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Article

Climate Change Influences the Livelihood Vulnerability of Small-Scale Fishermen Communities in Kaptai Lake

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Abstract: Climate change has a significant impact on the livelihood of the fishermen community of Kaptai Lake. Environmental disasters caused by climate shifts alter community resilience. The households which depend on fisheries are prone to the environmental fluctuations. There is limited research on the livelihood vulnerability of fishermen in the Kaptai Lake region. In this study, multi-methods strategy uses to evaluate the impact of environmental change on livelihood of the fisherman in Kaptai Lake region. The study includes questionnaire surveys, interview and focus group discussion to collect data and livelihood assessment of the fishermen community. This research explores the sensitivity, exposure, and adaptive capacity affecting the livelihood of fishermen in various way as a result of climate-induced effects on Kaptai Lake. The information was gathered from five regions Kaptai upazila including Puran Jelepara, Notun Jelepara, Soriyatpur, 16 no Tila, and Islampur. Data were collected from 100 households through field surveys conducted across the selected areas. The data was analyzed and categorized using the IPCC approach to the Livelihood Vulnerability Index (LVI). A total LV score of 0.40 suggests the community had medium coping ability with respect to climate fluctuations. Moderate exposure, low sensitivity and moderate adaptive capacity indicated potential vulnerabilities in livelihoods. Working with governments and local communities can create new perspectives of reducing climate risks, implementing more cost-effective adaptation measures, and social inclusion and empowerment to promote livelihoods.

Keywords: Kaptai Lake; livelihood vulnerability; Climate change; fishing community

1. Introduction

Bangladesh faces severe challenges as one of the most vulnerable countries to climate change (Mojid, 2020). Nowadays, climate change has become a major global issue. It mainly affects sectors that rely on natural resources, such as fisheries. These changes affect both freshwater ecosystems and marine-origin fish populations. Temperature changes, shifting rainfall patterns, and rising sea levels will alter aquatic ecosystems and fish stocks (Cheung et al., 2009), greatly impacting those who depend on fishery resources (Badjeck et al., 2010). In developing countries, small-scale fishing communities are vulnerable to climate-related disaster (Palut and Canziani, 2014). Fisheries already face challenges like excessive fishing, contamination of water bodies, and ecosystem degradation, and these are likely to worsen with the impacts of climate change (Brander, 2010; Sumaila et al., 2011). Bangladesh possesses a wide range of fisheries resources, which are broadly categorized into two main types: inland and marine fisheries (Shamsuzzaman et al., 2017; Sunny et al., 2017). Inland fisheries are divided into two main types: capture fisheries and culture fisheries. Capture fisheries cover about 3.89 million hectares, while culture fisheries cover about 0.82 million hectares. The inland aquatic habitats comprise rivers and estuaries (853,863 ha), the Sundarbans (177,700 ha), beels (114,161 ha), Kaptai Lake (68,800 ha), and floodplains (2,675,758 ha) (DoF, 2019). Although inland fisheries play a crucial role, they are often overlooked in studies on susceptibility to climate-related risks. Most research has instead focused on marine ecosystems and agriculture (Allison et al., 2009; Paukert et al., 2017).

Locations such as Kaptai Lake in Bangladesh serve as critical examples of how inland fisheries are affected by climate variability. This is especially significant in areas where communities heavily depend on these resources for their livelihoods. Small-scale fisheries, which are resource-dependent and own limited adaptive capacities, face severe threats from climate change (Allison et al., 2009). Over the years, changes in Kaptai Lake's ecosystem have led to a decline in fish diversity and production (Barua, Islam and Mitra, 2022). Climate change impacts fisheries by changing either water temperature, sea levels with extreme weather events and thereby buffering trends in fish stocks, migration patterns and habitat loss (Barange et al., 2018). These changes represent a major concern for artisanal fishers, usually disadvantaged and not provided with the tools necessary to adapt to such environmental shift. Cochrane, De Young, Soto and Bahri (2009) state that for vulnerable communities in many developing countries, which experience low levels of resource availability socio-economic conditions and weak governance. Climate change is likely to worsen these existing challenges (FAO, 2009). Climate change affects such as rising water levels and higher warmth expected to severely alter fish populations which is particularly crucial for the livelihoods of its direct dependents (Islam et al., 2014).

Kaptai Lake, Bangladesh's largest man-made lake, is situated in Rangamati, Chittagong (Fernando, 1980). It is formed by the Kaptai Dam on the Karnaphuli river, is characterized by its 'H'-shaped formation, the two arms of which met near Shuvalong with the Karnaphuli River. Kaptai Lake is crucial for small-scale fisheries, providing approximately 8,980 metric tons of freshwater fish annually (FRSS, 2012). The Kaptai Lake supports approximately 22,000 fishermen. The majority of fishermen are uneducated, lack access to fishing equipment (such as fishing gears and boats). They generally depend on fish dealers for capital and necessary tools and typically live on subsistence wages (Suman, 2023). The development of human resources mostly depends on the close relationship between education and society. The education profile of Lake fishermen shows a predominance of basic education, with no representation at the graduate level. Specifically, 15% were illiterate, 46% had primary education, 33% attained secondary education, and 6% reached the higher secondary level. Fishermen's houses were mainly constructed from bamboo and tin, mud with wooden supports, bamboo fences, and semi-pacca brick structures with tin or bamboo roofs, reflecting their economic constraints. Most fishermen did not have personal tube wells for drinking and domestic activities. They accessed water through shared tube wells. Only a small portion (36%) of tribal fishermen had access to sanitary latrines, while the majority were without proper sanitation. The fishermen communities had limited and inadequate health facilities, relying mostly on local village doctors due to their inability to afford proper medical treatment. During the ban period, many fishermen take loans from local informal lenders to support their families. Most poor fishermen fail to repay these loans, making them even more vulnerable economically and socially (Barua, Islam and Mitra, 2022).

This study uses the vulnerability assessment approach developed by the Intergovernmental Panel on Climate Change (IPCC), which conceptualizes vulnerability as a function of exposure, sensitivity, and adaptive capacity. It examines these components in relation to the livelihoods of fishers in Kaptai Lake and their responses to various climate alterations (Islam et al., 2014; Smit and Wandel, 2006). This tripartite model is extensively used in climate change research. It has also been customized for socio-ecological applications in many developing regions (Burton, 1993; Gallopín, 2006). By applying this model to an inland freshwater system like Kaptai Lake, the study situates itself within a broader discourse on climate vulnerability and resilience, emphasizing the role of socio-ecological interactions in shaping livelihood outcomes.

The concept of vulnerability regarding climate and environmental shifts is complex and interpreted in multiple ways (Adger, 2006; Bohle, Downing and Watts, 1994; Downing et al., 2005; IPCC, 2001; Blaikie et al., 2014). A system's vulnerability is determined by three components: the degree of exposure to a danger, the system's sensitivity to that danger, and its adaptive capacity to respond and recover (Smit and Wandel, 2006). Exposure describes how significantly a system is affected by external factors such as ecological disruptions, climatic events, or political and social challenges (Burton, 1993). Climate variability is exposure and, it varies seasonally with precipitation and temperature (Adger, 2006). Sensitivity is capability on how a system is vulnerable to get affected harmfully and it is determined by the overall effect of potential impacts. Adaptive capacity measures the capacity to adapt to environmental and social changes, reducing potential harm, managing adverse effects, and potentially gaining advantages (Smit and Wandel, 2006; Gallopín, 2006). Livelihood vulnerability refers to a community's or individual's vulnerability to climate fluctuations and their ability to adjust to these alterations. In this context, vulnerability indicates community's incapability to cope with the negative climatic effects. It includes exposure to risks, sensitivity to these risks, and the capacity to adapt (Adger, 2006).

Fishermen in Kaptai Lake face heightened vulnerability due to their dependence on the seasonal availability of fish, which is increasingly affected by changing climatic conditions (Cutter, Boruff and Shirley, 2006). The livelihoods of fishers in Kaptai Lake are increasingly threatened by climate-induced stressors such as erratic rainfall, rising temperatures, and declining fish availability. These communities possess limited adaptive capacity, minimal access to institutional support, and face socio-economic constraints that further exacerbate their vulnerability (Shamsuzzaman et al., 2020). Furthermore, research from other inland water bodies in South Asia shows that climate-induced changes in water temperatures and hydrological cycles have led to shifts in fish species populations and declining fish yields (Ficke, Myrick and Hansen, 2007). This study aims to address this research gap by applying the IPCC-based Livelihood Vulnerability Index (LVI) framework to assess the exposure, sensitivity, and adaptive capacity of small-scale fishers in Kaptai Lake. The results offer localized and policy relevant insights for building resilience in underrepresented inland fishing systems.

