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Assessment of Climate-Induced Vulnerabilities and Poverty Alleviation Potential of Dry Fish Industry: An Ecological and Socio-economic Study in Cox's Bazar District, Bangladesh

Abu Nayem Md. Kayes*, Tasnim Tabassum, Md. Al Mominur Rahman Khan

Department of Urban and Regional Planning, Pabna University of Science and Technology, Pabna-6600, Bangladesh; abu.nayem045@gmail.com; tasnimtabassum.593@gmail.com (T.T.); mominur.201726@s.pust.ac.bd (M.A.M.R.K).

*Correspondence: abu.nayem045@gmail.com.

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ABSTRACT

Climate change disrupts the ecosystem and decimates nature-dependent populations. The dried fish business in Cox's Bazar relies on raw fish. The community in Cox's Bazar district largely depends on these industries, which have contributed to poverty alleviation and local economic growth. However, they also have mixed ecological impacts, including positive outcomes and challenges such as waste generation. This paper assesses livelihood vulnerability in the coastal areas of Cox's Bazar and Kutubdia through the LVI, LVI-IPCC, and various statistical tests. Data collection involved a survey of 150 households at each site, two focus group discussions (FGDs) at each site, and one key informant interview (KII) in each area. The results indicate that Kutubdia Island is more vulnerable than Cox's Bazar, with an LVI value of 0.437. Initiatives for eco-friendliness, such as the adoption of Smart Solar Sun-Dryers, are being implemented. At the same time, the waste from this industry, which constitutes 14% of the waste in Cox's Bazar, is increasingly being reused for fish feed. These findings underscore the dual impact of this industry on the environment and its crucial role in the livelihoods of local communities. This will help policymakers formulate effective strategies for resource allocation, development planning, and policy formulation.

KEYWORDS

Vulnerability; poverty; climate change; smart solar sun dryer; dry fish industry.

1. Introduction

It has indeed contributed to global warming, with high temperature rises, growing emissions, and negative, differential impacts on the most vulnerable communities, who have contributed the least to the problem. According to the IPCC (2023), this is attributed to global climatic change resulting from the emission of greenhouse gases. According to statistics from the UN, it is estimated that approximately 40% of the world's population lives within 100 kilometres of the coastline, while

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the population of the coastlines is increasing faster than the global population. Coastal communities are facing challenges stemming from the decline of traditional industries and the impacts of climate change. Main challenges brought about by climate change, such as sea-level rise, flooding, and erosion, among others, threaten both the landscape and the livelihoods of these communities (Sørensen et al., 2018). More precisely, the increase in sea level, cyclones, and saltwater intrusions result in land degradation, which further causes negative impacts on agricultural productivity and reduces fishing opportunities (Islam et al., 2018; Magsi & Sheikh, 2017). Climate change impacts can be categorised into three orders: degradation of community capacity to reduce vulnerability, modification of agricultural landscapes and production patterns, and deterioration of livelihood assets and conditions (Huq et al., 2015).

The economic fabric of these regions is woven from diverse occupations, including fishing, farming, and tourism-related pursuits (Wahyudin, 2013; Ghosh, 2012). Also, a predominantly dry fish industry located in coastal areas of West Bengal (Payra et al., 2016) and Chittagong-Cox's Bazar region, along the Sylhet-Mymensingh – Comilla and Khulna-Barisal-Patuakhali regions (Dey et al., 2024) for the proximity of fresh supply of fish and favourable environmental conditions for sun drying (Joshua & Vasu, 2015). It is a traditional livelihood activity for low-income workers, especially in coastal communities and among fishermen, who often have limited literacy rates, as noted by Kamal et al. (2023) and Samanta et al. (2016). Due to the long shelf life and low manufacturing costs of dried fish, which facilitate long-term preservation, it is crucial for traditional livelihood activities among coastal communities, particularly among low-income individuals, as noted by Samanta et al. (2016). Women play a significant role in the drying process of fish. On the other hand, salaries and decision-making powers related to gender are subject to discrimination. The seasonality of this industry is characterised by a shift to other jobs during the off-seasons of the year. Research evidence suggests that despite these issues, the dried fish sector contributes significantly to the community's resilience through social relationships and traders' groups (Kamal et al., 2023; Mitu et al., 2021).

The dry fish industry plays a significant role in rural economies, providing employment and income for millions of poor fishermen and women through poverty alleviation and job creation (Giri & Biswas, 2018; Orewa & Iteke, 2017). This study aims to address existing research gaps in the dry fish sector by examining its role in mitigating climate change vulnerability, alleviating poverty, and balancing its ecological and climate-related impacts. It also explores how the dry fish industry has contributed to building resilience against climate vulnerabilities and identifies adaptation strategies that can strengthen these communities. To achieve these objectives, the study focuses on the following key questions: How has the industry contributed to reducing vulnerability? In what ways has it helped alleviate poverty among those involved? Moreover, what are the positive and negative impacts of the industry on the environment and climate?

1.1. Literature review

The dry fish industry, particularly in coastal and arid regions, is facing a significant threat from climate change, with profound implications for fish populations, fisheries, and the livelihoods of those dependent on this trade. Climate change-induced factors, such as increased temperatures and altered hydrologic patterns, are leading to more frequent river drying events and reduced hydrologic connectivity. These changes pose severe risks to freshwater fish species by limiting access to spawning habitats, as seen in ecosystems such as the Verde River basin (Jaeger et al., 2014). In the Arctic, the drying of tundra streams affects the genetic variations and population structure of species like the Arctic grayling, underscoring the challenges of maintaining biodiversity under climate stressors (Golden et al., 2021). Similar vulnerabilities are evident in Africa, where inland fisheries face rising temperatures and sea levels, which exacerbate the difficulties for local fishing communities (Udo & Akpan, 2021). Traditional preservation techniques, such as dry salting, may not be sufficient to address the anticipated effects of climate change on the dry fisheries sector (Khashroum, 2022).

Socioeconomic conditions, environmental factors and limited income diversification further compound the vulnerability of dry fishing communities. In Bangladesh, for example, the dry fish industry struggles with low income, poor literacy rates, and inadequate compensation during off-seasons, forcing many to seek alternative livelihoods (Kamal et al., 2023). Similar challenges are observed in Madagascar (Ranaivomanana & Mahafina, 2024) and Malaysia (Islam et al., 2022), where fishing communities' reliance on natural resources and lack of diversified income sources lead to heightened vulnerability and generalised poverty. In Colombia, despite fishing households earning more than non-fishing households, significant barriers, such as restricted access to financial markets and lower education levels, exacerbate their vulnerability (Maldonado et al., 2022). These challenges highlight the need for targeted policies to enhance resilience and diversify income sources within these communities (Omitoyin et al., 2021).

Despite these challenges, the dry fish industry plays a critical role in poverty alleviation, particularly in coastal communities. It is a vital source of livelihood, especially for women and contributes significantly to food and nutrition security due to its high micronutrient content (Pradhan et al., 2023). Research indicates that fishing households generally have a lower likelihood of living below the poverty line, highlighting the sector's potential to enhance food security and reduce poverty (Martuscelli, 2022). In Bangladesh, innovative models, such as the proposed social business on Maheshkhali Island, aim to empower local dry fish processors by eliminating intermediaries, thereby increasing their income and reducing poverty (Ullah & Uddin, 2015). Similar opportunities for poverty reduction exist in Nigeria, where the dry fish trade has shown profitability despite challenges such as high lending rates and transportation issues persisting (Orewa & Iteka, 2017).

