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Livelihood Vulnerability of Char Land Communities to Climate Change and Natural Hazards in Bangladesh: An Application of Livelihood Vulnerability Index

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Abstract

Bangladesh is one of the most vulnerable countries to climate change in the world. In general, Charland (Riverine Island) communities are frequently affected by floods, riverbank erosion, and other climatic hazards, which cause many to lose their sources of livelihoods and

properties and making them more vulnerable. Using survey data of 262 rural households, this study investigates the extent of livelihood vulnerability to climate change and natural hazards of the *Charland* communities by applying the climate change vulnerability index (CVI) (i.e. UN-IPCC vulnerability framework) and the livelihood vulnerability index (LVI) to develop context-specific interventions for building climate and livelihood resilience. The two approaches of vulnerability assessment were modified to incorporate local contexts and indigenous knowledge into 41 sub-components. The result shows that LVI and CVI values are different between *Charland* communities. The LVI index shows that households in *Char Jotindro-Narayan* (0.148) are more vulnerable than *Char Kulaghat* (0.139). The CVI values for *Char Jotindro-Narayan* (0.633) are slightly lower than for *Char Kulaghat* (0.639). The major vulnerability factors were identified as the social networks, food self-sufficiency, natural disasters, and climatic variability. The study also indicates that flood, riverbank erosion, unemployment, and access to communication, market, and basic service opportunities are the major biophysical and socioeconomic factors determining livelihood vulnerability. The context-specific sustainable policies and development initiatives are required to improve the adaptive capacity of *Charland* communities across Bangladesh and thereby building their climate and livelihood resilience.

Keywords: *Charland*, climate change, natural disaster, livelihood vulnerability, Bangladesh

1. Introduction

Bangladesh is the world's most climate hot spot country due to its low-lying terrain and geographic condition and climate change over time (Alam, 2017; IPCC, 2014). It is thought that climate change aggravates similar hazardous incidents, including floods, riverbank erosion, drought, cyclone, water logging, etc., which adversely influences socioeconomic improvement and living communities (Alam, 2016; Simotwo et al., 2018; Panthi et al., 2016). In Bangladesh, these climatic hazards often occur on delta and riverine islands (huge

sandbars that form in riverbeds as a result of silt and alluvium deposition) communities, specifically by the dynamic riverbank erosion and accumulation (Alam et al., 2017; Ahmed et al., 2019; Islam, 2018). These areas are known as char areas that are familiar with numerous natural hazards and socio-economic vulnerabilities. The impacts will differ for people who work in various occupations, e.g. agriculture, fisheries, business, etc. Every year, frequent riverbank erosion loses a great amount of agricultural and usable land of char communities (Alam, 2017). However, the communication structure of char land communities is also damaged by natural hazards that deny char residents equal opportunities to the economic and social benefits that mainland residents enjoy (Alam et al., 2017). These difficult scenarios are prevalent throughout Bangladesh's various char areas, which represent around 5% of the country's entire land (7200 sq. km) and population (6.5 million people) (Alam, 2017; Alam et al., 2017; EGIS, 2000). The most challenging fact for the char land people is inability to relocate to the mainland to seek employment opportunities, which result in migrations within the char region (Alam et al., 2020).

A climate change model projection estimated that the mean yearly and seasonal temperature would be increasing until 4.7°C in our country by the end up of the century (Christensen et al., 2007). The precipitation in the wet season will be expected to increase by 11%, while the winter arid time is expected to become notably thirstier; the rate and severity of cyclones in the Bay of Bengal are also expected to rise, leading to more heavy rainfall in coastline areas, culminating in extensive flooding and sea incursions (Christensen et al., 2007). Such challenges are damaging the livelihood and the landscape, providing the foundation for effective agricultural activities, such as cropping patterns, crop yields, insect infestations, and water availability. The households of char communities are frequently losing their agricultural products (e.g. yields, poultry, and livestock), as well as the human and financial

assets required to conserve their financial prosperity and overall persistence (Alam et al., 2018).

Climate change vulnerability has been described by the degree to which a system or civilization is susceptible to, or at danger of, and incapable of dealing with the deleterious climate change impacts (Schneider, 2007). Vulnerabilities of climate and their related consequences differ depending on the communities' geographical, temporal, and socioeconomic characteristics (Alam, 2016; Ayanlade et al., 2018; Panthi et al., 2016). As a outcome, vulnerability assessment assists in determining a community's adaptability level, which is the first step in developing adaptive strategy initiatives to decrease the risks connected with climate change-induced disasters (Alam, 2017; Erdiaw-Kwasie et al., 2019; Zhang et al., 2018; Toufique and Islam, 2014; Vignieri, 2015). People in developing nations are vulnerable due to their reliance on farming and poor earnings (UNDP, 2008). These constraints can stimulate the investigation of resource-poor societies' possible adaptive capabilities (Nelson, 2007; Folke, 2006). The degree to which humans are vulnerable to natural hazards in nearly all aspects of living, such as the human, social, financial, physical and natural dimensions, has risen (Oo, 2018; Ford, 2010).

Investigating and analyzing vulnerability requires a context-specific approach at all regional levels to develop effective policy and strategy and minimize harmful consequences on livelihoods (Adger, 2005; Bevacqua, 2018). The relationship between individuals and their social and biophysical environments is easily utilized to evaluate the development-policy framework using particular indicators (Eriksen, 2007), and showing perspective adaptation strategies (Gbetibouo, 2010). It can compare and assess the level of vulnerability as it varies over time, location, and allocation of resources (Preston, 2011). The primary difficulty in vulnerability assessment is developing strong and reliable indicators (Adger, 2006).

This study focuses on the char land region in Bangladesh. Geologically, Bangladesh is recognized as one of the world's biggest delta, which comprises about 230 rivers, encompassing three major rivers known as Ganges–Brahmaputra–Meghna (GBM), which contains massive inland bodies of water (Islam and Bhuiyan 2016, 2018; Monwar et al., 2018). In Bangladesh, coastline and riparian communities are the extremely vulnerable to the effects of climate induced hazards such as riverbank erosion, floods, cyclones, arsenic contamination, waterlogging, and salinity intrusion, etc. due to geographical context (Azad et al. 2013; Alam, 2016; Alam et al., 2017; Islam and Uddin, 2015; Islam 2013, 2014). Apart from the isolations suffered by char dwellers, the region is characterized by high precipitation rates that result in great riverbank erosion (around 150,000 square km) over the past 10 years (Alam, 2017; Huq, 2008; Mutton, 2004). Over 20 of the 64 districts are vulnerable to severe riverbank erosion, subsequent in the loss of 8700 hectares of land and the relocation of approximately 200,000 people per year (Alam, 2016; Alam et al., 2017; Ahsan, 2014; Barrett, 2014; CEGIS, 2012; IFAD, 2011). Despite these threats and vulnerabilities, riverine peoples frequently choose char regions owing to increasing population pressure and cumulative stress on scarce land areas (BBS, 2014). The char land communities are recognized among the poorest and the most exposed group to environmental dangers (Alam, 2017; CLP, 2010; Islam and Hossain, 2013). Adding to this, char residents are faced with inadequate communication networks, which excludes them from the services and advantages available to 'mainland' residents (Sarker et al., 2020; Thompson, 2000).

For the government, NGOs, or/and foreign donor organizations to actively and successfully intervene in the current situations faced by the char residents, reliable information, and in-depth study findings are required (IPCC, 2014; Islam, 2018; Alam, 2016; Alam et al., 2017). The policy action cannot occur unless the exact condition of char communities' vulnerability is understood (Alam et al., 2017; Sarker et al., 2020). The Bangladeshi government views the

vulnerability of char households to be a critical issue that must be addressed (GOB, 2011). This research intends to address this critical gap by implementing the IPCC vulnerability approach and building a livelihood vulnerability index (LVI) and a climatic vulnerability index (CVI). The study also seeks to investigate the range to which char communities are vulnerable regarding livelihood and climate change situations within rural communities in the char area of Bangladesh.

2. Materials and methods

2.1. Study area

The study was conducted at Phulbari Upazila in Kurigram and Lalmonirhat Sadar Upazila in the Lalmonirhat district of northern Bangladesh. Geographically this area situated between 25°52'0"N to 25°58'0"N latitude and 89°28'0"E to 89°33'0"E longitude (Fig.1). These regions are among the most vulnerable to natural hazards and considered as geographically remote riverine areas. The Dharla River crosses the study region, and poses lot of challenges including loss of livelihood assets, crops, and agricultural land, particularly in times of riverbank erosion. The regular flood and erosion of riverbank are a common phenomenon in the region that badly influence the char land communities (Mondal et al., 2020; Islam et al., 2019) (Figure 2).