2. Materials and methods

2.1. Study Area

In Bangladesh, freshwater fisheries significantly enhance the economy, culture, traditions, and eating habits of the population. One of the most abundant fisheries resources could be found in inland catch fisheries. Kaptai Lake is situated in south of Bangladesh (Hossain, 2014). Kaptai Lake is situated between the latitudes of latitude 22°20'-23°18' N and longitude 92°00'-92°26' E (Arafeen et al., 2024). Data were gathered from five locations within Kaptai Lake: Puran Jelepara, Notun Jelepara, Soriyatpur, 16 no Tila, and Islampur (Figure 1). Small-scale fishing communities, whose livelihoods mainly rely on fishing in Kaptai Lake, are present in these locations. The study areas are all situated within or around island-like settlements inside Kaptai Lake. These areas are geographically isolated, surrounded by water, and primarily inhabited by small-scale fishing communities. The local population relies heavily on fishing as their main source of livelihood.

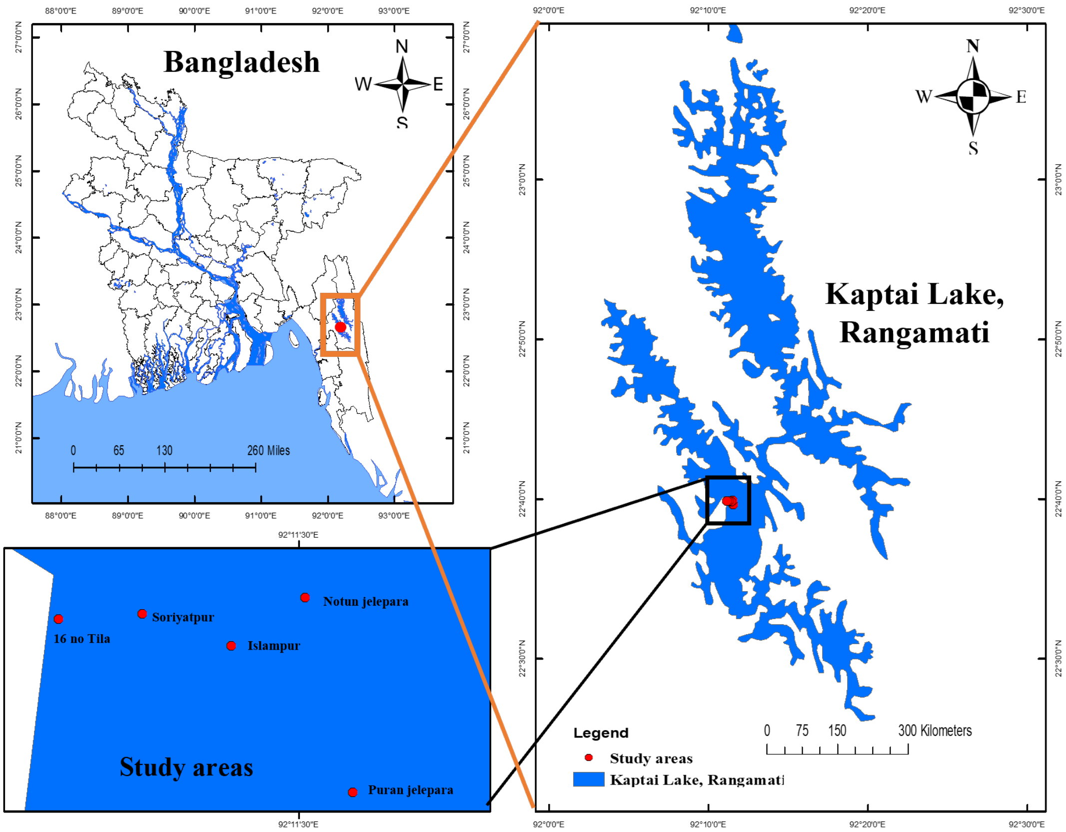

Figure 1. Map of the small-scale fishermen community sites from where survey data was collected.

2.2. *Design of the Study and Methodology*

The research analyzed the relationship between adaptive capacity variables and households' livelihood vulnerability. The research employed a quantitative approach, utilizing household surveys conducted through structured interview schedules.

2.3. *Sampling Strategy and Sample Size*

A field survey was conducted in selected areas of Kaptai Lake. It collected data on different aspects of fishermen's livelihood vulnerability. Data collection was conducted using a combination of cluster sampling and stratified sampling approaches. Using the cluster sampling technique, the survey was first narrowed down to five unions within Kaptai Upazila. From these, Kaptai Union was selected for the survey. Subsequently, the stratified sampling method was used to randomly select five areas where small-scale fishing communities reside. Finally, households within each selected area were randomly chosen for data collection (Ahsan and Warner, 2014).

About 100 fishermen were chosen from among the five areas. Data were collected from fishermen and their family members who have settled in the study area over the last two decades. The main respondent from every family was the family information about the family and its head. Cluster sampling techniques (Hahn, Riederer and Foster, 2009; Organization, 2011) were utilized for gathering data from the research area. The sample size calculation uses a this uses a confidence interval of 95%, 10% margin of error, 50% expected occurrence rate and Design effect (DEFF) =1 (Afrin, Shakil and Minhaz, 2024). The baseline proportion of indicators used for the LVI was assumed to be 50%, as this is the standard value commonly applied for sample size calculations when the actual proportion of predictors is unknown. The sample size was determined using the following widely recognized cluster sampling formula (Hahn, Riederer and Foster, 2009):

$$n = \text{DEFF} \times \left[\frac{z^2 \times P \times q}{e^2}\right]$$

where, n = sample size; DEFF = 1; z = 1.96 (95% confidence interval); p =0.5; q = 0.5; e = 0.10.

2.4. *Data collection*

In this study, both primary and secondary data were utilized to achieve the research objectives. Primary quantitative data were collected through structured questionnaires, personal interviews, and group discussions. A structured questionnaire was first developed to obtain quantitative information. Structured questionnaires are commonly used as effective tools for collecting data, particularly in rural areas and communities that depend on natural resources. They help compare data and make it easier to measure vulnerability indicators. This is especially useful in studies on socio-ecological systems and livelihoods (Chambers, 1994).

Preparing a questionnaire is crucial for gathering information about the livelihood status of fishermen in the chosen area. Before creating the final questionnaire, it was designed with the specific aim of the study in mind. The completed questionnaire is displayed in Appendix–A. Following this, an interview schedule was prepared to gather more in-depth qualitative insights. The interview schedule was developed in both Bengali and English, with the final report prepared in English. Its design was informed by an extensive literature review of similar studies (Alam, 2017; Didar-Ul Islam, Bhuiyan and Ramanathan, 2015; Sarker et al., 2019) drawing key information and relevant aspects from previous research. To ensure clarity and respondent comprehension, the interview schedule was pre-tested on a small sample of randomly selected households, and necessary wording revisions were made. Additionally, expert feedback was incorporated to finalize the survey instrument. Both the questionnaire and interviews were used during the field survey to ensure comprehensive data collection and to triangulate the findings. Group discussions were conducted to validate the information and gather additional insights into community-wide adaptation practices. Both male and female members of fishing households were included in the study. The survey was conducted in August 2024 by a team of three trained enumerators. To ensure accuracy in data collection, the enumerators participated in a full-day training session prior to field deployment. A "random walk" method was used to select households within each location. This approach has been proven effective for cluster-based surveys in previous vulnerability and climate hazard studies (Organization, 2005). The first household was selected by flipping a Bangladeshi coin and following a 120-degree directional rule to maintain randomness and uphold ethical research standards (Hahn, Riederer and Foster, 2009). The selected areas represent a range of socio-economic and geographic conditions of small-scale fishing communities. Data collection covered multiple dimensions of livelihood vulnerability, including socio-demographic characteristics, livelihood strategies, social networks, health, food, water, and exposure to climatic variability and disasters.

Furthermore, the index measuring vulnerability was formulated using appropriate secondary datasets. Between 2001 and 2023, data regarding yearly rainfall along with maximum and minimum temperatures was obtained from www.weather-atlas.com (Afrin, Shakil and Minhaz, 2024).

