Household's Agricultural Vulnerability to Climate Induced Disasters: A Case on South-west Coastal Bangladesh

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Abstract

Climatic events have a significant impact on south-western coastal agriculture in Bangladesh. The purpose of this study was to assess household's agricultural vulnerability to climate-induced disasters and to identify the sub-indicators of adaptive capacity that determine the agricultural vulnerability to climate-induced disasters of south-western coastal households in Bangladesh. The vulnerability has been calculated by taking the Intergovernmental Panel on Climate Change (IPCC) concept through an Agricultural Vulnerability Index (AVI). Then, the ordered logit model has been employed to identify the key sub-indicators of adaptive capacity that determine the agricultural vulnerability to climate-induced disasters. A survey of 346 household heads from the two villages (181 household's head from Sutarkhali and 165 household's head from Nalian) of Sutarkhali Union of Dacope Upazila under Khulna District has been used in this study. Findings reveal that the mean score of Sutarkhali is 0.703 (high) for exposure, 0.762 (high) for sensitivity, 0.397 (low) for adaptive capacity and finally, the AVI is 0.689 (high). In the same fashion, Nalian has an average score of 0.658 (high) for exposure, 0.681 (high) for sensitivity, 0.410 (low) for adaptive capacity, and finally 0.643 (high) for the AVI. Non-farm employment, ownership of livestock, access to irrigation pump, improved crop diversification/ saline tolerant High Yielding Variety (HYV) crops, and access to farm credit have been found statistically significant sub-indicators of adaptive capacity that determine the agricultural vulnerability of both study sites. Finally, it is recommended that the intervention required for coastal adaptation of agriculture should be initiated by respective authorities.

Key words: Climate-induced disasters, agricultural vulnerability index, coastal adaptation, south-western coastal Bangladesh

1. Introduction

A number of studies have been used to understand the concept of vulnerability to climate disasters in the different fields of society. The aspect cannot be easily applied because so many issues associated with its events and the effects (Adger et al., 2005; Cardona, 2013; Nelson et al., 2010; o'Brien et al., 2004). Generally, there are two elements related to the vulnerability to climate disasters: consequence as an incidence of an extreme event, which can be recognized as climatically extreme sensitivity (e.g. crop failure, land fertility loss, salinity on land) and the community's resilience to the event (e.g. physical and economic resources, adaptation mechanisms) (Luers et al., 2003; Nelson et al., 2010). However, the widespread impact of climatic disasters especially throughout the agricultural sector has become more and more severe over time. The disasters associated with climate variables such as coastal flooding, cyclones, river erosions, and tidal surge with increasing severity have an impact on the agricultural industry throughout the significant decrease of agriculture production, enhancing crop failure, and increasing farmed animals overall survival (Harvey et al., 2014; Morton, 2007). A wide range of natural and biological mechanisms which drive productivities in agricultural systems, land management and forestry are significantly impacted by inter-annual, monthly and regularly distribution of climate parameters e.g. temperature, radiation, precipitation, water-vapor pressure in the atmosphere and the wind (Easterling et al., 2007). The effects of this climatic variability on agriculture seem to be the most detrimental site. For instance, conventional extreme weather effects of climate change endanger the survival of the people who rely on agriculture (Rosenzweig et al., 2014; Zhai & Juzhong, 2009). Due to climate fluctuations, agricultural production and productivity adjustments are significantly segregated across the various areas of the globe (Lipper et al., 2014).

As agriculture is one of the most climate-infected areas, attempts to highlight and evaluate the overall level of agricultural vulnerability are taken by producing comparative variables focusing on the numerous parameter of vulnerability, the exposure, sensitivity, and adaptive capacity of agroecological systems (Neset et al., 2019). In fact, several literature studies (Acheampong et al., 2014; Aleksandrova et al., 2016; Gbetibouo et al., 2010; Islam et al., 2014; Li et al., 2016; Li et al., 2015; Monterroso et al., 2014; Sujakhu et al., 2018; Wiréhn et al., 2015) took place across a multitude of dimensions covering various areas of agriculture, such as farming, livestock, fisheries, and forestry. These studies were mainly aimed at helping decision-makers to detect 'access points' in prioritization of adaptation capital, raising awareness about climatic risk and uncertainty, monitoring the implications of adaptation strategies and understanding limitations of the social and environmental scheme that contributes greatly to vulnerability. Overall, the majority of all these researches indicate 'a brief look' on the vulnerability of agricultural systems by incorporation of some frequently used determinants.

However, Bangladesh is regarded as an agrarian-economy dependent growing nation (Nasim et al., 2019) where agricultural households, specifically in the coastal region (Chen & Mueller, 2018; Chowdhury et al., 2012; Hoque et al., 2019; MoA, 2013; Shamsuddoha & Chowdhury, 2007; Younus, 2017; Younus & Kabir, 2018), has become increasingly vulnerable with increasing climatic fluctuations and severe weather occurrences (coastal flooding, tidal storm, cyclone, etc.), with the agricultural devastation (salinization, water shortage, and soil degradation), throughout the timespan (Hoque et al., 2019; Khanom, 2016). For instance, the very last two massive-cyclone occasions, namely, Sidr and Aila, took place in 2007 and 2009, triggering a great number of human deaths. They have led to failure in the agricultural sector, livestock farming, and resources. They also have a deterioration in economic and environmental functions (Shamsuddoha & Chowdhury, 2007; Younus, 2017). In the meantime, approximately 63% of the coastal arable land territory is hampered by varying levels of soil salinity due to these climate disasters (Hoque et al., 2019; MoA, 2013). Nevertheless, adjusting to an increasing rate of climate induced disasters have become the greatest problem, contributing to a growing demand for better expanded mitigation options, in order to protect coastal people's agricultural properties and resources, and to extrapolate more changing climate in the long term (Brown et al., 2018; Quader et al., 2017; Younus & Kabir, 2018). Therefore, it is extremely important that agricultural vulnerability to climate disasters is assessed to develop and apply intended adaptation policies as well as to characterize major concern sections for agricultural improvement.

Until now, household's agricultural vulnerability analysis studies, particularly in the south-west coastal region of Bangladesh, have not been extensively or adequately characterized. Though there is a substantial number of vulnerability studies (Ahsan & Warner, 2014; Bhuiyan et al., 2017; Hoque et al., 2019; Islam et al., 2014; Islam et al., 2013; Mullick et al., 2019; Rabby et al., 2019; Rakib et al., 2019; Uddin et al., 2019; Younus, 2017; Younus & Kabir, 2018) have found but there is hardly a single study to assess the agricultural vulnerability of household's to climate-induced disasters in the south-western coastal Bangladesh. Therefore, this study was focused on assessing agricultural vulnerability to climate-induced disasters of south-west coastal Bangladesh using agricultural vulnerability indicators under the umbrella of climate-induced disasters vulnerability components of exposure, sensitivity, and adaptive capacity which have been widely used and recognized by the Intergovernmental Panel on Climate Change (IPCC) and recent studies on climate change. This study has also identified indicators of adaptive capacity that determine the agricultural vulnerability to climate-induced disasters of south-western coastal households in Bangladesh which has also not been assessed by any previous studies in Bangladesh. Further, this analysis has made it easier to understand the agricultural vulnerability of the household's regionally in south-western coastal Bangladesh.

