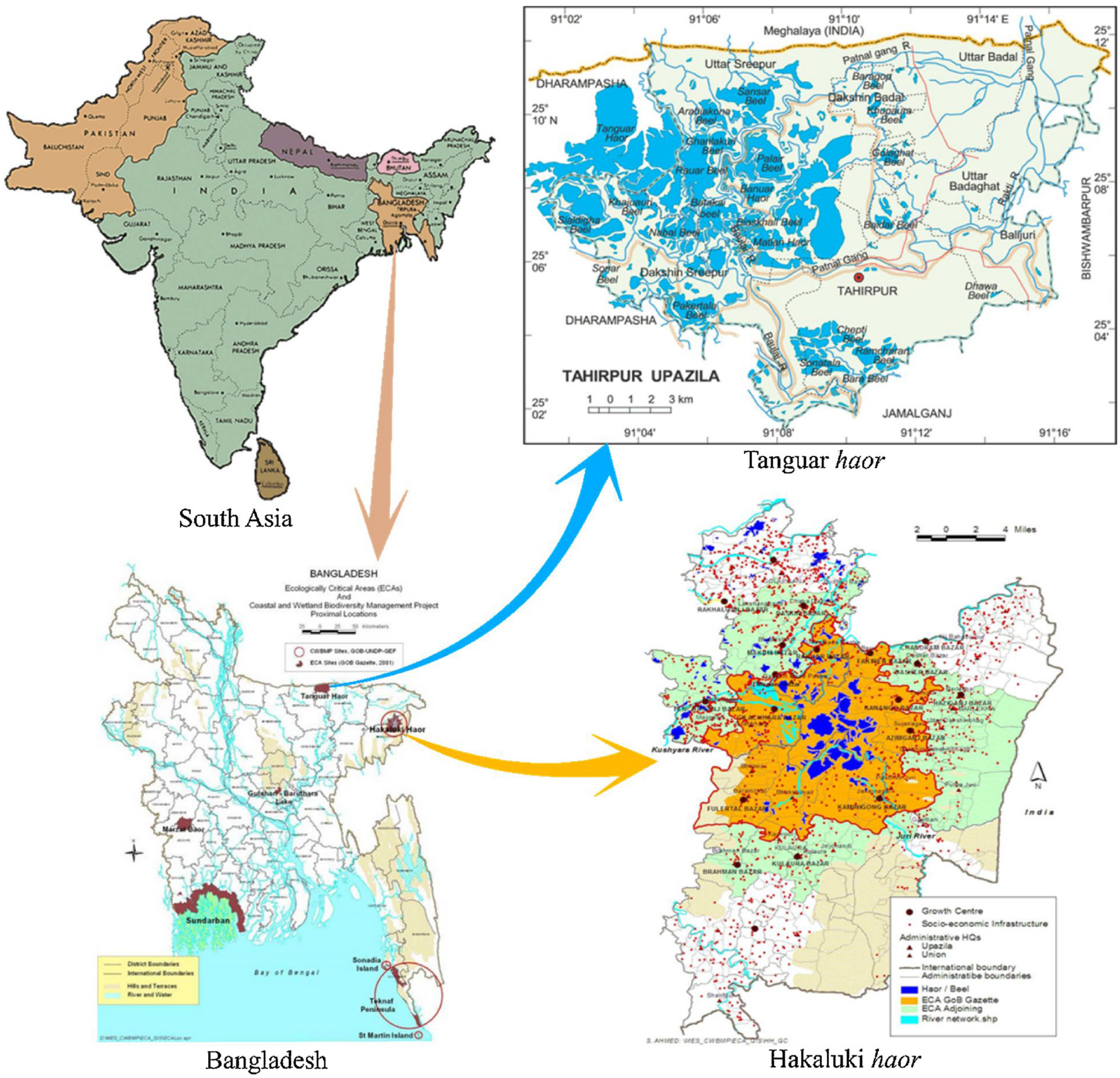

Fig. 1. Study areas and location of data collection villages.
Source: Department of Environment, Bangladesh Government and IUCN, Bangladesh.

Nagar under Juri; Suja Nagar and Borni under Baralekha sub-districts.

Most of the villages surrounding the *haor* have access to a permanent road network that provides motor access to union councils and sub-districts throughout the year, and the villages have access to health, education and electricity services. Community members living in these villages mostly depend on agriculture and fisheries for their livelihoods (see also Rahman et al., 2018b). Most of the *haor* area has a single paddy (most widely cultivated crop) crop rotation, while some parts have multiple rotations. Although fishing is a common livelihood practice in the areas, this has been significantly reduced because of the government's wetland fisheries property right decentralization policy (Rahman et al., 2015). Consequently, many fishers rely on open access fishing grounds like rivers and canals. However, the depletion of fish in these grounds has reduced the viability of this livelihood practice.

