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Research article

Does climate change stimulate household vulnerability and income diversity? Evidence from southern coastal region of Bangladesh

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ABSTRACT

Bangladesh is one of the most climate-vulnerable countries globally, where the livelihood of agro-based dependent people became vulnerable due to different natural hazards, especially in the southern coastal part. This study investigates the influence of climate change on household vulnerability and income diversity, data collected from the climate-vulnerable coastal areas of Bangladesh. Both panel data regression and structural equation model were employed to examine the vulnerability status, whereas income diversity was measured through diversity index and "Type-66" livelihood strategy. Results reveal that sources of income have diversified over time. However, the study also reveals that climate change-especially the increase in salinity has affected crop production, resulting in increased income vulnerability of small and marginal farmers who are highly reliant on farm income. Moreover, findings reveal that climate change has influenced households to diversify into low-income sources that do not help to overcome their income vulnerability. Therefore, a cooperative land management system, establishment of embankment, training, and skill development programs are needed to generate feasible alternative income sources to improve the livelihood of coastal people.

1. Introduction

Global climate has been changing due to natural forces and anthropogenic activities, especially emissions of greenhouse gases and changes in land-use patterns in recent decades (IPCC, 2007). Therefore, climate change is a burgeoning concern across the world. It is anticipated that climate change would have significant impacts on food security and agricultural incomes in developing countries like Bangladesh, with a disproportionate effect on the welfare of the rural poor (Alam et al., 2018). However, climate change poses several biophysical and socio-economic challenges in the coastal region (Adnan et al., 2020). For instance, several climate changes issues such as salinity intrusion, flooding, increasing cyclone frequency, etc., curb agricultural productivity, which is the principal means of livelihood in the coastal region of Bangladesh (Habiba et al., 2015). As the largest deltas in the world, Bangladesh is a highly climate-vulnerable country (Ahmed et al., 2021; Alam et al., 2020; Sarker et al., 2020) because of its geographical location, flat and low-lying landscape, population density, etc. (Ayers et al., 2014; Biswas, 2013). The adverse effects of climate change have dwindled not only the country's overall agricultural productivity but also economic development to a greater extent (Biswas, 2013).

The coastal areas of Bangladesh cover a distance of 710 km in a total of ninety *Upazilas* (sub-administrative area) of fifteen districts in the south and south-east (Ahmad, 2019). These areas consist of approximately 20 percent of the total land area and over 30 percent of cultivable lands of the country (Minar et al., 2013). Although the coastal region has greater potential for development, almost 37% of the coastal land is affected by salinity (Salehin et al., 2018; SRDI, 2010). In the coastal zone of Bangladesh, 8142 km^2 (5.5% of the country) land is salt-affected, and these salt-affected areas are increasing at a rate of 146 km^2 per year (SRDI, 2010). Besides, about 35 million people are currently residents in the coastal region of Bangladesh (Ahmad, 2019), who are the ultimate

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victims of climate change. Despite the fact that the country's coastal zone is rich in natural resources, widespread poverty, non-sustainable resource usage, and regular natural disasters (such as cyclones) represent a substantial threat to the lives and livelihoods of coastal residents (Islam et al., 2016).

However, climate change has a substantial adverse consequence on the loss of agricultural productivity, loss of agro-diversity, loss of soil quality and vegetation, and eventually the deterioration of livelihood of coastal communities in Bangladesh (Abdullah et al., 2019). Due to severe salinity problems, the soil became unfavorable to produce crops; thus, the land-use pattern has changed over the years. On the other hand, a substantial portion of rice fields has been converted into shrimp farming in recent years due to changes in land-use patterns and a conducive environment for shrimp farming (Kabir and Eva, 2014). It is observed that small farmers in coastal regions are bound to lease their land to the large farmers or elite people due to the shortage of capital required for converting their rice field into shrimp farming and low productivity of agricultural crops (Shawon et al., 2018). Therefore, the sources of income of the surrounding people are changing and becoming limited, which resulted in more poverty and vulnerability in this area. Apart from climate change, another human-made cause, including the construction of embankment, has also brought negative consequences on the livelihood of coastal people, although it has some beneficial effects on society (Adnan et al., 2020). Although embankments protect the polder area from moderately severe storm surges and fluvial-tidal floods (Adnan et al., 2019), the construction of embankments enforces to change the land-use pattern in the coastal areas (Abdullah et al., 2019). Embankment separates the floodplain from the adjacent rivers caused land subsidence within the polder area. However, land subsidence and inadequate drainage are responsible for frequent pluvial flooding in coastal areas, which ultimately influence people's livelihood and income patterns (Adnan et al., 2019; Roy et al., 2017; Ishtiaque et al., 2017).

There are several studies demonstrate that households living in coastal regions are subject to more vulnerable and have limited income diversification than those located in the exterior region of Bangladesh (Sarker et al., 2020; Alam et al., 2018; Kabir et al., 2016a, b; Toufique and Yunus, 2013). However, people living in the coastal areas are forced to diversify their income sources to combat the climate change impact (Kabir et al., 2016a). Several motives prompt households and individuals to diversify activities, income, and assets (Daud et al., 2018). The motives are usually categorized into pull factors and push factors (Barrett et al., 2001). The first set of motives are traditionally termed as push factors such as disaster risk management (Bell et al., 2021), seasonality of agricultural activities (Penning-Rowsell et al., 2013), liquidity constraints or limited assets and income (Islam et al., 2014; Saha, 2017), natural disasters (Ishtiaque and Ullah, 2013) which induce households to self-provision in several goods and services. The second set of motives comprises the pull factors that include new employment opportunities created by market development (Saha, 2017; Bernzen et al., 2019), perceived economic opportunities (Ishtiaque and Ullah, 2013; Mallick and Vogt, 2014), and environmental stressors (Bernzen et al., 2019). The increased income diversity usually enhances more flexibility because it offers more possibilities for replacing poverty and expansion opportunities.

Recent literature shows that income diversification is an essential strategy for rural households to cope with disasters in arid and semiarid regions (Wan et al., 2016). Agricultural change, livelihood diversification, and migration are examples of adaptation strategies (Aryal et al., 2020) that can reduce people's vulnerabilities to adverse impacts of climate hazards and ensure sustainability (Bhowmik et al., 2021). Therefore, diversifications are desirable policy objectives since they give households more options to improve livelihood security and raise their living standards. Verschuur et al. (2020) highlighted the Social Security Net (SSN) intervention as a response and recovery measure for coastal areas due to increased opportunities for household income diversification. Income diversification is a useful strategy for managing disaster risk and improving social welfare since climate change erodes the capabilities of coastal people in Bangladesh to mitigate vulnerability (Huq et al., 2015). However, Ishtiaque and Nazem (2017) revealed that natural disasters, i.e., floods, predominantly drop the income of coastal people by approximately 70%, and consequently, people tend to migrate for a diversified income source. Although there are several studies on vulnerability and adaptive measures of climate change in coastal areas of Bangladesh, little is known about (i) how income diversity changed over the years in the coastal areas; (ii) how different types of vulnerability, i.e., income, agricultural, climate, and integrated household changed over the last two decades in coastal areas; (iii) how climate change influence the income diversity and vulnerability in coastal areas. Therefore, this study aims to provide a comprehensive understanding of the impact of climate change on the agricultural communities (i.e., income diversity and vulnerability) in the coastal areas of Bangladesh. This study contributes to the extant literature focused on coastal areas by filling the research gaps mentioned above. However, the findings can facilitate policy development by exploring the relationship between climate change, income diversity and vulnerability, in order to develop a rational strategy for alleviating vulnerability in the study area and other similar regions across the globe.