2. Conceptualization of Vulnerability

The basic principle of vulnerability contains a series of concepts aligned with the various phases in which the assessment of the agricultural vulnerability to climate disasters has allowed to take (Hoque et al., 2019). The vulnerability has been connected to or linked with abstract ideas such as perseverance, sensitivity, ability to adapt, destructiveness, and potential danger (Li et al., 2016). It is clear that there have been no common vulnerability theoretical underpinnings in the same situation (Füssel, 2007). This study has incorporated the basic idea of vulnerability assessment using the IPCC indicators. Vulnerability is defined as "the extent to which the agricultural system of a household is vulnerable or unable to comply with the consequences of climate disasters" (Parry et al., 2007). We, therefore, have used a range of 0 to 1 for developing the agricultural vulnerability index where 0 indicates least vulnerability and 1 indicates higher vulnerability. The assessment for the agricultural vulnerability to climate-induced disasters has been summarized through three indicators (see Table 1 for details): (a) exposure (the extent of climatic stressful events); (b) sensitivity (agriculture system that has been negatively affected or is susceptible to climatic stimuli); and (c) adaptive capacity (efficiency of households to adapt with climate disasters, address the impacts and seize opportunities).

3. Materials and Methods

3.1 Study Sites

A quantitative approach has been adopted to ascertain how local socio-economic factors and bio-physical influences of climate-induced disasters which are responsible for agricultural vulnerability. A multi-stage sampling technique was used to identify the study sites. First of all, we have placed the spatial emphasis on Dacope Upazila (sub-district) under Khulna district (South-west coastal region) of Bangladesh. Locating on the South-eastern part of Khulna district, this Upazila covers an area of around 991 km^2 including a forestry conservation area of 494.69 km^2. In 1906, Dacope has been established as a Thana (kind of sub-district), which later became an Upazila in 1983. This Upazila is comprised of one paurashava, nine wards, fifteen mahallas, nine unions, twenty-six inhabited mauzas, and ninety-seven villages (Statistics, 2013). This region contains a flat land with a natural land slope bounded by the Sundarbans (the world's largest mangrove forest) and the Bay of Bengal from the south-west and the south directions, accordingly. This is an unripe deltaic slope where the length of the belt rarely reaches above the height of the sea level. The rivers in this Upazila are the basic flow stream. Therefore, the rivers e.g. Pasur, Shibsa, Manki, Bhadra have a substantial influence on both surface and groundwater quality due to natural tidal movement (Parishad, 2005). Being with the coastal belt, the study region frequently faces different disasters like- cyclones, tidal surges, heavy rainfall, river erosion, etc. Moreover, two back-to-back destructive cyclones: Sidr in 2007 and Aila in 2009 have subsequently impacted the area. Finally, we selected two villages including Sutarkhali and Nalian, randomly, under the Sutarkhali union of the Upazila as the study sites.

3.2 Vulnerability Indicators

Exposure, sensitivity, and adaptive capacity are the key elements to determine vulnerability to climate variation and change (Parry et al., 2007). In this study, exposure refers to the occurrences, intensities, and magnitudes of climate-induced disasters and positions of the agricultural land from the river to which agriculture-based households systems are susceptible (McCarthy et al., 2001). Exposure indicators that have selected for the two study sites characterize the position of agricultural land from the river; occurrences, intensities and magnitude of climate-induced hazards in the study sites; and standard deviation of past 15 years temperature and precipitation in Khulna district.

Sensitivity is the extent to which a system of households or communities is negatively affected or immune to climate stimuli (Parry et al., 2007). In this study, sensitivity sub-indicators have included reduction of irrigation water availability; salinity severity on arable land; irrigation potential loss of cultivable land; agricultural properties loss; agricultural production trend loss; cropping intensity loss; income loss from agriculture; and food security loss to climate-related hazards over the last 15 years in the study sites.

We define adaptive capacity as the household's capability or potential to respond to climate-induced catastrophe as well as to cope with its consequences and to seize opportunities (McCarthy et al., 2001). In this study, the adaptive capacity of a household has been taken as annual savings, formal education, high household size, non-farm employment, ownership of livestock, agrochemical/fertilizer supply, improved seeds supply, access to irrigation pump, gardening with mangrove trees improved crop diversification/ saline tolerant High Yielding Variety (HYV) crops, access to large farm size, access to farm credit, membership in Non-government Organizations (NGOs)/Community Based Organizations (CBOs) and share of embankments/ dams around the farmland.

Table 1: Major vulnerability indicators, sub-components and hypothesized functional relationship comprising for agricultural vulnerability index (AVI) developed for two villages of Dacope upazila.

Vulnerability Indicators	Sub-indicators	Unit of Measurement	Adapted source	Hypothesized Relationship
Exposure	Position of agricultural land from the river	Dummy; 1= near, 0= far away	Developed for the purpose of questionnaire (Hoque et al., 2019; Sujakhu et al., 2018)	Higher value reflects higher exposure. Higher exposure = Higher Agricultural Vulnerability
	Standard deviation of annual rainfall	Number (Last 15 years)		
	Standard deviation of annual temperature	Number (Last 15 years)		
	Higher intensity of cyclone	Dummy; 1= yes, 0= no		
	Occurrences of river erosion	Dummy; 1= yes, 0= no		
	Higher intensity of tidal surge	Dummy; 1= yes, 0= no		
Sensitivity	Reduction of irrigation water availability	Dummy; 1= yes, 0= no	Developed for the purpose of questionnaire (Hoque et al., 2019; Pandey et al., 2015; Tessema & Simane, 2019)	Higher value reflects higher sensitivity. Higher sensitivity = Higher Agricultural Vulnerability
	Salinity severity on arable land	Dummy; 1= yes, 0= no		
	Irrigation potential loss of cultivable land	Dummy; 1= yes, 0= no		
	Agricultural properties loss	Dummy; 1= yes, 0= no		
	Agricultural production trend loss	Dummy; 1= yes, 0= no		
	Cropping intensity loss	Dummy; 1= yes, 0= no		
	Income loss from agriculture	Dummy; 1= yes, 0= no		
	Food security loss	Dummy; 1= yes, 0= no		
Adaptive Capacity	Annual savings	Dummy; 1= yes, 0= no	Developed for the purpose of questionnaire (Hoque et al., 2019; Tessema & Simane, 2019; Tsue et al., 2014)	Lower value reflects lower adaptive capacity. Lower adaptive capacity = Higher Agricultural Vulnerability
	Formal education	Dummy; 1= yes, 0= no		
	High household size	Dummy; 1= yes, 0= no		
	Non-farm employment	Dummy; 1= yes, 0= no		
	Ownership of livestock	Dummy; 1= yes, 0= no		
	Agrochemical/Fertilizer supply	Dummy; 1= yes, 0= no		
	Improved seeds supply	Dummy; 1= yes, 0= no		
	Access to irrigation pump	Dummy; 1= yes, 0= no		
	Gardening with mangrove trees	Dummy; 1= yes, 0= no		
	Improved crop diversification/HYV crops	Dummy; 1= yes, 0= no		
	Access to large farm size	Dummy; 1= yes, 0= no		
	Access to farm credit	Dummy; 1= yes, 0= no		
	Membership in NGOs/CBOs	Dummy; 1= yes, 0= no		
	Share of embankments/dams	Dummy; 1= yes, 0= no		