Addressing the vulnerabilities faced by dry fishing communities requires a comprehensive approach that incorporates both multifaceted and targeted adaptation and policy interventions. Research indicates that poverty among fishermen is exacerbated by low income, inadequate fishing gear and insufficient education, necessitating interventions that empower marginalised groups, particularly women (Kahar & Broto, 2023). However, effective policy implementation is often hindered by poor coordination among government units, a lack of infrastructure, and inadequate access to financial resources (Nurkaidah et al., 2016). Moreover, poverty in fisheries is intertwined with broader social issues, including gender inequality and community exclusion, which complicates alleviation efforts (Jentoft et al., 2010). Gender mainstreaming policies are essential, as current regulations often overlook the protective aspects for women in fisheries, perpetuating their poverty (Purwanti et al., 2022). Therefore, a holistic strategy involving local governments, educational institutions, and the private sector is crucial to enhance community participation, improve resource management, and ultimately foster sustainable economic development in these vulnerable communities (Jentoft et al., 2010; Purwanti et al., 2022; Nurkaidah et al., 2016).

The dry fish industries also have both positive and negative impacts on the ecology. According to Khashroum (2022), traditional practices can increase environmental pressures on fish through overfishing and habitat degradation, thereby posing a threat to the long-term sustainability of the industry (Khashroum, 2022). Together with this fact comes the socio-economic vulnerability of dry fishing communities, most of which lack the wherewithal and infrastructure to cope with such changeable conditions. In Bangladesh, for instance, dry fishers face challenges such as low income and inadequate compensation during off-seasons, which force them to exploit natural resources unsustainably (Kamal et al., 2023). Similar patterns of ecological strain and socioeconomic vulnerability are evident in Madagascar (Ranaivomanana, 2024) and Malaysia (Islam et al., 2022), where the over-reliance on natural resources heightens the environmental impact of the dry fish industry.

2. Profile of study region

Cox's Bazar is a mountainous area and home to the longest natural sea beach in the world (Wikipedia, 2024). In Bangladesh, Cox's Bazar area has some of the worst rates of hunger and poverty (Maclean, 2019). It contains three islands: Saint Martin, Kutubdia, and Moheskhali. For this study, two different locations from Cox's Bazar district are selected. The first is "Kaisarpara" village, Uttor Dhurung union, Kutubdia Upazila (sub-district). More precisely, the area is located between "21° 54′ 24.3246" north latitude and 91° 51′ 23.5182" east longitude," shown in Figure (1). The second one is the "Nazirartek" village, locally known as "Chor," located in Cox's Bazar's Sadar Upazila (sub-district). More precisely, the area is located between "21° 27′ 53.2584" east latitude and 91° 57′ 1.6848" north longitude," as shown in Figure (2). The main reason behind selecting these two study areas is that they are most concentrated on dry fish industries and two well-known coastal areas of Bangladesh, which have faced several natural disasters over the decades.

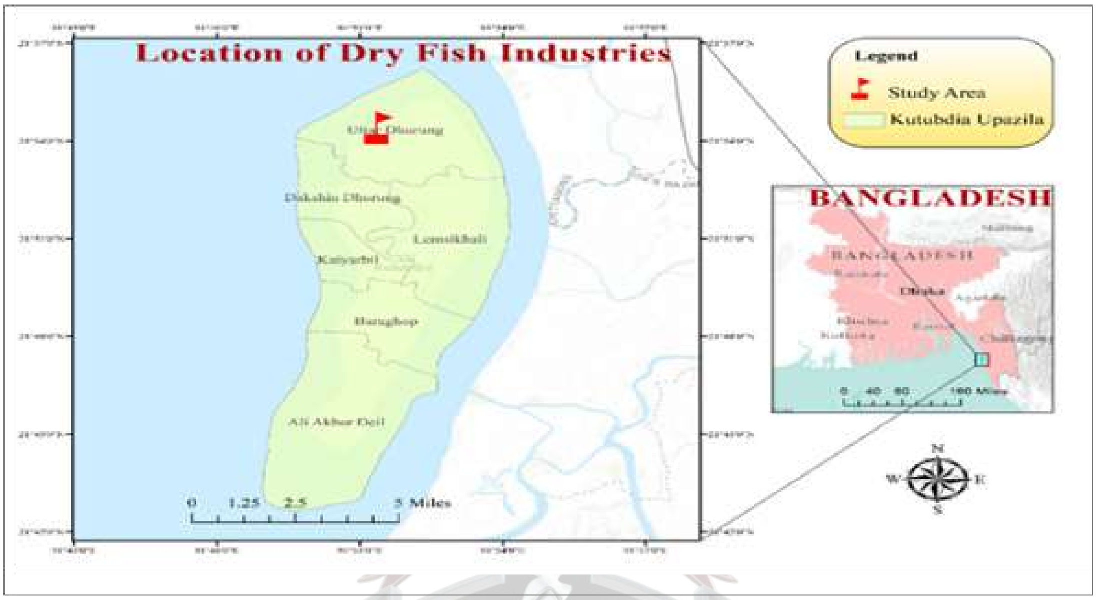

Figure 1. Survey point in Kutubdia.

3.1 Characteristics of the village, Kaisarpara, Kutubdia

With a population of just over 125,000, Kutubdia is an island and an Upazila (sub-district) with an area of 215.80 square kilometres. It is regarded as one of the most remote and vulnerable islands in the area (Alam & Alam, 2023; BFRI, 2020). It is surrounded by water; the Bay of Bengal is in the west, and the Kutubdia Channel is in the east. The primary mode of transport is boat, which helps to communicate the Island with the mainland and transport goods. Recently, it was connected to the national grid via a 33 kV line (Dhaka University, 2023).

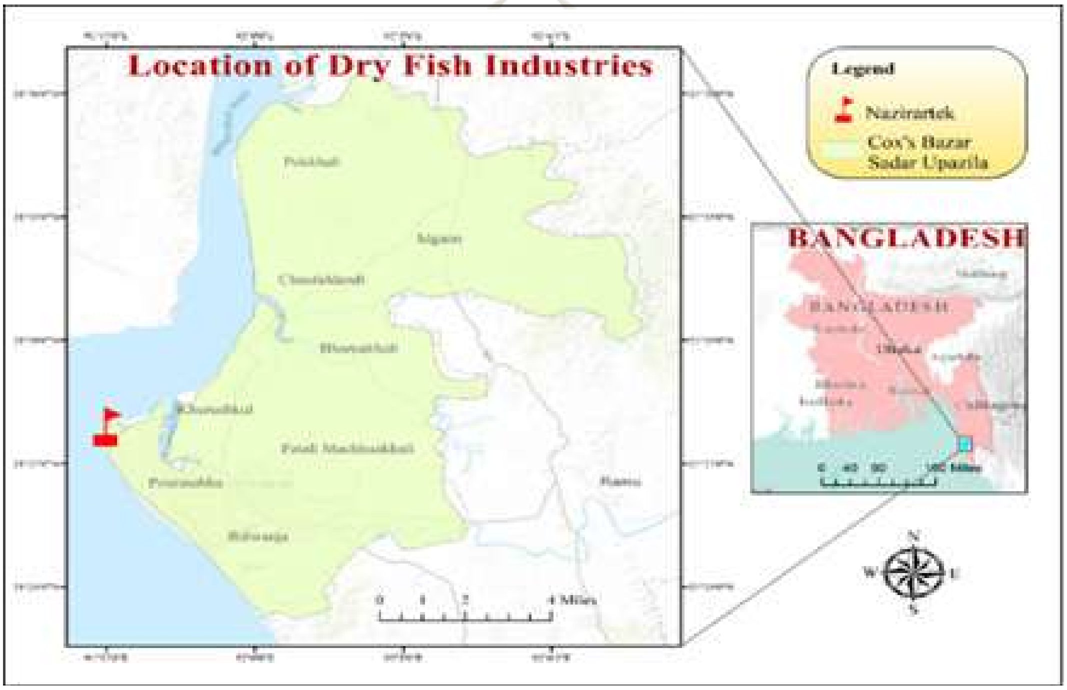

Figure 2. Survey point in Cox's Bazar's Sadar Upazila.