The paper is organized as follows. In the following sections, the data and method used are outlined. Then, the estimated result of income diversity and vulnerability situation over time and the effects of climate change on income diversity and vulnerability are presented and discussed. Finally, concluding remarks are provided, and some policy implications are discussed.

2. Methodology

2.1. Study area, sampling, and data collection

This study considered 20 years of timespan from 1995 to 2015 because a relatively longer time period is required to explore the effect of climate change. Respondents were randomly selected from three *Upazilas* (Sub-administrative areas), which were chosen from three districts based on the degree of severity of climate change impact. The study areas were as followed: Khulna (Dakope *Upazila*), Shatkhira (Shamnagar *Upazila*), and Bagherhat (Shoronkhola *Upazila*). Figure 1 shows the map of the study areas which are the most vulnerable to climate change in Bangladesh. The total number of respondents for the sample survey in each district was 150. Thus 450 respondents were surveyed from three *Upazilas* of three districts. The households in each *Upazila* were randomly selected based on a list of farming households. The head of the family/household was given priority to respond to the questions. In the absence of the head, another senior informed person of the family/household was requested to respond. However, in many cases, either elderly males or females responded in the presence of all family members. An interview schedule was designed to capture the relevant data, and the draft interview schedule was pre-tested by interviewing ten respondents; thus, necessary modifications were made accordingly. Section A of the interview schedule focused on the socioeconomic profile of the households and overviews on farm management, domestic resources, income, and other income-generating practices of the household. Section B covered the state of production, associated loss and damage due to extreme events, extension services, NGO/Association supports in the study areas. Section C emphasized awareness and understanding of climate change and salinity problems. Section D provided the questions on coping options to address salinity intrusion caused by extreme events. The meteorological data (temperature, rainfall, cyclone, salinity) were collected from three local meteorological stations of three districts.

2.2. Measurement of income diversity

Income diversity has been measured in two ways: income diversity index and “Type 66” livelihood strategy. The income diversity index

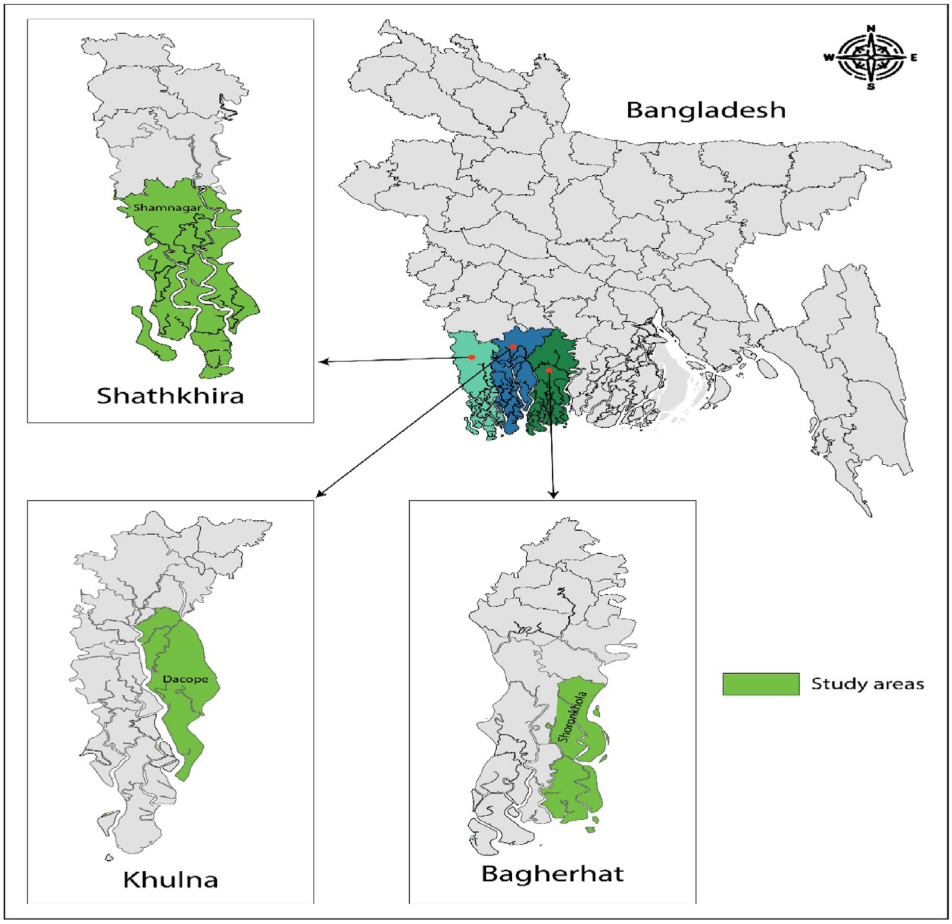


Figure 1. Map of the study areas.

estimates the livelihood typologies of the respondents where it captures both income shares and in a single figure which can be compared across the sample groups. Chang (1997) proposed the income diversity index described the diversity best in terms of both the number of activities and the distribution of total income between them. The income diversity index is measured by the following formula proposed by Chang (1997):

$$\text{Income diversity} = \frac{1}{\textit{Sum of squares of proportional contributions to total income}}$$

The maximum index value equals to the number of income sources, which can be attained if total income is equally distributed between each source.

The study also employed the "Type 66" livelihood strategy of Ellis (2000), where sample households were classified according to simple typology based on household income sources. On inspection of the household income data, it was decided that the principal types of activity could be broadly described as crop production, livestock production, fish production, and non-farm income (taken into account of all non-own farming income). The typology was constructed based on a "break-point" of income sources that comprised two-thirds of total income (66%), resulting in 11 classes (including "mixed type") of livelihood strategy, as shown in Table 1. This method helps to examine how much diversity was achieved by the households in each income activity. In addition, the results obtained using this method help this study to find a possible indication of how climate change influences the income diversity of the households.

2.3. Measurement of vulnerability

In this context, vulnerability is defined as expected poverty, or in other words, as the probability that a household's consumption will lie below the predetermined poverty line in the near future. This study assumes that the total income a person earned spends on his or her household consumption. Following Chaudhuri (2003), for a given household h, the vulnerability has defined as the probability of its consumption is below the poverty line at time $t+1$:

$$V_{ht} = Pr\left(ln\ c_{h,t+1} < \ln \underline{c}\right)$$

Table 1. Categories of "Type 66" livelihood strategies.