3.3 Data Collection and Sample Size Determination

Both primary and secondary data have been used in this study. Primary data have been collected through a structured interview schedule from the households of both study sites in the period between January and May, 2019. The interview schedule has been approved by the supervisors of the study and the thesis review committee. A group of trained data enumerators have collected the data. Households have been selected using systematic random sampling with an interval of every 10th household from the starting point. We have used the corresponding widely used formula for determining the sample size (Naing et al., 2006):

$$n = \frac{Z^2 P\,(1-P)}{d^2}$$

$$n' = \frac{NZ^2 P\,(1-P)}{d^2\,(N-1) + Z^2 P\,(1-P)}$$

Where n = Sample size; n′ = Sample size with finite population correction; Z = The standard normal deviate, corresponding to a significance criterion of 0.05 (95%) = 1.96; d = Margin of error, we will tolerate which is ±0.05; P = Incidence rate or proportion predicted, corresponding to a significance criterion of 0.5 (50%) and N = Total population, we have included total 3451 households including 1810 households from Sutarkhali and 1641 households from Nalian (Statistics, 2013).

$$n = \frac{(1.96)^2\ \times 0.5\,(1-0.5)}{(0.05)^2} = 384.2$$

$$n' = \frac{3451 \times (1.96)^2\ \times 0.5\,(1-0.5)}{(0.05)^2\,(3451-1) +\ (1.96)^2\ \times 0.5\,(1-0.5)} = 345.8 \approx 346$$

Thus, we have enrolled 346 households head from the two villages of Sutarkahli union. To reduce the variance, we have used stratified sampling for data collection including 181 households head from Sutarkhali and 165 households head from Nalian. Participants who were not willing to participate, have been excluded from this study. Secondary data has been used in this study for calculating the standard deviation of the last 15 years temperature and precipitation in the Khulna district. We have extracted this data from the Bangladesh Meteorological Department (BMD) of Khulna.

3.4 Development of the Agricultural Vulnerability Index

A composite vulnerability index has been developed for each study site through the determination of exposure, sensitivity, and adaptive capacity. This method calculates a vulnerability index for a set of indicators using an aggregated mean. By averaging the sub-indicators score within each indicator, Equation (1) has been taken into account to determine each indicator score (exposure, sensitivity, and adaptive capacity).

$$DO_i = \frac{\sum_{k=1}^{n} (SIS)_k}{k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where DO_i is the indicator-scores (exposure, sensitivity, and adaptive capacity) of vulnerability index 'i', which is the average of all sub-indicators within each indicator (here SIS_k is the score of each sub-indicator within the concerned indictor and k is the total number of sub-indicators within the concerned indicator that have been indicated in Table 1). After the calculation of the "Exposure", "Sensitivity" and "Adaptive Capacity" scores, Equation (2) has been used to calculate the agricultural vulnerability index as like as (Inostroza et al., 2016).

$$AVI_i = \frac{E + S + (1-AC)}{3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where AVI_i, E, S and AC represent the agricultural vulnerability index, exposure, sensitivity and adaptive capacity of each study site, respectively. The analysis has been conducted by using Statistical Package for Social Sciences (SPSS 20.0) and Microsoft Excel (Version 2013).

3.5 Vulnerability Analysis

Finally, we have used a ordered logit model (Tsue et al., 2014) with a view to identifying the sub-indicators of adaptive capacity that determine the agricultural vulnerability to climate-induced disasters for both study sites. It is a regression model with ordinal dependent variables that are "low", "medium", and "high" and used to see how the responses to other questions can predict or determine the ordinal outcomes (Fullerton, 2009). Here, with the categorized dependent variable, the model had been stated as:

$$\Pr\,(Y \le j) = \text{In}\,\left(\frac{\Sigma \text{pr}\,(Y \le j)|X}{1 - \Sigma \text{pr}\,(Y \le j)|X}\right) = \alpha_j + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_{14} X_{14}\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, Y = Agricultural vulnerability to climate induced disasters for each household of each study site (which is categorized into 3: low = 0, medium = 1 and high = 2); α = threshold; β_1-β_{14} = estimated parameters; X_i are the sub-indicators of adaptive capacity. Agricultural vulnerability classes for each household have been regressed as outcome variables which have also been calculated by using Equation (1) and Equation (2). At the same time, the sub-indicators of adaptive capacity have been regressed as explanatory variables. The analysis has been performed on STATA (Windows Version 13.0). By considering p-value <0.05 as statistical significance, the analysis has been conducted.

4. Results and Discussion

The analysis of agricultural vulnerability is disclosed in two segments for both study sites. The first segment is concerned with determining the different vulnerability measurements with estimates of AVI through the indicators and sub-indicators (Table 2) and the second deals with estimating different adaptive capacity determinants of agricultural vulnerability to climate-induced disasters through ordered logistic regression (Table 3)

4.1 Exposure

Households differ from exposure (Coulibaly et al., 2015; Pachauri et al., 2014; Sujakhu et al., 2018), but due to a lack of absolute data, the inclusion of climate variability data is very difficult. We, therefore, have extracted community level data for rainfall and temperature during the last 15 years from the BMD of Khulna. However, for each household, we have obtained data for the distance of agricultural land from the river and intensity and occurrences of climate-induced hazards as exposure. In total six sub-indicators have been used to evaluate the household's "exposure" position. The sub-indicators of exposure include the position of agricultural land from the river, the standard deviation of rainfall, the standard deviation of temperature, the intensity of cyclone and tidal surge, and the occurrences of river erosion. The substantial hazards in the surveyed site have been found cyclone, river erosion, and tidal surge with varying intensities, magnitudes, and impacts on agricultural production (Table 2).