3.2 Characteristics of the study area, Cox's Bazar's Sadar Upazila

Cox's Bazar main subdivision is the most well-known district of Bangladesh for its natural beauty. In Cox's Bazar's Sadar Upazila, there are over 20,000 workers and 1,500 producers specialising in dried fish. The connectivity is significantly better than that of Kutubdia Upazila (sub-district) (Kamal et al., 2023). The study area is well-connected to the CBD (Central Business District) and the district town and is also a popular tourist destination. These industries are privileged to have a marketing opportunity. This district and the capital of Bangladesh are now connected by train.

4. Methods

4.1 Data sources and collection techniques

A household questionnaire survey was conducted in both study areas from May to June 2024. To delve deeper into this, focus group discussions were conducted with 8-10 fishermen and workers from dry fish industries in each study area. Besides, key informant interviews were conducted with veteran fishermen who had been in this profession for a long time. These interviews were supplemented by in-depth elaboration of the pros and cons of various adaptation strategies adopted by them. Secondary data were obtained from NASA Power, the (LGED), and the (BBS).

4.1.1 Sample size for household survey

The Yamane formula is used to determine the sample size for a household survey, which is a prevalent and widely used method. Using a 90% level of confidence, 10% precision, and 50% prevalence, the required sample size has been calculated with the Yamane formula as follows:

Here, n = sample size for household survey, N (Number of households). According to the BFRI (2020), Cox's Bazar's Sadar Upazila, 1 number. Ward has 4,532 households, and Kutubdia Upazila, Uttor Dorong Union, has 4,889. e (Margin of error) = 0.10, $n = 4532/(1+4532 * (0.10)2)$ = 98 sample size of household for Cox's Bazar's Sadar Upazila and $n = 4889/(1+4889 * (0.10)2)$ = 98 sample for Kutubdia Upazila. However, due to the logistical implications and the fact that it was a single research work with no external funding, a reduced sample size of approximately 75 households per area was selected. This will translate to a total of 150 samples in both areas on sunny days.

4.2 Assessing Vulnerability through Livelihood Vulnerability Index (LVI)

Researchers commonly employ two approaches to estimate LVI. A proposal by Hahn was among them to estimate vulnerability due to climate change (Hahn et al., 2009). Some researchers used the balance-weighted technique, which included calculating the LVI (Adu et al., 2018). This method employs a three-step calculation approach and has been used by several studies due to its structured framework, which addresses both the primary and secondary components of family livelihoods. This study used the IPCC concept of vulnerability to climate change in calculating the LVI for each chosen family.

In the framework by (Hahn et al., 2009), seven primary variables were used, while this study has, in addition, two major components developed to make a total of nine: Socio-demographic Profile (SDP), Social Network (SN), Health (H), Water (W), Livelihood Strategies (LS), Food (F), Resources (R), Ecosystem (E), and Natural Disasters & Climate Vulnerability (NDCV). While the conventional LVI includes some ecosystem-related variables, this study delineates Ecosystem, Natural Disasters, and Climate Variability as separate elements to more accurately represent local conditions (Basiru et al., 2022). The Ecosystem component highlights community reliance on natural resources and services, while Natural Disasters and Climate Variability underscore the escalating effects of climatic extremes (Basiru et al., 2022).

These data were collected using various qualitative and quantitative tools and then coded in SPSS. Microsoft Excel was used to standardise the data using equations (2), and the choice of equation depends on the relationship between the minor components and vulnerability.

If the variable has a positive relationship with vulnerability:

$$\text{Index } X_{iu} = \frac{X_{id} - Min\ X_i}{Max\ X_i - Min\ X_i} \quad \text{.... (2) (Hahn et al., 2009)}$$

If the variable has a negative relationship with vulnerability:

$$\text{Index } X_{iu} = \frac{Max\ X_i - X_{iu}}{Max\ X_i - Min\ X_i} \quad \text{......(3) (Adu et al., 2018)}$$

In this equation, Index Xiu denotes the standardised index value of the study area. At the same time, Xiu signifies the actual value for each sub-indicator, expressed in formats such as percentages, ratios, degrees Celsius, or counts. Max Xi represents the maximum value for the sub-component across both areas, and Min Xi indicates the minimum value for the indicators in both areas. For indicators expressed as percentages, the maximum value is 100, and the minimum value is 0. Before assigning the maximum and minimum values of MSD (mean standard deviation) of the monthly average of the maximum, minimum, and precipitation, the daily temperature standard deviation is calculated for each month using equation (4).

$$SD = \frac{\sqrt{\sum (X_i - \mu)^2}}{N} \quad \text{......(4) (Gupta, 2014)}$$

In equation (4), SD represents the standard deviation, Xi represents the average monthly value for maximum temperature, minimum temperature, or precipitation, μ represents the mean value of the average monthly data, and N represents the number of months. After calculating the value, the maximum and minimum values are assigned.

Then, the significant components are combined from several sub-components; therefore, using equation (5), the Index value for the primary component is calculated.

$$M_k = \frac{\sum_{i=1}^{n} Index\ Xi}{n} \quad \text{............ (5) (Adu et al., 2018)}$$

In the equation (5), Mk denotes the index value for n principal components. The aggregate of indices Xi represents the summation of the standardised values of all minor components inside the "k" main components, and n denotes the total minor components. Following the computation of the index value for principal components, the LVI for each research region is determined using equation (6).

$$LVI_U = \frac{(W_{SDP}SDP_U + W_{SN}SN_U + W_H H_U + W_W W_U + W_{LS}LS_U + W_F F_U + W_R R_U + W_E E_U + W_{NDCV}NDCV_U}{W_{SDP} + W_{SN} + W_H + W_W + W_{LS} + W_F + W_R + W_E + W_{NDCV}} \quad \text{............ (6)}$$

(Hahn et al., 2009)

In the equation, LVIu represents the index value for each study area, Wx represents the number of minor components under each major component, and finally, SDPu, SNu, Hu, Wu, LSu, Fu, Ru, Eu, and NDCVu are the values calculated by equation (5) for the primary component. The LVI scaled from zero, meaning minimal vulnerability, to 0.6, which means high vulnerability (Adu et al., 2018).

4.3 Determining LVI–IPCC through the IPCC Framework

Another way to calculate livelihood vulnerability is LVI – IPCC. The significant difference between these two methods is that this method uses three weights instead of one to evaluate vulnerability. In this technique, the significant components are categorised into exposure, adaptive capacity and sensitivity. With this more detailed and accurate explanation, vulnerabilities are better understood.

For this three-factor contributing model, the significant component is initially identified using equation (7).

$$CF_c = \frac{\sum_{i=1}^{n} W_{li}\, M_{ic}}{\sum_{i=1}^{n} W_{li}} \quad \text{.........(7) (Yamane, 1967)}$$

In equation (7), CFc denotes the contributing factor value, Wli represents the number of subcomponents beneath the central component for each contributing factor, and Mic signifies the index value for the primary component, as computed using equation (5). Upon determining the contributing component value, the aggregate value (LVI-IPCC) is calculated using equation (8).

(LVI-IPCC) = (E-A) x S …………. (8) (Hahn et al., 2009)

In this equation no (8), E stands for exposure, A stands for adaptive capacity, and S stands for sensitivity. From zero (least susceptible) to one (most vulnerable), the LVI-IPCC Index is ranked (Hahn et al., 2009). The LVI was estimated using Microsoft Office Excel 2013, following the methods provided by Hahn et al. (2009).