2.5. Methods of Data Analysis

2.5.1. Determining the Livelihood Vulnerability Index: LVI (IPCC)

In this study, the Livelihood Vulnerability Index (LVI) framework proposed by Hahn et al. (Hahn, Riederer and Foster, 2009), along with the IPCC vulnerability framework (IPCC, 2001), was employed. Both models incorporate three core components: exposure, sensitivity, and adaptive capacity. The LVI is a tool used to assess community vulnerability to climate variability by combining multiple indicators into one index. This approach provides a standardized way to compare different regions or groups. It incorporates both quantitative data (e.g., income, access to services, climate trends) and qualitative perceptions (e.g., perceived risk, coping strategies) to generate a comprehensive measure of climate vulnerability (Hahn, Riederer and Foster, 2009). Assessing a community's livelihood vulnerability helps determine its susceptibility to environmental hazards. It also measures the community's capacity to adapt to these challenges. This approach has been widely supported by previous research (Huang, Liu and Ma, 2011; Simane, Zaitchik and Foltz, 2016). The objectives of the research were accomplished through the use of the LVI. A vulnerability index was created by combining the individual elements of each core component. Then, an overall average was calculated in a standard way. Equation 1 was used to make the values of these elements uniform. This helped adjust for differences in their measurement scales. An index with normalized values varied from 0 to 1 (Afrin, Shakil and Minhaz, 2024).

$$Index_{Si} = \frac{S_i - S_{min}}{S_{max} - S_{min}} \quad (1)$$

The study investigated several components of a household's socio-demographic profile, including income-generating activities, community ties, healthcare access, nutrition, water availability, environmental changes and natural hazards. The standardized values of these indicators were compared to the actual values. Afterwards, the value for each key element was calculated using Equation 2 (Afrin, Shakil and Minhaz, 2024).

$$M = \frac{\sum_{i=0}^{n} Index_{Si}}{n} \quad (2)$$

In this study, Equation 3 was used to calculate the weighted average of the means of all major components. This was done for each dimension of the IPCC-based Livelihood Vulnerability Index. Where M is one of the seven primary elements: the population characteristics, income-generating activities, community ties, healthcare access, nutrition, and water availability and CVD components. IndexSi indicates all individual elements denoted by i who compose those primary elements and n sub-component per each element (Afrin, Shakil and Minhaz, 2024).

$$CF = \frac{\sum_{i=0}^{n} W_{Mi} Mi}{\sum_{i=0}^{n} W_{Mi}} \quad (3)$$

CF stands for exposure, sensitivity, or adaptive capacity and the 3 vulnerability components listed by the IPCC. W_{Mi} indicates how many primary elements are included within each dimension, whereas Mi is the weighted value for every primary component.

This study used the average of the highest and lowest yearly temperatures, along with annual rainfall data, to assess climate variability over 20 years. It also recorded the percentage of families harmed by natural disasters like property loss or deaths during that time. Demographic information, including the proportion of households led by a male head, the types of livelihood strategies utilized (for instance, their primary reliance on fishing or other sources), and the strength of their social networks, was collected to understand community structure and resilience. Ultimately, the study evaluated sensitivity by assessing nutritious food and safe drinking water status and the population's physical health status (Table 1), combining exposure, sensitivity, and adaptive capacity to create the IPCC-based Livelihood Vulnerability Index. The LVI (IPCC) was derived by synthesizing the components of exposure, sensitivity, and adaptive capacity, utilizing Equation 4 to integrate these three dimensions (Afrin, Shakil and Minhaz, 2024).

$$LVI\ (IPCC) = \frac{E+S+(1-AC)}{3} \quad (4)$$

The LVI is shown using the IPCC's approach to measuring vulnerability, which is known as the Livelihood Vulnerability Index (IPCC). The adaptive capacity (AC) was obtained through the weighted averaging of social background, income strategies, and support systems, The sensitivity score (S) was computed similarly using Health, Food, and Water, and E for the evaluated exposure score (associated with the primary element: Climate Variability and Disasters) (Afrin, Shakil and Minhaz, 2024).

AC was calculated by taking one (1) minus the original value. This calculation assumes that exposure, sensitivity, and adaptive capacity are not directly linked, but are influenced by local geographical conditions. As anticipated in this study, the LVI (IPCC) was projected to show a direct relationship with exposure and sensitivity, and an inverse relationship with adaptive capacity (Ford and Smit, 2004). The index in this study was computed by inverting the adaptive capacity score, using the formula (1 – dimension score). In this context, the scores ranged from 0 (low risk) to 0.6 (high risk), with values between 0.45 and 0.55 indicating a moderate level of susceptibility.

Table 1. Classification of primary elements based on contributing aspects of vulnerability according to the IPCC.

IPCC Vulnerability Component	Major Component	Sub Component
Exposure	Climate Variability and catastrophes	• The percentage of families significantly affected by disasters • Proportion of households that were not alerted prior to the disaster • Proportion of households facing injury or mortality • Average standard yearly highest thermal reading • average standard yearly thermal reading means • Yearly average of precipitation mean standard
Sensitivity	Healthcare access	• Percentage of households that typically do not seek care from a trained medical professional. • Percentage of homes without access to a hygienic latrine. • Proportion of households with a member suffering from chronic illness. • Proportion of households with a member who missed work due to illness
	Food	• Percentage of households that do not meet their protein needs through fishing • Percentage of households that don't receiving support during the fishing ban. • Mean diversity index of fishing products • Proportion of families without year-round food storage.
	Water	• Proportion of families that rely on natural water sources • Proportion of families without a reliable water source • Proportion of families that store water for domestic use and drinking.
Adaptive Capacity	Socio-demographic characteristics	• Standardized mean age of individuals engaged in fishing • Percentage of families led by males • Percentage of fishermen with a formal education • Percentage of family members who have gone to school • Percentage of households with all members in the working-age group (15–65 years) • The proportion of fisherman who possess fishing equipment • The proportion of fisherman who possess a boat
	Livelihood strategies	• Percentage of households whose expenses primarily rely on fishing • The proportion of families having an alternative earning source • Average diversity index of alternative income sources • Percentage of households that work with other fisherman communities • Percentage of households that have emergency funds

	Social networks	• The proportion of fisherman with a license • The proportion of fishermen who received government assistance for generating other sources of income when fishing was prohibited • Percentage of fisherman who get local government supports • Percentage of fisherman who have family or friends helping them • Percentage of fisherman who belong to a social or non-governmental organization in their locality

2.5.2. Statistical assessment using the Kruskal-Wallis H test and the Ordered Logit Model

Livelihood vulnerability was assessed using a three-point ordinal scale. The Kruskal-Wallis H test was applied to evaluate the variation in vulnerability across different groups based on adaptive capacity indicators. This non-parametric test is widely regarded as an effective method for examining associations between nominal independent variables and an ordinal dependent variable (Khan et al., 2021). Similarly, an ordered logistic regression model was utilized to examine the relationship between adaptive capacity indicators and livelihood vulnerability (Fullerton, 2009). This model is particularly suitable for analyzing datasets where the dependent variable is ordinal in nature. Earlier research has used ordered logistic regression to explore and determine the main factors contributing to livelihood vulnerability (Sujakhu et al., 2018). The following expression defines the ordered logit model:

$$Pr(Y \leq j) = ln\left(\frac{\Sigma\, Pr(Y \leq j \mid X))}{1 - \Sigma\, Pr(Y \leq j \mid X}\right) = \alpha\_j + \beta\_1\, X\_1 + \beta\_2\, X\_2 + \ldots + \beta\_15\, X\_15 \qquad (5)$$

Here, Y indicates the vulnerability level, α is the threshold, β_1–β_{15} are the estimated values for the predictors, and X_i are the independent variables.

The vulnerability score for each household was determined using the LVI-IPCC framework. Based on this score, households were classified into three categories: low vulnerability (score < 0.45), moderate vulnerability (score between 0.45 and 0.55), and high vulnerability (score > 0.55). These categories were established by calculating the average range between the minimum and maximum values of the sub-components (Tsue, Nweze and Okoye, 2014). Household adaptive capacity indicators were included as explanatory variables (Table 2).

Table 2. Description of dependent and independent variables.

Variables	Unit
Independent	
Degrees of Livelihood Vulnerability	Ordinal scale: High =2, Moderate =1, and Low =0.
Dependent	
Age (<15 or >65)	Dummy; 1 = Yes, 0 = No
Attended School	Dummy; 1 = Yes, 0 = No
Collaborate	Dummy; 1 = Yes, 0 = No
Fishing Boat	Dummy; 1 = Yes, 0 = No
Fishing Gear	Dummy; 1 = Yes, 0 = No
License	Dummy; 1 = Yes, 0 = No
Support from relatives or friends	Dummy; 1 = Yes, 0 = No
Membership in organizations	Dummy; 1 = Yes, 0 = No
Saving	Dummy; 1 = Yes, 0 = No

2.6. Analytical procedure

Descriptive statistical methods, including mean, standard deviation, and percentage, were employed to analyze and interpret the data. Microsoft Excel 2016 for Windows and SPSS 25.0 were then used to handle and analyze the data.

2.7. Moral Deliberations

During the research, every potential ethical factor was taken into account. The participants gave their agreement before the interview schedule was created, and their names were kept private. The interviewer provided every participant with a detailed explanation of the study's objective. Additionally, the data set preserved anonymity and secrecy.

2.8. Indicator Selection and Weighing Rationale

The indicators and subcomponents in this study were chosen based on their relevance to the local context of small-scale fishing communities and their alignment with the IPCC framework. Their selection was guided by previous research and published applications of the Livelihood Vulnerability Index in similar settings. Each indicator was included as it represents an important aspect of exposure, sensitivity, or adaptive capacity affecting fishermen's livelihoods. Equal weighting was applied to all indicators and major components, following Hahn et al. (2009), to ensure fairness and consistency in the absence of strong empirical evidence for assigning different weights (Hahn, Riederer and Foster, 2009).

2.9. Limitations

The LVI method has certain limitations. It assigns equal weight to all indicators, which might not show their actual importance. Factors like healthcare access or disaster impacts could influence livelihoods more than others. The data is mostly self-reported, which may introduce bias or errors, and selecting indicators can be subjective. Additionally, since the data was gathered at a single point in time, it may not reflect seasonal or long-term changes (Hahn, Riederer and Foster, 2009).