Strategy ID	Category shares in total income	Strategy type
1	Crop income ≥ 66%	Principally crops
2	Livestock income ≥ 66%	Principally livestock
3	Fish income ≥ 66%	Principally fish
4	Non-farm income ≥ 66%	Principally non-farm
5	Crop income and livestock income together ≥ 66% Crop income < 66%, but > non-farm income or fish income Livestock income < 66%, but > non-farm income or fish income	Crop + Livestock
6	Crop income and fish income together ≥ 66% Crop income < 66%, but > non-farm income or livestock income Fish income < 66%, but > non-farm income or livestock income	Crop + Fish
7	Crop income and non-farm income together ≥ 66% Crop income < 66%, but > livestock income or fish income Non-farm income < 66%, but > livestock income or fish income	Crop + Non-farm
8	Livestock income and fish income together ≥ 66% Livestock income < 66%, but > crop income or non-farm income Fish income < 66%, but > crop income or non-farm income	Livestock + Fish
9	Livestock and non-farm income together ≥ 66% Livestock income < 66%, but > crop income or fish income Non-farm income < 66%, but > crop income or fish income	Livestock + Non-farm
10	Fish income and non-farm income together ≥ 66% Fish income < 66%, but > crop income or livestock income Non-farm income < 66%, but > crop income or livestock income	Fish + Non-farm
11	More than two income sources are ≤ 66%	Mixed

where V_{ht} is the vulnerability of household h at time t, $c_{h,t+1}$ denote the consumption of household h at time $t+1$ and $\underline{c}$ stands for the poverty line of household consumption.

Again,

$$ln\ c_h = X_h\beta + \varepsilon_h \tag{1}$$

where c_h stands for per capita consumption expenditure for household h, X_h represents a vector of observable household characteristics (containing both idiosyncratic and community elements), β is a vector of parameters, and ε_h is a mean-zero disturbance term that captures households' idiosyncratic factors (shocks) contributing to differential levels of per capita consumption for households with the same characteristics.

However, the vulnerability to poverty of household h with characteristics X_h can now be calculated using the coefficient estimates of the Eq. (1) in the following manner:

$$\widehat{V}_h = \widehat{Pr}\left(\ln c_h < \ln\underline{c} \middle| X_h\right) = \Phi\left(\frac{\ln\underline{c} - X_h\widehat{\beta}}{\widehat{\sigma}}\right) \tag{2}$$

Meanwhile, Φ denotes the cumulative density of the standard normal distribution and $\widehat{\sigma}$ is the standard error of the Eq. (1).

Household's future consumption is further assumed to be dependent upon uncertainty about some idiosyncratic and community characteristics. To have a consistent estimate of parameters, it is necessary to allow heteroskedasticity, that is, variances of the disturbance term to vary. This can take the following functional form:

Table 2. List of variables considered for socio-demographic vulnerability assessment.

Variable	Description	Coded
Age of household head	The age of the household head	Continuous
Education of household head	Years of schooling	Continuous
Family size	Total number of a family member	Continuous
Dependency ratio	Total family members divided by the number of earning person/s	Continuous
Occupation of household head	Primary income activity of the household head	Categorical
Homestead area	Decimal of land that household own as homestead area	Continuous
Own land	Decimal of land that a household owns	Continuous
Household asset	Total assets of a household in monetary value (BDT)	Continuous
Association member	Whether household member actively involved in any association	Binary (1 if yes, 0 otherwise)
Access to drinking water	Whether household has proper access to drinking water	Binary (1 if yes, 0 otherwise)
Access to electricity	Whether household has access to electricity	Binary (1 if yes, 0 otherwise)
Types of cooking energy	Types of cooking energy (wood, coal, fuel, gas) that households use	Categorical

$$\sigma^2_{e,h} = X_h\theta + \eta_h \tag{3}$$

where β and θ are parameter estimates obtained from the three-step Feasible Generalized Least Squares (FGLS) procedure suggested by Amemiya (1977).

Using the estimates β and θ, the expected log of consumption and the variance of log consumption for each household h are, respectively, estimated as:

$$\widehat{E} = [lnC_h|X_h] = X_h\widehat{\beta} \tag{4}$$

$$\widehat{V} = [lnC_h|X_h] = \sigma^2_{e,h} = X_h\widehat{\theta} \tag{5}$$

Finally, the estimates of β and θ obtained through this FGLS method can be used to estimate the vulnerability to poverty of household h through the following generalization of the Eq. (2):

$$\widehat{V}_h = \Phi\left(\frac{ln\underline{c} - X_h\widehat{\beta}}{\sqrt{X_h\widehat{\theta}}}\right) \tag{6}$$

Clearly, the estimation of vulnerability to poverty depends on the following elements: the distributional assumption of normality of log consumption, the choice of the poverty line $\underline{c}$, the expected level of log consumption and the expected variability of log consumption. The higher the level of expected consumption and expected consumption variability, the lower the vulnerability is. This study identifies the possible sources of vulnerability, and for each source, several sub-indicators (variables) are also identified through literature review and field survey. They are as follows:

2.3.1. Socio-demographic vulnerability

Socio-demographic vulnerability indices are assumed to be based on the likelihood of a given socio-demographic shock, or set of shocks that force to moves consumption of a household below a minimum given level[1] or forces the consumption level to stay below the given minimum requirement if it is already below that level (Chaudhuri, 2003). The

[1] The study used the poverty line of different regions estimated by Bangladesh Bureau of Statistics (BBS).

Table 3. List of variables considered for agricultural vulnerability assessment.

Variable	Description	Coded
Cultivated land	Decimal of land that household own as cultivated land	Continuous
Fallow land	Decimal of land that household own as fallow land	Continuous
Pond area	Decimal of land that household own as pond area	Continuous
Leased out	Decimal of land that household leased out	Continuous
Rented out	Decimal of land that household rented out	Continuous
Soil type	The predominant soil type of the farmers' plots (bele, bele do-ash, do-ash, etel do-ash, etel)	Categorical
Cropping pattern	Whether or not a farmer planted a given crop along with fish (gher farming)	Binary (1 if crop + gher, 0 otherwise)
Access to extension services	Whether or not a farmer receives agricultural extension services (agricultural advice, technological/input support, etc.)	Binary (1 if yes, 0 otherwise)
Credit support	Whether or not a farmer receives any credit support for production	Binary (1 if yes, 0 otherwise)

factors mentioned in Table 2 were selected according to the literature on similar vulnerability to poverty studies (Laila, 2013; Lee et al., 2021). For effective natural hazard mitigation and implementation process, it is crucial to quantify the multifaceted nature of the socio-demographic vulnerability, especially in the context of disaster risk reduction strategies.

2.3.2. Agricultural vulnerability

Agricultural vulnerability indices are assumed to be based on the likelihood of a given agricultural shock, or set of shocks, that moves consumption of households below a given minimum level or forces the consumption level to stay below the given minimum requirement if it is already below that level. Table 3 shows the factors selected for measuring agricultural vulnerability. Biophysical factors influence cropping decisions (Kurukulasuriya and Mendelsohn, 2008). For instance, soil type can interfere with the type of crops that farmers can plant in their fields and can reduce the ability of farmers to adopt specific coping strategies in response to climate change (Naeem et al., 2015). Moreover, the cropping pattern and access to extension services of farmers may affect the management strategies. Besides, farmers with more secure access to credit may be able to produce through a wider suite of agricultural activities.

2.3.3. Climate vulnerability

Climate vulnerability indices are estimated based on the likelihood of a given climate shock eliminating household consumption below a certain minimum level or forcing the cost of living below a given minimum requirement if it is already below that level. The factors mentioned in Table 4 were selected to estimate the climate vulnerability based on similar literature (Islam et al., 2014; Alam et al., 2018). The southwest coastal region of Bangladesh is mainly affected by tropical cyclones, storm surges, tidal surges, tidal floods, salinity intrusion, and sea-level rise (Alam et al., 2018). Temperature extremes and heavy precipitation in this region increased during the 1991–2010 period compared to the 1960–1979 periods (Bhowmik et al., 2021). High-intensity short-term rainfall has also been reported as another major climatic event by coastal communities of Bangladesh (ICCCAD, 2019). The negative impact of soil and water salinity on crops, fish, and livestock has increased in this coastal belt (Alam et al., 2017).