The analysis has found that the overall mean exposure for Sutarkhali and Nalian is 0.703 and 0.658 respectively, which is considered to have higher agricultural vulnerability exposure for both study sites (Mean Score> 0.640). Households have disclosed the necessity of pre-monsoon precipitation to ascertain the season of harvesting. Most households' farmland have been based on the harvesting rainwater during the monsoon season, and the significantly reduced precipitation rate could affect households by impacting agriculture more (Sujakhu et al., 2016; Sujakhu et al., 2018). Extreme cyclone strength with a tidal wave induces large-scale flooding (Islam et al., 2015) and damages crops and land in large areas (Hoque et al., 2019; Rahman, 2010), leading to saline intrusion (Hoque et al., 2019) and water shortages (Sujakhu et al., 2018) that are regarded as a major problem as an irrigation system. Extreme cyclone magnitude has been identified in 2007 and 2009 with higher tidal surges and coastal flooding in the coastal region of Bangladesh (Islam et al., 2015; Shahid, 2012). The threat of cyclone and the tidal surge has strongly felt by agriculture farmers. Besides, the position of agricultural land within or nearby the river and frequent occurrences of riverbank erosion have also been exposed a higher threat to livelihood (Hoque et al., 2019) as well as the agriculture sectors in both study sites. Taken broadly (Table 2), it could be noted that location and distance of farmland from the river, climatic hazards, and climate variability for all households are more or less common in both study sites which ultimately leads to a higher or lower vulnerability. Climate-induced events has been exacerbated the exposure and vulnerability of the areas to water shortages, saline severity, dropping irrigation potential, crop production loss, properties loss, and food scarcity. More unpredictable climatic hazards with climate variation might worsen the current agricultural risks.

4.2 Sensitivity

Agricultural sensitivity refers to the probability of impacts of climate-induced disasters on the agricultural sector (Hoque et al., 2019). Findings (Table 2) reveal that eight variables have been used to analyze the "sensitivity" of the households for both areas. This analysis reveals that relative sensitivity in both regions are 0.762 in Sutarkhali and 0.681 in Nalian, and that agricultural sensitivity to climate-induced disasters would consider high in both study sites (Mean Score> 0.640). In both study sites, the greater agricultural vulnerability of vulnerable households has been caused by higher salinity and decreasing crop production trend and cropping intensity. In the last 15 years, due to cyclone Sidr and Aila and other climate-related hazards, salinity intrusion through the coastal flooding due to cyclone and tidal surge, sea-level rise, and river erosion have been reported by respondents of both study sites which decreased the irrigation water availability, irrigation potential of the land, crop production, and cropping intensity in both study sites. Moreover, land owned by highly vulnerable households could be subject to salinity intrusion and other risks from climate-induced disasters. Most of the household's do not irrigate land, loss crop production, loss cropping intensity, and loss agricultural income due to greater risks of saline water intrusion and irrigation water scarcity (Islam et al., 2015; Pandey & Jha, 2012; Sujakhu et al., 2018).

Agricultural system in the both study sites has also faced considerable challenges due to the notable changes in the frequency and intensity of events linked to climate during the last decades. Climate-induced disasters could affect crop growth, food safety, farming, and fish farming and severely damage the forestry sector. Besides, the livelihoods and food safety of small-scale farmers have been threatened by disasters and the number of people in need of food assistance was increased after disasters, especially when vulnerable populations are affected (Conforti et al., 2018; Islam et al., 2015).

4.3 Adaptive Capacity

A total of fourteen variables (Table 2) have been used to evaluate "adaptive capacity" status. The results demonstrate that the average adaptive capacity index is 0.397 in Sutarkhali and 0.410 in Nalian, which suggests that the adaptive capacity of agricultural households to climate-induced disasters is low in both study sites (Mean Score< 0.540). However, higher annual savings of the households have a positive influence in order to overcome unprecedented situations related to climate-induced extreme events (Piya et al., 2016). Results indicate that most households with lower annual savings in the two study sites could not raise their agricultural and subsistence investments with greater vulnerability. Although they make an attempt to increase their annual savings through the cultivation and selling of mangrove trees, the increasing intensity and magnitude of climate hazards like cyclones Sidr and Aila with tidal surge and coastal flooding in Bangladesh during 2007 and 2009 (Islam et al., 2015) nevertheless have exhausted their savings.

Households with less-educated heads and small household sizes are at higher risk, indicating that education and lower household size have decreased their capacity to deal with the climate risks. The literature shows that households with illiterate heads and lower size with less economically active members are more fragile and less resilient than households with literate heads and more economically active person (Nadeem et al., 2009; Opiyo et al., 2014). Results depict that absence of households' head education have increased the agricultural vulnerability of the households by limiting its capacity to deal with extreme events and access to agricultural resources and mechanisms in both study sites whereas Sutarkhali is highly vulnerable to the absence of high household size with less economically active members in the households. Households with a greater proportion of non-farming total income are less vulnerable to climate-driven disasters in agriculture. In general, the moderate percentage of non-agriculture income have achieved in most of the households in both study sites as like as (Sujakhu et al., 2016).

Agrochemical/fertilizer supply, improved seeds supply with crop diversification or saline tolerant HYV crops, and access to irrigation pumps have been identified as major sub-indicators of adaptive capacity that determine vulnerability in previous studies (Tsue et al., 2014; Wiréhn et al., 2015). Similarly, this study has identified the lower access to improved seeds, lower access to crop diversification or saline tolerant HYV crops, and lower access to irrigation pumps in both study sites. Although agrochemical/fertilizer supply has been found at a moderate level in Nalian, there is a lack of supplies in Sutarkhali. Social engagement with strong institutional power and improved infrastructure sharing has improved the adaptive capacity (Pandey & Jha, 2012; Smit & Wandel, 2006). The results demonstrate that households with lower access to large farm size and farm credit are agriculturally vulnerable to climate-induced disasters in both study sites. Comparably, membership in CBOs/ NGOs and share of embankments/dams around agricultural land have found moderate to higher access in both study sites.