3.2. Tanguar haor

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

The villages located around the Tanguar *haor* are highly dispersed and small in size. Usually, these villages are established on small natural or artificial hillocks that protect the community from flood water. Consequently, during the rainy season, these villages are completely surrounded by water, like small islands. There is subsequently no permanent road network access to the sub-districts and other urban areas. Boats provide the only means of transport during rainy season. Most of the villages do not have adequate access to health, education and electricity services throughout the year, and the households largely depend on agriculture and fisheries for their primary livelihood activities. Unlike Hakaluki *haor*, the number of fishermen is higher because there is a formal fisheries co-management scheme in place (see also Rahman et al., 2018a,b).

4. Methods

We used a community-based participatory approach to data collection and analysis in order to understand the exposure experiences and perceptions of different livelihood groups (Kosmowski et al., 2016). Following a case study research design (Yin, 1994) we conducted a contextual analysis of livelihood exposure to climatic stresses in the north-eastern floodplain of Bangladesh. The strength of the case study approach is its ability to enable intensive observation within 'real life' settings, involving a large number of variables and their co-variation (Yin, 1994; Gerring, 2004; Ford et al., 2010). Working within the case study design, we adopted a mixed-methods strategy that combined qualitative and quantitative methods to help generate more systematic observations and analyses of the empirical phenomena (Feilzer, 2009; Johnson et al., 2007). The advantage of this approach is methodological overlap, which enables a degree of validation and triangulation to enhance reliability (Bergman, 2011; Östlund et al., 2011).

4.1. Data collection

We purposively selected 12 case study villages from the two study areas using four selection criteria: i) the selected village should on the bank of the *haor*; ii) villages that are close to each other should be avoided, where 'close' was defined on the basis of relative distance between two villages; iii) the village should have a recent history of experiencing climate stresses; and iv) the majority of the population of the village should depend on the *haor* resources for their livelihood activities. Following these criteria, we selected eight villages from Hakaluki *haor* and four villages from Tanguar *haor* for data collection. All villages were identified in separate meetings held in the respective union offices (Fig. 1). We involved local government representatives (e.g., union council chairmen, and members) and local leaders in the process of selection as they were highly knowledgeable on the different climatic stresses affecting the areas and villagers' livelihood activities (see also Rahman et al., 2018b).

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

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

Quantitative data were collected though surveys with randomly selected households from the 12 villages. The size of the villages in Hakaluki *haor* varied between 100–150 households, while in Tanguar *haor* the village size varied between 70–100 households. We surveyed at least 25% of total households in each village, resulting in a sample size of 236 and 118 households from Hakaluki and Tanguar *haors* respectively. We interviewed the head of households, and in case of their absence, interviewed the most senior adult household member present. The survey began by identifying the major livelihood activities of the household head and also noted secondary and tertiary livelihood activities. The number of total employed persons and their livelihood activities per household were also discussed. Additional questions focused on the major stresses encountered by the household and how the household head perceived different stresses in terms of their livelihood activities (based on duration, frequency and loss of livelihood outcomes or by the survival of their livelihood activities in the presence of the stresses) (see Table 2).

Table 1
Kay issues discussed in focus group discussions.

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

4.2. Data analysis

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

Quantitative data on household-level perspectives of stress intensity were measured categorically. In order to analyze these data, we used ordered logistic regression to see how different stress and non-stress variables (e.g., duration, frequency, crop loss and survival to a stress, livelihood diversities, natural resource dependency for main livelihood

Table 2
Variable description and descriptive statistics.