4.3.1. Limitations of LVI and LVI-IPCC

The LVI and LVI-IPCC frameworks exhibit drawbacks, including oversimplified aggregation that may overlook intricate relationships, limited local applicability due to their generalised structure, and a static categorisation of vulnerability that does not account for evolving situations over time.

4.4 Comparison of mean value (Independent sample t-test)

This research employed an independent sample t-test to compare the differences in several minor components and validate the LVI value. The equation required for the independent sample t-test is:

$$t = \frac{X1 - X2}{\sqrt{\frac{SDp^2}{N1} - \frac{SDm^2}{N2}}} \quad \text{.........(9) (Gupta, 2014)}$$

In equation (9), t stands for the t-test value, X1 is the mean value of the first group, X2 stands for the mean value of 2nd group, SDp is the standard deviation of the first group, and SDm is the standard deviation of the 2nd group, N1 is the number of observations for the first group and finally N2 stands for several observations for 2nd group.

Ethics Statement

Ethics approval was obtained from the Chairman of the Department of Urban and Regional Planning, Pabna University of Science and Technology (Ethics Committee). Additionally, participants provided informed consent to participate in this study.

5. Results

5.1 LVI between Kutubdia Island and Cox's Bazar's Sadar Upazila

Table no (1) represents the major and minor LVI (Livelihood Vulnerability Index) values adopted for this study at various locations in Cox's Bazar District, with a particular emphasis on dry-fishing communities and industries mainly based on the exploratory analysis of the study area, some key minor-components were developed and modified, which differ from other studies.

Indicator number	Sub-component	Kutubdia	Cox's Bazar's Sadar Upazila	Major component	Kutubdia	**Cox's Bazar's Sadar Upazila**
1	Percentage of Female-headed household	0.17	0.27	Socio-demographic profile (SDP)	0.341	0.354
2	Percentage of household head schooling	0.09	0.12			
3	Percentage of disabled family members	0.07	0.07			
4	Percentage of working members under the age of 15	0.20	0.19			
5	Dependency ratio	0.70	0.65			
6	Percentage of other job opportunities	0.82	0.83			
7	Percentage of dependency on other occupation	0.25	0.28	Livelihood strategies (LS)	0.179	0.250
8	Natural resources and livestock index	0.28	0.40			
9	Percentage of shift to another job after nine-month	0.15	0.17			
10	Percentage of bad condition of business	0.04	0.15			
11	The ratio of money borrowed and land from a neighbour	0.81	0.82	Social Network (SN)	0.464	0.473
12	Percentage of assistance received from government/NGO	0.09	0.21			
13	Percentage of local residency	0.49	0.39			
14	Percentage of deficiency of food faced by the household	0.24	0.19	Food (F)	0.600	0.597
15	Percentage of having three or two times meal	0.69	0.66			
16	Percentage of better food facilities after nine-month	0.87	0.94			
17	Percentage of facing skin problems after working in the dry fish industry	0.24	0.27	Health (H)	0.405	0.367
18	Distance from home to clinic	0.80	0.52			
19	Percentage of health issues due to climate change	0.24	0.27			
20	Percentage of not taking treatment from hospital	0.34	0.41			
21	Percentage of having land	0.95	0.95	Resources (R)	0.808	0.803
22	Percentage of accommodation facilities from the industry owner	0.87	0.78			
23	Percentage of having own house	0.55	0.65			
24	Percentage of households that grow livestock	0.86	0.83			

25	Time to bring drinking water (min)	0.36	0.09	Water (W)	0.324	0.132
26	Percentage of water availability problem	0.39	0.09			
27	Percentage of difference in test of water from near area	0.22	0.21			
28	Percentage of decrease in fish quantity	0.47	0.43	Ecosystem (E)	0.453	0.450
29	Percentage of Disappeared fish species	0.40	0.47			
30	Percentage of decrease in size of the fish	0.45	0.43			
31	Percentage of caught fish with potential for growth	0.49	0.47			
32	MSD of the monthly average of the average maximum daily temperature	0.37	0.26	Natural disaster and climate variability (NDCV)	0.429	0.294
33	MSD of the monthly average of the average minimum daily temperature	0.37	0.24			
34	Number of natural disasters faced	0.68	0.44			
35	MSD of the monthly average precipitation	0.30	0.24			
Total LVI for both areas						
Kutubdia :				0.437		
Cox's Bazar's Sadar Upazila:				0.411		

Note: Indicators 6, 11, 15, 16,21, 22, and 23 have inverse relationship with the vulnerability

Household head schooling (0.12) is higher in Cox's Bazar's Sadar Upazila than in Kutubdia Island, indicating that, in this perspective, Cox's Bazar's Sadar Upazila is more vulnerable than Kutubdia Island. Conversely, the LVI values for the minor components of working members under 15 (0.20), dependency ratio (0.7), and other job opportunities in the area (0.82) indicate that Kutubdia Island is more vulnerable than Cox's Bazar's Sadar Upazila based on these components. As a tourist destination, Cox's Bazar and Sadar Upazila generate more sources of income, followed by Kutubdia. This makes it more convenient for the fraction of family members with disabilities, as the LVI is the same for both places.

The combination of all the sub-factors into one main factor, namely socio-demographic data (SDP). The overall value of LVI for socio-demographic data (SDP) is 0.341 for Kutubdia Island and 0.354 for Cox's Bazar's Sadar Upazila. This means that Cox's Bazar's Sadar Upazila is weaker than Kutubdia Island in terms of socio-demographic factors, as the LVI value is higher for Cox's Bazar Sadar Upazila.

The second major component is Livelihood Strategies (LS), which comprises four minor components. The highest LVI values for Cox's Bazar's Sadar Upazila are observed in dependency on other occupations (0.28), shift to another occupation after nine months (0.17), and poor business conditions (0.15). Therefore, all these minor components indicate greater vulnerability in this area compared to Kutubdia Island. The overall LVI score for the primary component of Livelihood Strategies is also higher for Cox's Bazar's Sadar Upazila, at 0.250, indicating greater vulnerability. This is because, for the sub-component of natural resources and livestock index, Cox's Bazar's Sadar Upazila has a score of 0.40, which is higher than that of Kutubdia Island, where people have better access to natural resources and grow livestock.

The third major component is the Social Network (SN), comprising three minor components. Although the first two minor components have a positive relationship with vulnerability, an inverse relationship is used here. Therefore, despite having lower LVI scores, the ratio of borrowing and lending money, as well as assistance from the government or NGOs, indicates greater vulnerability for Kutubdia Island compared to Cox's Bazar's Sadar Upazila. The last sub-sector, the local residential area, has a higher value for Kutubdia Island (0.49) than Cox's Bazar's Sadar Upazila, indicating a higher vulnerability. The weakness of this overall factor is evident in Cox's Bazar's Sadar Upazila, with a value of 0.473.

The fourth essential element is food (F), including three minor components. All LVI values are higher for the kutubdiya Island (0.600), indicating greater vulnerability. Approximately 34.7% of the households in these two areas are unable to afford three meals a day, and 18.7% of these households are located on Kutubdiya Island. Around 56.7% of households do not face food deficiency while working in the dry fish industry, with 30.7% of these households being from Cox's Bazar's Sadar Upazila. As a result, Cox's Bazar's Sadar Upazila is slightly less vulnerable than Kutubdia Island, with a vulnerability score of 0.597.