Table 2: Indexed dimensions of vulnerability and sub-components for assessing agricultural vulnerability

Vulnerability Indicators	**Sub-indicators**	**Sub-indicators Score**		**Vulnerability Indicators Score**	
		Sutarkhali	**Nalian**	**Sutarkhali**	**Nalian**
Exposure	Position of agricultural land from the river	0.61	0.55	0.703	0.658
	Standard deviation of annual rainfall	1.00	1.00		
	Standard deviation of annual temperature	0.43	0.43		
	Higher intensity of cyclone	0.78	0.76		
	Occurrences of river erosion	0.75	0.62		
	Higher intensity of tidal surge	0.65	0.59		
Sensitivity	Reduction of irrigation water availability	0.73	0.70	0.762	0.681
	Salinity severity on arable land	0.78	0.82		
	Irrigation potential loss of cultivable land	0.80	0.77		
	Agricultural properties loss	0.62	0.57		
	Agricultural production trend loss	0.81	0.74		
	Cropping intensity loss	0.91	0.82		
	Income loss from agriculture	0.69	0.59		
	Food security loss	0.45	0.44		
Adaptive Capacity	Annual savings	0.40	0.43	0.397	0.410
	Formal education	0.38	0.40		
	High household size	0.38	0.56		
	Non-farm employment	0.64	0.59		
	Ownership of livestock	0.27	0.18		
	Agrochemical/Fertilizer supply	0.33	0.48		
	Improved seeds supply	0.31	0.28		
	Access to irrigation pump	0.26	0.19		
	Gardening with mangrove trees	0.64	0.65		
	Improved crop diversification/HYV crops	0.27	0.24		
	Access to large farm size	0.31	0.21		
	Access to farm credit	0.40	0.39		

Membership in NGOs/CBOs	0.45	0.47		
Share of embankments/dams	0.52	0.67		
Agricultural Vulnerability Index **$AVI_i = (E + S + (1 - AC))/3$**			**0.689**	**0.643**

Mean Score < 0.540 = Low
Mean Score 0.540 - 0.640 = Medium
Mean Score > 0.640 = High
Source: Field Survey, 2019

4.4 Vulnerability

Overall, the agricultural vulnerability index score of Sutarkhali (0.689) and Nalian (0.643) (Table 2) indicates that the households are highly vulnerable to climate-induced disasters (Mean Score> 0.640) in both study sites. The results of ordered logistic regression (Table 3) elucidate that various sub-indicators of adaptive capacity have been used to assess the prevalence of agricultural vulnerability to climate-induced disasters at both sites of the study. In total, five sub-indicators have been noted statistically significant ($p<0.01$ to $p<0.05$) for both study sites. The ordered regression analysis exhibits that no access to non-farm employment, no ownership of live stocks, and no access to irrigation pumps are extremely significant ($p<0.01$) for the two study sites. At the same time, no improved crop diversification/HYV crops have been found statistically significant ($p<0.05$) for both study sites. Similarly, no access to large farm size has been also statistically significant ($p<0.01$ to $p<0.05$) for both study sites. These five sub-indicators of adaptive capacity have played an important role in determining the agricultural vulnerability of the households in both sites. Moreover, no access to improved seed supply ($p<0.05$) and no share of embankments/ dams ($p<0.01$) have been recorded statistically significant determinants of agricultural vulnerability for the households of Sutarkhali, whereas, lower household size ($p<0.01$), no access to agrochemical/fertilizer supply ($p<0.01$), and no membership in NGOs/CBOs ($p<0.01$) have been reported statistically significant determinants of agricultural vulnerability for the households of Nalian.

Access to non-agricultural income is viewed as a risk reduction approach as well as a post-crisis coping approach (Heitzmann et al., 2002). Households in our study sites have poor adaptation potential due to a lack of involvement in alternatives subsistence alternatives including no access to non-farm income. This result is consistent with the previous study by (Sujakhu et al., 2018). Parallelly, livestock has an impact on the household's vulnerability levels, leading them to transition from low to moderate or high (Nkondze et al., 2014). Such finding is quite similar to this study. Meanwhile, smallholder farmers in Dhading, Nepal, are less vulnerable after integrating livestock domestication with crop production. Ownership of livestock is essential for this type of integration (Panthi et al., 2016; Sujakhu et al., 2018). In comparison to conventional varieties crops and cultivated high yield varieties are related to the improved crop variety class (Evenson & Gollin, 2002). The adoption of no high yield crop diversity and no access to irrigation pumps had been described as the critical factors of low adaptive capacity to assess agricultural livelihood vulnerability to climate change in coastal Bangladesh. Variation of improved crop variety and irrigation pumps have influenced the adaptive capacity and resulted in a differential level of vulnerability to climate change (Hoque et al., 2019). Reported observations are similar to our study results for both study sites on access irrigation pumps and improved crop diversification or saline tolerant HYV crops. A logistic regression model has been used to illustrate the major determinants of the vulnerability of farming households to environmental degradation in Nigeria which has found access to credit, land fragmentation, and land tenure security as the major determinants (Tsue et al., 2014). Such result is close to our findings concerning no access to farm credit in both study sites.

Seeds that are resistant to climate change can boost rates by up to 25% relative to current rates with contemporary seeds by 2050 under the climatic variations projected in Africa (Islam et al., 2016). The previous studies have also found the benefits of climate-resilient seeds (Cacho et al., 2020; Tessema & Simane, 2019). The higher agricultural vulnerability has been found in Sutarkhali as a result of a lack of improved seed supply, which is similar to a prior research on smallholder farmer vulnerability to climatic variability and change. In addition, agriculture will rely heavily on embankment farming as a viable approach (Islam et al., 2015), where agricultural vulnerability to no sharing of embankments/dams around the farmland has been found significant in our study results in Sutarkhali.

The key drivers of poverty in Nigeria included household size, female-headed households, and agricultural activities solely, according to a logistic regression model (Edoumiekumo et al., 2013). In terms of household size, that report reflects our findings in the Nalian. Moreover, better use of farming technologies such as better fertilizer application can be related to the significant average increases in productivity per hectare of the wetland agro-ecological system in the agriculture portfolio (Tessema & Simane, 2019), whereas in our study in Nalian, agricultural vulnerability to a lack of agrochemical/fertilizer supply has been demonstrated to be significant. Another significant attribute that influences the community's or household's vulnerability is the social network. Limited engagement in leadership selection, low membership in community-based organizations, least farming experience, and the largest number of non-working days per month are all factors contributing to the lowland agro-ecological system's increased vulnerability in Ethiopia (Tessema & Simane, 2019). That study also supports our results in the Nalian regarding membership in NGOs/CBOs.

Table 3: Determinants of vulnerability classes in the households (Highlighted variables were significant at both study sites)