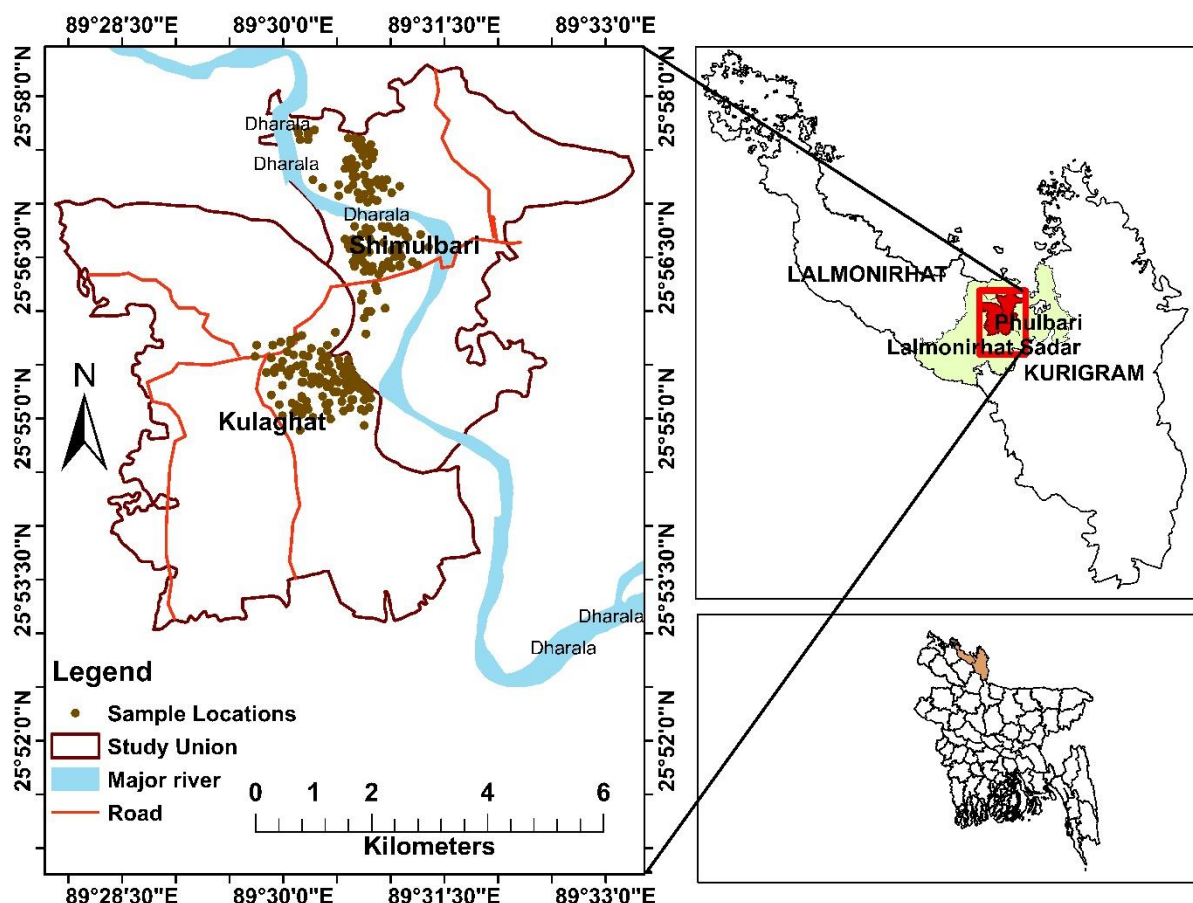


Fig. 1. Map presenting the location of the study region.

The study villages were purposively chosen based on the extent of their natural hazards especially flood and riverbank erosion, which has been reported by previous research papers, local expert views, policy documents, and newspapers. The respondents from these villages were elected randomly for the survey. The study determined on two main constituencies (i) the community which has relatively easy access to the mainland and (ii) the communities living in proximity to the Dharla River. Although both regions are frequently affected by natural hazards, they have their own uniqueness on the basis of communication system, education, health services, and different livelihood assets. The studied village in Phulbari Upazila was Char Jotindro-Narayan, and the distant villages in Lalmonirhat Sadar Upazila were Kulaghat char.



Riverbank erosion



Riverbank area



Char land cultivation

Fig. 2. Dharla river-bank erosion and livelihoods.

2.2. Sample size estimation

To estimate the sample size Cochran's formula (1977) was applied (Eq. 1). According to the BBS (2011), these two selected villages from Phulbari and Lalmonirhat Sadar Upazila were a total of 823 households. The appraised sample size was 262 (131 for Char Jotindro-Narayan in Phulbari Upazila and 131 for Kulaghat char in Lalmonirhat Sadar Upazila). The confidence level was 95%, while the margin of error (confidence interval) was 5%, respectively (Cochran, 1977).

$$n = \frac{n_0}{1 + \frac{(n_0-1)}{N}} \quad (1)$$

Where,

n = Sample size for the given population

n_0 = Sample size of an infinitive population

N = Population size

2.3. Questionnaire and data collection

The survey was performed using a semi-structured questionnaire, focus group discussions (FGDs), and face-to-face interviews between January and February 2020. A total of 20 pretest surveys were conducted to examine the transparency of the questionnaire, its appropriateness for contributors, the time required for per interview, and any potential impediments that could occur during the survey. After that, the questionnaire was finalized, consisting of three sections (i) adaptive capacity, (ii) exposure and, (iii) sensitivity, as well as eight major livelihood components. The household head was the main targeted respondent. The survey was in the local language. A multi-stage sampling technique was used to identify respondent households. Moreover to surveys, two focus group discussions (FGDs) were conducted in each village by groups of 10-12 family heads to collect perspectives on various climatic and socioeconomic variables. These thoughts were subsequently utilized to cross certify the survey results. Questions involved in the survey questionnaire are defined as the major components in Table 1. Analysis of Livelihood vulnerability index (LVI) and Climate Vulnerability Index (CVI) values was obtained utilizing Microsoft Excel and SPSS 24.

2.4. Context-specific framework approach

Climate vulnerability refers to the extent to which environmental, geophysical, and socioeconomic conditions are susceptible and incapable to deal with the negative effects of climate change (IPCC, 2007). Climate vulnerability is a composite and sophisticated legislative issue, engaging with social, economic, political, and environmental elements at

global, nationwide, and local levels (Adger, 2005; 2006). Climate vulnerabilities and their related impacts differ across sectors and contexts depending on the geographical, temporal, and socioeconomic characteristics (Alam, 2016; Ayanlade et al. 2018; Jurgilevich, 2017). The context-specific approach responds with knowledge of the complicated historical and contemporary context in which any action is being performed, as well as the potential influence and engagement that any activities may have on that context. Therefore, to characterize a specific context of a study area, it needs to evaluate the interactions between temporal, geographical, social, financial, political, and resource or livelihood capital factors. Climate change effects will modify the biophysical features of the context and influence the interplay between multiple aspects that regulate the dynamics of climate vulnerability (O'Brien, 2007; Thornton, 2014). While it is needed to realize how to identify a context, this is also needed to fix what context must be recognized for develop adaptation policies at various levels (e.g., nationwide, sub-national, or local) (Leichenko, 2014; Erdiaw-Kwasie et al., 2019). In our study, we follow the context-specific approach (Figure 3). Context identification is a great tool to specify and characterization of the context. In our study, after the context is identified, we specify the livelihoods exposure to the climatic vulnerability on context and consequence basis. This phase involves determining the sensitivity of livelihood activities while considering the accessibility and usage of various capital resources for developing and spreading livelihood strategies. There are some steps to accessing adaptive capacity which include government, NGOs institutional planning for fixing the virtue and connectivity to capital assets. For the LVI framework in the study, we identified 8 major components comprising 41 sub-components under the 5 livelihoods capitals: human, natural social, physical, and financial. These consists of food, water, health, socio-demographic profile, livelihood strategies, social network, natural disasters, and climatic variability. This context-specific LVI technique adopted will investigate the actual circumstances of

livelihood vulnerability. The ultimate phase of the approach is an evaluation of adaptation plans to reduce context-specific vulnerability, and prevent unfavorable outcomes.