Variables	Variable description	Sample questions	Response scale	Hakaluki	Tanguar
dur_drou	Duration of drought: the number of day respondents observe as water scarce period for both fishing and irrigation	How many days do you consider as drought in a season?	Number of days	52.19 (± 14.21)	37.41 (± 8.45)
int_drou	Interval of drought: number of occurrence of drought events in last 10 years	How many times have you experienced water scarce situations in last 10 years?	Number of times	2.53 (± 0.69)	2.66 (± 0.63)
loss_drou	Crop loss due to drought: degree to which a farmer or fisher lose crop due to drought	To what extent the water scarce situation does affect your production?	0 = marginal loss 1 = moderate loss 2 = extreme loss	19 (8.05%) 208 (88.14%) 9 (3.81%)	37 (31.36%) 81 (68.64%) 0 (0.00%)
surv_drou	Crop survival during drought: number of days a cropping practice can survive during drought days	How many days your farming or fishing practices can survive under drought?	Number of days	24.56 (± 5.48)	26.80 (± 3.51)
dur_ff	Duration of flash-flood: the number of day respondents observe as flash-flood period for both fishing and irrigation	How many days do you consider as flash-flood in a season?	Number of days	17.74 (± 6.81)	14.98 (± 3.14)
int_ff	Interval of flash-flood: number of occurrence of flash-flood events in last 10 years	How many times have you experienced flash-flood situations in last 10 years?	Number of times	2.88 (± 0.97)	2.84 (± 0.65)
loss_ff	Crop loss due to flash-flood: degree to which a farmer or fisher lose crop due to flash-flood	To what extent the flash-flood situation does affect your production?	0 = marginal loss 1 = moderate loss 2 = extreme loss	27 (11.44%) 30 (12.71%) 179 (75.85%)	6 (5.08%) 18 (15.25%) 94 (79.66%)
surv_ff	Crop survival during flash-flood: number of days a cropping practice can survive during flash-flood days	How many days your farming or fishing practices can survive under flash-flood?	Number of days	10.22 (± 6.04)	8.83 (± 5.96)
dur_rf	Duration of regular flood: the number of flood day respondents observe as negatively affecting both fishing and cultivation	How many days do you consider regular flood as destructive to your agricultural or fishing practices?	Number of days	117.62 (± 26.24)	122.35 (± 19.58)
int_rf	Interval of regular flood: number of occurrence of negatively affecting regular flood events in last 10 years	How many times have you experienced water destructive regular flood situations in last 10 years?	Number of times	2.83 (± 0.81)	2.75 (± 0.66)
loss_rf	Crop loss due to regular flood: degree to which a farmer or fisher lose crop due to regular flood	To what extent the regular flood situation does affect your production?	0 = marginal loss 1 = moderate loss 2 = extreme loss	127 (53.81%) 84 (35.59%) 25 (10.59%)	83 (70.33%) 27 (22.88%) 8 (6.79%)
surv_rf	Crop survival during regular flood: number of days a cropping practice can survive during regular flood days	How many days your farming or fishing practices can survive under the flood situation?	Number of days	26.47 (± 6.89)	27.40 (± 6.42)
dur_er	Duration of extreme rainfall: the number of day respondents observe as extreme rainfall days	How many days do you consider as extreme rainfall in a season?	Number of days	22.27 (± 5.07)	14.83 (± 3.20)
int_er	Interval of extreme rainfall: number of occurrence of extreme rainfall events in last 10 years	How many times have you experienced extreme rainfall situations in last 10 years?	Number of times	2.64 (± 0.83)	2.69 (± 0.59)
loss_er	Crop loss due to extreme rainfall: degree to which a farmer or fisher lose crop due to extreme rainfall	To what extent the extreme rainfall situation does affect your production?	0 = marginal loss 1 = moderate loss 2 = extreme loss	225 (95.33%) 10 (4.23%) 1 (0.42%)	11 (9.32%) 95 (80.50%) 12 (10.17%)
surv_er	Crop survival during extreme rainfall: number of days a cropping practice can survive during extreme rainfall days	How many days your farming or fishing practices can survive under extreme rainfall?	Number of days	28.39 (± 5.52)	12.03(± 5.91)
liv_div	Livelihood diversity: number of livelihood activities, the household members are involved in	How many occupational diversities do you and your household members have?	Number of occupations	1.67 (± 0.68)	1.94 (± 0.68)
main_prof	Main profession: main livelihood activity that generates the largest portion of household income	Do you depend on natural resources for your livelihood activities?	0 = No 1 = Yes	19 (8.05%) 217 (91.95%)	8 (7.78%) 110 (93.22%)
crop_div	Crop diversity: number of crops the farmers cultivate or type of fish a fisher catches each year	How many types of crops do you cultivate? Or, do you fish only small fishes or large and small fishes both?	Number of crops	1.52 (± 0.5)	1.28 (± 0.47)
rot_crop	Crop rotation: number of seasons for crop cultivation or fishing	How many times do you cultivate your land in a year? Or, in how many seasons do you fish?	Number of season	1.46 (± 0.67)	1.36 (± 0.72)
lan_cul	Land type for cultivation: in the wetlands of Bangladesh, there are two types of land: 1) land remains inundated during flood season also known as low land and 2) land never remains under water except for extreme flood, also known as high land	Do you cultivate both low and high land? Or, do you fish in both open and common fishing grounds?	0 = No 1 = Yes	170 (72.03%) 66 (27.97%)	95 (80.51%) 23 (19.49%)
Intensity of drought	Effect of drought on the livelihood activities of the respondents	To what extent drought affects your livelihood activities?	1 = marginally 2 = moderately 3 = extremely	72 (30.51%) 157 (66.53%) 7 (2.97%)	54 (45.76%) 63 (53.39%) 1 (0.85%)
Intensity of flash-flood	Effect of flash-flood on the livelihood activities of the respondents	To what extent flash-flood affects your livelihood activities?	1 = marginally 2 = moderately 3 = extremely	31 (13.14%) 45 (19.07%) 160 (67.8%)	7 (5.93%) 29 (24.58%) 82 (69.49%)

(*continued on next page*)

Table 2 (*continued*)