The fifth major component, Health (H), shows that Kutubdia Island has a higher overall vulnerability index (0.405), indicating greater vulnerability compared to Cox's Bazar's Sadar Upazila. An independent t-test (table 2) reveals a significant difference in the mean distance from home to clinic (P=0.000 < 0.05). The average distance from home to the clinic for households in Kutubdia is 19.75 km, whereas, in Cox's Bazar's Sadar Upazila, the average distance is 12.79 km. Due to the nature of their work, many individuals face skin problems when handling materials without proper safety measures. According to the respondents in this study, 50.7% of people experience skin issues, with 26.7% of these cases originating from Cox's Bazar's Sadar Upazila.

Table 2. Comparison of Clinic Distances Between two area.

F		Levene's Test for Equality of Variances		t-test for Equality of Means		Mean
		Sig.	t	df		
Distance of clinic from home	Equal variances assumed	31.028	0.000	9.28	148	Kutubdia 19.75km
	Equal variances are not assumed.			9.28	117.72	Cox's Bazar's Sadar Upazila 12.79km

Another important major component is Water (W), which is divided into three minor components. The vulnerability index is 0.324 for Kutubdia Island and 0.132 for Cox's Bazar's Sadar Upazila. As the index is higher for Kutubdia Island, households in this area are more vulnerable to water-related issues. Statistical evidence supporting this finding is provided by an independent sample t-test (table 3), the results of which are detailed below:

Table 3: Comparison of Water Collection Time Between two area.

F		Levene's Test for Equality of Variances		t-test for Equality of Means		Mean
		Sig.	t	df		
Time to bring drinking water	Equal variances assumed	103.21	0.000	7.909	148	Kutubdia 14.45 min
	Equal variances are not assumed.			7.909	92.550	Cox's Bazar's Sadar Upazila 3.79 min

Table 3 shows a significant difference (p=0.000 < 0.05) in the time taken to collect drinking water. Households in Kutubdia Island take an average of about 14.45 minutes, underlining a greater challenge compared to Cox's Bazar's Sadar Upazila, where the average time is just 3.79 minutes.

According to the survey, 82% of households use borewells, and many neighbours in Kutubdia rely on boreholes. Additionally, 8% of homes in Kutubdia and 6.7% in Cox's Bazar's Sadar Upazila utilise electric household appliances. Power tools and downhole wells are also used by 7.3% of homes; Cox's Bazar's Sadar Upazila is home to all of these. In comparison to aspects surrounding Cox's Bazaar, these data emphasise the difficult circumstances Kutubdia Island residents face while attempting to obtain drinking water, thereby intensifying their overall heightened susceptibility. The dry fish business is closely tied to environmental concerns, climate change, and ecology. Fish is a vital part of human nutrition and health, and it forms a significant building block of daily survival due to its high protein and iodine content. Given this, the present research introduces a new primary component called Ecosystem (E), comprising four minor components.

Informed sources through FGD and KII, the sources of raw fish for the Cox's Bazar dry fish sector were found to originate from many other sources, including other countries. Bay of Bengal fish, on the other hand, is the only source of income for the Kutubdia Island industry. It has created dependence, and as such, Kutubdia fishermen and business owners capture fish that might grow bigger. Nonetheless, the values of the vulnerability index for Kutubdia and Cox's Bazar are significantly close, 0.453 and 0.450, respectively, meaning Kutudia Island is somewhat at greater threat. They reported that climate change hurts the ecology of the sea. They further said that fewer and fewer fish are found nowadays compared to the past.

The ninth and final main component is Natural Disaster and Climate Vulnerability-NDCV. Being surrounded by rivers and the sea, Kutubdia experiences a higher frequency of natural disasters. The average maximum temperature per year, which was 32.762°C in Kutubdia and 31.618°C in Cox's Bazar, fluctuated significantly between the two municipal areas from 2013 to 2022. Similarly, Cox's Bazar received an average of 6,934.42 mm of rainfall per year from 2013 to 2022, while Kutudia received an average of 7,044.41 mm. This is the reason behind the increased frequency of floods in Kutubdia. The vulnerability index also establishes this, with a score of 0.429, indicating that Kutubdia Island is more vulnerable than Cox's Bazar's Sadar Upazila. The general conclusion obtained from the findings was that both areas are vulnerable to climate change; however, Kutubdia has a higher score of 0.437 compared with Cox's Bazar's Sadar Upazila at 0.411.

5.2 LVI - IPCC

The first research question regarding the LVI–IPCC is shown in the table (4). According to the IPCC, enhancing climate change adaptation reduces the vulnerability to climate change. According to Table 4, Kutubdia is more exposed to climate change and natural disasters, with a value of 0.429, compared to Cox's Bazar. In addition, Kutubdia also shows greater sensitivity towards the impacts of climate change, at 0.524, compared to Cox's Bazar, at 0.481. The focus group discussions, however, revealed that some modern strategies have been adapted to the dry fish industry in Cox's Bazar's

Sadar Upazila. It is revealed that among the 64.7 per cent of households that solely depend on the dry fish industry, 32.7 per cent come from Cox's Bazar. This has hence provided a high value of the LVI–IPCC for the contributing factor of adaptive capacity, 0.350, indicating that this industry is mitigating low community climate change vulnerability through its adaptation strategies. Overall, the values of IPCC – LVI for Cox's Bazar Sadar are –0.027, and for Kutubdia Island, they are 0.057. According to Hann, the vulnerability scale ranges from –1, indicating less vulnerability, to +1, indicating greater vulnerability (Hahn et al., 2009). Thus, Kutubdia is more vulnerable than Cox's Bazar.

Table 4. LVI-IPCC calculation for constructing factor.

IPCC contributing factors to vulnerability	Cox's Bazar's Sadar Upazila	Kutubdia
Adaptive capacity	0.350	0.319
Sensitivity	0.481	0.524
Exposure	0.294	0.429
LVI–IPCC	-0.027(less vulnerable)	0.057More vulnerable)

This analysis highlights the increased vulnerability of Kutubdia Island to climate change in comparison to Cox's Bazar's Sadar Upazila, underscoring the need for adaptation strategies to mitigate these impacts.

5.3 Role of dry fish industry in poverty alleviation

Economic growth and employment generation are primary mechanisms for poverty reduction. An industry becomes sustainable when it has a sufficiently large and skilled workforce. Table 5 indicates that 36% of respondents have not transitioned to another sector despite having alternative sources of income available to them. Additionally, approximately 51.3% of respondents reported that they do not have an alternative income source aside from the dry fish industry.

Table 5. Cross tabulation between alternative source of income and tendency to shit to another sector.

Crosstab				
Yes		Shift to another sector.		Total
		No		
Alternative source of income	Yes	12.7%	36.0%	48.7%
	No	18.7%	32.7%	51.3%
Total		31.3%	68.7%	100.0%

Figure 3 shows that 39% of respondents are involved in the dry fish industry due to generational ties, 27% lack other skills, and 19% have not found alternative employment in the area. This data indicates that the dry fish industry is the primary sector for employment generation. The Focus Group Discussion report provides an overview of the employment structure, and these two sections highlight how the dry fish industry contributes to poverty reduction through the creation of employment opportunities.