3. Results

3.1. Socioeconomic Profile of Small-Scale Fishing Households

Over the past five decades, climatic trends have significantly impacted households in the region. The community possess diverse age classes, religion and alternate income source (Figure 2). Most households are male-headed, have at least three dependents, and have at least one chronically ill member. Table 3 provides an overview of the main socio-demographic features of the households surveyed. Approximately 52% of fisherman engage with other groups to fish. 48% of homes contained individuals with chronic illnesses. Climate fluctuations and disaster elements have affected almost every home. Fishermen aged 36 to 55 make up the largest proportion, exceeding two-thirds of the total (Figure 2).

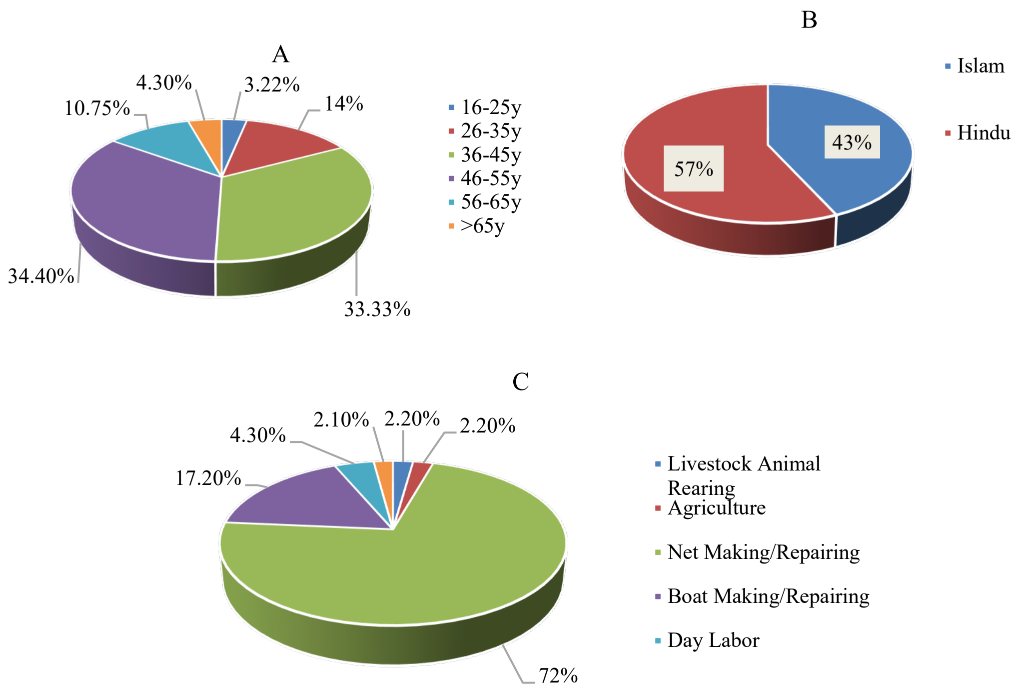

Figure 2. General features of fishermen of Kaptai Lake obtained from authors' survey data: (A) Percentage of fisherman by age group, (B) Percentage of fishermen by religion, and (C) Percentage of fishermen with various alternative income sources.

Table 3. Key element values, subcomponent values along with the lowest and highest values of the subcomponent values obtained from authors' survey data (n = 100).

Major Components	**Subcomponents**	**Unit**	**Values (Max.–Min.)**
Socio-demographic profile	Standardized average age of fishermen	Mean ± SE (years)	46.38 ± 1.14 (71–23)
	Percentage of households under male leadership	Percentage (%)	100 (100–0)
	Percentage of school-attending fishermen.	Percentage (%)	72 (100–0)
	Percentage of household members who have formal education.	Percentage (%)	29.53 (100–0)
	Percentage of households without members younger than 15 or older than 65	Percentage (%)	24 (100–0)
Livelihood strategies	Percentage of boat ownership among fishers	Percentage (%)	44 (100–0)
	Percentage of fishing gear ownership among fishers	Percentage (%)	46 (100–0)
	Percentage of fishermen whose households' expenses primarily depend on fishing	Percentage (%)	100 (100–0)
	Percentage of households with alternative income sources	Percentage (%)	100 (100–0)
	Average diversity index of alternative income sources	Mean ± SE (numbers)	0.45 ± 0.015 (1–0)
	Percentage of households that are participating in joint fishing operations with other communities	Percentage (%)	52 (100–0)
	Percentage of households with financial reserves for emergencies	Percentage (%)	39 (100–0)
Social networks	Percentage of fishers obtaining help from personal networks	Percentage (%)	25 (100–0)
	Percentage of local government support among the fishing population	Percentage (%)	100 (100–0)
	Percentage of fishers authorized through licensing	Percentage (%)	18 (100–0)
	Percentage of fishers who are members of community or social organizations	Percentage (%)	74 (100–0)
	Percentage of fishermen receiving government support for alternative income generation during the ban period	Percentage (%)	0 (100–0)
Health	Percentage of households not seeking treatment from qualified doctors	Percentage (%)	18 (100–0)
	Percentage of families with at least one member suffering from chronic illness	Percentage (%)	48 (100–0)
	Proportion of families experiencing work absences caused by health issues	Percentage (%)	57 (100–0)
	Percentage of families without access to sanitary latrines	Percentage (%)	24 (100–0)
Food	Percentage of families unable to meet their protein needs through fishing	Percentage (%)	0 (100–0)
	Percentage of households without sufficient food reserves for the whole year	Percentage (%)	100 (100–0)
	Percentage of households without access to government aid during the fishing ban	Percentage (%)	0 (100–0)

Water	Average fishing product diversity index	Mean ± SE (numbers)	0.34 ± 0.02 (1.37–0.25)
	Proportion of families relying on natural water sources	Percentage (%)	63 (100–0)
	Percentage of families that store water for daily use and drinking	Percentage (%)	11 (100–0)
Climate variability and disasters`	Percentage of households severely affected by disasters	Percentage (%)	29 (100–0)
	Percentage of households not receiving pre-disaster warnings	Percentage (%)	30 (100–0)
	Percentage of families experiencing injury or death due to disasters	Percentage (%)	21 (100–0)
	Mean standard annual maximum temperature	Mean ± SE (°C)	32.08 ± 1.12 (37.4–25.8)
	Mean standard annual minimum temperature	Mean ± SE (°C)	22.02 ± 1.41 (27.5–13.9)
	Mean standard annual rainfall	Mean ± SE (mm)	95.08 ± 28.03 (264–2)

***Note: Max: Maximum, Min: Minimum, SE: Standard Error.

3.2. Index of livelihood-related vulnerability

Index of Livelihood-Related Vulnerability includes socio-demographic profile, including income-generating activities, community ties, healthcare access, nutrition, water availability, environmental changes and natural hazards. The Livelihood Vulnerability Index (IPCC) is expressed as a number from 0 to 1, where:

- 0 represents the lowest vulnerability, or very resilient
- 1 signifies the highest level of vulnerability or lowest level of resilience.

In this context, The Livelihood Vulnerability Index (IPCC) was found to be 0.40, indicating a moderate level of vulnerability. The score suggests that the fishermen of Kaptai Lake are moderately susceptible to the negative effects of climate change. They may not be the most at-risk, but they are also not very resilient and likely struggling with challenges related to changing climate, such as altering fish availability, water levels or consistency of income.

3.2.1. Exposure

The elements of natural hazards and changing climate patterns are examples of exposure. The results suggested that the Kaptai Lake area is very much prone to changing climate patterns and natural hazards. An exposure score of 0.39 indicates that Kaptai Lake and its neighboring regions tend to receive moderately aggressive climate conditions such as:

- Severe climatic occurrences such as infrequent landslides, flooding, and storms.
- Average shifts in temperature and precipitation.
- Alterations in season change the productivity of the lake ecosystem.

This moderate score of 0.39 while the scale is between 0 to 1, means that although risks relating to climate change do exist, they are not as intense in this area. This result shows that while there is some vulnerability to climate change and natural catastrophes, there is none on the extreme or critical levels and hence the region remains better off than most people in high climate risk areas.

3.2.2. Sensitivity

Sensitivity is one of the elements, which also include food, water, and health. The results indicated that the smaller fishing families at Kaptai Lake are in poorer sensible condition (0.37). In all of the three frames, they were found to be living in high degrees of vulnerability for health. Water was shown to be the least vulnerable (Figures 3–5).

3.2.3. Ability to adjust and cope with change

Adaptive capacity encompasses demographic structure, income-generating methods, as well as community relationships. The results showed that Kaptai Lake's small scale fishermen households had a moderate adaptive capacity of 0.55. The framework of livelihood strategies had the highest ability for adaptation. There were relatively little adaptive capacities with respect to water (Figures 3–5).