Explanatory Variables	Sutarkhali			Nalian		
	Coeff.	**OR**	**p-value**	**Coeff.**	**OR**	**p-value**
Annual savings						
Yes (Ref.)						
No	0.71	2.04	0.082	0.99	2.69	0.067
Formal education						
Yes (Ref.)						
No	0.38	1.47	0.360	1.00	2.72	0.068
High household size						
Yes (Ref.)						
No	0.56	1.75	0.178	1.39	4.04	0.008**
Non-farm employment						
Yes (Ref.)						
No	1.78	5.94	<0.001**	1.59	4.94	0.006**
Ownership of livestock						
Yes (Ref.)						
No	1.96	7.11	<0.001**	2.30	10.07	0.002**
Agrochemical/Fertilizer supply						
Yes (Ref.)						
No	0.83	2.30	0.072	1.89	6.63	0.001**
Improved seeds supply						
Yes (Ref.)						
No	1.07	2.92	0.022*	1.17	3.23	0.068
Access to irrigation pump						
Yes (Ref.)						
No	1.70	5.52	0.002**	2.29	9.88	0.002**
Planting mangrove trees						
Yes (Ref.)						
No	0.73	2.09	0.093	0.93	2.55	0.111
Improved crop diversification/HYV crops						
Yes (Ref.)						
No	1.13	3.11	0.027*	1.28	3.61	0.046*
Access to large farm size						
Yes (Ref.)						
No	1.01	2.75	0.067	1.26	3.54	0.078
Access to farm credit						
Yes (Ref.)						
No	1.09	2.98	0.035*	1.90	6.73	0.002**
Membership in NGOs/CBOs						
Yes (Ref.)						
No	0.75	2.11	0.079	2.02	7.59	0.001**
Share of embankments/dams						
Yes (Ref.)						
No	1.50	4.50	0.001**	0.90	2.46	0.110
Cut1	4.87			7.27		
Cut2	9.39			13.79		
Number of observations	181			165		
LR chi^2 (14)	178.32			209.15		
Prob> chi^2	<0.001			<0.001		
Pseudo R^2	0.50			0.63		
Log likelihood	-86.55			-60.02		

(Coeff.: Coefficient; OR: Odd Ratio; Ref: Reference; ** p<0.01; * p<0.05)
Source: Field Survey, 2019

5. Conclusion and Recommendations

The agricultural vulnerability of the households to climate-induced disasters has been assessed through the use of a composite vulnerability index and quantitative methodologies. Particularly, contextual and location suitable exposure, sensitivity, and adaptive capacity indicators have been used. At the same time, numerous adaptive capacity sub-indicators have been found significant that determine the household's agricultural vulnerability in both study sites. Non-farm employment, ownership of livestock, access to irrigation pump, improved crop diversification/ saline tolerant HYV crops, and access to farm credit are the main predictors of agricultural vulnerability especially in light of socio-economic and spatial disparities. Throughout the two villages and perhaps in other coastal regions, the determinants that have been outlined in this research might assist to develop the proper adaptation strategies to the household's agricultural vulnerability to climate-induced disasters in south-western coastal Bangladesh.

However, depending on research results and respondents demand, this study recommends that the administration interference should be strengthened:

Intensive handling of irrigation water. In order to support farmers' access to irrigations water for crop production facilities, the respective authority should prioritize adequate water management and access to irrigation pump.

Improved seed supply, crop diversification and saline tolerant high yielding variety crops. To increase cultivation output and cropping intensity, the concerned entities should concentrate on cultivation diversification through the introduction and production of more improved seeds as well as high-yielding saline tolerant crop varieties.

Data availability

The data that support the findings of this study are available from the corresponding authors upon request.

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Conflict of interest

No.

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Ethical considerations

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6. References

Acheampong, E. N., Ozor, N., & Owusu, E. S. (2014). Vulnerability assessment of Northern Ghana to climate variability. *Climatic Change*, *126*(1-2), 31-44. https://doi.org/10.1007/s10584-014-1195-z

Adger, W. N., Brooks, N., Bentham, G., Agnew, M., & Eriksen, S. (2005). *New indicators of vulnerability and adaptive capacity*. Tyndall Centre for Climate Change Research Norwich.

Ahsan, M. N., & Warner, J. (2014). The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks–A case study in the south-western coastal Bangladesh. *International Journal of Disaster Risk Reduction*, *8*, 32-49. https://doi.org/10.1016/j.ijdrr.2013.12.009

Aleksandrova, M., Gain, A. K., & Giupponi, C. (2016). Assessing agricultural systems vulnerability to climate change to inform adaptation planning: an application in Khorezm, Uzbekistan. *Mitigation and Adaptation Strategies for Global Change*, *21*(8), 1263-1287. https://doi.org/10.1007/s11027-015-9655-y

Bhuiyan, M. A. H., Islam, S. D.-U., & Azam, G. (2017). Exploring impacts and livelihood vulnerability of riverbank erosion hazard among rural household along the river Padma of Bangladesh. *Environmental Systems Research*, *6*(1), 25. https://doi.org/10.1186/s40068-017-0102-9

Brown, S., Nicholls, R. J., Lázár, A. N., Hornby, D. D., Hill, C., Hazra, S., Addo, K. A., Haque, A., Caesar, J., & Tompkins, E. L. (2018). What are the implications of sea-level rise for a 1.5, 2 and 3° C rise in global mean temperatures in the Ganges-Brahmaputra-Meghna and other vulnerable deltas? *Regional Environmental Change*, *18*(6), 1829-1842. https://doi.org/10.1007/s10113-018-1311-0

Cacho, O. J., Moss, J., Thornton, P. K., Herrero, M., Henderson, B., Bodirsky, B. L., Humpenöder, F., Popp, A., & Lipper, L. J. C. C. (2020). The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. *162*(3), 1213-1229. https://doi.org/10.1007/s10584-020-02817-z