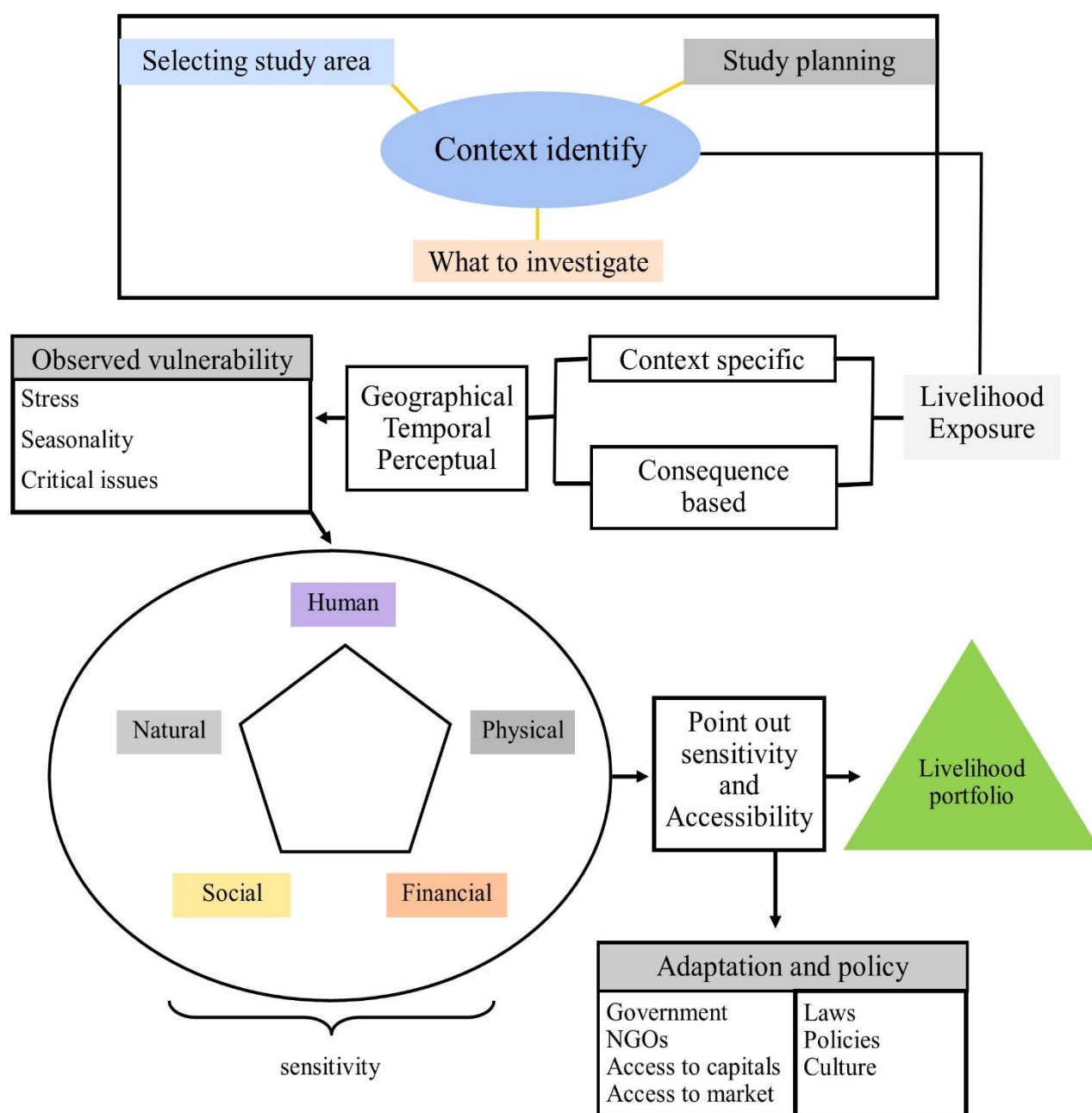


Fig. 3. A context-specific framework approach for livelihood vulnerability

2.5. Vulnerability analysis

Vulnerability refers to the status of a personal or group to stresses caused by alterations in socio-economic and environmental factors that disrupt livelihoods (Adger, 1999).

Vulnerability estimation reveals the communal systems and materials result within the framework and recognized the susceptible people and sensitive factors to climatic hazards (Adger, 2006; Ford et al., 2010; Tavares et al., 2015). Vulnerability is determined by the function of three primary dimensions, which are sensitivity, exposure, and adaptive capacity (IPCC, 2007) by the following Eq. (2)

$$\text{Vulnerability} = f(\text{Exposure, sensitivity, adaptive capacity}) \quad (2)$$

In general, vulnerability is a positive function to sensitivity and exposure of the system and a negative function to adaptive capability (Ford et al., 2010; Ford and Smit, 2004; Alam, 2017). Community views of social identity influence outlining climate risk opinion and resulting adaptive capacity (Frank et al., 2011). For this study, we used LVI (Alam, 2017; Hahn et al., 2009; Alam et al., 2017) and CVI (Pandey and Jha, 2012; Alam, 2016; Alam, 2017) to measuring livelihood vulnerability of char land communities and evaluate the comparative degree of the major participating parameters under the comprehensive IPCC framework. The IPCC livelihood framework approach measures vulnerability using three key functions: sensitivity, exposure, and adaptive capacity. In the study, we utilized a compound index-basis LVI with all major assets of households which including human, social, physical, financial and natural of a Sustainable Livelihood Framework (SLF), which provides a superior assimilation with adaptive capacity and sensitivity. Numbers of scholars have utilized this similar technique (Alam, 2016; Alam et al., 2017; Sarker et al., 2019; Gerlitz et al., 2017; Orencio et al., 2013). The LVI method attentions on assessing the strong suit of present livelihood status, health, food, and water reserve features, as well as households ability to modify these approaches in reply to exposures that are related with climate change (Hahn et al., 2009). The weighted balanced and comprehensive strategy based on LVI and CVI was used, with local and traditional knowledge factored into the indicator selection. In our study, LVI comprises eight major components, comprising livelihood strategies, social network,

socio-demographic profile, accessibility to water, food, and health, and the negative effects of climatic variability and natural disaster described further into 41 sub-components together (Table 1). These components were built on the review of literature, local condition, and local expert views on each major component, and owing to the simplicity of the technique, further significant indicators are encompassed for this study. The outcomes are comparative and are determined on a scale of 0 (least vulnerable) to 1 (most vulnerable). To assess the least and most vulnerable groups, an intra and inter-group cross-comparison is performed. The LVI was calculated using the balanced weighted technique (Hahn et al., 2009; Alam et al., 2017; Pandey and Jha, 2012). Each sub-component participates equally to the total index, even though the each main component has a varying numeral of sub-component. Since each sub-component was calculated at a distinct scale, these were standardized as follows Eq. 3

$$Index_{sd} = \frac{S_d - S_{min}}{S_{max} - S_{min}} \quad (3)$$

Where, S_d = Original sub-component for the study area, S_{min} and S_{max} denote the minimum value and maximum value of each sub-component correspondingly. These minimum values and maximum values were used to develop the standardized index. The percentage of different components was determined using a scale ranging from 0 to 100. After collecting the sub-components values, the average of each sub-components was computed applying Eq. 4, which produces the major components value.

$$M_d = \frac{\sum_{i=1}^n index_{s_{di}}}{n}$$

(4)

Where, M_d = one of the major components for the study site, $index_{s_{di}}$ = subcomponents and n = numbers of sub-components of each major component.

When each values of the eight major components for the study area were computed, they were then averaged by Eq. 5 to get the study area LVI.

$$LVI_d = \frac{\sum_{i=1}^8 w_{Mi} M_{di}}{\sum_{i=1}^8 w_{Mi}}$$

(5)

Which can also be expressed as-

$$LVI_d = \frac{w_{SDP}SDP_d + w_{LS}LS_d + w_{SN}SN_d + w_HH_d + w_FF_d + w_WW_d + w_{ND}ND_d + w_{CV}CV_d}{w_{SDP} + w_{LS} + w_{SN} + w_H + w_F + w_W + w_{ND} + w_{CV}}$$

(6)

Where, LVI_d = Livelihood vulnerability of the study site d , that equals the eight major components weighted average. Each weights of the major components, w_{mi} , are obtained by the numbers of sub-components which constitute each major component. The weights were involved so that each sub-components participated equally in the overall LVI.

The exposure (Exp) index contained climate variability (CV) and natural disasters (ND) and was computed using Eq. 7.

$$Exp = \frac{W_{exp1}ND + W_{exp2}CV}{W_{exp1} + W_{exp2}}$$

(7)

Where, W_{exp1} and W_{exp2} expressed the weight of natural disasters and climate vulnerability correspondingly.

The index of sensitivity (Sen) includes food (F), health (H), and water (W), and calculated using Eq.8.

$$Sen = \frac{W_{sen1}H + W_{sen2}F + W_{sen3}W}{W_{exp1} + W_{exp2} + W_{exp3}}$$

(8)

Where, W_{exp1} , W_{exp2} and W_{exp3} were expressed the weights of three major components health, food, and water correspondingly.