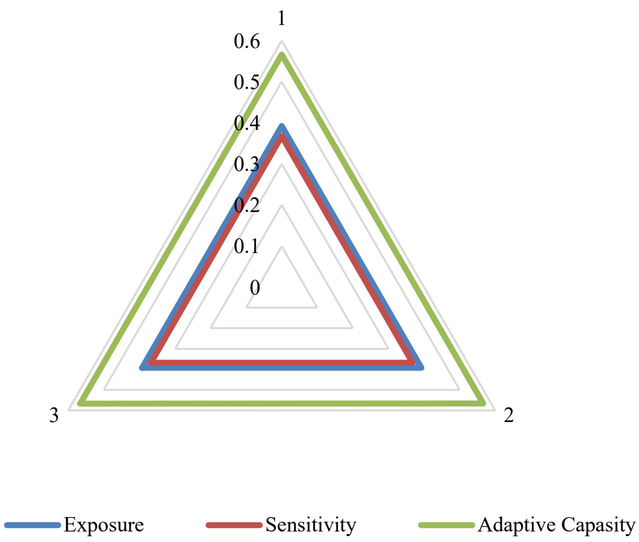

Figure 3. Livelihood Vulnerability Index based on the IPCC framework dimensions of Kaptai Lake fisher's households represented using a vulnerability triangle diagram.

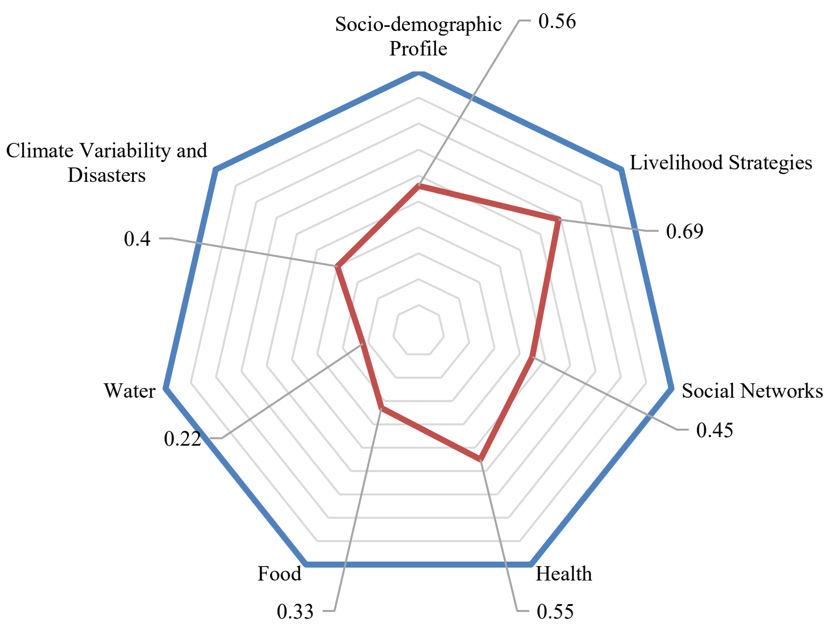

Figure 4. Radar diagram illustrating the core components of the IPCC-based Livelihood Vulnerability Index.

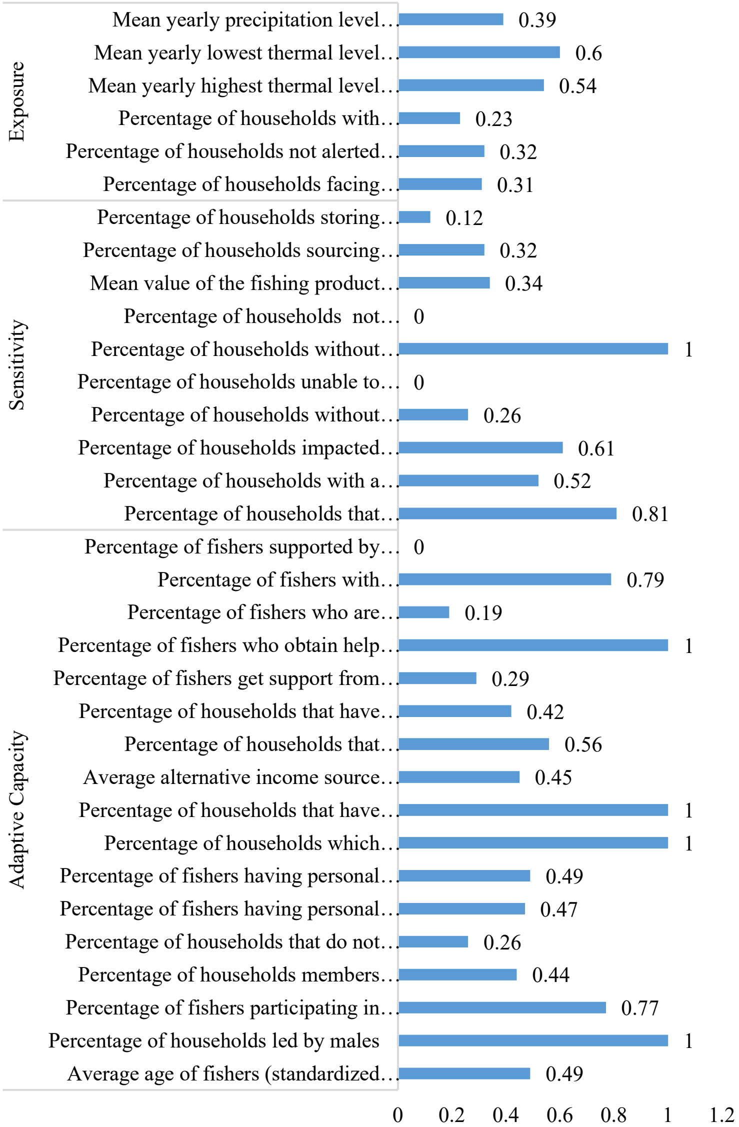

Figure 5. Proportion of subcomponents within the IPCC dimensions.

3.3. Factors Influencing Household Livelihood Vulnerability

3.3.1. Evaluating the mean differences in adaptive capacity indicators affecting livelihood vulnerability

The Kruskal Wallis test was conducted to assess the influence of adaptive capacity indicators on household livelihood vulnerability. As shown in Table 4, the results indicate the presence of livelihood vulnerability caused by climate-related disasters among households in the study area. Households without fishing boats exhibited a significantly higher mean rank (60.84) compared to those owning boats (39.73), indicating greater vulnerability ($\chi^2 = 15.96$, $p < 0.001$). Similarly, households lacking fishing gear showed higher vulnerability with a greater mean rank (62.39) than those with gear (39.08), and the difference was statistically significant ($\chi^2 = 19.47$, $p < 0.001$). Furthermore, households without savings were more likely to face increased livelihood vulnerability, as reflected by a higher mean rank (59.70) relative to households with savings (38.80) ($\chi^2 = 15.43$, $p < 0.001$). In contrast, characteristics such as the presence of aged or very young members ($\chi^2 = 0.84$, $p = 0.359$), school attendance of household heads ($\chi^2 = 0.07$, $p = 0.787$), collaboration with others ($\chi^2 = 0.64$, $p = 0.426$), fishing license ownership ($\chi^2 = 0.67$, $p = 0.412$), support from relatives ($\chi^2 = 1.51$, $p = 0.219$), and organizational membership ($\chi^2 = 1.24$, $p = 0.266$) did not show statistically significant differences in vulnerability levels.

Table 4. Mean difference of the various adaptive capacity indicators related to livelihood vulnerability.

Characteristics	Mean Rank	χ2	*p*-value
Age (<15 or >65)			
No	54.70	0.84	0.359
Yes	49.10		
Attended School			
No	51.80	0.07	0.787
Yes	50.11		
Collaborate			
No	52.73	0.64	0.426
Yes	48.52		
Fishing Boat			
No	60.84	15.96	<0.001 **
Yes	39.73		
Fishing Gear			
No	62.39	19.47	<0.001 **
Yes	39.08		
License			
No	51.55	0.67	0.412
Yes	46.03		
Support from relatives or friends			
No	52.43	1.51	0.219
Yes	45.02		
Membership of organizations			
No	56.38	1.24	0.266
Yes	49.03		
Saving			
No	59.70	15.43	<0.001**
Yes	38.80		

Note: *p*-value obtained from Kruskal-Wallis H test; ** p <0.01; * p <0.05.