Cardona, O. D. (2013). The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. In *Mapping vulnerability* (pp. 56-70). Routledge.
Chen, J., & Mueller, V. (2018). Coastal climate change, soil salinity and human migration in Bangladesh. *Nature climate change*, *8*(11), 981-985. https://doi.org/10.1038/s41558-018-0313-8
Chowdhury, A., Haque, M., Hoque, M., & Rokonuzzaman, M. (2012). Adoption of BRRI dhan47 in the coastal saline areas of Bangladesh. *Agricultural Journal*, *7*(5), 286-291. https://doi.org/10.3923/aj.2012.286.291
Conforti, P., Ahmed, S., & Markova, G. (2018). impact of disasters and crises on agriculture and food security, 2017.
Coulibaly, J. Y., Mbow, C., Sileshi, G. W., Beedy, T., Kundhlande, G., & Musau, J. (2015). Mapping vulnerability to climate change in malawi: spatial and social differentiation in the Shire River Basin. *American Journal of Climate Change*, *4*(03), 282. https://doi.org/ 10.4236/ajcc.2015.43023
Easterling, W. E., Aggarwal, P. K., Batima, P., Brander, K. M., Erda, L., Howden, S. M., Kirilenko, A., Morton, J., Soussana, J.-F., & Schmidhuber, J. (2007). Food, fibre and forest products. *Climate change*, *2007*, 273-313.
Edoumiekumo, S., Tombofa, S., & Moses, T. (2013). Multidimensional energy poverty in the South-South Geopolitical zone of Nigeria. *Journal of Economics and Sustainable Development*, *4*(20), 96-103.
Evenson, R. E., & Gollin, D. (2002). *Crop variety improvement and its effect on productivity*. CABI Pub.
Fullerton, A. S. (2009). A conceptual framework for ordered logistic regression models. *Sociological methods & research*, *38*(2), 306-347. https://doi.org/10.1177/0049124109346162
Füssel, H.-M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. *Global Environmental Change*, *17*(2), 155-167. https://doi.org/10.1016/j.gloenvcha.2006.05.002
Gbetibouo, G. A., Ringler, C., & Hassan, R. (2010). Vulnerability of the South African farming sector to climate change and variability: an indicator approach. In *Natural Resources Forum* (Vol. 34, No. 3, pp. 175-187). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/j.1477-8947.2010.01302.x
Harvey, C. A., Rakotobe, Z. L., Rao, N. S., Dave, R., Razafimahatratra, H., Rabarijohn, R. H., Rajaofara, H., & MacKinnon, J. L. (2014). Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1639), 20130089. https://doi.org/10.1098/rstb.2013.0089
Heitzmann, K., Canagarajah, R. S., & Siegel, P. B. (2002). *Guidelines for assessing the sources of risk and vulnerability.* Social Protection Discussion Paper Series No. 218. https://documents1.worldbank.org/curated/en/370781468762886906/pdf/313720SP0021801public1.pdf
Hoque, M. Z., Cui, S., Xu, L., Islam, I., Tang, J., & Ding, S. (2019). Assessing Agricultural Livelihood Vulnerability to Climate Change in Coastal Bangladesh. *International journal of environmental research and public health*, *16*(22), 4552. https://doi.org/10.3390/ijerph16224552
Inostroza, L., Palme, M., & de la Barrera, F. (2016). A heat vulnerability index: spatial patterns of exposure, sensitivity and adaptive capacity for Santiago de Chile. *PLOS one*, *11*(9). https://doi.org/10.1371/journal.pone.0162464
Islam, M. A., Shitangsu, P. K., & Hassan, M. Z. (2015). Agricultural vulnerability in Bangladesh to climate change induced sea level rise and options for adaptation: a study of a coastal Upazila. *Journal of Agriculture and Environment for International Development (JAEID)*, *109*(1), 19-39.
Islam, M. M., Sallu, S., Hubacek, K., & Paavola, J. (2014). Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh. *Regional Environmental Change*, *14*(1), 281-294. https://doi.org/10.1007/s10113-013-0487-6
Islam, M. N., Malak, M. A., & Islam, M. N. (2013). Community-based disaster risk and vulnerability models of a coastal municipality in Bangladesh. *Natural Hazards*, *69*(3), 2083-2103. https://doi.org/10.1007/s11069-013-0796-6
Islam, S., Cenacchi, N., Sulser, T. B., Gbegbelegbe, S., Hareau, G., Kleinwechter, U., Mason-D'Croz, D., Nedumaran, S., Robertson, R., & Robinson, S. J. G. F. S. (2016). Structural approaches to modeling the impact of climate change and adaptation technologies on crop yields and food security. *10*, 63-70. https://doi.org/10.1016/j.gfs.2016.08.003
Khanom, T. (2016). Effect of salinity on food security in the context of interior coast of Bangladesh. *Ocean & Coastal Management*, *130*, 205-212. https://doi.org/10.1016/j.ocecoaman.2016.06.013
Li, X., Philp, J., Cremades, R., Roberts, A., He, L., Li, L., & Yu, Q. (2016). Agricultural vulnerability over the Chinese Loess Plateau in response to climate change: Exposure, sensitivity, and adaptive capacity. *Ambio*, *45*(3), 350-360. https://doi.org/10.1007/s13280-015-0727-8
Li, Y., Xiong, W., Hu, W., Berry, P., Ju, H., Lin, E., Wang, W., Li, K., & Pan, J. (2015). Integrated assessment of China's agricultural vulnerability to climate change: a multi-indicator approach. *Climatic Change*, *128*(3-4), 355-366. https://doi.org/10.1007/s10584-014-1165-5

Lipper, L., Thornton, P., Campbell, B. M., Baedeker, T., Braimoh, A., Bwalya, M., Caron, P., Cattaneo, A., Garrity, D., & Henry, K. (2014). Climate-smart agriculture for food security. *Nature climate change*, *4*(12), 1068-1072. https://doi.org/10.1038/nclimate2437

Luers, A. L., Lobell, D. B., Sklar, L. S., Addams, C. L., & Matson, P. A. (2003). A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico. *Global Environmental Change*, *13*(4), 255-267.

McCarthy, J. J., Canziani, O. F., Leary, N. A., Dokken, D. J., & White, K. S. (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

MoA, F. (2013). Master plan for agricultural development in the southern region of Bangladesh. *Ministry of Agriculture (MoA, Government of Bangladesh) and United Nations Food and Agriculture Organization, Dhaka, Bangladesh*, *122*.

Monterroso, A., Conde, C., Gay, C., Gómez, D., & López, J. (2014). Two methods to assess vulnerability to climate change in the Mexican agricultural sector. *Mitigation and Adaptation Strategies for Global Change*, *19*(4), 445-461. https://doi.org/10.1007/s11027-012-9442-y

Morton, J. F. (2007). The impact of climate change on smallholder and subsistence agriculture. *Proceedings of the national academy of sciences*, *104*(50), 19680-19685.

Mullick, M. R. A., Tanim, A., & Islam, S. S. (2019). Coastal vulnerability analysis of Bangladesh coast using fuzzy logic based geospatial techniques. *Ocean & Coastal Management*, *174*, 154-169. https://doi.org/10.1016/j.ocecoaman.2019.03.010

Nadeem, S., Elahi, I., Hadi, A., & Uddin, I. (2009). Traditional knowledge and local institutions support adaptation to water-induced hazards in Chitral, Pakistan. *Traditional knowledge and local institutions support adaptation to water-induced hazards in Chitral, Pakistan.*

Naing, L., Winn, T., & Rusli, B. (2006). Practical issues in calculating the sample size for prevalence studies. *Archives of orofacial Sciences*, *1*, 9-14.

Nasim, F. A., Hoque, M. Z., Haque, M. E., Islam, M. S., Parveen, N., Chakma, S., & Afrad, M. S. I. (2019). How does adoption of crop variety reduce the impact of drought in agriculture and mitigate food insecurity of smallholder farmers? A case study on BUdhan1 rice variety in Bangladesh. *Asian Journal of Agricultural Extension, Economics & Sociology*, 1-12. https://doi.org/10.9734/ajaees/2019/v30i330114

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T. B., & Ringler, C. (2010). *Food security, farming, and climate change to 2050: scenarios, results, policy options* (Vol. 172). Intl Food Policy Res Inst.