The adaptive capacity (AdaCap) index was computed using following Eq. 9.

$$AdaCap = \frac{W_{ad1}SDP + W_{ad2}LS + W_{ad3}SN}{W_{ad1} + W_{ad2} + W_{ad3}}$$

(9)

Where, W_{ad1} , W_{ad2} and W_{ad3} were expressed the weights of three major components socio-demographic profile, livelihood strategies, and social networks correspondingly.

The index value of the IPCC three-dimension functions sensitivity, exposure, and adaptive capacity were applied to calculate the weighted average of the Climate Vulnerability Index (CVI) as follows:

$$CVI = 1 - \left| \left\{ \frac{N1Exp - N2 Ada.cap}{(N1 + N2)} \right\} \right| * \left\{ \frac{1}{Sen} \right\}$$

(10)

Where, N_i = Numbers of major components in the i^{th} vulnerability dimension. The value of each dimension varied to a minimum of 0 and a maximum of 1.

2.6. IPCC Framework Approach

The IPCC framework combines the eight major components into three dimensions: sensitivity, exposure, and adaptive capacity. This three participating factors are integrated using Eq. 11.

$$LVI - IPCC_d = (Exp - Ada.cap) * Sen$$

(11)

Where, $LVI - IPCC_d$ = LVI for the community, d , denotes the IPCC vulnerability framework. LVI-IPCC index value ranged to -1 (least vulnerable) and the maximum to 1 (most vulnerable).

The selection of meaningful and robust parameters particular to regional communities is a key issue connected with vulnerability analysis (Adger, 2006; Alam, 2016; Alam et al., 2017; Etwire et al., 2013; Salvati and Carlucci, 2014). However, this limitation is overcome by an exhaustive literature study, firsthand observations, and expert views to get representative and

319 complete results. The adopted approach may be used to estimate and compare the
 320 susceptibility of other rural populations because of the method's flexibility, which allows for
 321 adjustments in indicators based on the conditions of a particular state of an area, sector, or
 322 community.

Table 1.

Livelihood Vulnerability Index (LVI) components and indicators developed for this study (HHs = households; NGOs = nongovernmental organizations)

	Major components	Sub-components or indicator	units	Score/values	Sources
Adaptive capacity	Socio-demographic profile	Dependency ratio	Ratio	If 1:3, then score =1 , if more = 0	DHS, 2006; Sadekin, 2018; Madhuri., 2014; Alam, 2017
		Percent of HHs were the head of the HH has not joined school	Percentage	Yes = 1, No = 0	Hahn et al., 2009; Bhuiyan et al., 2017; Alam, 2017
		Average number of family members in the HHs	count		Hahn et al., 2009; Alam, 2017
	Livelihood strategy	Percent of households dependent only on agriculture as a main income source	Percentage	Yes = 1, No = 0	Madhuri., 2014; Alam et al., 2017; Shah et al., 2013
		Percent of the HHs taking traditional control measures to reduce the adverse impacts?	Percentage	Yes = 1, No = 0	Developed for this study
		Percent of HHs have saving account	Percentage	Yes = 1, No = 0	Developed for this study
		Percent of HHs have rent out farming land	Percentage	Yes = 1, No = 0	Developed for this study

Percent of HHs who don't attempt homestead gardening	Percentage	Yes = 1, No = 0	Alam et al., 2017
Percent of HHs that has no farming approaches to survive with erosion	Percentage	Yes = 1, No = 0	Dapar., 2016
Percent of HHs that have no place for relocation if erosion or disaster occur	Percentage	Yes = 1, No = 0	Dapar., 2016
Percent of HHs who have burden of loan	Percentage	Yes = 1, No = 0	DHS, 2006; Sadekin, 2018
Social network Percent of HHs who have not gone to their local government for help in the previous 12 months.	Percentage	Yes = 1, No = 0	Sadekin, 2018; Madhuri., 2014; WHO/RBM (2003); Shah et al., 2013
Percent of HHs received help from relatives, neighbors	Percentage	Yes = 1, No = 0	Jakariya et al., 2020; Alam, 2017
Percent of HH received government and organizational support	Percentage	Yes = 1, No = 0	Azam, 2019; Alam, 2017
Percent of household getting credit facilities	Percentage	Yes = 1, No = 0	Azam, 2019; Bhuiyan et al., 2017
Percent of HHs involved in non-farm activities?	Percentage	Yes = 1, No = 0	Alam, 2017; Panthi, et al., 2016
Percent of HHs involved in cooperative society or any organization?	Percentage	Yes = 1, No = 0	Alam et al., 2017; Hahn et al., 2009
Percent of HHs getting any training from government organizations?	Percentage	Yes = 1, No = 0	Developed for this study
Percent of HHs getting any training from a non-government organization?	Percentage	Yes = 1, No = 0	Developed for this study

Sensitivity	Health	Percent of HHs getting any information on new technology or varieties from agri. Extension officer?	Percentage	Yes = 1, No = 0	Alam et al., 2017
		Percent of HHs with experience any waterborne disease	Percentage		Developed for this study
		Percent of HHs those family members suffering from chronic disease	Percentage	Yes = 1, No = 0	Alam et al., 2017; Hahn et al., 2009; Oo, 2018
		Percent of HHs who don't attend a local doctor through illness	Percentage	Yes = 1, No = 0	Alam, 2017; Ford, 2014; Fraser, 2011
		Percent of HHs receiving treatment in government hospitals	Percentage	Yes = 1, No = 0	Madhuri., 2014; Madhav, 2010
		Percent of HHs in which a family member skipped work due to disease in the previous two weeks	Percentage	Yes = 1, No = 0	Alam, 2017; Sadekin, 2018; Ahsan, 2014
		Percent of HHs having sanitary latrines	Percentage	Yes = 1, No = 0	Alam et al., 2017; Gbetibouo, 2010; Preston, 2011
	Food	Average number of months HHs work to find food	Count		Alam, 2017; World Bank.,1998; Hahn et al., 2009
		Percent of HHs who don't save crops	Percentage	Yes = 1, No = 0	Hahn et al., 2009; Sadekin, 2018
		Percent of HHs missing their farming land	Percentage	Yes = 1, No = 0	Alam, 2017
		Percent of HHs facing food insecurity and malnutrition are increasing in the	Percentage	Yes = 1, No = 0	Developed for the purposes of this study

		previous 10 years?			
Water		Percent of HHs reporting water conflicts	Percentage	Yes = 1, No = 0	Sujakhu, 2019; Alam. 2017
		Percent of HHs using unsafe drinking water (pond, river, water hole, arsenic-contaminated water)	Percentage	Yes = 1, No = 0	Alam, et al., 2017; Azam, 2019.
		Percent of HHs receiving water from a distant (more than 0.5 km) water source (tube well)	Percentage	Yes = 1, No = 0	Alam, 2016; Jacobson, 2018
Exposure	Natural disasters	Percent of households affected by floods and riverbank erosion during last 10 years?	Percentage	Yes = 1, No = 0	Bhuiyan et al., 2017 Dapar., 2016
		Percent of agricultural land affected by erosion	Count	Yes = 1, No = 0	Dapar., 2016; Alam, 2016
		Average number of other natural calamities during previous 10 years	Percentage		Bhuiyan et al., 2017
		Percent of HHs faced movement in previous 10 years	Percentage	Yes = 1, No = 0	Alam, 2017; Bhuiyan et al., 2017
		Percent of HHs loss livestock due to natural disaster during previous 10 years?	Percentage	Yes = 1, No = 0	Alam, 2017; Bhuiyan et al., 2017
Climatic variability		Facing progressively increasing temperature from previous 10 years	Percentage	Yes = 1, No = 0	Shah et al., 2018 ; Hahn et al., 2009; Alam et al., 2017
		Facing gradully decreasing rainfall from previous 10 years	Percentage	Yes = 1, No = 0	Developed for the purposes of this study
		Facing progressively growing	Percentage	Yes = 1, No	Alam, 2017; Alam et

riverbank erosion from previous 10 = 0 al., 2017
year

3. Results and discussion

In this segment, the outcomes of LVI, and CVI are summarized from the survey. The LVI outcome values are shown in Table 2.

Table 2 outlines the factors that contribute toward vulnerability for each region. The differences in LVI and CVI values between the study area show that the vulnerability of Char Jotindro-Narayan and Kulaghat char households differ overall and regarding the specific components and sub-components mentioned below.