Table 4. List of variables considered for climate vulnerability assessment.

Variable	Description	Coded
Salinity	Salinity concentration of the reported area in dS/m	Continuous
Rainfall	The quantity of rain falling within the reported area in a particular year in mm	Continuous
Cyclone	Number of cyclones faced by the reported area in a year	Continuous
Minimum temperature	Average minimum temperature of the reported area of the year in °C	Continuous
Maximum temperature	Average maximum temperature of the reported area of the year in °C	Continuous

2.3.4. Integrated household vulnerability

The socio-demographic, agricultural, and climatic factors of each region were included to develop the integrated household vulnerability indices in different years. Then, the integrated vulnerability assessment approaches were adopted to explore the overall change in vulnerability over the years in the coastal regions of Bangladesh.

2.4. Assessment of sway of climate change on vulnerabilities

In the nonparametric matching method, the research assumes that there was no measurement problem or sampling error (Sherlund et al., 2002), and therefore the nonparametric approaches did not rely on any specific functional and distributional form. Consequently, we employed the random-effects model to check the robustness of our results with the nonparametric matching method. However, the study first tested whether the fixed or random-effects model was appropriate for this data set using the Hausman test (Hausman, 1978) and found that the random-effects model provided a better fit. This indicates that the household-level independent variables (x_{it}) are uncorrelated with the individual effects (α_i). Therefore, in this case, the random-effects model was better. It specifies as follows:

$$y_{it} = \beta \acute{X_{it}} + (\alpha_i + \varepsilon_{it}),\ \text{Where } \varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2)\ \text{and}\ \alpha_i \sim IID\ (0,\ \sigma_\alpha^2)$$

where $\alpha_i + \varepsilon_{it}$ treated as an error term consisting of two components: an individual-specific component, which does not vary over time, and a remainder component, which is assumed to be uncorrelated over time, allowing for the time-invariant variables to play the role of explanatory variables. It is important to mention that the researcher estimates the random-effects model with common support. This ensures the exclusion of control observations that are not "nearby" to the propensity score distribution of the observations.

2.5. Structural equation modeling

The study assumed that household's income vulnerability (V_{ht}) is the function of agricultural vulnerability (AgV_{ht}) and socio-demographic vulnerability (SDV_{ht}) expressed as:

$$V_{ht} = \alpha + b_1 AgV_{ht} + b_2 SDV_{ht} + \epsilon_{ht}$$

where AgV_{ht} is the function of agricultural factors along with the climate vulnerability (CV_{ht}). And CV_{ht} is the function of climate factors. Similarly, SDV_{ht} is the function of social and demographic factors. Therefore, the equations can be written as:

$$\begin{aligned} AgV_{ht} = {} & \alpha + \beta_1 cultivatedland_{ht} + \beta_2 soiltype_{ht} + \beta_3 fellowland_{ht} \\ & + \beta_4 croppingpattern_{ht} + \beta_5 pondarea_{ht} + \beta_6 extservice_{ht} \\ & + \beta_7 leasedout_{ht} + \beta_8 credit_{ht} + \beta_9 rentedout_{ht} + \gamma CV_{ht} + \varepsilon_{ht} \end{aligned}$$

where, $CV_{ht} = \alpha + \gamma_1 salinity_{ht} + \gamma_2 rainfall_{ht} + \gamma_3 cyclone_{ht} + \gamma_4 mintemperature_{ht} + \gamma_5 maxtemperature_{ht} + \vartheta_{ht}$

And,

$$\begin{aligned} SDV_{ht} = {} & \alpha + \theta_1 hhage_{ht} + \theta_2 ownland_{ht} + \theta_3 hheducation_{ht} + \theta_4 asset_{ht} \\ & + \theta_5 familysize_{ht} + \theta_6 associationmember_{ht} + \theta_7 dependency_{ht} \\ & + \theta_8 hhoccupation_{ht} + \theta_9 electricity_{ht} + \theta_{10} homesteadarea_{ht} \\ & + \theta_{11} cookingenergy_{nt} + \varepsilon_{ht} \end{aligned}$$

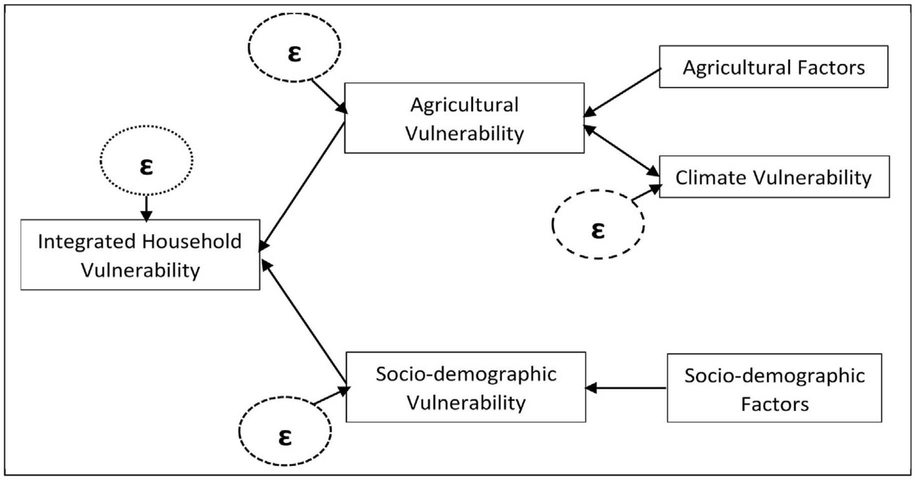


Figure 2. The framework of the path analysis diagram of structural equation modeling.

Table 5. Mean income diversity indices in the study areas over the decades.

Year	Khulna		Bagerhat		Satkhira		Average	
	Mean Index	Std. deviation	Mean Index	Std. deviation	Mean Index	Std. deviation	Mean Index	Std. deviation
1995	1.55	0.59	1.45	0.55	1.51	0.60	1.51	0.58
2005	1.85	0.74	1.84	0.60	1.86	0.49	1.85	0.62
2015	1.92	0.58	1.93	0.52	2.02	0.62	1.95	0.57

Using these equations, a path analysis diagram was constructed as a structural equation modeling like Figure 2.

3. Results and discussion

3.1. Income diversity

Generally, the motives behind income diversity are to achieve income from as many sources as possible to ensure financial stability even when one income source dries up. Conversely, households also diversify their income when returns to their assets endowed from the production decrease. This study found that households' mean income diversity index has increased significantly over the decades in the study area (Table 5). Results showed that the mean income diversity index was 1.95 in 2015, which is greater than the year of 2005 (1.85) and 1995 (1.51). It indicates that diversification has taken place more in the recent decade compared to previous decades. However, the income diversity index has also gradually increased across the study regions over the decades (Table 5). Smallholder farmers in coastal areas are using different on-farm income diversification strategies such as growing drought-tolerant crops, mixed farming, changing planting dates, etc. In the same way, they are also adopting several off-farm income activities such as selling household assets, migrating entire households, and decreasing food consumption/changing diets as their diversification techniques to cope with climate change (Roy and Basu, 2020).