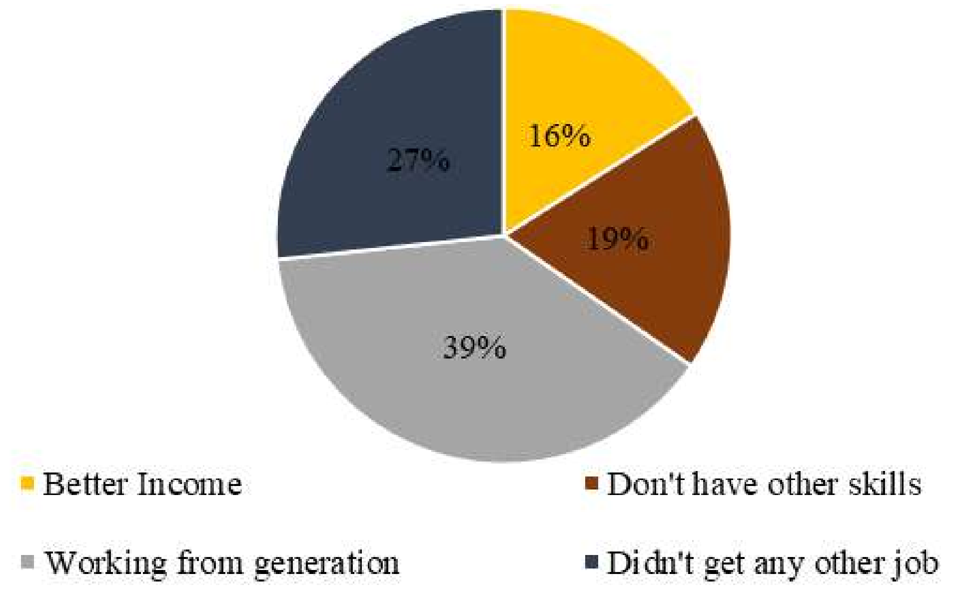

Fig 3. Reason of working in dry fish industries.

5.4 Positive and negative impact of dry fish industries on ecology

The dry fish industry has a direct impact on two grounds: air and water pollution. In Cox's Bazar's Sadar Upazila, the use of chemicals in the industry is more prevalent compared to Kutubdia, where the use is comparatively lower. Again, a considerable amount of waste is generated by this industry, and 84.7% of the waste is disposed of near water bodies (Table 6), which ultimately affects the local ecology. The positive side, however, is that 15.3% of the industries recycle their waste to produce fish food used in land-based fish farming. Another negative impact is the odour produced by the industry, which pollutes the air around it. The waste disposed into water bodies causes it to flow into other places, and the fish populations have decreased compared to their initial levels.

Table 6. Disposal Place of wastage generated from dry fish industry.

		Reuse	Waterbody
Study Area	Kutubdia	1.3%	48.7%
	Cox's Bazar	14.0%	36.0%
Total		15.3%	84.7%

Statistical evidence was also found. A chi-square test (table 7) has been conducted to see if there is any impact of this industry on ecology.

Null hypothesis: There is no effect of chemicals used and processing/catching small fish, which has the potential to grow more in the decreasing of fish size, decreasing in the quantity of fish and disappearance of fish species.

Alternative hypothesis: There is an effect of chemicals used and the processing and catching of small fish, which has the potential to lead to a decrease in fish size, a decrease in fish quantity, and the disappearance of fish species.

Table 7. Chi-square test to explore impact in ecology.

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	11.545[a]	1	0.001		
Continuity Correction	5.808	1	0.016		
Likelihood Ratio	5.508	1	0.019		
Fisher's Exact Test				0.026	0.026
N of Valid Cases	150				
Phi = 0.277					

The Pearson chi-square value is 0.001 < 0.05, so the null hypothesis is rejected, indicating a significant impact of chemical use on the catch of small fish, which has the potential to grow more, contributing to the decrease in fish size, quantity, and disappearance of fish species. The phi value is 0.277, indicating a moderate impact. Moreover, another impact is identified through the Focus Group Discussion (FGD) mentioned below.

5.5 Report of Focus Group Discussion

Two FGDs were conducted in different locations of the Cox's Bazar district, one in Nazirartek (Cox's Bazar's Sadar Upazila), where the largest dry fish industries are located, and another in Kutubdia Island. A group of 6 to 8 people attended the discussion. The "Ecosystem" component was included in response to persistent input from key informant interviews and focus group discussions. Participants underscored the significance of natural systems for sustenance and climate resilience. Their contributions identified a deficiency in the original framework and facilitated the delineation of pertinent indicators, ensuring the component aligned with local goals and environmental conditions. The objective of the FGD was:

- To explore the problems of the people.
- Employment scenario in every stage of the drying process.
- The impact of environmental change on the lives and ecosystems.
- To explore the adaptation strategies they adopt against climate change.

Findings on Employment: There are several differences between these two points in terms of connectivity, investment opportunities, job options, and causes of the jobs. The raw materials, that is, fish, are gathered in two ways. At the Kutubdia point, the industry owners catch fish directly from the Bay of Bengal. However, at Nazirartek Point, the industry owners purchase fish from suppliers' third-party owners located near the industry site or from Chittagong.

These collected fish are sent to the sorting area by 4-5 workers. For the sorting process, 10-15 workers are appointed daily. Again, around 9-10 workers are appointed on a nine-month contract basis, each with a fixed salary. They not only sort out the fresh fish but also spread the selected fishes on elevated platforms from the ground, locally called "Macha."

However, the wages are too low for the laborers. According to Habiba, a day labourer from Nazirartek, they earn 400 BDT per day, and the availability of work is 18-20 days per month. In contrast, female labourers from Kutubdia receive 200 BDT per day for the same work. The prepared fish are then cut or uncut and set to dry for 10 to 14 days. After this period, the workers sort the dried fish again to better quality. This industry is highly effective in creating employment, generating income for residents, increasing government revenue, and reducing poverty in this region.

Findings on the impacts of climate change on ecology: Ecology is the primary victim of climate change, and it highly affects companies whose core business depends on natural resources, such as the dried fish industry. This industry is entirely dependent on raw fish from the ocean and the fishermen and workers who have been associated with it for generations. Their observations and experiences can be cited as important evidence about climatic changes and their effect on the ocean ecosystem. According to the household survey, approximately 38.67% of respondents have been involved in this industry for generations.

From Kutubdia, Moin Uddin, a fisherman and businessperson of the dry fish industry, said, "Earlier, we needed to run the boat for only 1.5 hours and catch a sufficient amount of fish".

"Nowadays, we have to drive 4-6 hours and still do not get as much fish as before." Likewise, another dry fish businessman, Mir Kashem, said, "Earlier, we used to dry 20 tons of fish every month. Nowadays, we hardly manage to get 10 tons of raw fish to dry." Having observed this phenomenon, a fisherman named Minhaj remarked, "One type of fish which turns colour with the water's hue, like the jellyfish, has increased immensely in recent times. Because of them, other fishes are abandoning the place, and so we catch very few." He informed that 10 species of fish, locally called Patra, Arfula, Chaindavuga, Lakka, some kinds of shrimp, and Guara, had either vanished or their number decreased over time.

Mir Kashem also mentioned that the uncertain rainfall hampered fish drying badly, causing losses. In such cases, to recover losses, they typically take out loans at a high interest rate.

Adaptation Strategies: Although people cannot control climate change, its impacts are pervasive; however, they can adopt strategies to mitigate its harmful effects. In this research, the following adaptation strategies adopted by the respondents of Narirartek, Cox's Bazar are:

1. Adoption of Smart Solar Sun Dryers.
2. Diversification in fish drying techniques.
3. Diversification of livelihoods.
4. Adoption of storage systems for raw and dried fish (In limited industry).

In contrast, the people of Kutubdia are far behind in adopting adaptation strategies. The present strategies being adopted by them are:

1) changing fishing grounds,

2) taking loans,

3) diversifying livelihoods through the salt industry and cultivation of groundfish and

4) using nets, which is forbidden by the government.

6. Discussion

6.1 Field observations versus results

Field observations have recorded that, compared to other areas, Cox's Bazar's Sadar Upazila has better schooling facilities and a far more developed communication system. These, among other minor components of adaptive capacity, place Cox's Bazar's Sadar Upazila at a relatively high level of resilience. Many working NGOs are involved in the region, and a well-developed market with substantial investment and technological development ensures job opportunities. Being an urbanised area, Cox's Bazar's Sadar Upazila offers various alternative employment opportunities. Secondly, most of the employers in Cox's Bazar's Sadar Upazila provide accommodation facilities to their workers, which is certainly not a typical case in Kutubdia. It can be inferred from these observations that the vulnerability is lower in Cox's Bazar's Sadar Upazila due to its high adaptive capacity. In support, it can be seen from the LVI calculations represented in Figures 4 and 5 that adaptive capacity in Cox's Bazar's Sadar Upazila is higher compared to the other areas.