Neset, T.-S., Wiréhn, L., Opach, T., Glaas, E., & Linnér, B.-O. (2019). Evaluation of indicators for agricultural vulnerability to climate change: The case of Swedish agriculture. *Ecological Indicators*, *105*, 571-580. https://doi.org/10.1016/j.ecolind.2018.05.042

Nkondze, M. S., Masuku, M. B., & Manyatsi, A. M. (2014). The impact of climate change on livestock production in Swaziland: The case of Mpolonjeni area development Programme. *Journal of Agricultural Studies*, *2*(1), 1-15. https://doi.org/10.5296/jas.v2i1.4416

o'Brien, K., Leichenko, R., Kelkar, U., Venema, H., Aandahl, G., Tompkins, H., Javed, A., Bhadwal, S., Barg, S., & Nygaard, L. (2004). Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change*, *14*(4), 303-313. https://doi.org/10.1016/j.gloenvcha.2004.01.001

Opiyo, F. E., Wasonga, O. V., & Nyangito, M. M. (2014). Measuring household vulnerability to climate-induced stresses in pastoral rangelands of Kenya: Implications for resilience programming. *Pastoralism*, *4*(1), 10. https://doi.org/10.1186/s13570-014-0010-9

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Ipcc.

Pandey, R., & Jha, S. (2012). Climate vulnerability index-measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India. *Mitigation and Adaptation Strategies for Global Change*, *17*(5), 487-506. https://doi.org/10.1007/s11027-011-9338-2

Pandey, R., Kala, S., & Pandey, V. P. (2015). Assessing climate change vulnerability of water at household level. *Mitigation and Adaptation Strategies for Global Change*, *20*(8), 1471-1485. https://doi.org/10.1007/s11027-014-9556-5

Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., & Pandey, V. P. (2016). Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal. *Regional Environmental Change*, *16*(4), 1121-1132. https://doi.org/10.1007/s10113-015-0833-y

Parishad, D. U. (2005). Union Statistics of Dacope Upazila Parishad up to 2005. *Khulna: Dacope Upazila Parishad*.

Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4). Cambridge University Press.

Piya, L., Joshi, N. P., & Maharjan, K. L. (2016). Vulnerability of Chepang households to climate change and extremes in the Mid-Hills of Nepal. *Climatic Change*, *135*(3-4), 521-537. https://doi.org/10.1007/s10584-015-1572-2

Quader, M. A., Khan, A. U., & Kervyn, M. (2017). Assessing risks from cyclones for human lives and livelihoods in the coastal region of Bangladesh. *International journal of environmental research and public health*, *14*(8), 831. https://doi.org/10.3390/ijerph14080831

Rabby, Y. W., Hossain, M. B., & Hasan, M. U. (2019). Social vulnerability in the coastal region of Bangladesh: An investigation of social vulnerability index and scalar change effects. *International Journal of Disaster Risk Reduction*, *41*, 101329. https://doi.org/10.1016/j.ijdrr.2019.101329

Rahman, M. (2010). Impact of riverbank erosion hazard in the Jamuna floodplain areas in Bangladesh. *Journal of Science Foundation*, *8*(1-2), 55-65. https://doi.org/10.3329/jsf.v8i1-2.14627

Rakib, M., Sasaki, J., Pal, S., Newaz, M. A., Bodrud-Doza, M., & Bhuiyan, M. A. (2019). An investigation of coastal vulnerability and internal consistency of local perceptions under climate change risk in the southwest part of Bangladesh. *Journal of environmental management*, *231*, 419-428. https://doi.org/10.1016/j.jenvman.2018.10.054

Rosenzweig, C., Elliott, J., Deryng, D., Ruane, A. C., Müller, C., Arneth, A., Boote, K. J., Folberth, C., Glotter, M., & Khabarov, N. (2014). Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. *Proceedings of the national academy of sciences*, *111*(9), 3268-3273.

Shahid, S. (2012). Vulnerability of the power sector of Bangladesh to climate change and extreme weather events. *Regional Environmental Change*, *12*(3), 595-606. https://doi.org/10.1007/s10113-011-0276-z

Shamsuddoha, M., & Chowdhury, R. K. (2007). Climate change impact and disaster vulnerabilities in the coastal areas of Bangladesh. *COAST Trust, Dhaka*.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global Environmental Change*, *16*(3), 282-292. https://doi.org/10.1016/j.gloenvcha.2006.03.008

Statistics, B. B. o. (2013). *District Statistics 2011* (Khulna, Issue Complementary). S. a. I. D. Ministry of Planning, Government of the People's Republic of Bangladesh. http://203.112.218.65:8008/WebTestApplication/userfiles/Image/District%20Statistics/Khulna.pdf

Sujakhu, N. M., Ranjitkar, S., Niraula, R. R., Pokharel, B. K., Schmidt-Vogt, D., & Xu, J. (2016). Farmers' perceptions of and adaptations to changing climate in the Melamchi valley of Nepal. *Mountain Research and Development*, *36*(1), 15-30. https://doi.org/10.1659/MRD-JOURNAL-D-15-00032.1

Sujakhu, N. M., Ranjitkar, S., Niraula, R. R., Salim, M. A., Nizami, A., Schmidt-Vogt, D., & Xu, J. (2018). Determinants of livelihood vulnerability in farming communities in two sites in the Asian Highlands. *Water International*, *43*(2), 165-182. https://doi.org/10.1080/02508060.2017.1416445

Tessema, I., & Simane, B. (2019). Vulnerability analysis of smallholder farmers to climate variability and change: an agro-ecological system-based approach in the Fincha'a sub-basin of the upper Blue Nile Basin of Ethiopia. *Ecological Processes*, *8*(1), 5. https://doi.org/10.1186/s13717-019-0159-7

Tsue, P., Nweze, N., & Okoye, C. (2014). Vulnerability of farming households to environmental degradation in developing countries: Evidence from North Central Nigeria. *Journal of Economics and Sustainable Development*, *5*(24), 206-216.

Uddin, M. N., Islam, A. S., Bala, S. K., Islam, G. T., Adhikary, S., Saha, D., Haque, S., Fahad, M. G. R., & Akter, R. (2019). Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. *Applied geography*, *102*, 47-57. https://doi.org/10.1016/j.apgeog.2018.12.011

Wiréhn, L., Danielsson, Å., & Neset, T.-S. S. (2015). Assessment of composite index methods for agricultural vulnerability to climate change. *Journal of environmental management*, *156*, 70-80. https://doi.org/10.1016/j.jenvman.2015.03.020

Younus, M. A. F. (2017). An assessment of vulnerability and adaptation to cyclones through impact assessment guidelines: A bottom-up case study from Bangladesh coast. *Natural Hazards*, *89*(3), 1437-1459. https://doi.org/10.1007/s11069-017-3027-8

Younus, M. A. F., & Kabir, M. A. (2018). Climate change vulnerability assessment and adaptation of bangladesh: Mechanisms, Notions and Solutions. *Sustainability*, *10*(11), 4286. https://doi.org/10.3390/su10114286

Zhai, F., & Juzhong, Z. (2009). *Agriculture Impact of Climate Change: A General equilibrium Analysis with Special Reference to Southeast Asia.* Asian Development Bank Institute. ADBI Working Paper 131.