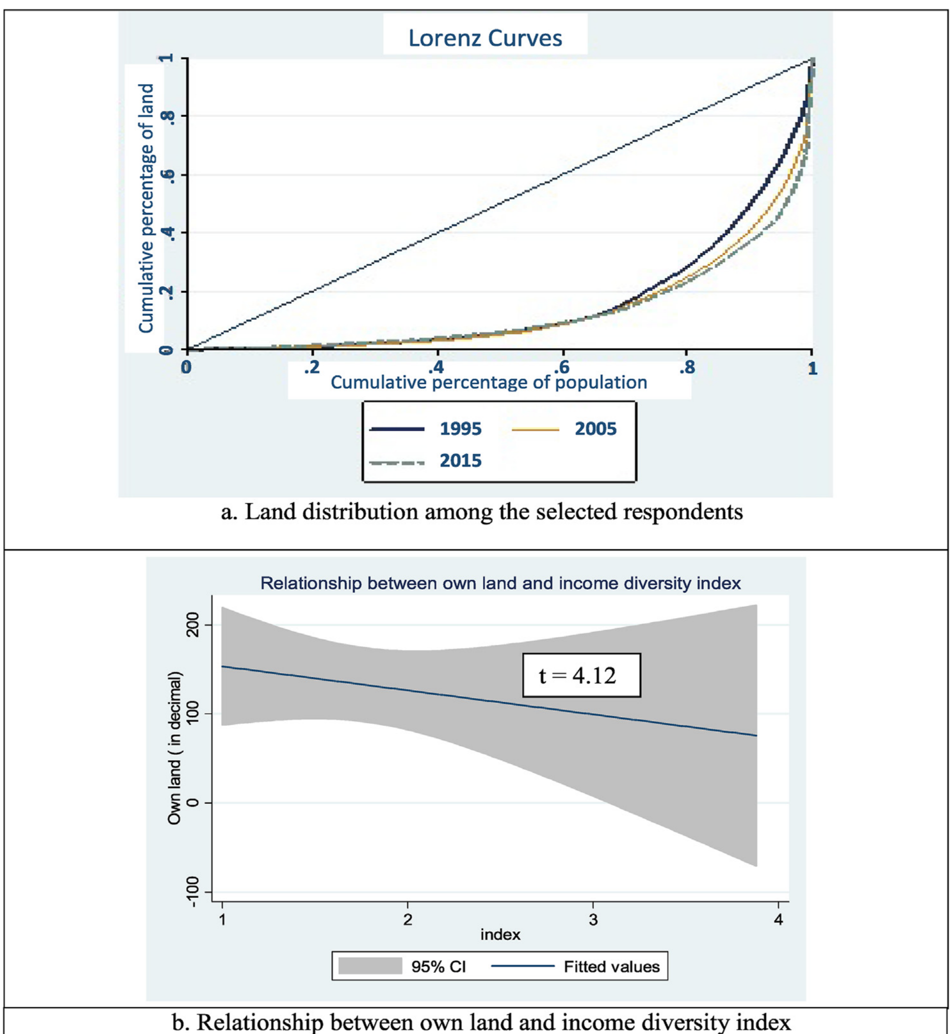
Table 6. "Type 66" distribution of households, by income sources over the decades (%).

Income Sources	1995	2005	2015
Principally Crop	21.33	↓9.33	↓8.67
Principally Fisheries	8.67	↑16.00	↓8.00
Principally Livestock	6.00	↓2.67	↓0.67
Principally Non-farm	36.00	↓33.33	↓30.67
Crop + Fisheries	2.00	↑4.00	↑6.67
Crop + Livestock	5.33	↓2.00	↓1.33
Crop + Non-farm	5.33	↓4.00	↑10.00
Livestock + Fisheries	0.67	↑2.00	↓0.00
Livestock + Non-farm	1.33	↑3.33	↓0.67
Fisheries + Non-farm	4.67	↑8.00	↓6.67
Mixed (more than two sources)	8.67	↑15.33	↑26.67
Total	**100**	**100**	**100**

Similarly, Table 6 illustrates how people have diversified their income from one source to another during the last two decades. In 1995, 6 percent of farmers earned more than 66 percent of their total household income from only livestock which was reduced to 0.67 percent in 2015. A similar trend also has been found in the case of principally non-farm activities. Additionally, the study found that farmers' involvement in the fisheries sector increased from 8.67 percent in 1995 to 16 percent in 2005 because of increasing saline water and conducive environment for fish culture, particularly shrimp farming, which is a dominant fish culture in the coastal areas of Bangladesh. However, the share of involvement in the fisheries sector decreased to 8 percent in 2015, which does not necessarily imply that farmers returned to their traditional crop farming. The rationale behind this decrease is rice cultivation becoming impossible due to severe salinity problems, which is, on the contrary, favorable for shrimp production. Hence, rice land has converted to shrimp farming which is known as "*Gher farming.*" Excessive shrimp farming in the coastal region has brought adverse effects on rice production because of the intrusion of saline water in the rice field; thus, the small farmers were unable to sustain the rice farming and move to mixed earning sources (Kabir and Eva, 2014). In this region, shrimp farming practices have caused enormous loss not only of crop production but also loss of fruit and other indigenous floral species, fresh water crisis for drinking, and so on (Paul and Vogl, 2011). It is observed that small landowners could not continue shrimp farming due to the necessity of a land management system for shrimp farming. Nupur (2010) found that 80% of respondents strongly agreed that the lack of technical knowledge and modern method among the small farmers for shrimp culture reduces its productivity. Therefore, it is observed that income from fisheries dropped in 2015 than in 2005 (Table 6). On the other hand, small landowners or small farmers were bound to lease their land to the large farmers and influential people due to the negative externalities of shrimp farming. Prolonged saline water logging in shrimp ponds accelerates leaching base materials and increases soil acidity (Ali, 2006). As a result, the land holding of small and marginal farmers has declined during the past decades while large farmers have acquired more land in the coastal region (Shawon et al., 2018). After losing their land and leaving the small-scale crop or shrimp farming, small landholders and poor farmers had no choice but to work as day laborers in the shrimp farm or trying to earn extra income from mixed sources (combining two or more income sources) for their livelihood. Eventually, dependency on only crop or fisheries or livestock income sources is narrowing in recent times, and income sources are diversifying. This is also the reason for the significant reduction in farmers' income from the crop sector over the decades, which is reflected by the results where about 21 percent of farmers earned more than 66 percent of their household income from only crop sector in 1995, but it reduced to about 9 percent in the year 2015.

However, income from mixed sources (more than two sources) has increased significantly during the last two decades. For example, it is found that in 1995, only 9 percent of farmers were earning more than 66 percent of the total household income from more than two sources, and it increased to 27 percent in 2015, implies that recently people are trying to earn from different sources rather than depending on only one source of income. Thus, the involvement in a mixed category somehow reflects a higher involvement in diversification as compared to all other alternatives.