Variables	Variable description	Sample questions	Response scale	Hakaluki	Tanguar
Intensity of regular flood	Effect of regular flood on the livelihood activities of the respondents	To what extent regular flood affects your livelihood activities?	1 = marginally	139 (58.90%)	88 (74.58%)
			2 = moderately	77 (32.63%)	20 (16.95%)
			3 = extremely	20 (8.47%)	10 (8.47%)
Intensity of extreme rainfall	Effect of extreme rainfall on the livelihood activities of the respondents	To what extent extreme rainfall affects your livelihood activities?	1 = marginally	229 (97.03%)	24 (20.34%)
			2 = moderately	7 (2.97%)	79 (66.95%)
			3 = extremely	0 (0.00%)	15 (12.71%)

Note: Standard deviations and percentages are in parentheses.

activities, crop diversity, rotation of crops, and cultivated land types including high and low lands) interact with household perceptions regarding each stress event. Before performing the regression analysis, we calculated the Pearson correlation coefficients among the independent variables to understand if multicollinearity existed among the variables, and identified that the variables were not strongly correlated to each other. The regression models helped us to identify the statistically significant variables determining respondents' perceptions regarding the effects of the individual stresses. Data were analyzed for both study areas as two different samples derived from two different populations (ie., Hakaluki *haor* and Tanguar *haor*).

5. Results

5.1. Livelihood activities and potential climatic stresses

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

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

5.2. Temporal nature of climatic stresses

Drought occurs during the winter and pre-monsoon period ranging from early December to early May causing river water flows to decrease substantially. Flash-flooding is not a regular phenomenon, with respondents noting that it occurs every three to four years, generally between early April and late June. However, this type of climate stress has the potential to cause total production failures, especially on farms.

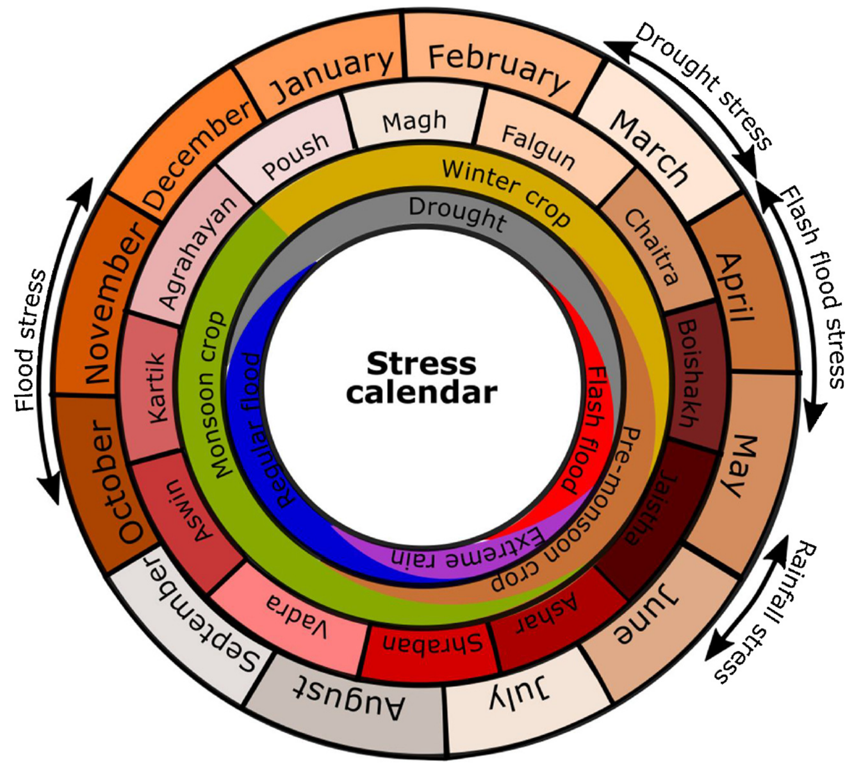

Fig. 2. Stress calendar of the study areas.

Although the respondents mentioned extreme rainfall as a stress, it was not reported as having a significant effect on their major livelihood activities in both study areas. Extreme rainfall usually occurs in the early monsoon, and therefore contributes to both flash-flooding and regular seasonal floods. Regular seasonal flooding is a common phenomenon resulting from upstream river flow and monsoon rain, occurring between mid-June and late November, and contributes to maintaining the wetland ecosystem. However, if this rainfall is prolonged at a high intensity in late monsoon for five days or more (Nowreen et al., 2015), it can significantly affect both fishing and agricultural livelihood activities (see Fig. 2).