3.1. Livelihood vulnerability index

The value of LVI in Kulaghat char (0.402) was more than Char Jotindr-Naran under Lalmonirhat Sadar and Phulbari Upazila, respectively (Table 2). These LVI values denote that the households of Kulaghat char and Char Jotindr-Naran had a distinct level of vulnerability. Kulaghat char households were faced with more problems than Char Jotindr-Naran, owing to lack of accessibility to financial resources, and health care and educational opportunities, as well as intense exposure to climatic vulnerability (Table 2). The study shows that the two household groups had similar socio-demographic profile, natural disasters, but lot of differences in several sub-component such as social network, livelihood strategies, food, and climatic variability. The dependency ratio of household head is higher in Char Jotindr-Naran than in Kulaghat char. The value of livelihoods strategy is lower in Char Jotindr-Naran (0.22525) while higher in Kulaghat char (0.3275) (Table 2). The social network indexing value varied slightly among the study areas. The social network and food index values were higher in Char Jotindro-Narayan with the value of (0.350111) and (0.588)

345 correspondingly as compared to (0.588) and (0.512542) in Kulaghat char households; these
 346 findings are explained more in detail below.

Table 2.

Indexed value of the major components and sub-components consist of livelihood vulnerability index (where HHs = households).

Major components	Indexed value of each component		Sub-components or indicators	Indexed value of each sub-component (indicator)	
	Char Jotindro-narayan	Kulaghat char		Char Jotindro-narayan	Kulaghat char
Socio-demographic profile	0.289	0.284	Dependency ratio	0.045	0.041
			Percent of HHs where the head of the HH has not attended school	0.53	0.523
			Average number of family members in the HHs	0.292	0.287
Livelihood strategy	0.225	0.327	Percent of households dependent only on agriculture as a main income source	0.265	0.424
			Percent of the HHs taking traditional control measures to reduce the adverse impacts?	0.273	0.333
			Percent of HHs have saving account	0.098	0.129
			Percent of HHs have rent out farming land	0.136	0.106
			Percent of HHs who don't attempt homestead gardening	0.129	0.227
			Percent of HHs that has no farming approaches to survive with erosion	0.553	0.689

Social network	0.350111	0.315	Percent of HHs that have no place for relocation if erosion or disaster occur	0.098	0.492
			Percent of HHs who have burden of loan	0.25	0.22
			Percent of HHs who have not gone to their local government for help in the previous 12 months	0.75	0.811
			Percent of HHs received help from relatives, neighbors	0.553	0.538
			Percent of HH received government and organizational support	0.379	0.311
			Percent of household getting credit facilities	0.371	0.212
			Percent of HHs involved in non-farm activities?	0.386	0.356
			Percent of HHs involved in cooperative society or any organization?	0.159	0.189
			Percent of HHs getting any training from government organizations?	0.159	0.068
			Percent of HHs getting any training from a non-government organization?	0.22	0.182
			Percent of HHs getting any information on new technology or varieties from agri. Extension officer?	0.174	0.174
			Percent of HHs with experience any waterborne disease	0.538	0.394
Health	0.315	0.323333	Percent of HHs those family members suffering from chronic disease	0.182	0.159

			Percent of HHs who don't attend a local doctor through illness	0.038	0.159
			Percent of HHs receiving treatment in government hospitals	0.697	0.879
			Percent of HHs in which a family member skipped work due to disease in the previous two weeks	0.174	0.144
			Percent of HHs having sanitary latrines	0.265	0.205
Food	0.588	0.512	Average number of months HHs work to find food	0.745	0.799
			Percent of HHs who don't save crops	0.258	0.326
			Percent of HHs missing their farming land	0.879	0.523
			Percent of HHs facing food insecurity and malnutrition are increasing in the previous 10 years?	0.47	0.402
Water	0.020	0.04	Percent of HHs reporting water conflicts	0.023	0.045
			Percent of HHs using unsafe drinking water (pond, river, water hole, arsenic-contaminated water)	0.038	0.045
			Percent of HHs receiving water from a distant (more than 0.5 km) water source (tube well)	0	0.03
Natural disasters	0.781	0.781	Percent of households affected by floods and riverbank erosion during last 10 years?	0.962	0.955
			Percent of agricultural land affected by erosion	0.955	0.856
			Average number of other natural	0.628333	0.716

			calamities during previous 10 years		
			Percent of HHs faced movement in previous 10 years	0.811	0.871
			Percent of HHs loss livestock due to natural disaster during previous 10 years?	0.553	0.508
Climatic variability	0.671	0.717	Facing progressively increasing temperature from previous 10 years	0.932	0.955
			Facing gradually decreasing rainfall from previous 10 years	0.689	0.871
			Facing progressively growing riverbank erosion from previous 10 year	0.394	0.326

Overall livelihood vulnerability index:

Char Jotindro-narayan: 0.391, Kulaghat char: 0.402

Source: Field Survey, 2021

347 The outcomes of the major components are displayed in the spider diagram (Fig. 4). The
348 climatic variability value in Char Jotindro-Narayan is lower with the value of (0.671), while
349 in Kulaghat char, it was (0.717). The value of natural disasters in both char communities was
350 similar because of their low-lying geography and extreme vulnerability for flood disasters
351 with enormous riverbank erosion.

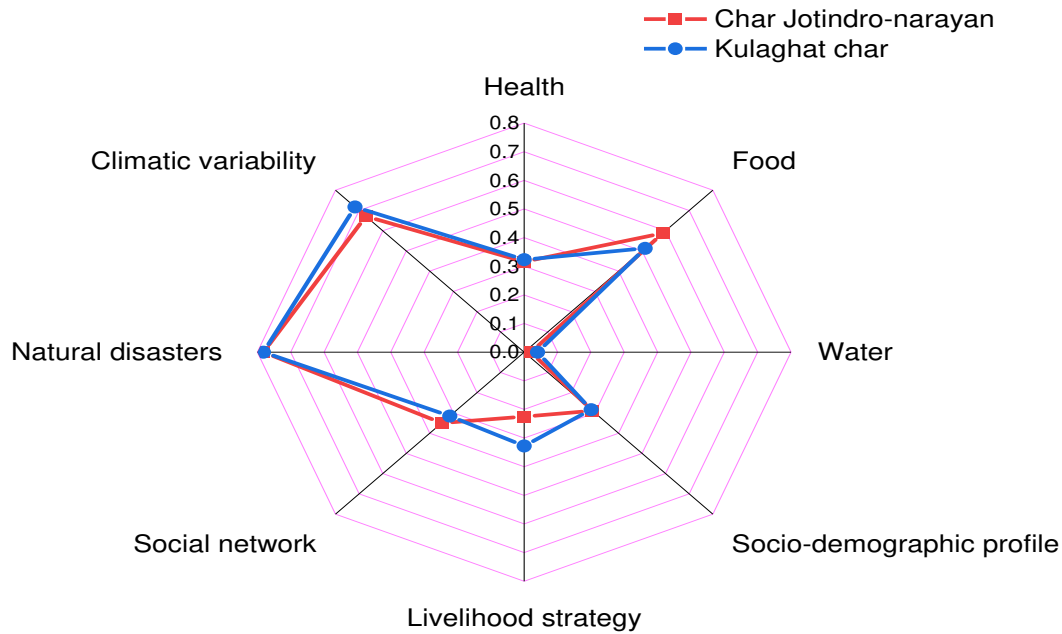


Fig. 4. The spider diagram of major components of LVI for both study areas.

Source: Field survey, 2021

3.2. Climate vulnerability index

The outcomes of climate vulnerability index (CVI) for the study area is presented in Table 3.

The CVI values denote there was almost no distinction between the two char communities, but the values in Kulaghat char (0.639) are slightly higher than Char Jotindro-Narayan (0.633).

Figure 5 reveals the vulnerability triangle, this exhibits the score participating elements for the sensitivity, exposure, and adaptive capacity. The result shows that the households of Char Jotindro-Narayan have higher sensitivity in the basis of access to food, health, and water with a value of (0.331), while it shows lower in Kulaghat char with the value of (0.316). The study reveals that the char land communities of Kulaghat char are slightly exposed than Char Jotindro-Narayan. However, both study regions are equally affected by flood and riverbank erosion per year and are most vulnerable.

Table 3.

Indexed dimensions of climate vulnerability of Char Jotindro-narayan and Kulaghat char

Contributing elements to vulnerability	Char Jotindro-narayan	Kulaghat char
Adaptive capacity (socio-demographic, livelihood strategies and social network)	0.291	0.315
Sensitivity (Health, food, water)	0.331	0.316
Exposure (Natural disasters and climatic variability)	0.74	0.757
Climate Vulnerability Index (CVI)	0.633	0.639
LVI-IPCC	0.148	0.139

Source: Field Survey, 2021

LVI-IPCC vulnerability index outcomes represent that the Char Jotindro-Narayan households are most vulnerable than the char Kulaghat households with the index value of (0.148) and (0.139) correspondingly (Table 3).