Moreover, as depicted by Figure 3, the Lorenz curve showed (Figure 3a) that around 80 percent of the population held only 23 percent of land in the study area in 1995, and this trend of unequal distribution has increased over time. This is because the land use decision of small landowners relies upon the prominent farmers in the southern coastal areas of Bangladesh due to force rent out or rent in (Pouliotte et al., 2009). Hence, income diversity gradually increases with the decrease of land ownership (statistically significant), indicating that small and marginal farmers went for different livelihood options with the reduction of their own land (Figure 3b). This finding is consistent with Adri and Simon (2018). They found that small landholders in coastal areas shift to urban areas or other professions to diversify their livelihood and income sources, resulting in potential victims of income diversity. Therefore, an increasing number of people have to move into the off-farm sector both at the local level and beyond if they aspire to escape from risk and poverty (Ahsan et al., 2011). Besides, diversification of rural households is often necessary for agriculture-based peasant economies because of risks such as variation in soil quality, household and crop disease, price shocks, unpredictable rainfall, and other weather-related events (Udoh and Nwibo, 2017).



a. Land distribution among the selected respondents

b. Relationship between own land and income diversity index

Figure 3. Land distribution and income diversity. 3a. Land distribution among the selected respondents. 3b. Relationship between own land and income diversity index.

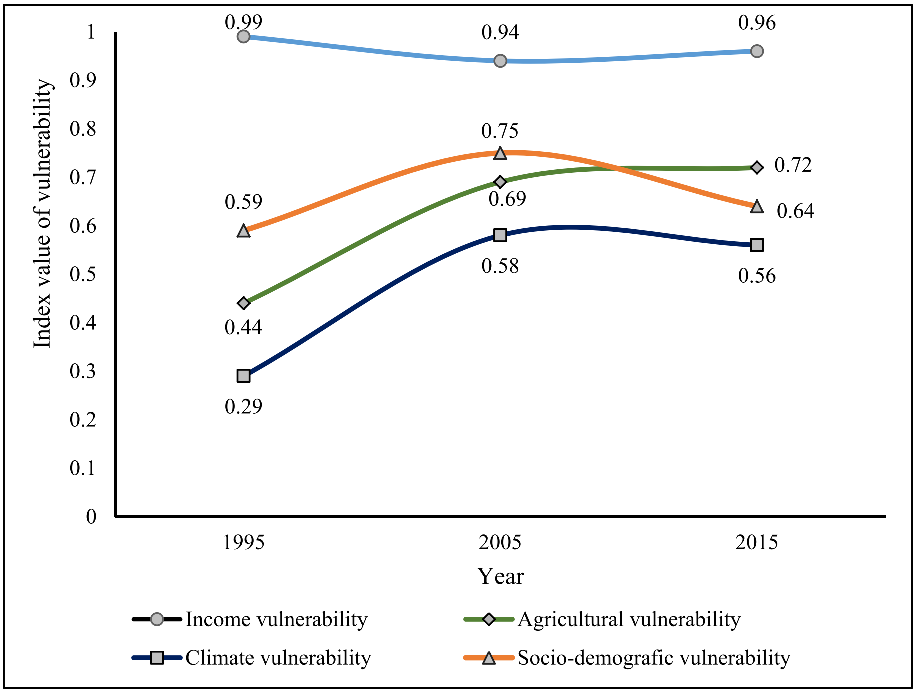


Figure 4. Mean household vulnerability indexes over the decades.

3.2. Vulnerability situation in the coastal areas of Bangladesh

In the coastal region, many people became landless and had to work as day laborers, which exposed the vulnerable situation. Figure 4 shows that the integrated household income vulnerability had decreased from 0.99 in 1995 to 0.94 in 2005, and then it started to increase prior to 2015 (0.96). The rationale behind farmers' involvement in principally fisheries sector especially in shrimp farming from 1995 to 2005 has expanded, and it was caused by increasing saline water. In contrast, crop fields transferred to the shrimp culture because of the availability of brackish water, and capable farmers have got more opportunities to invest. Since shrimp culture is more profitable than crop production, almost all the farmers were involved in shrimp culture, and the income vulnerability has decreased in the first decade (1995–2005). But involvement in shrimp culture with less efficient management of technology augmented the soil salinity and affected the production, which has amplified the income vulnerability in the latter decade (2005–2015).

Results also revealed that the household's socio-demographic vulnerability of the coastal areas in Bangladesh increased in the first decade from 0.59 to 0.75 and then decreased to 0.64 in the next decade (Figure 4). When people are socially affected, this vulnerability can increase further. However, in the 21st century, we now face another-perhaps more devastating environmental threat, namely global warming and climate change, which could cause irreversible damage to land and water ecosystems and loss of production potential (Tschakert et al., 2019). Results revealed that, in 1995, climate vulnerability was 0.29, which increased severely to 0.58 in 2005 and remained almost steady until 2015 at 0.56. Because of the volatile environment in the coastal areas of Bangladesh, uncertainty compels agricultural households to be more reluctant to engage in new activities. This was particularly the case for poor households who typically have a higher absolute risk aversion attitude (Yesuf and Bluffstone, 2009). Besides, rural poor have less access to lucrative alternative activities like shrimp culture than their better-off counterparts because of high barriers to entry (Mamun, 2016; Islam et al., 2011).

As follows the climate vulnerability, the agricultural vulnerability also increased sharply from 0.44 to 0.69 in 2005 and then slowly increased to 0.72 in 2015. Farmers are trying to adapt some techniques, which reduces the agricultural and climate vulnerabilities in the second decade (2005–2015), such as modifying the pond and crop field structure (gher), planting of a saline-tolerant rice variety in delay, allowing the soil to dry out succeeding the rice harvest, and approaching accumulated saltwater with freshwater during rice cultivation (Kabir et al., 2016a). For instance, salt-tolerant varieties such as *BINA dhan-8* and *BINA dhan-10* have been cultivated in the *Boro* season by farmers in Satkhira, Khulna, and Bagerhat districts (Sinha et al., 2014). Besides, to cope with the climate and agricultural vulnerability in coastal regions, farmers cultivate *BRRI dhan-47*, a variety that requires less water, and tolerance capacity to saline soil is relatively high (Alam et al., 2013).

Table 7. Effects of climate change on income diversity (Random effect model).

Variables	Co-efficient	Std. Err.	P-value
Homestead land (decimal)	0.0012	0.0007	0.2132
Cultivated land (decimal)	– 0.0001**	0.0008	0.0153
Pond area (decimal)	– 0.0005	0.0007	0.4976
Cropping pattern (1 if crop + gher, 0 otherwise)	0.2561***	0.0396	0.0000
Extension services (1 if receive, 0 otherwise)	0.1222**	0.0561	0.0295
Credit support (1 if credit receive, 0 otherwise)	– 0.0111	0.0561	0.8456
Salinity (dS/m)	0.0392***	0.0118	0.0012
Rainfall (mm)	0.0042**	0.0016	0.0113
Cyclone (frequency/year)	– 0.0173	0.0582	0.7672
Minimum temperature (^{0}C)	– 0.1606	0.1515	0.2909
Maximum temperature (^{0}C)	0.0255	0.0789	0.7512
Constant	4.7909	5.5695	0.3900
Wald chi2 (12)	133.2502 [0.0000]		
Number of observations	450		
R-square	0.2313		

Notes: **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

3.3. Effects of climate change on income diversity and vulnerability

This study runs the random effect model (through Hausman test support) to explore the substantial relationship between climate change and income diversity. Table 7 reveals the effect of climate variables on income diversity. Results show that salinity and rainfall significantly affect the household's income diversity. The results resonate with the findings of Ahmed et al. (2019). Historically, the livelihoods of coastal people of Bangladesh predominantly relied upon natural resources, and most of them practiced pastoral and arable farming, and fishing. But the portion of people engaged in farming activities has decreased over the years due to salinity intrusion, irregular rainfall patterns, and excessive heat in the coastal areas (Ahmed et al., 2019). In addition, there is often a premise that sea-level rise drives saltwater intrusion, and many studies have highlighted the capacity of farmers is reduced to engage in agriculture when salinity levels are high (Faruque et al., 2017; Uddin et al., 2014). This scenario of gradual salinity intrusion into the coastal areas of Bangladesh is very threatening to the primary production system, and coastal biodiversity. For instance, as people converted freshwater areas through the intrusion of saline water for shrimp culture, the soil salinity of the surrounding area has increased, which is damaging livestock grazing (Alam et al., 2017). The frequency of consumption of livestock, crops, and fish in the coastal areas of Bangladesh has decreased due to these agrobiodiversity changes (Kabir et al., 2016b). These changes in food habits might also lead to considerable negative consequences for agricultural production systems and working capabilities for the rural populations across the coastal belt of Bangladesh (Rahman et al., 2011). Therefore, the households of the study area are suffering from income diversity due to climate change, and hence, income diversification couldn't help to enhance the poor's household income.