Climatic events are perceived as being a stress on livelihoods when they take place or extend beyond the expected period. For example, drought stress prevails for approximately 6 months in the study area. However, drought as a climatic stress is only observed between February and March, when surface water (including rivers and canals and rainfall) for *Boro* rice irrigation reaches its lowest level. Although, drought was not considered a major stress for the Tanguar *haor* agricultural communities because of the presence of large water sources, it was strongly observed in the Hakaluki *haor* data, especially where there were insufficient water sources available. We discuss this spatial nature of exposure in more detail in Section 5.3. Although pre-monsoon or *Aush* rice is not widely cultivated in our study areas, drought was reported to affect land and seedling preparation for this crop. Drought was also reported as increasing the risk of insect infestation for both *Boro* rice and other short-rotation crops like mustard seed, cucumber, beans and coriander. Flash-flooding was perceived as a stress if it appears suddenly with a strong current during the *Boro* harvesting period in late April to early May. Under such a situation, farmers are forced to harvest pre-matured rice which reduces their expected production levels. *Aman* or monsoon rice is generally cultivated in the agricultural fields located peripherally to the villages, and not in the wetland areas themselves. This rice can thrive under flood conditions for a relatively long period, but it can also be affected if the regular flood extends beyond the harvesting period to November. Such a situation also delays land preparation for *Boro* plantation, and prolongs the cultivation period increasing its susceptibility to flash-flooding. On the other hand, fishermen perceived both flash-flooding and seasonal flooding in a different way than farmers. They reported having inadequate physical capital (e.g., artisanal boat and other fishing equipment) for fishing in high current flash-flood conditions and highly inundated regular flood waters (see Fig. 2). Therefore, fishermen perceive these stresses as a cause of fish catch decline, while farmers perceive them as a total crop failure threat.

Taken together (Sections 5.1 and 5.2), we can observe that respondents determined the temporal nature of different climatic stresses based on their livelihood activities, the nature of the outputs and the seasonality of production activities and the physical appearance of different stresses, which is consistent with the first proposition (see Section 2.1).

5.3. Spatial nature of climatic stresses

Both Hakaluki and Tanguar *haors* function as temporary reservoirs for upstream river flow. Consequently, river water inflow and outflow govern the flooding regime of both areas. However, rainfall within the Bangladeshi territory also contributes to flooding. From the community stress map of Hakaluki (Fig. 3), it can be observed that there are four trans-boundary rivers that carry water to the *haor,* including Juri, Panai, Borodol and Konthinala. While these four rivers play a major role in water inflow, there are a number of permanent and non-permanent hilly streams that also contribute to water flow. Importantly, all of these streams come from small hills located around the Hakaluki (inside Bangladesh), which dry up during the drought period. However, Juri river is the only outflow of flood water, which combines with Kushiara river near Fenchuganj sub-district. Notably, Baradal, Fanai, and Konthinala rivers join with the Juri river at different locations within the *haor*. Beyond serving as the main water channels inside the *haor*, these rivers and canals work as the main sources of irrigation during drought periods (see Fig. 3). However, river bank erosion and siltation, which are both considered natural phenomena of the rivers in Bangladesh (Deb and Ferreira, 2015), has significantly reduced their