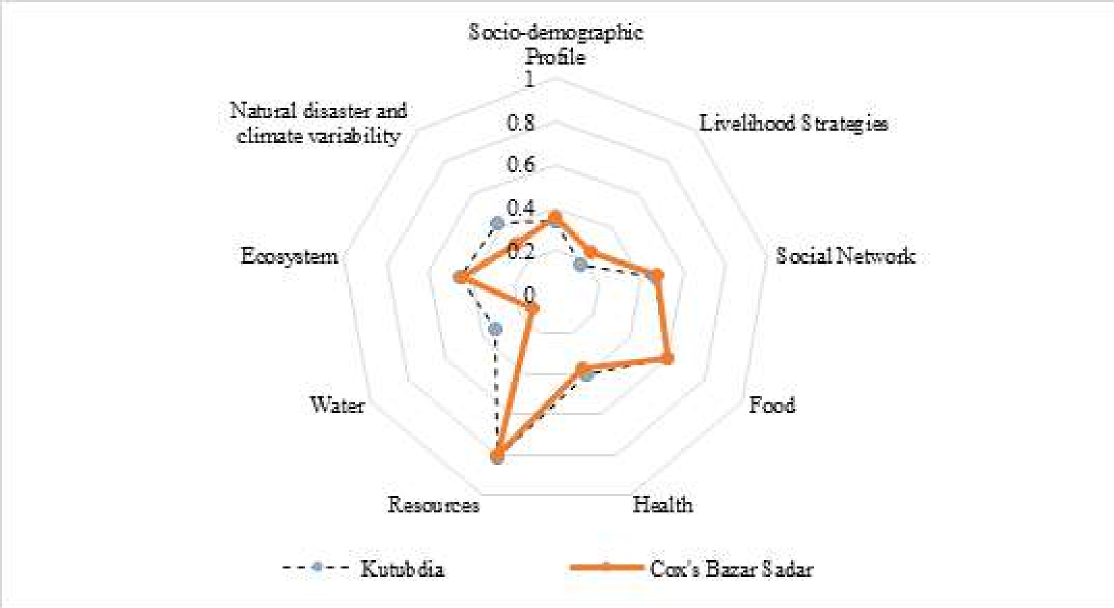

Fig 4. Spider diagram of major component.

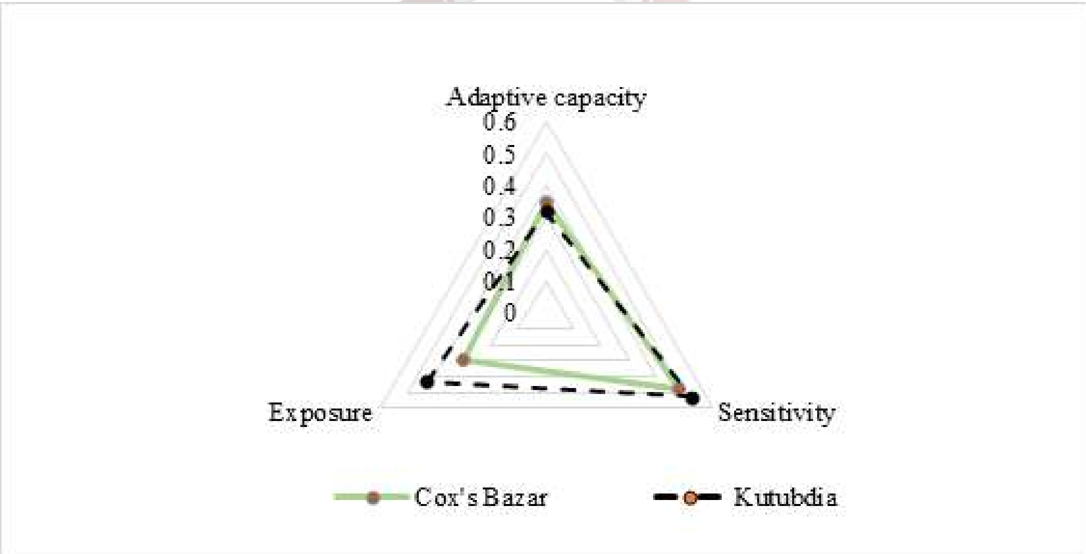

Fig 5. Triangle diagram from LVI-IPCC of study area.

Regarding exposure, critical areas have been identified through field observations in Kutubdia. The housing conditions are not good, and almost all the houses are made of bamboo and tin, making them easily destroyable. According to the survey, 100% of respondents and the community expressed an urgent need for improvement in the water supply, specifically regarding the adequate number of tube wells. The access roads also remain seriously damaged, mainly due to frequent natural disasters. People become accustomed to these disasters and do not fear them, although the proximity of homes and industries to the Bay of Bengal—less than 200 meters in many places—raises their risk factor. In contrast, the case of Cox's Bazar's Sadar Upazila is different. Houses are located 1 to 5 kilometres away from the seashore, with good road connectivity and a high percentage of brick wall houses. Cox's Bazar's Sadar Upazila is also prone to various types of natural disasters; however, the frequency and intensity are much lower than in the case of Kutubdia.

Field observations indicate that Kutubdia is more exposed to climate change impacts than Cox's Bazar's Sadar Upazila. The findings shown in Figures 4 and 5 indicate that Kutubdia has a heightened susceptibility to natural catastrophes and climatic variability, hence rendering it more sensitive to climate change.

Geographically, the two areas are separated by a very short distance; hence, their ecosystems and resources are almost identical. People from these two regions share similar practices, including rearing livestock and poultry, as well as tree plantations. However, the quality of water in Kutubdia is significantly poorer than in Cox's Bazar.

Health is yet another crucial parameter where Cox's Bazar's Sadar Upazila has clear advantages. The area has over three to four hospitals, including a government hospital with competent doctors and more than one dispensary within a half-kilometre distance. In contrast, Kutubdia has only one hospital, which is uninhabited, with most houses vacant and lacking competent medical staff and equipment. There is also the scarcity of job availability and lower wages in Kutubdia, which make it impossible for most people to afford three meals a day or even food with the right amount of nutrition.

These observations collectively suggest that Kutubdia is more vulnerable in terms of exposure, indicating that its sensitivity and overall vulnerability will be higher, as shown in Figures 4 and 5.

Table 8 presents the results of the paired two-sample t-test, evaluating the mean values of critical components in the study areas to determine if there is a significant difference between them. Table 8 indicates that the p-values for all major components are < 0.05. As a result, all null hypotheses have been rejected, indicating a statistically significant difference between the two sites for all essential components.

Table 8. Two-sample t-test results between Cox's Bazar and Kutubdia for the primary component.