3.3.2. Assessing adaptive capacity indicators in relation to livelihood vulnerability

For the surveyed unions, the ordered logistic regression model was applied to identify the indicators of adaptive capacity that influence the household's livelihood vulnerability due to climate-related disasters. Estimated results of the ordered logit model in identifying the adaptive capacity indicators that characterize the livelihood vulnerability due to climate-induced disasters among the participants are demonstrated in Table 5. In this study, the likelihood of household livelihood vulnerability was significantly characterized by ownership of fishing gear, which exhibited a strong positive association with vulnerability levels. Households that did not own fishing gear were approximately 8.91 times more likely to experience high and moderate levels of livelihood vulnerability compared to those that did ($p <$ 0.05). Although not statistically significant, households without membership in community or social organizations showed a potential association with vulnerability, being 2.43 times more likely to face high and moderate vulnerability than those with membership (p = 0.091). Similarly, households that did not receive support from relatives or friends had a higher likelihood (AOR = 1.96) of experiencing increased vulnerability, though this relationship was not statistically significant (p = 0.189). Other variables such as lack of school attendance (AOR = 1.40, p = 0.496), absence of fishing boats (AOR = 1.02, p = 0.982), and not having licenses (AOR = 1.51, p = 0.436) also indicated positive but statistically insignificant associations with livelihood vulnerability. Notably, household saving was negatively associated with livelihood vulnerability (AOR = 0.80), suggesting reduced odds of vulnerability among households that maintained savings, although this finding was also statistically insignificant (p = 0.793).

Table 5. Estimated parameters of adaptive capacity indicators in identifying the risk factors associated with livelihood vulnerability.

Characteristics	**Coeff.**	**AOR [95% CI]**	***p*-value**
Age (<15 or >65)			
No	0.414	1.51 [-0.58-1.41]	0.415
Yes			
Attended School			
No	0.340	1.40 [-0.64-1.32]	0.496
Yes			
Collaborate			
No	0.612	1.84 [-0.24-1.46]	0.157
Yes			
Fishing Boat			
No	0.020	1.02 [-1.66-1.70]	0.982
Yes			
Fishing Gear			
No	2.187	8.91 [0.01-4.37]	0.049*
Yes			
License			
No	0.411	1.51 [-0.63-1.45]	0.436
Yes			
Support from relatives or friends			
No	0.674	1.96 [-0.33-1.68]	0.189
Yes			
Membership of organizations			
No	0.886	2.43 [-0.14-1.91]	0.091
Yes			
Saving			
No	-0.217	0.80 [-1.84-1.41]	0.793
Yes			

Note: Coeff.: Coefficient; AOR: Adjusted Odd Ratio; p- value obtained from Ordered logistic regression; ** $p < 0.01$; * $p < 0.05$.

4. Discussion

Vulnerability assessment provides a methodology to pinpoint weak units and analyze factors that increase their degree of exposure sensitivity and adaptability (Preston, Yuen and Westaway, 2011; Shukla, Sachdeva and Joshi, 2016). A significant volume of agricultural vulnerability assessments has been accomplished in the developing world for the purpose of recommending adaptation measures (Deressa et al., 2009). To explore the adaptive capacity indicators that affect the socio-economic profile's proneness to the climate extreme events, this study was carried out around the Kaptai Lake in Bangladesh. This study, at the very onset, attempted to evaluate the household's susceptibility to livelihood challenges. The Livelihood Vulnerability Index (LVI) aims to pinpoint locally relevant sources and expressions of vulnerability to support the development of tailored resilience strategies (Tewari and Bhowmick, 2014). The LVI calculated in this study shows a moderate level of vulnerability (0.40), indicating that the fishermen of Kaptai Lake are not the most vulnerable but are also far from being resilient. The vulnerability is driven by the moderate exposure (0.39) to climate variability and disasters, combined with moderate adaptive capacity (0.55) and low sensitivity (0.37). These findings align with existing research indicating that climate change poses a serious threat to fisheries, because they rely heavily on natural ecosystems and limited adaptive capacities (Allison et al., 2009). Exposure to environmental, financial, or political threats place a heavy burden on susceptible communities, reduces their productivity and resource availability, which results in a disaster situation (Ambinakudige, 2009).

The term exposure refers to all physical, social, and environmental components that are vulnerable to climate disasters. This research considers the occurrence rates of threats like windstorms, landslides, and waterlogging (Birkmann, 2011). The exposure score of 0.39 for climate variability and disasters indicates that Kaptai Lake and its surrounding populations are moderately exposed to climate risks. Similar issues have been reported in previous research on inland fisheries in developing nations, when fluctuations in water temperature and hydrological cycles result in lower fish production (Preston, Yuen and Westaway, 2011). Climate-induced disasters are becoming more frequent and intense in South Asia (Rahaman, Harun and Ferdous, 2024). Nations facing both economic hardship and climate vulnerability, including

Bangladesh, Cambodia, Guinea-Bissau, and Haiti, are highly susceptible to climate hazards and encounter serious difficulties in managing these risks due to economic constraints. Improvements in these countries must be supported through adaptation grants and techniques for coping and adaptable capacities (Birkmann and Welle, 2015). Furthermore, fish habitat degradation, altered breeding cycles, and altered migration patterns could result with modest exposure to temperature changes and rainfall variability, which would ultimately lead to decreased fish stocks and lower yields. Studies looking at how freshwater fisheries are affected by climate change have observed these effects (Ficke, Myrick and Hansen, 2007).

Sensitivity was found to be relatively low in this study (0.37), with limited medical resources and poor sanitation making health the most susceptible area in the context of vulnerability. Nearly half of the households surveyed (52%) have chronically ill members, and 26% lack access to sanitary latrines, creating significant public health risks. However, health emerges as a significant contributor to sensitivity, as 82% of households generally had not taken treatment from qualified doctors. Poor health conditions reduce the adaptive capacity of fishing families in the face of climate variability, as labor availability and productivity are negatively impacted during times of crisis (Allison, 2004). Addressing these health-related vulnerabilities is critical to reducing overall sensitivity and enhancing community resilience against future climate impacts (IPCC, 2014).

The adaptive capacity of the fishermen was moderate (0.55), with livelihood strategies showing the highest level of resilience. Substitute livelihood options, including net making and repair, offers some buffer against the loss of fishing opportunities during periods of climate variability. However, the study revealed a weak social network, which limits the fishermen's ability to receive external support during crises. This score reflects some strengths, particularly in livelihood strategies, but also highlights significant weaknesses, particularly in social networks and institutional support. Social networks, a critical component of adaptive capacity, are weak within the community. Only 29% of fishermen receive support from relatives or friends, and only 19% have access to a fishing license, limiting their formal engagement in fisheries management. Ownership of fishing gear and household savings are key determinants of livelihood vulnerability among fishing households affected by climate-related disasters. Households lacking these assets consistently exhibited higher levels of vulnerability, with fishing gear ownership showing a particularly strong influence. Although social and institutional factors such as organizational membership, support from relatives, and education were positively associated with vulnerability, these relationships were not statistically significant. These findings are consistent with previous studies (Allison and Ellis, 2001), which emphasize the critical role of physical assets and financial capital in shaping adaptive capacity. Overall, the results suggest that improving access to productive assets and encouraging household savings are effective strategies for reducing livelihood vulnerability in climate affected fishing communities.

Moreover, traditional approaches to risk management and adaptation may not adequately tackle the issues related to reducing exposure; therefore, it is essential to create new ideas specifically designed for low-income nations that have a significant or swiftly growing number of people vulnerable to gradual threats like rising sea levels. In terms of adaptive capacities and insurance, it is crucial to observe that although the total financial losses are considerably higher in developed nations, multiple nations also exhibit comprehensive insurance schemes. This means that people and businesses in wealthier countries are more likely to be compensated for their losses, while those in poorer countries often lack adequate insurance (Birkmann and Welle, 2015; Mechler et al., 2020). To strengthen the economic resilience of Kaptai Lake's fishing communities, policy interventions should focus on strengthening adaptive capacities by promoting education, alternative livelihood opportunities, and enhancing social safety nets. Minimizing vulnerability and increasing resilience necessitate advancements in governance, diminishing corruption, and strengthening coping strategies (Birkmann and Welle, 2015). Moreover, collaboration with government agencies to improve infrastructure and disaster preparedness will help reduce exposure to extreme climate events. Without significant interventions, the moderate vulnerability of these communities could worsen as climate alteration accelerates. Rising occurrence and severity of extreme weather events may degrade fish habitats, disrupt livelihoods, and strain health and sanitation systems further (Ficke, Myrick and Hansen, 2007). Weak adaptive capacities such as limited financial savings, poor access to training, and lack of institutional support may leave the communities ill-prepared for future shocks, increasing their dependency on unsustainable coping mechanisms like high-interest loans (Adger et al., 2003). Future climate scenarios suggest that rising occurrence and severity of adverse environmental conditions could degrade fish habitats, disrupt fishing activities, and intensify socio-economic challenges. Rising temperatures and erratic rainfall are likely to affect fish breeding and migration patterns, leading to declining fish stocks and further economic instability for fishing households. Without targeted interventions, these moderate vulnerabilities could escalate, pushing communities into deeper poverty and food insecurity (Adger, 2006). Health and sanitation systems must be prioritized to reduce community sensitivity to climate impacts. Implementing community health programs and improving access to clean water and sanitation facilities are essential for mitigating health-related vulnerabilities (IPCC, 2014). Finally, institutional support must be enhanced. Policymakers should focus on providing equitable access to fishing licenses, subsidies during fishing bans, and skill development programs to build long-term resilience.