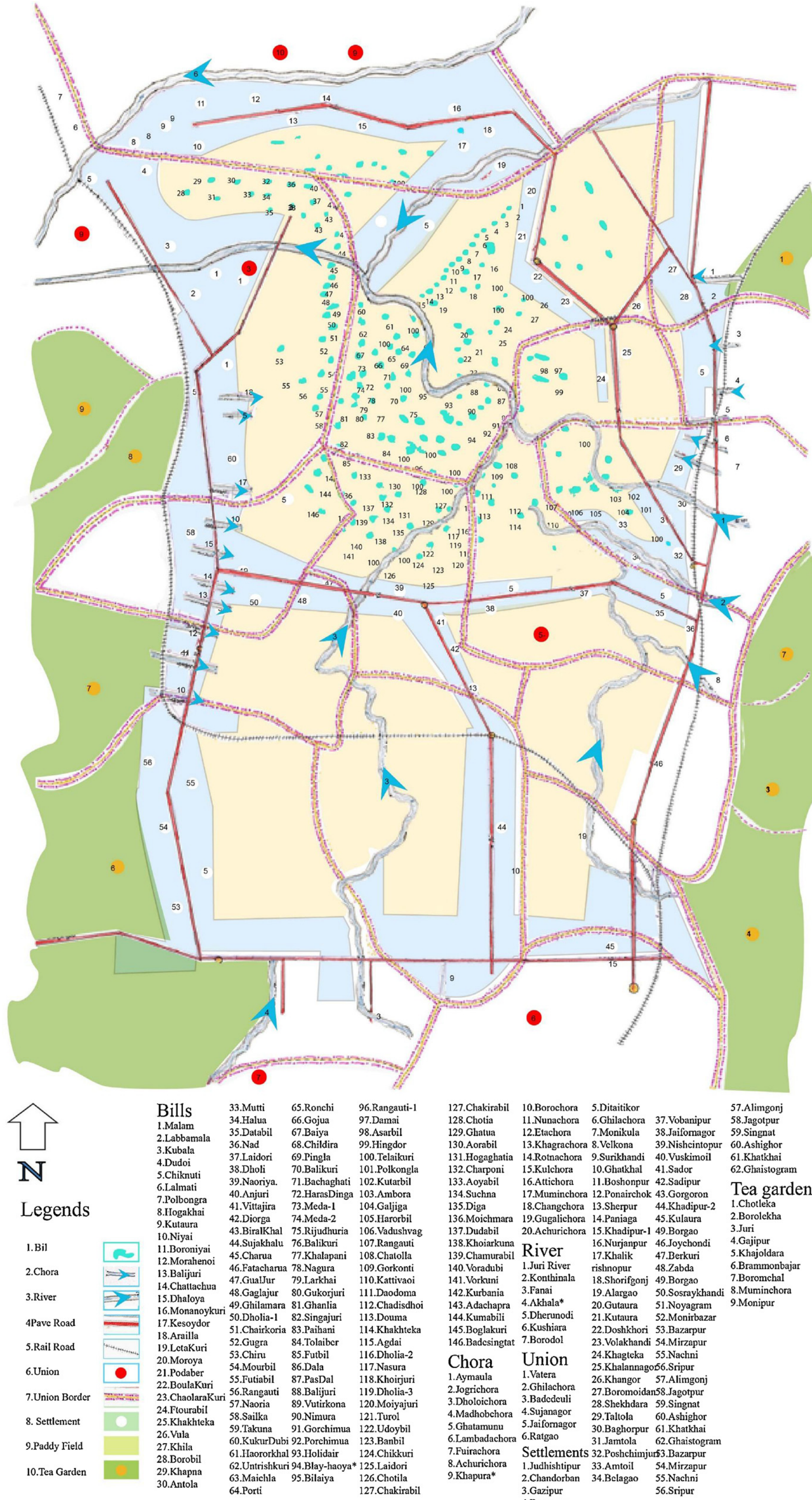

Fig. 3. Stress map of Hakaluki *haor*.

water carrying and storage capacity. For example, standing on the bank of the Juri river, one key informant in Hakaluki *haor*, who is both a local farmer and a community leader involved in different environmental conservation activities initiated by government and non-government organizations, stated:

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

the drought season".

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

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

Beyond these relationships with drought, the loss of river carrying capacity was also reported by respondents as contributing to flash-flooding. For example, the existing canals and silted Juri river were described as not being sufficient to drain flash-flood water in Kushiara river within the period of time required to maintain the desired water levels for rice harvesting (see Fig. 3). Here, siltation was identified as causing water stagnation which reduced the time interval between flash-flooding and regular seasonal floods.

The geographic features of Tanguar *haor* are different from those of Hakaluki *haor*. Tanguar is part of a larger *haor* system, which also includes Maitan, Samnagar, Boroduma, Veramara, Shonir *haors*. A large river network flows and distributes water within this *haor* system, including Jadukata, Udalkhali, Ambarkhali, Patlai and Baulai rivers (Fig. 4), all part of the Surma river tributary. In addition, more than 50 small permanent and non-permanent streams originating from the hills of Meghalaya contribute to water inflow. Unlike Hakaluki *haor*, the flood water passes through all of these rivers and finally flows into the Surma river through the Baulai river (Fig. 4). The *beels* inside the Tanguar *haor* are deeper and larger than those of Hakaluki *haor*, increasing its water retention capacity. Here, respondents suggested that drought was not a major problem, instead identifying that flash-flooding was the major climatic event affecting the single rotation rice crop cultivated in the *haor*. From the field visit during the *Boro* rice harvesting period, we observed that the entire *haor* was flooded within five days, resulting in an almost total crop failure. To explain the severity of flash-flooding, one key informant from Tanguar *haor*, who is a local farmer and a leader of a community cooperative group, noted:

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

Fig. 4. Stress map of Tanguar *haor*.

them have rotted."

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

These results support the second proposition, that the bio-physical changes of the *haors* have altered the flooding and irrigation patterns, converting a regular rainfall and river water flow event into a water stagnancy problem. This new bio-physical feature has the potential to exacerbate the intensity of production losses, particularly for farmers (see Section 2.2).

5.4. Exposure determinants of the affected community members

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

Tables 3 and 5 provide the descriptions of the ordered logistic regression results for how the respondents considered the stress intensity of different climatic events in the Hakaluki and Tanguar *haors* respectively, while Tables 4 and 6 report the odds ratios of the models. We find that in the case of drought, natural resource dependency for main livelihood activities, duration of drought, crop loss and crop survival capacity are statistically significant in Hakaluki, while in Tanguar the duration of drought, crop loss and crop survival capacity are statistically significant. Hence, it is observed that commonalities between the cases in identifying drought stress determinants. Notably, the respondents emphasized the length of drought and the extent to which their crops can survive in the stressed period as key, which are interactive in nature and indicates that drought perception is built upon their crop's resilience to drought. However, in the case of flash-flood both study areas showed that livelihood diversity and crop loss due to flash-flood are statistically significant, although there were perceptional differences. The models suggest that livelihood diversity is negatively related to stress intensity in Hakaluki, which is opposite to the finding for Tanguar *haor*. This is likely due to an over dependency on natural resources in the Tanguar *haor* communities, which is comparatively lower in Hakaluki. On the other hand, unlike drought, crop resilience against flash-flooding does not contribute to perceptions of its intensity since it often causes total crop loss. Thus, crop loss appears as the significant determinant variable for perception of the intensity of flash-floods.