Interestingly, cropping pattern has come as a highly significant factor that influences the income diversity, which means the households involved in the shrimp culture or any other fish culture in the crop field (locally named as "gher") along with crop production are more income diversified. Because when people have one rigid source of income, they have limited opportunities to diversify their income, and eventually, they are more vulnerable to risk exposure. On the other hand, having more than one income source promotes income diversity, less vulnerability to crop failure, and ultimately sustainable livelihood. Ahmed et al. (2008) pointed out that mixed fish and crop production can strengthen the sustainable livelihood of the coastal shrimp farming households. As expected, the cultivated land has a significant negative effect on income diversification. This is because the more decimal land under crop cultivation, the more dependency on only income from crops, hence the less chance of income diversification. However, the extension supports positively influence the income diversity of coastal people. After getting extension support from the government or other associations, coastal people are very much aware of alternative income-generating activities.

In the southern part of Bangladesh, climate risks, especially salinity, cyclone, and heavy rainfall, have led to agricultural vulnerability. Literature found that a significant number of local rice varieties (*Kalojira*, *Najirsail*, *Boran*, etc.) have already been extinct from the coastal area because of high salinity intrusion (Islam et al., 2015). Moreover, the area under shrimp culture drastically increased from 140 thousand ha in 2000 to 258 thousand ha in 2019 (DoF, 2019), which impacted crop production in the recent decade. It is argued that increasing salinity leads to reduce crop production by 2.50 percent, tree growth by 2 percent, and vegetation coverage by 1.87 percent per year (Dutta and Iftekhar, 2004). On the other hand, as small and marginal farmers are not getting adequate income support from the crop sector, as well as high investment in shrimp farming and increased competitiveness, make shrimp farming riskier for them. That is why this study also attempts to estimate the effects of climate change on agricultural vulnerability. Results revealed that cyclones, minimum temperature, salinity, and rainfall significantly impact agricultural vulnerability (Table 8).

Table 8. Effects of climate change on agricultural vulnerability (Random effect model).

Variables	Co-efficient	Std. Err.	P-value
Cultivated land (decimal)	0.0001	0.0000	0.2161
Fellow land (decimal)	0.0064***	0.0017	0.0000
Pond area (decimal)	0.0005	0.0004	0.2623
Leased out land (decimal)	0.0005*	0.0002	0.0594
Rented out land (decimal)	0.0011	0.0009	0.2172
Cropping pattern (1 if crop + gher, 0 otherwise)	–0.232***	0.0122	0.0000
NGO extension services (1 if receive, 0 otherwise)	–0.1766***	0.0218	0.0000
Credit support (1 if credit receive, 0 otherwise)	–0.3396***	0.0197	0.0000
Salinity (dS/m)	0.0465***	0.0070	0.0000
Rainfall (mm)	0.0009**	0.0004	0.0344
Cyclone (frequency/year)	0.0351*	0.0192	0.0692
Minimum temperature (^{0}C)	0.0568**	0.0269	0.0361
Maximum temperature (^{0}C)	0.0205	0.0329	0.5343
Constant	–1.7902	1.1809	0.1292
Wald chi2 (14)	86.6998 [0.0000]		
Number of observations	450		
R-square	0.2772		

Notes: *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels, respectively.

Over the decades, the average minimum temperature of the study area has increased gradually; thus, the crop yield is negatively affected by the change of temperature. Islam et al. (2008) found that a 1 °C increase in maximum temperature at vegetative, reproductive, and ripening stages decreased the *Aman* rice production by 2.94, 53.06, and 17.28 tons, respectively. Heavy rainfall in the offseason and cyclones caused the damage of crops in the coastal areas, leading to an increase in agricultural vulnerability. Literature found that a 1 mm increase in rainfall at vegetative, reproductive, and ripening stages decreased the *Aman* rice production by 0.036, 0.230, and 0.292 tons, respectively (Habiba et al., 2015). The study also found that fallow land and leased-out land have a positive and significant effect on agricultural vulnerability, whereas farmers who followed the "crop + gher" cropping pattern were less vulnerable to climate change. When a farmer has more land in terms of fallow and leased out, its reluctant farmers to cultivate agricultural crop in a more engaged way and thus have maximum agricultural vulnerability. Besides, NGO extension services and credit support have a negative and significant effect on agricultural vulnerability. This implies that credit support and NGO extension services assist coastal people in reducing their agricultural vulnerability. Credit support enhances coastal farmers' ability to invest in their cropping field and efficient use of inputs to increase agricultural productivity and decrease vulnerability. On the other hand, extension support would assist farmers in endorsing better adaptive measures to climate change, such as changing cropping patterns, planting climate resilient varieties, control of saline water intrusion into agricultural land, homestead and floating gardening, etc., which ultimately reduce the agricultural vulnerability.

Most importantly, the study found that salinity has a positive and significant relation with agricultural vulnerability implies agricultural vulnerability increases with salinity (Table 8). The high intrusion of saline water into the farm field increases the availability of brackish water for shrimp culture. This brackish water slowly alters the chemical properties of the pond water and soil. Besides, the expansion of shrimp farming in Bangladesh is often unregulated, uncontrolled, and uncoordinated (Afroz and Alam, 2013; Paul and Vogl, 2011; Alam et al., 2005). The poor management of the shrimp culture made the agricultural lands unsuitable for crop production. Since most of the farmers practiced shrimp culture as a profitable business in the first decade (1995–2005), the mismanagement of the shrimp culture damaged their crop fields, and