Integrating renewable energy sources and incorporating life cycle assessment (LCA) approaches highlight the importance of sustainable practices in mitigating environmental impacts, particularly those driven by climate change. Emphasizing energy efficiency, renewable integration, and adaptive solar control strategies align with broader climate mitigation principles and supports resilient planning within both urban and rural environmental systems (Carbonari, Scarpa and Mendez Plaza, 2022). The partial or complete replacement of coal-based power plants with solar thermal technologies, such as Solar Power Tower (SPT) and Parabolic Dish Systems (PDS), offers significant potential for reducing greenhouse gas emissions. These systems achieve higher energy conversion efficiencies, resulting in less energy loss and enhancing their competitiveness with conventional fossil fuel-based power generation. In the context of India, where coal combustion remains a major contributor to CO_2 and other atmospheric pollutants, the integration of SPT and PDS systems particularly in high-insolation regions such as Jodhpur can play a critical role in climate change mitigation. By decreasing reliance on coal, these technologies directly reduce emissions, thereby supporting the transition toward a low-carbon energy mix (Sovetova et al., 2025). Indoor air pollution remains a significant public health concern, exacerbating respiratory diseases and increasing vulnerability to climate-related stressors, especially in low-income regions. Advanced air purification technologies such as photocatalytic oxidation (PCO) offer promising co-benefits for both climate mitigation and health improvement by degrading harmful VOCs and pathogens (Tapia-Brito and Riffat, 2025). Photocatalytic air purifiers using TiO_2, such as the MopFan device developed by Tapia-Brito et al., have shown potential in reducing indoor pollutants and viruses while consuming low energy (Tapia-Brito et al., 2022). These innovations support both climate resilience and public health, particularly in vulnerable communities.

5. Conclusion

Kaptai Lake and its surrounding communities experience a moderate level of exposure to climate risks**,** with a Livelihood Vulnerability Index (LVI) score of 0.40. This survey shows that fishermen in Kaptai Lake are somewhat susceptible to the impacts of changing climate. Fishermen ability to adapt was average (0.55), however livelihood diversification by alternative income sources revealed moderate resilience. Yet, the absence of strong social networks and limited access to state and local resources point to major failings in how well the community is able to weather climate-induced disasters. However, limited institutional support and weak social networks continue to constrain the community's ability to cope effectively with climate-induced shocks (Islam et al., 2014; Smit and Wandel, 2006). Strengthening asset ownership and promoting household saving behaviors could be effective to reduce vulnerability among small-scale fishing communities. Future research should explore the nuanced roles of social capital and institutional support, as their influence may become more apparent under different contextual or temporal conditions. To develop livelihood security and decrease the vulnerability faced by the fishermen, this study recommends policy intervention measures for promoting adaptive capacity that primarily include education, skill development and improved access to social and institutional support. Working together with government agencies and local organizations to strengthen disaster preparedness and infrastructure will also help in reducing the community's exposure to future climate risks (Allison et al., 2009; Birkmann, 2011). Finally, this work yields nuanced understanding of the climate risks facing Kaptai Lake’s fishers and provides a blueprint to develop adaptive measures for continued economic security in light of current patterns of climate transformation.

Author Contributions

Nayem Mahmud Akash: Data Collection, Methodology, Data curation, Formal Analysis and Writing –original draft. Md. Sarwar Hossian: Data curation, Writing – original draft. Md Istiaque Haidar: Investigation, Visualization, Methodology. Helena Khatoon: Writing – review & editing, Methodology. Tashrif Mahmud Minhaz: Conceptualization, Supervision, Writing – review & editing, Validation. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

Data will be made available on request.

References

Adger, W.N. (2006) "Vulnerability," *Global Environmental Change*, 16(3), pp. 268–281. Available at: https://doi.org/10.1016/j.gloenvcha.2006.02.006.

Adger, W.N. *et al.* (2003) "Adaptation to climate change in the developing world," *Progress in development Studies*, 3(3), pp. 179–195. Available at: https://doi.org/10.1191/1464993403ps060oa.

Afrin, S., Shakil, A. and Minhaz, T.M. (2024) "Climate change triggered livelihood vulnerability of small-scale fishermen along the coastal belt of Cox's Bazar, Bangladesh," *Bangladesh Maritime Journal*, 8(1), pp. 83–107.

Ahsan, Md.N. and 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, pp. 32–49. Available at: https://doi.org/10.1016/j.ijdrr.2013.12.009.

Allison, E.H. (2004) "The fisheries sector, livelihoods and poverty reduction in Eastern and Southern Africa," in *Rural livelihoods and poverty reduction policies*. Routledge, pp. 235–251.

Allison, E.H. and Ellis, F. (2001) "The livelihoods approach and management of small-scale fisheries," *Marine Policy*, 25(5), pp. 377–388. Available at: https://doi.org/10.1016/S0308-597X(01)00023-9.

Allison, E.H. *et al.* (2009) "Vulnerability of national economies to the impacts of climate change on fisheries," *Fish and Fisheries*, 10(2), pp. 173–196. Available at: https://doi.org/10.1111/j.1467-2979.2008.00310.x.

Ambinakudige, S. (2009) "The Global Coffee Crisis and Indian Farmers: The Livelihood Vulnerability of Smallholders," Canadian Journal of Development Studies / Revue canadienne d'études du développement, 28(3–4), pp. 553–566. Available at: https://doi.org/10.1080/02255189.2009.9669229.

Arafeen, M.S. *et al.* (2024) "Present Status of Fish Diversity of the Kaptai Lake, Bangladesh," *Journal of the Bangladesh Agricultural University*, 22(4), pp. 506–516. Available at: https://doi.org/10.3329/jbau.v22i4.78869.

Badjeck, M.-C. *et al.* (2010) "Impacts of climate variability and change on fishery-based livelihoods," *Marine Policy*, 34(3), pp. 375–383. Available at: https://doi.org/10.1016/j.marpol.2009.08.007.

Barange, M. *et al.* (2018) "Impacts of climate change on fisheries and aquaculture," *United Nations' Food and Agriculture Organization*, 12(4), pp. 628–635.

Barua, P., Islam, M. and Mitra, A. (2022) "Socio-economic condition of the indigenous fishermen in and around an artificial lake for Bangladesh," *MOJ Eco Environ Sci*, 7(5), pp. 162–169.

Birkmann, J. (2011) "First- and second-order adaptation to natural hazards and extreme events in the context of climate change," *Natural Hazards*, 58(2), pp. 811–840. Available at: https://doi.org/10.1007/s11069-011-9806-8.

Birkmann, J. and Welle, T. (2015) "Assessing the risk of loss and damage: exposure, vulnerability and risk to climate-related hazards for different country classifications," *International Journal of Global Warming*, 8(2), pp. 191–212. Available at: https://doi.org/10.1504/IJGW.2015.071963.

Blaikie, P. *et al.* (2014) *At Risk: Natural Hazards, People's Vulnerability and Disasters*. 2nd ed. London: Routledge. Available at: https://doi.org/10.4324/9780203714775.

Bohle, H.G., Downing, T.E. and Watts, M.J. (1994) "Climate change and social vulnerability: Toward a sociology and geography of food insecurity," *Global Environmental Change*, 4(1), pp. 37–48. Available at: https://doi.org/10.1016/0959-3780(94)90020-5.

Brander, K. (2010) "Impacts of climate change on fisheries," *Journal of Marine Systems*, 79(3), pp. 389–402. Available at: https://doi.org/10.1016/j.jmarsys.2008.12.015.

Burton, I. (1993) *The Environment as Hazard*. Guilford Press.

Carbonari, A., Scarpa, M. and Mendez Plaza, F.I. (2022) "Urban Covered Courtyards in Mediterranean Climates : a method for optimizing environmental control strategy," in. GBR. Available at: https://air.iuav.it/handle/11578/330569.

Chambers, R. (1994) "Participatory rural appraisal (PRA): Analysis of experience," *World Development*, 22(9), pp. 1253–1268. Available at: https://doi.org/10.1016/0305-750X(94)90003-5.

Cheung, W.W.L. *et al.* (2009) "Projecting global marine biodiversity impacts under climate change scenarios," *Fish and Fisheries*, 10(3), pp. 235–251. Available at: https://doi.org/10.1111/j.1467-2979.2008.00315.x.

Cutter, S.L., Boruff, B.J. and Shirley, W.L. (2006) "Social Vulnerability to Environmental Hazards," in *Hazards Vulnerability and Environmental Justice*. Routledge.

Deressa, T.T. *et al.* (2009) “Determinants of farmers’ choice of adaptation methods to climate change in the Nile Basin of Ethiopia,” *Global Environmental Change*, 19(2), pp. 248–255. Available at: https://doi.org/10.1016/j.gloenvcha.2009.01.002.

Didar-Ul Islam, S.M., Bhuiyan, M.A.H. and Ramanathan, AL. (2015) “Climate Change Impacts and Vulnerability Assessment in Coastal Region of Bangladesh: A Case Study on Shyamnagar Upazila of Satkhira District,” *Journal of Climate Change*, 1(1–2), pp. 37–45. Available at: https://doi.org/10.3233/JCC-150003.