We observe large differences in the extreme rainfall models between the study areas. While crop loss due to extreme rainfall is the only significant variable in the case of Hakaluki, the Tanguar *haor's* model suggests that crop diversity, rotation of crops, duration of extreme rainfall and crop loss are the significant variables. These differences likely occur because of the proximity of Tanguar *haor* to the Meghalayan mountain region of India. Extreme rainfall in this area, accompanied by similar stress within the territory of Bangladesh, increases the potential of high water flow levels. In contrast, Hakaluki *haor* has diverse surrounding land forms and resource use practices which would reduce the negative impacts of extreme rainfall. In the case of regular flooding, the models indicate that flood interval and loss are significant for Hakaluki, while crop diversity, loss and survival capacity are significant for Tanguar. Notably, the stress interval is only

Table 3
Exposure determinants of Hakaluki *haor* communities.

Drought		Flash-flood		Extreme rainfall		Regular flood	
Variable	Coefficient	variables	Coefficient	variables	Coefficient	variables	Coefficient
dur_drou	0.033***	dur_ff	0.056	dur_er	0.114	dur_rf	0.003
	(0.012)		(0.036)		(0.103)		(0.008)
int_drou	0.067	int_ff	0.054	int_er	−0.235	int_rf	0.679***
	(0.248)		(0.195)		(1.015)		(0.247)
loss_drou	4.462***	loss_ff	4.214***	loss_er	3.641***	loss_rf	3.604***
	(0.830)		(0.595)		(1.347)		(0.426)
surv_drou	−0.052*	surv_ff	0.027	surv_er	−0.109	surv_rf	0.008
	(0.030)		(0.043)		(0.077)		(0.031)
liv_div	0.140	liv_div	−0.754***	liv_div	−1.482	liv_div	0.441
	(0.247)		(0.289)		(1.381)		(0.293)
main_prof	1.392**	main_prof	−0.664	main_prof	13.261	main_prof	0.515
	(0.646)		(0.829)		(20.432)		(0.753)
crop_div	−0.175	crop_div	0.172	crop_div	0.231	crop_div	0.376
	(0.291)		(0.354)		(0.692)		(0.324)
rot_crop	−0.263	rot_crop	−0.510	rot_crop	1.096	rot_crop	0.517
	(0.277)		(0.371)		(0.799)		(0.365)
lan_cul	−0.188	lan_cul	−0.195	lan_cul	−1.660	lan_cul	−0.160
	(0.430)		(0.568)		(1.611)		(0.503)
/cut1	4.808	/cut1	1.499	/cut1	16.893	/cut1	7.601
	(1.678)		(1.584)		(1.437)		(1.786)
/cut2	10.524	/cut2	5.432			/cut2	11.963
	(1.948)		(1.748)				(1.950)
Log likelihood	−129.517	Log likelihood	−92.679	Log likelihood	−12.845	Log likelihood	−103.611
Likelihood ratio χ^2	89.15***	Likelihood ratio χ^2	211.44***	Likelihood ratio χ^2	37.35***	Likelihood ratio χ^2	209.95***
Pseudo R^2	0.256	Pseudo R^2	0.533	Pseudo R^2	0.593	Pseudo R^2	0.503

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

Table 4
Odds ratios of exposure determinants Hakaluki *haor* communities.

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

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

statistically significant for regular flooding in Hakaluki *haor*, since this area is highly affected by siltation loads in its major water channels resulting in water stagnancy (see Section 3). The models show that despite considerable perceptional differences between the two cases, both communities considered crop loss as an important determinant for all the stresses, while other non-climatic variables were important based on stress type. Nevertheless, the community members also valued climatic variables in describing stress, which indicates that the stress exposure perceptions of the communities are determined by both climatic and non-climatic variables, supporting the third proposition.

6. Discussion

Livelihood exposure to different climatic extremes is a product of interactions between the climatic (e.g., nature of extreme, frequencies and extent) and non-climatic properties (e.g., resource use behaviors, seasonality of livelihood activities and geographic properties) of a system. The results reported in this study suggest that a climatic

Table 5
Exposure determinants of Tanguar *haor* communities.