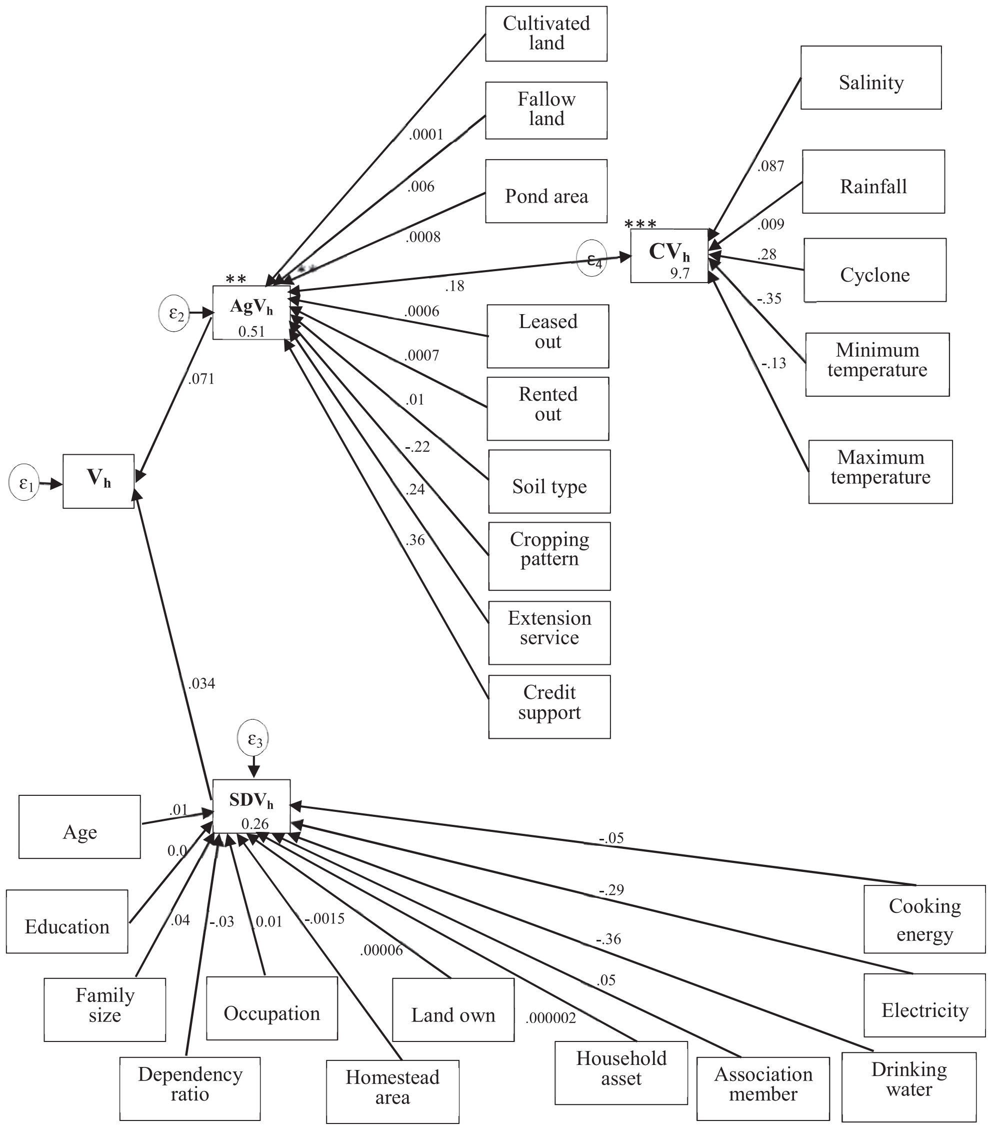


Figure 5. Structural equations model for households' income vulnerability. *Notes: *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent levels, respectively.*

therefore it becomes unsuitable for growing agricultural crops. This result was in line with the study of Kabir and Eva (2014).

The agricultural vulnerability affects the income status of the coastal people because small and marginal farmers were unable to take risks as their agricultural vulnerability increased due to climate change, i.e., heavy rainfall, salinity intrusion, temperature fluctuation, and cyclone (e.g., *Ayla, Sidre, Kal-Baisakhi*). To support this statement, the study then constructed a path analysis diagram of the Structural Equations Model (SEM) (Figure 5), assuming integrated household vulnerability (Vh) is the function of agricultural vulnerability (AgVh) and socio-demographic vulnerability (DVh). Again, agricultural vulnerability is the function of agricultural factors along with climate vulnerability (CVh).

Figure 5 revealed the pathway of how agricultural vulnerability and climate vulnerability influenced the household's integrated vulnerability in the study area. The path analysis diagram showed that the climate vulnerability affects the agricultural vulnerability significantly at a 1 percent level. Results also revealed the positive and significant relationship at a 5 percent level between agricultural and integrated household vulnerability. As a result, the change of climate factors induced agricultural vulnerability, which has a significant positive effect on the vulnerability status of the households. However, agricultural income is the main source of total income for rural people, and this income is the significant factor for reducing the overall household's vulnerability status and poverty reduction among agricultural households (Alamgir et al., 2018; Mat et al., 2012; El-Osta and Morehart, 2008). The study revealed that 40.67 percent of respondents were involved in crop farming as their main occupation, where 56.67 percent of the total respondents had the lower amount (1-50 decimal) of lands in coastal areas. Therefore, climate change affects their traditional crop farming and pushes them to diversify their income sources which, however, did not help them to come out from the vulnerability to poverty. Climate change, especially salinity increases, is multiplying the crisis by declining cultivated land and inaccessibility to freshwater supply. At the same time, natural disasters increase agricultural vulnerability and affect the socio-economic patterns, i.e., income diversity of the victims and increase food security crises, especially in the coastal and rural areas.

4. Conclusion

About a quarter of the total population lives in the coastal areas of Bangladesh. The coastal area is frequently affected by floods, river erosion, salinity, and tropical cyclone, making people's livelihood more vulnerable. In a developing country like Bangladesh, income-source diversification is a key livelihood strategy for improving the livelihood of rural people. This paper investigated whether this income diversification helps coastal people to overcome their vulnerabilities. Using the "Type-66" livelihood strategy, the study found that the income of the households was primarily dependent on principal crops or principally non-farm activities such as wage employment in rural enterprises, transport operations, construction labor etc. in two decades ago, whereas households' income depends on mixed (more than two sources) activities in the later and therefore, dependency on principally non-farm and crops gradually decreased over the years. Along with crop farming, the shrimp farming, non-agricultural enterprises, and migration to urban areas had become the predominant diversified income source in coastal regions. A major portion of the lands was being used for shrimp farming in coastal areas. However, the lack of a proper land management system in shrimp culture influences higher soil salinity in the rice fields. Therefore, small-scale farmers are bound to lease their lands to large farms, becoming unemployed and try to earn from other sources, which leads to increase income diversity of the households.

The study also calculated the climate vulnerability as well as the agricultural vulnerability and integrated household vulnerability. The change in climate factors affected agricultural production, which in turn, is a similar reason for income diversification. Therefore, the diversified income sources could not help the farmers to come out of the income vulnerability since their sources of income, except crops, are not compatible with their knowledge and skills. Hence, the cooperative land management system can be established where shrimp farming will be conducted under a community-based management system which will empower the marginal landholders by weakening the political nexus of the large and the elites. The salinity tolerant rice varieties or other crops, floating gardening, mixed farming (rice + gher) can be practiced in a more extensive way to reduce the climate and income vulnerability in the coastal areas. Besides, the government should take initiatives to establish and strengthen the embankment so that poor people can go back to their own cultivation system, which will reduce the vulnerability and poverty in the coastal areas.

Declarations

Author contribution statement

Md. Jahid Ebn Jalal: Conceived and designed the experiments; Performed the experiments; Wrote the paper.

Md. Akhtaruzzaman Khan: Conceived and designed the experiments; Analyzed and interpreted the data.

Md. Emran Hossain: Analyzed and interpreted the data; Wrote the paper.

Sudhakar Yedla: Contributed reagents, materials, analysis tools or data.

G. M. Monirul Alam: Conceived and designed the experiments; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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