DoF (2019) *Yearbook of Fisheries Statistics of Bangladesh 2018–2019*. Fisheries Resources Survey System (FRSS), Department of Fisheries, Dhaka, Bangladesh, pp. 35–38.

Downing, T.E. *et al.* (2005) “Assessing vulnerability for climate adaptation.” Available at: https://cgspace.cgiar.org/bitstreams/8bc8f3be-f135-4004-9d8d-af176b55d1bd/download.

Fernando, C.H. (1980) “The fishery potential of man-made lakes in Southeast Asia and some strategies for its optimization.,” *BIOTROP Special Publication* [Preprint]. Available at: https://agris.fao.org/search/en/providers/123819/records/64735be108fd68d54602a4a0.

Ficke, A.D., Myrick, C.A. and Hansen, L.J. (2007) “Potential impacts of global climate change on freshwater fisheries,” *Reviews in Fish Biology and Fisheries*, 17(4), pp. 581–613. Available at: https://doi.org/10.1007/s11160-007-9059-5.

Fisheries Resources Survey System (FRSS) (2012) *Fisheries Statistical Yearbook of Bangladesh*, vol. 28. Dhaka, Bangladesh: Department of Fisheries, p. 46.

Food and Agriculture Organization (FAO) (2009) *Climate change implications for fisheries and aquaculture: Overview of current scientific knowledge*. FAO Fisheries and Aquaculture Technical Paper, no. 530. Rome, Italy: FAO.

Ford, J.D. and Smit, B. (2004) “A Framework for Assessing the Vulnerability of Communities in the Canadian Arctic to Risks Associated with Climate Change,” *Arctic*, 57(4), pp. 389–400.

Fullerton, A.S. (2009) “A Conceptual Framework for Ordered Logistic Regression Models,” *Sociological Methods & Research*, 38(2), pp. 306–347. Available at: https://doi.org/10.1177/0049124109346162.

Gallopín, G.C. (2006) “Linkages between vulnerability, resilience, and adaptive capacity,” *Global Environmental Change*, 16(3), pp. 293–303. Available at: https://doi.org/10.1016/j.gloenvcha.2006.02.004.

Hahn, M.B., Riederer, A.M. and Foster, S.O. (2009) “The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique,” *Global Environmental Change*, 19(1), pp. 74–88. Available at: https://doi.org/10.1016/j.gloenvcha.2008.11.002.

Hossain, M.A.R. (2014) “An overview of Fisheries sector of Bangladesh,” *Research in Agriculture Livestock and Fisheries*, 1(1), pp. 109–126. Available at: https://doi.org/10.3329/ralf.v1i1.22375.

Huang, J., Liu, Y. and Ma, L. (2011) “Assessment of regional vulnerability to natural hazards in China using a DEA model,” *International Journal of Disaster Risk Science*, 2(2), pp. 41–48. Available at: https://doi.org/10.1007/s13753-011-0010-y.

Intergovernmental Panel on Climate Change (IPCC) (2001) *Climate Change 2001: Impacts, Adaptation, and Vulnerability*. Cambridge, UK: Cambridge University Press.

Intergovernmental Panel on Climate Change (IPCC) (2014) *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Islam, Md.M. *et al.* (2014) “Vulnerability of fishery-based livelihoods to the impacts of climate variability and change: insights from coastal Bangladesh,” *Regional Environmental Change*, 14(1), pp. 281–294. Available at: https://doi.org/10.1007/s10113-013-0487-6.

Khan, A. *et al.* (2021) “Mental health impacts of COVID-19 outbreak and associated drivers among university students in Bangladesh,” *Minerva Psychiatry*, 62(2). Available at: https://doi.org/10.23736/S2724-6612.20.02108-1.

Mechler, R. *et al.* (2020) “Loss and Damage and limits to adaptation: recent IPCC insights and implications for climate science and policy,” *Sustainability Science*, 15(4), pp. 1245–1251. Available at: https://doi.org/10.1007/s11625-020-00807-9.

Mojid, M.A. (2020) “Climate change-induced challenges to sustainable development in Bangladesh,” *IOP Conference Series: Earth and Environmental Science*, 423(1), p. 012001. Available at: https://doi.org/10.1088/1755-1315/423/1/012001.

Organization, W.H. (2005) "Immunization coverage cluster survey: Reference manual," in *Immunization coverage cluster survey: reference manual*. Available at: https://pesquisa.bvsalud.org/portal/resource/pt/who-69087

Organization, W.H. (2011) "Tuberculosis prevalence surveys: a handbook," in *Tuberculosis prevalence surveys: a handbook*. Available at: https://pesquisa.bvsalud.org/portal/resource/pt/who-44481.

Palut, M.L.P.J.P. and Canziani, O.F. (eds.) (2014) *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK: Cambridge University Press. Available at: https://plymsea.ac.uk/id/eprint/5834/.

Paukert, C.P. *et al.* (2017) "Designing a global assessment of climate change on inland fishes and fisheries: knowns and needs," *Reviews in Fish Biology and Fisheries*, 27(2), pp. 393–409. Available at: https://doi.org/10.1007/s11160-017-9477-y.

Preston, B.L., Yuen, E.J. and Westaway, R.M. (2011) "Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks," *Sustainability Science*, 6(2), pp. 177–202. Available at: https://doi.org/10.1007/s11625-011-0129-1.

Rahaman, A., Harun, M. and Ferdous, J. (2024) "Factors of Climate-Induced Migration in South Asia: A Security Question," in *Handbook of Migration, International Relations and Security in Asia*. Springer, pp. 1–17.

Sarker, M.N.I. *et al.* (2019) "Livelihood Vulnerability of Riverine-Island Dwellers in the Face of Natural Disasters in Bangladesh," *Sustainability*, 11(6), p. 1623. Available at: https://doi.org/10.3390/su11061623.

Shamsuzzaman, Md.M. *et al.* (2017) "Fisheries resources of Bangladesh: Present status and future direction," *Aquaculture and Fisheries*, 2(4), pp. 145–156. Available at: https://doi.org/10.1016/j.aaf.2017.03.006.

Shamsuzzaman, Md.M. *et al.* (2020) "The economic contribution of fish and fish trade in Bangladesh," *Aquaculture and Fisheries*, 5(4), pp. 174–181. Available at: https://doi.org/10.1016/j.aaf.2020.01.001.

Shukla, R., Sachdeva, K. and Joshi, P.K. (2016) "Inherent vulnerability of agricultural communities in Himalaya: A village-level hotspot analysis in the Uttarakhand state of India," *Applied Geography*, 74, pp. 182–198. Available at: https://doi.org/10.1016/j.apgeog.2016.07.013.

Simane, B., Zaitchik, B.F. and Foltz, J.D. (2016) "Agroecosystem specific climate vulnerability analysis: application of the livelihood vulnerability index to a tropical highland region," *Mitigation and Adaptation Strategies for Global Change*, 21(1), pp. 39–65. Available at: https://doi.org/10.1007/s11027-014-9568-1.

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

Sovetova, M. *et al.* (2025) "The Potential of Small-Scale Solar Organic Rankine Cycle Systems for Decentralised Power Generation in Africa | Research and Reviews in Sustainability." Available at: https://doi.org/10.5334/rss.1.

Sujakhu, N.M. *et al.* (2018) "Determinants of livelihood vulnerability in farming communities in two sites in the Asian Highlands," *Water International*, 43(2), pp. 165–182. Available at: https://doi.org/10.1080/02508060.2017.1416445.

Sumaila, U.R. *et al.* (2011) "Climate change impacts on the biophysics and economics of world fisheries," *Nature Climate Change*, 1(9), pp. 449–456. Available at: https://doi.org/10.1038/nclimate1301.

Suman, K.H. (2023) "4. Small Fish, Big Roles: Unlocking the Scenario of Biodiversity and Conservation Challenges of Small Indigenous Fish Species (SIS) of Kaptai Lake, Bangladesh," *Small in Scale Big in Contributions*, p. 36.

Sunny, A.R. *et al.* (2017) "Present status of hilsa shad (Tenualosa ilisha) in Bangladesh: A review," *Journal of Entomology and Zoology Studies*, 5(6), pp. 2099–2105. Available at: https://doi.org/10.22271/j.ento.2017.v5.i6ac.2848.

Tapia-Brito, E. and Riffat, S. (2025) "Design and performance analysis of a MopFan-based multi-stage air purification system for indoor pollution control," *Green Technology & Innovation*, 1(2), p. 7100.

Tapia-Brito, E. *et al.* (2022) "Experimental Investigation of a MopFan-Based Photocatalytic Air Purification Device.," *Future Cities & Environment* [Preprint]. Available at: https://nottingham-repository.worktribe.com/OutputFile/10082568.

Tewari, H.R. and Bhowmick, P.K. (2014) "Livelihood vulnerability index analysis: An approach to study vulnerability in the context of Bihar," *Jàmbá: Journal of Disaster Risk Studies*, 6(1), pp. 1–13.

Tsue, P.T., Nweze, N. and 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), pp. 206–216.