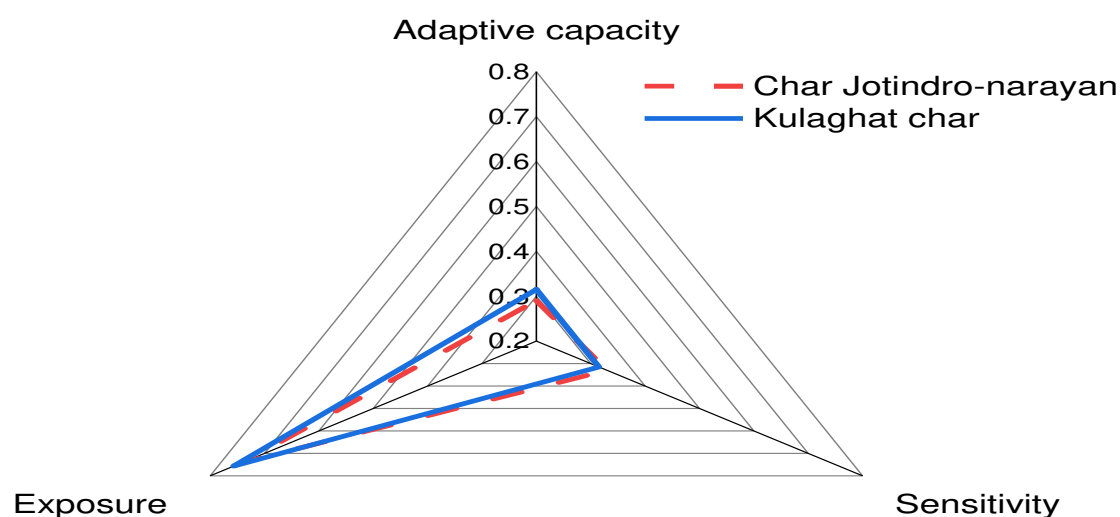


Fig. 5. The vulnerability triangle diagram of the dimensions of the Climate Vulnerability Index.

Source: Field Survey, 2021

3.3. Livelihood vulnerability

The outcomes show that the livelihood vulnerability condition in Kulaghat char was higher than the Char Jotindro-Narayan households. The most significant contributing components values of livelihood strategy (0.327), health (0.323), water (0.04), and climate variability (0.717) were higher in Kulaghat char than Char Jotindro-Narayan, which were 0.225; 0.315; 0.020, and 0.671 respectively (Table 2).

The livelihood strategy components contribution in Kulaghat char represents that these community households mainly depend on farming for their main earnings and food safety. Riverbank erosion and floods regularly damage their agricultural land, crops, etc. where households have no farming strategies to cope with these situations, and the few households practiced homestead gardening to fight against high natural hazards and climatic variability. The agriculture-based livelihoods can leave households in a more vulnerable position if they lack the option to diversify their livelihood plan (Alam et al., 2017; Alam, 2016; Mirza, 2003). In the Kulaghat char region, the water component had an even more impact on vulnerability. In this region households were used unsafe drinking water from the pond, river, water hole/tube wells, and majority of these have been reported to be infected by arsenic. In conversations, this was noticeable that households were conscious of the hazards of imbibing arsenic-contaminated water, then alternatives are frequently inaccessible; water conflict is also a problem among communities, with disputes frequently arising over water accessibility and property rights, such as ownership. The finding shows that households of the char Kulaghat are more vulnerable on health-related issues that impact both people and cattle. People in rural locations drive a greater distance for attend health-care facilities, and availability to veterinary competence is also inadequate due to poor communication systems. The findings revealed that the number of waterborne diseases and chronically ill people in Char Jotindro-Narayan was higher than in the Kulaghat char. These affected people are

regularly denied normal government care owing to limited accessibility. The study found that the Kulaghat char household's perceived temperature and rainfall fluctuation rates over the last 10 years are more than the Char Jotindro-Narayan.

The results show that both char land households are vulnerable, but Char Jotindro-Narayan households are more vulnerable than Kulaghat char due to its residents living far away from the mainland. This is most likely owing to services given by government and non-governmental groups, improved social networks and communication, educational amenities, and comfortable relocation through natural catastrophes (Alam et al., 2017; Sarker et al., 2019). Char Jotindro-Narayan households generally have a poorer range of education and a greater prevalence of malnutrition. Traditional views (especially surrounding local remedies for health difficulties) and a lack of education generate community obstacles that influence family vulnerability and adaptive capability (Alam et al., 2016; Jones and Boyd, 2011).

Riverbank erosion is the general problem in char regions, and these study locations experience it frequently. The degree of riverbank erosion within Char Jotindro-Narayan is larger than in Kulaghat char. The overall LVI and CVI index was high index value in Kulaghat char. The Char Jotindro-Narayan households are mainly struggling higher than Kulaghat char households with natural disasters, social networking, and food security due to the proximity of the river Dharla. Similar outcomes are obtained in a few research (Alam, 2016; Sarker et al., 2019). The CVI (Table 3) shows vulnerability to climate-driven hazards by providing index values of sensitivity, adaptive capacity, and exposure to climate change. The results in Table 3 show that by IPCC-LVI index, Char Jotindro-Narayan is the highest vulnerable area with less adaptive capability than households of Kulaghat char. Char Jotindro-Narayan households has lower income sources, a higher reliance on agriculture, a higher dependence ratio, and a better education level.

3.4. Policy implications and lesson learning

426 A context-specific intervention program for char communities is required. To promote
427 societal resilience, reduce the sensitivity of habitat conditions, and increase individual
428 stability to solve livelihood issues, particularly for female-headed households. The
429 participation of different GO and NGO safety net programs is insufficient in the areas; it
430 should be greatly enlarged. Moreover, on a long-term basis, the development of a
431 communication network, transportation system, basic services accessibility, and market
432 facilities for other livelihoods plans is also crucial. Access to financing for poor farmers
433 should be promoted to help improve their access to resources and technology, which is
434 critical for their adaptability. Although the char households' livelihood depends mainly on
435 agriculture, agricultural institutions should be encouraged to generate new crop varieties and
436 promote technology-transfer mechanisms. This would improve the resilience of vulnerable
437 households of the char land communities in Bangladesh.

438 The intensity of livelihoods vulnerability of a community is mainly depending on their assets
439 and natural resources. The context-specific views represent the vulnerability intensity into a
440 distinct scale, which also varies by the term of geographic location, perceptual responses, and
441 temporal/ seasonal stress or critical issues with community livelihoods capitals. In a
442 devolving country like Bangladesh, climate change effects including floods and riverbank
443 erosion are especially affected the (bar land) char land communities which damages natural
444 resources and their saving that resulting making more vulnerable. A large number of
445 farmland and crops are damaged due to floods and riverbank erosion that reducing the
446 financial growth of the community. The study reveals that, peoples in the community who are
447 aware and adoption different measure to stand against the floods, riverbank erosion, critical
448 issues or other stresses they are least vulnerable. Therefore, to decreasing the sensitivity of
449 livelihoods vulnerability in such char communities policymakers could amplify these above

offers of training and additional services, especially for basic needs, information, and communication technologies.

4. Conclusion

Geologically, Bangladesh is the most natural disaster susceptible country because of its low-lying landscape and climate change. Char regions are separated from the interior land and found across the country's enormous river-delta system. Using survey data, this study investigated the extent of adaptive capacity and vulnerability of the char households of Bangladesh applying vulnerability framework. The char areas are commonly impacted by environmental hazards, including flood, riverbank erosion, heatwave, and drought, which greatly loses their livelihood assets. The outcomes represent that the study regions are the greatest vulnerable to climate change and natural disaster, where sensitivity and exposure level exceed adaptive capacity. The study reveals that the food, social network components, natural disasters, and climatic variability are the major drivers increasing both char land communities' vulnerability. The LVI and CVI outcomes represent that both char communities are vulnerable to natural disasters and climatic variability. However, disparities in sub-component values among char communities suggest that climate change vulnerability varies even within units of individuals undertaking in same livelihood activities. A long-term sustainable development strategy that includes road construction, tree plantation, employment opportunities, and capacity building will be beneficial in building resilience among households in such vulnerable regions in Bangladesh.

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Conflict of interest

None

References

476 Adger, W.N., 1999. Social vulnerability to climate change and extremes in coastal Vietnam.
477 World Dev. 27, 249–269.