Drought		Flash-flood		Extreme rainfall		Regular flood	
Variable	Coefficient	variables	Coefficient	variables	Coefficient	variables	Coefficient
dur_drou	0.092** (0.040)	dur_ff	−0.026 (0.127)	dur_er	0.283*** (0.097)	dur_rf	0.038 (0.030)
int_drou	−0.045 (0.442)	int_ff	−0.594 (0.520)	int_er	1.369 (0.497)	int_rf	−0.451 (0.811)
loss_drou	3.596*** (0.911)	loss_ff	9.780*** (0.258)	loss_er	5.617*** (1.058)	loss_rf	5.203*** (1.452)
surv_drou	−0.152* (0.089)	surv_ff	0.095 (0.146)	surv_er	−0.108 (0.079)	surv_rf	−0.180* (0.102)
liv_div	0.298 (0.403)	liv_div	0.904* (0.527)	liv_div	0.066 (0.423)	liv_div	−0.372 (0.757)
main_prof	−2.083 (1.708)	main_prof	34.855 (1.344)	main_prof	−0.397 (1.602)	main_prof	−1.394 (2.682)
crop_div	0.622 (0.780)	crop_div	0.867 (1.111)	crop_div	1.866** (0.845)	crop_div	2.174** (1.145)
rot_crop	−0.740 (0.661)	rot_crop	1.624 (0.172)	rot_crop	−1.450** (0.706)	rot_crop	−0.347 (0.772)
lan_cul	−0.436 (0.873)	lan_cul	15.938 (1.336)	lan_cul	0.490 (0.944)	lan_cul	−0.235 (1.239)
/cut1	0.198 (3.643)	/cut1	11.883 (10.259)	/cut1	10.090 (3.237)	/cut1	3.359 (5.241)
/cut2	6.458 (3.784)	/cut2	19.323 (5.675)	/cut2	16.374 (3.700)	/cut2	8.633 (5.483)
Log likelihood	−103.61134	Log likelihood	−31.748	Log likelihood	−49.260	Log likelihood	−19.018
Likelihood ratio χ^2	209.95***	Likelihood ratio χ^2	117.14***	Likelihood ratio χ^2	103.20***	Likelihood ratio χ^2	133.95***
Pseudo R^2	0.5033	Pseudo R^2	0.649	Pseudo R^2	0.5116	Pseudo R^2	0.779

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

Table 6
Odds ratios of exposure determinants Tanguar *haor* communities.

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

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

extreme appears as a stress when it directly influences the major livelihood activities and production systems. They also suggest that the exploitation of capital assets for future livelihood sustainability depends on these interactions.

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

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

Rapid environmental and geographic changes due to uncoordinated adaptation actions, human intervention and natural phenomenon can compound the intensity of climatic extremes (Grimm et al., 2008). The results suggest that the depletion of natural water channels increases the chance of drought, loss of fishing grounds and flood effects in both Hakaluki and Tanguar *haors*, previously argued by Huq et al. (2004) (see Section 2.2). Consequently, a stress event could occur without extreme climatic events, suggesting that climatic impact characterization and forecasting based on historical data may not be sufficient for policy responses. Recognizing this limitation, Grimm et al. (2008) suggested that spatially continuous information containing land cover change is necessary for monitoring such effects. Such an approach has wider implications for assessing future vulnerability, because climate models have limited application to derive the impacts of land cover change, and are more useful for understanding changes to mean conditions. Moreover, land cover changes have the potential to alter the available ecosystem services either by reducing productivity (e.g., agricultural and fishery productivity) or by creating new opportunities for production (e.g., conversion of agricultural land to shrimp farms due to increased salinity in the southern part of Bangladesh).

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

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

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

6.3. Contribution of participatory stress assessment

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

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

7. Conclusion

Climate change, as a locally felt global phenomenon, requires a considerable degree of contextualized knowledge in order to inform the design, implementation and evaluation of adaptation actions. This reality has led to an increasing focus on how community members interact with climatic stresses when sustaining their living based on their own understandings of such stresses. This paper offers a range of empirically-grounded insights to how the spatio-temporal properties of local resource systems influence the exposure of rural livelihoods to climatic stresses in the north-eastern floodplains of Bangladesh, and how these serve to mediate communities' perceptions of such stress. Specifically, we found that the climatic stresses on rural livelihoods were catalyzed by human-induced environmental degradation and local resource use behaviors, contextual features which include both socio-economic and bio-physical properties. Moreover, a climatic event appeared as a stress to livelihood sustainability when it happened in an untimely manner and directly affected the production process. We also found that human stress perceptions varied with the level of locally-driven innovation and adoption of new technologies, which supports the important role of local experience and knowledge in adaptation planning. In order to make local adaptation planning more effective, equitable and sustainable in the north-eastern floodplain region of Bangladesh, there remains an urgent need for more empirical research to further assess the extent to which local livelihoods are affected by different climate stresses, and how different communities in the region are adapting in response to perceived exposure. Although the Bangladesh government's climate and local development plans have emphasized infrastructural flood protection in the study area, our results suggest that such policies may have a strong negative consequence on local bio-physical properties, limiting the natural flood protection capacity of the area. Further in-depth assessment of the effectiveness of short-term flood protection in the study areas that better considers its cross-sectoral (e.g., agriculture, fisheries, biodiversity) relevance and ecological appropriateness is warranted. There is also a need to better understand how different communities are already managing their perceived stresses through fostering traditional knowledge systems, supporting local innovation networks and adapting livelihood practices in order to inform local adaptation policies.

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