Major Components	Mean	Std. Deviation(SD)	Standard Error Mean	t-value	Degree of freedom	Significance (2-tailed)
Socio-Demographic Profile	1.15	0.61	0.18	6.53	11	0.00
Livelihood Strategies	1.29	0.58	0.21	6.25	7	0.00
Social Network	1.03	0.63	0.26	4.01	5	0.01
Food	0.90	0.63	0.26	3.50	5	0.02
Health	1.11	0.55	0.19	5.75	7	0.00
Resource	0.69	0.55	0.19	3.57	7	0.01
Water	1.27	0.45	0.18	6.95	5	0.00
Ecosystem	1.05	0.53	0.19	5.55	7	0.00
Natural Disaster and Climate Variability	1.14	0.48	0.17	6.71	7	0.00

6.2 Justification of results by comparing with other research

According to a study by Toufique and Yunus, the LVI for the socio-demographic profile of coastal areas was 0.348 (Toufique & Yunus, 2013). As can be noted, our results, which range between 0.341 and 0.354, are very close to that analysis. Additionally, their study suggests that people residing near the sea are more susceptible than those residing some distance away from it. This is also consistent with our findings, where Kutubdia, being a place close to and surrounded by the sea, shows higher vulnerability, with an LVI value of 0.437. The same applies to Cox's Bazar, which is also situated in a coastal area but is significantly less vulnerable, with a slightly lower LVI value of 0.411, thereby placing it at a relatively safe distance from the ocean.

According to ACAPS 2020 (ACAPS, 2020) in a report entitled "Cox's Bazar Upazila Profiles," 70% of Cox's Bazar's Sadar Upazila's economy is driven by occupations in trade and service industries, including hospitality, labour, and trade-related to fishing, together with small and medium enterprise industries. Next in importance are occupations in manufacturing and industry, particularly in construction. On the other hand, the economy of Kutubdia is primarily based on agriculture and fishing, which suggests a lower level of employment compared to that in Cox's Bazar's Sadar Upazila. It thus somewhat closes the economic gap, as our study's findings show that the dependency level on specific jobs and the difficulty in switching to another job are higher in the case of Kutubdia.

On the aspect of natural disasters, what also emerged in the ACAPS report (ACAPS, 2020) was that while both regions are vulnerable, Cox's Bazar's Sadar Upazila is not likely to experience a direct hit of cyclones, though remaining susceptible to the effects of strong winds, storm surge, and flooding. In contrast, Kutubdia reportedly faces more climatic vulnerabilities, including climate-induced displacements resulting from various disasters, saltwater overflow, and extreme drought during summer days, which hinder agricultural practices. All these make Kutubdia more vulnerable, with an LVI score of 0.429 against 0.294 for Cox's Bazar's Sadar Upazila upazila. This further confirms the conclusion drawn from our study.

Our research also examines the skills of local people in both areas and further investigates how the dry fish industry contributes to poverty reduction. A study by Ullah and Uddin (2015) was conducted in Moheskhali, an Upazila of Cox's Bazar district, which is similar to Kutubdia. Their study further shows that almost all dry fish producers belong to the low-income group; despite several development programs, efforts to alleviate poverty have not been able to reach the poorest segments of society. The dry fish industry is very prominent, with an ever-increasing demand in both local and international markets, indicating a growing potential for income and employment.

Comparative research findings indicate that, overall, wages and employment are higher in Cox's Bazar's Sadar Upazila, as it has a high demand and a larger market for dry fish. This industry is pivotal for reducing poverty in this area, thus showing that the economy is progressing differently in Cox's Bazar's Sadar Upazila compared to Kutubdia. It calls for focused interventions to overcome the vulnerabilities identified in the latter sub-district.

Finally, this study found that the people of these coastal areas face socio-economic difficulties and lack access to alternative job opportunities. A similar study conducted in Nigeria found that natural disasters brought socioeconomic distress to the victims (Ogunleye & Arohunsoro, 2024). Another research in Hong Kong reveals that the coastal region confronts issues of elevated poverty rates and significant deterioration of coastal resources (Sekarningrum & Yunita, 2019). This aligns completely with this study.

6.3 Advantages and disadvantage of Smart Solar Sun Dryer as an Adaptation Strategy

The Smart Solar Sun Dryer is a technique that utilises solar energy to dry fish. Majorly it involves placing the solar panel on top of a greenhouse-like structure. Through solar energy, the setup could drive a heater that provides the required temperature for drying fish. During the field visit, it was found that two organisations, including the Coastal Foundation and the Ministry of Fisheries and Livestock, have experimentally provided this technology to local users. The benefits and drawbacks of this were noted after using it for months.

Advantages:

- No Electricity Needed: It does not use a single watt of electricity.
- Better Quality: It produces fish of higher quality than traditional drying methods.
- Drying in any Weather Condition: It can be used even on rainy days for drying purposes.
- Efficient: It can dry the fish in less than a week.
- Less Labour Needed: Manpower required to dry fish is reduced.
- Eco-Friendly: The mechanism is easy to handle and eco-friendly.

• Higher Market Value: Dried fish produced through this technique commands higher market prices. While traditionally dried fish is sold at 1,200 BDT per kilogram, fish dried with the solar sun dryer is sold at 2,000 BDT per kilogram.

Disadvantages:

- Insect Infestation: Treated with chemicals to prevent insect attacks after some days.
- Lower Quantity: The quantity of the output is lower compared to traditional drying techniques.
- Financial Losses: The lower quantity puts the seller in a dilemma about how to sell more fish, thereby sustaining financial losses.

Against the backdrop of changing climate conditions, sudden rainfall, and natural disasters, the Smart Solar Sun Dryer acts as an effective alternative. Whereas the traditional methods have to remain suspended during the rainy seasons and often get damaged by sudden rainfall, this solar-based strategy enables continuous processes and thus becomes resilient for fish drying in inclement weather conditions.

7. Conclusion and Recommendations

The coastal area of Bangladesh is prominent for its fisheries, salt production, and dry fish industries. Dry fish, being a preservable product, is an excellent attraction to national and international tourists. A large group of local people has been engaged in this industry for so many decades. This community and the business are greatly affected and dependent upon environmental factors, especially climate. It is among the significant sources of employment for the illiterate and other marginalised members of society.

This study will analyse the effects of climate change on the livelihoods of those engaged in this business using the IPCC-LVI methodology. It will hence attempt an in-depth analysis of all the various sectors of livelihood in the community. The research also attempts to discover how this industry works towards reducing poverty and is one important avenue that enables poverty reduction in these areas.

Specific to this research, the study identifies unique adaptation strategies developed by communities in their fight against climate change. This adds new minor and major components related to the livelihoods of this community and the dry fish industry, aspects that previous research has not addressed but are instrumental in understanding the sector. These findings can serve as a guideline to help frame the supply chain framework and are likely to attract the attention of government authorities as the industry continues to be fragmented and unorganised.

The current study recommends more vibrant NGO support in Kutubdia compared to Cox's Bazar's Sadar Upazila, as Cox's Bazar's Sadar Upazila has already received privileged support. The people of Kutubdia are the most vulnerable and suffer the most; hence, support is essential in this direction.

Project-Based Implementation of Smart Technology and Machinery: Smart technology and machinery should be introduced on a project basis, accompanied by low interest rates and flexible instalments. For example, "Aman Traders," a company in Cox's Bazar's Sadar Upazila, has achieved enormous success by adopting innovative technology and has already been endorsed and awarded by the government.

Policy and Framework Development: Policies and frameworks should be formulated to guide the timing of fish harvest and storage. Through the implementation of the time-bound fishing approach, it would be easier to enforce the storage of fish to be dried using innovative technology during off-seasons, thereby reducing the environmental and ecological impact.

Market Framework Development: Design a comprehensive framework for the market, enabling better organisation and continued investment attraction, thereby enhancing market value. This will generate new employment opportunities, higher incomes, and scaling up businesses.

Health Effects of Chemical Use in Smart Solar Sun Dryers: This study will investigate the potential health effects of chemical use in Smart Solar Sun Dryers and whether it can lead to health issues in the local population.

Controlling the Disadvantages of Smart Solar Sun Dryers: This will involve identifying ways to mitigate the current disadvantages of Smart Solar Sun Dryers, thereby enhancing their effectiveness and efficiency.

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