478 Adger, W.N., Vincent, K., 2005. Uncertainty in adaptive capacity. *Comptes Rendus Geosci.*
479 337, 399–410.

480 Adger, W.N., Vulnerability. 2006. *Glob. Environ. Chang.* 16, 268–281.

481 Ahmed, I., Alam, M., Jimmy, A., Fatema, K., Islam, M., Ahsan, G., Khan, N., 2019. Climate
482 change induced migration: empirical evidences from the southwest coastal region of
483 Bangladesh. *Int. J. Environ. Sustain Dev.* 3 (4), 116–126.

484 Ahsan, M.N., Warner, J., 2014. The socioeconomic vulnerability index: A pragmatic
485 approach for assessing climate change led risks—A case study in the south-western
486 coastal Bangladesh. *Int. J. Disaster Risk Reduct.* 8, 32–49.

487 Alam, G.M.M., 2016. An assessment of the livelihood vulnerability of the riverbank erosion
488 hazard and its impact on food security for rural households in Bangladesh. In: PhD
489 Thesis. School of Commerce, University of Southern Queensland, Australia.

490 Alam, G.M.M., 2017. Livelihood Cycle and Vulnerability of Rural Households to Climate
491 Change and Hazards in Bangladesh. *Environ. Manage.* 59, 777–791.

492 Alam, G.M.M., Alam, K., & Shahbaz, M., 2016. Influence of institutional access and social
493 capital on adaptation choices: Empirical evidence from vulnerable rural households in
494 Bangladesh. *Ecol Econ*, 130: 243-251.

495 Alam, G.M.M., Alam, K., & Shahbaz, M., Sarker, M.N.I., 2020. Hazards, food insecurity and
496 human displacement in rural riverine Bangladesh: Implications for policy. *Int J. of Dis.*
497 *Ris. Red.*, 43: 101364.

498 Alam, G.M.M., Alam, K., Mushtaq, S., 2018. Drivers of Food Security of Vulnerable Rural
499 Households in Bangladesh: Implications for Policy and Development. *South Asia Econ.*
500 *J.* 19, 43–63.

501 Alam, G.M.M., Alam, K., Mushtaq, S., Clarke, M.L., 2017. Vulnerability to climatic change
502 in riparian char and river-bank households in Bangladesh: Implication for policy,
503 livelihoods and social development. *Ecol. Indic.* 72, 23–32.

504 Ayanlade, A., Radeny, M., & Akin-Onigbinde, A. I., 2018. Climate variability/change and
505 attitude to adaptation technologies: a pilot study among selected rural farmers '
506 communities in Nigeria. *GeoJournal*. 83(2), 319-331.

507 Azad, A.K., Hossain, K.M., & Nasreen, M., 2013. Flood induced vulnerabilities and
508 problems encountered by women in northern Bangladesh. *International Journal of*
509 *Disaster Risk Science*. 4(4), 190–199.

510 Bangladesh Bureau of Statistics (BBS), 2011. Bangladesh Population Census 2011, Statistics
511 Division, Ministry of Planning, Government of the People's Republic of Bangladesh,
512 Dhaka.

513 Bangladesh Bureau of Statistics (BBS), 2014. Statistical Pocketbook; BBS: Dhaka,
514 Bangladesh.

515 Barrett, A., Hannan, M., Alam, Z., Pritchard, M., 2014. Impact of the Chars Livelihoods
516 Programme on the Disaster Resilience of Chars Communities. Available online:
517 [https://www.gdnonline.org/resources/impact%20of%20clp%20on%20the%20disaster%20](https://www.gdnonline.org/resources/impact%20of%20clp%20on%20the%20disaster%20resilience%20of%20char%20communities%20[final].pdf)
518 [resilience%20of%20char%20communities%20\[final\].pdf](https://www.gdnonline.org/resources/impact%20of%20clp%20on%20the%20disaster%20resilience%20of%20char%20communities%20[final].pdf) (accessed on 15 March
519 2019).

520 Bevacqua, A., Yu, D., Zhang, Y., 2018. Coastal vulnerability: Evolving concepts in
521 understanding vulnerable people and places. *Environ. Sci. Policy*. 82, 19–29.

522 CARE-Bangladesh and DFID-B., 2002. The Findings of the Northwest Rural Livelihoods
523 Baseline; CARE-Bangladesh and DFID-B: Dhaka, Bangladesh.

Center for Environmental and Geographic Information Services (CEGIS), 2012. Prediction of River Bank Erosion Along the Jamuna, the Ganges the Padma and the Lower Meghna Rivers in 2012; Centre for Environment and Geographic Information Services: Dhaka, Bangladesh.

Christensen, J.H., Hewitson, B., et al., 2007. Regional climate projections. In: Solomon, S. (Ed.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.

CLP, 2010. Impact of earlier recruitment into the CLP on mother and child nutritional status among chars dwellers. In: *Chars Livelihoods Program. Rural Development Academy Campus, Bogra, Bangladesh*.

Cochran, W. G., W, J., Sons, 1977. *Sampling techniques*.

EGIS, 2000. Riverine Chars in Bangladesh-environmental dynamics and management issues. In *Environment and GIS Support Project for Water Sector Planning (EGIS)*; University Press Limited: Dhaka, Bangladesh.

Erdiaw-Kwasie, M. O., Abunyawah, M., & Yamoah, O., 2019. ‘After the disaster comes destination thoughts’: A review and conceptualization of consolidative disaster adaptive capacity model. *International Journal of Disaster Risk Reduction*, 35, 101098.

Eriksen, S.H., Kelly, P.M., 2007. Developing credible vulnerability indicators for climate adaptation policy assessment. *Mitig. Adapt. Strateg. Glob. Chang.* 12, 495–524.

Etwire, P.M., Al-Hassan, R.M., Kuwornu, J.K.M., Osei-Owusu, Y., 2013. Application of livelihood vulnerability index in assessing vulnerability to climate change and variability in Northern Ghana. *J. Environ. Earth Sci.* 3, 157–170.

Folke, C., 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Glob. Environ. Chang.* 16, 253–267.

549 Ford, J.D., Keskitalo, E., Smith, T., Pearce, T., Berrang, L., Duerden, F., Smit, B., 2010. Case
550 study and analogue methodologies in climate change vulnerability research. Wiley
551 Interdiscip. Rev. Clim. Change. 1, 374–392.

552 Ford, J.D., Smit, B., 2004. A framework for assessing the vulnerability of communities in the
553 Canadian Arctic to risks associated with climate change. Arctic. 57, 389–400.

554 Frank, E., Eakin, H., Lopez-Carr, D., 2011. Social identity, perception and motivation in
555 adaptation to climate risk in the coffee sector of Chiapas, Mexico. Glob. Environ. Change
556 21, 66–76.

557 Gbetibouo, G.A., Ringler, C., Hassan, R., 2010. Vulnerability of the South African farming
558 sector to climate change and variability: An indicator approach. Nat. Resour. Forum. 34,
559 175–187.

560 Gerlitz, J.Y., Macchi, M., Brooks, N., Pandey, R., Banerjee, S., Jha, S.K., 2017. The
561 Multidimensional Livelihood Vulnerability Index—an instrument to measure livelihood
562 vulnerability to change in the Hindu Kush Himalayas. Clim. Dev. 9, 124–140.

563 GoB (Government of Bangladesh), 2011. The Sixth Five-year Plan, 2011–2015. Ministry of
564 Planning Govt. of the People’s Republic of Bangladesh, Dhaka, Bangladesh.

565 Hahn, M.B., Riederer, A.M., Foster, S.O., 2009. The livelihood vulnerability index: a
566 pragmatic approach to assessing risks from climate variability and change—a case study
567 in Mozambique. Glob. Environ. Change. 19, 74–88.

568 Huq, S., Ayers, J., 2008. Climate change impacts and responses in Bangladesh. In Briefing
569 Note Prepared for the European Parliament; International Institute for Environment and
570 Development: London, UK; Policy Department Economic and Scientific Policy, DG
571 Internal Policies of the Union: Brussels, Belgium.

572 Iffat, M., Mbuya., Nkosinathi., 2016. Water, Sanitation, Hygiene, and Nutrition in
573 Bangladesh: Can Building Toilets Affect Children's Growth? World Bank
574 Study: Washington, DC: World Bank.

575 Intergovernmental Panel on Climate Change (IPCC), 2014. Climate Change 2014: Impacts,
576 Adaptation and Vulnerability, Fifth Assessment Report. In Intergovernmental Panel on
577 Climate Change; Cambridge University Press: Cambridge, UK.

578 International Fund for Agricultural Development (IFAD), 2011. How Does International
579 Price Volatility Affect Domestic Economies and Food Security? Office of Knowledge
580 Exchange, Research and Extension, Food and Agriculture Organization of the United
581 Nations (FAO): Rome, Italy.

582 IPCC, 2007. Climate change 2007: Impacts, adaptation and vulnerability, Fourth assessment
583 report. In: Intergovernmental Panel on Climate Change. Cambridge University Press,
584 Cambridge, UK.

585 Islam, A.R.M.T., Shen, S., Yang, S., Hu, Z., Chu, R., 2019. Assessing recent impacts of
586 climate change on design water requirement of Boro rice season in Bangladesh.
587 Theoretical and Applied Climatology 135(1):1-17. DOI: 10.1007/s00704-019-02818-8.

588 Islam, M.R., 2018. Climate Change, Natural Disasters and Socioeconomic Livelihood
589 Vulnerabilities: Migration Decision Among the Char Land People in Bangladesh. Soc.
590 Indic. Res. 136, 575–593.

591 Islam, M.R., Hossain, D., 2013. Island Char resource mobilization (ICRM): Changes of
592 livelihoods of vulnerable people in Bangladesh. Soc. Indic. Res. 117, 1033–1054.

593 Islam, S. M. D., 2014. Geoelectrical and hydrogeochemical studies for delineating seawater
594 intrusion in coastal aquifers of Kalapara upazila, Patuakhali, Bangladesh. Unpublished
595 Masters Thesis, Department of Environmental Sciences, Jahangirnagar University,
596 Dhaka.

597 Islam, S. M. D., Bhuiyan, M. A. H., 2016. Impact scenarios of shrimp farming in coastal
 598 region of Bangladesh: an approach of an ecological model for sustainable management.
 599 Aquaculture International. 24(4), 1163–1190. [https://doi.org/10.1007/s10499-016-9978-](https://doi.org/10.1007/s10499-016-9978-z)
 600 z.

601 Islam, S. M. D., Bhuiyan, M. A. H., 2018. Sundarbans mangrove forest of Bangladesh:
 602 causes of degradation and sustainable management options. Environmental
 603 Sustainability. 1(2), 113–131. <https://doi.org/10.1007/s42398-018-0018-y>.

604 Islam, S.M. D., Uddin, M. J., 2015. Impacts, vulnerability and coping with cyclone hazard in
 605 coastal region of Bangladesh: a case study on Kalapara upazila of Patuakhali district.
 606 Jahangirnagar University Environmental Bulletin. 4, 11–30.

607 Jones, L., Boyd, E., 2011. Exploring social barriers to adaptation: insights from western
 608 Nepal. Glob. Environ. Change. 21, 1262–1274.

609 Jurgilevich, A., Räsänen, A., Groundstroem, F., Juhola, S. A., 2017. Systematic review of
 610 dynamics in climate risk and vulnerability assessments. Environ. Res. Lett. 12, 013002.

611 Leichenko, R., Silva, J.A., 2014. Climate change and poverty: Vulnerability, impacts, and
 612 alleviation strategies. Wiley Interdiscip. Rev. Clim. Chang. 5, 539–556.

613 Mirza, M., 2003. Climate change and extreme weather events: can developing countries
 614 adapt? Clim. Policy. 3, 233–248.

615 Mondal, M.S.H., Murayama, T., Nishikizawa, S., 2020. Assessing the flood risk of riverine
 616 households: A case study from the right bank of the Teesta River, Bangladesh,
 617 International Journal of Disaster Risk Reduction,
 618 <https://doi.org/10.1016/j.ijdrr.2020.101758>.

619 Monwar, M.M., Mustafa, M.G., Khan, N.A., Hossain, M.S., Hossain, M.M., Majumder,
 620 M.K., Chowdhury, R.M., Islam, M.A., Chowdhury, M., Alam, M.S., 2018. Indigenous

621 adaptation practices for the development of climate resilient ecosystems in the Hail
622 Hoar, Bangladesh. *Global Social Welfare*. 5(2), 125–136.

623 Mutton, D., Haque, C.E., 2004. Human Vulnerability, Dislocation and Resettlement:
624 Adaptation Processes of River-bank Erosion-induced Displacees in Bangladesh.
625 *Disasters*. 28, 41–62.

626 Nelson, D.R., Adger, W.N., Brown, K., 2007. Adaptation to Environmental Change:
627 Contributions of a ResiliencenFramework. *Annu. Rev. Environ. Resour.* 32, 395–419.

628 O’Brien, K., Eriksen, S., Nygaard, L.P., Schjolden, N.E., 2007. Why different interpretations
629 of vulnerability matter in climate change discourses. *Clim. Policy*. 7, 73–88.

630 Oo, A.T., Van Huylenbroeck, G., Speelman, S., 2018. Assessment of climate change
631 vulnerability of farm households in Pyapon District, a delta region in Myanmar. *Int. J.*
632 *Disaster Risk Reduct.* 28, 10–21.

633 Orencio, P.M., Fujii, M., 2013. An Index to Determine Vulnerability of Communities in a
634 Coastal Zone: A Case Study of Baler, Aurora, Philippines. *Ambio*. 42, 61–71.

635 Pandey, R., Jha, S., 2012. Climate vulnerability index-measure of climate change
636 vulnerability to communities: a case of rural lower Himalaya, India. *Mitig.Adapt. Strat.*
637 *Glob. Change*. 17, 487–506.

638 Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., Pandey, V.P., 2016. Livelihood
639 vulnerability approach to assessing climate change impacts on mixed agro-livestock
640 smallholders around the Gandaki River basin in Nepal. *Regional Environmental Change*.
641 16(4), 1121–1132.

642 Preston, B.L., Yuen, E.J., Westaway, R.M., 2011. Putting vulnerability to climate change on
643 the map: A review of approaches, benefits, and risks. *Sustain. Sci.* 6, 177–202.

644 Salvati, L., Carlucci, M., 2014. A composite index of sustainable development at the local
645 scale: Italy as a case study. *Ecol. Indic.* 43, 162–171.

646 Sarker, M.N.I., Wu, M., Alam, G.M.M., Shouse, R.C., 2019. Livelihood Vulnerability of
647 Riverine-Island Dwellers in the Face of Natural Disasters in Bangladesh. *Sustainability*
648 11, 1623.

649 Sarker, M.N.I., Wu, M., Alam, G.M.M., Shouse, R.C., 2020. Livelihood resilience of riverine
650 island dwellers in the face of natural disasters: Empirical evidence from Bangladesh.
651 *Land use policy* 95, 104599

652 Schneider, S.H., 2007. Climate change: impacts, adaptation and vulnerability. In: ParryML,
653 Canziani OF, Palutikof JP, Van der Linden PJ, Hanson CE (eds) *Contribution of*
654 *working Group-II to the fourth assessment report of the intergovernmental panel on*
655 *climate change*. Cambridge University Press, Cambridge, pp 779–810.

656 Simotwo, H. K., Mikalitsa, S. M., Wambua, B. N., 2018. Climate change adaptive capacity
657 and smallholder farming in trans-Mara East sub-County, Kenya. *Geoenvironmental*
658 *Disasters*. 5(5). <https://doi.org/10.1186/s40677-018-0096-2>.

659 Tavares, A.O., Santos, P.P.D., Freire, P., Fortunato, A.B.F., Rilo, A., SA, L., 2015. Flooding
660 hazards in the Tagus estuarine area: the challenge of scale invulnerability assessments.
661 *Environ. Sci. Policy*. 51, 238–255.

662 Thompson, P.M., 2000. Bangladesh Char Lands: A Review of Assets and Change.
663 International Center for Living aquatic Resource management (ICLARM), Dhaka.

664 Thornton, P.K., Ericksen, P.J., Herrero, M., Challinor, A.J., 2014. Climate variability and
665 vulnerability to climate change: A review. *Glob. Chang. Biol.* 20, 3313–3328.

666 Toufique, K. A., Islam, A., 2014. Assessing risks from climate variability and change for
667 disaster-prone zones in Bangladesh. *International Journal of Disaster Risk Reduction*.
668 10, 236–249.

669 UNDP, 2008. Human Development Reports 2007/8. In *Fighting Climate Change: Human*
 670 *Solidarity in a Divided World*; Human Development Report Office (HDRO), United
 671 Nations Development Programme: New York, NY, USA. pp. 1–115.
 672 Vignieri, S., 2015. How to adapt to climate change. *Science*, 349(6248), 599 – 600.
 673 <https://doi.org/10.1126/science.349.6248.599-f>.
 674 Zhang, Q., Zhao, X., Tang, H., 2018. Vulnerability of communities to climate change:
 675 application of the livelihood vulnerability index to an environmentally sensitive region
 676 of China. *Climate and Development*. <https://doi.org/10.1080/17565529.2018.1442808>.