

Assessing Social Vulnerability to Cyclones in Coastal Bangladesh: A Livelihood and IPCC-VI Based Analysis of Kalapara Upazila

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Abstract: This study evaluates cyclone-induced social vulnerability in Kalapara Upazila, Bangladesh, using the Livelihood Vulnerability Index (LVI) and IPCC Vulnerability Index (IPCC-VI) frameworks. Based on responses from 180 households representing approximately 540 individuals, the analysis highlights that Latachapli, Khaprabhanga, and Lalua unions exhibit the highest vulnerability scores (LVI = 0.37; IPCC-VI = 0.026, 0.024, and 0.023 respectively). These unions are highly exposed (EI > 0.41) and moderately sensitive (SI \approx 0.34), but only modestly adaptive (AI \approx 0.34), making them the most at risk. Survey results indicate that 100% of respondents reported cyclone shelters in poor condition and 95% noted inefficiencies in relief distribution, lack of housing guidelines (90%), and weak coordination between government agencies and NGOs (87%). Cyclone impact data show significant damage from past events, including 94 deaths during Sidr (2007) and widespread housing and infrastructure losses. Despite improvements in early warning dissemination—evidenced by a reduced death toll of just 3 during Mahasen (2013)—critical challenges remain in local preparedness, institutional coordination, and livelihood protection. This study underscores the urgent need for localized, multi-dimensional adaptation strategies that strengthen cyclone shelters, improve disaster governance, and address socio-economic fragilities to enhance community resilience in coastal Bangladesh.

Keywords: Cyclone vulnerability, livelihood vulnerability index (LVI), IPCC vulnerability index (IPCC-VI), climate resilience

Introduction

The frequency and intensity of natural hazards have significantly increased in recent decades (Huggel et al., 2015; Aksha et al., 2019; Islam et al., 2017, 2020). This escalation has amplified interactions between humans and the environment, exposing people and assets to greater risk and increasing community vulnerability. The concept of vulnerability, initially developed by social scientists in the 1970s, provides a valuable lens through which to examine risk perception and disaster impact across different populations (Wisner et al., 2004; Birkmann, 2006; Schneiderbauer & Ehrlich, 2004).

Social vulnerability (SV) refers not merely to the physical proximity to hazards but to the social, economic, and political conditions that influence a population's ability to anticipate, respond to, and recover from disasters (Yoon, 2012; Juran & Trivedi, 2015). These disparities

explain why identical hazards may affect communities in drastically different ways (Morrow, 2008). Despite growing academic interest, holistic analyses of social vulnerability in cyclone-prone areas remain limited. SV arises from structural inequalities—such as income disparity, marginalization, and lack of political agency—which stratify society and hinder adaptive responses (Chen et al., 2013). Hence, understanding the socio-economic and political context of at-risk populations is essential for effective disaster risk reduction (Ribot, 2009). In Bangladesh, coastal communities are particularly susceptible due to widespread poverty, high dependence on natural resources, limited infrastructure, and exposure to multiple hazards, including cyclones, storm surges, flooding, riverbank erosion, and sea-level rise (Kibria, 2011; Alam et al., 2018; Islam et al., 2014; Rahman & Islam, 2019). Between 1877 and 2009, Bangladesh experienced over 150 cyclones, many of which inflicted catastrophic losses. For instance, Cyclone Aila (2009) displaced 3 million people, while Cyclone Sidr (2007) caused 3,406 fatalities and extensive property damage (Mallick et al., 2011; Paul, 2009). Vulnerability is heightened by socio-demographic variables such as age, gender, education, housing quality, and access to sanitation and health services (Chen et al., 2013). Thus, SV is a multidimensional construct that requires comprehensive assessment for effective mitigation planning (Cutter & Finch, 2008; Armas, 2008; Mendes, 2009).

The Social Vulnerability Index (SoVI) developed by Cutter et al. (2003) has become a widely used framework for evaluating SV in diverse regions including Asia (Zhou et al., 2014), Africa (Apotsos, 2019), Latin America (Hummell et al., 2016), and Europe (Torok, 2017). Local adaptations of SoVI, such as those by Le Roux et al. (2015) in South Africa and Aksha et al. (2019) in Nepal, demonstrate its versatility in capturing context-specific vulnerabilities and resilience capacities.

This study aimed to assess social vulnerability to cyclones in Kalapara Upazila using two well-established frameworks: the Livelihood Vulnerability Index (LVI) and the IPCC Vulnerability Index (IPCC-VI). It examined the core components of vulnerability—exposure, sensitivity, and adaptive capacity—to identify the unions most at risk and the underlying factors contributing to their vulnerability. The study also explored farmers' and community members' perceptions of cyclone impacts on livelihoods, agriculture, health, education, and essential services. In addition, it evaluated the effectiveness of local disaster management mechanisms, including cyclone shelters, early warning systems, and institutional coordination, which are crucial for enhancing resilience in cyclone-prone areas.

Although disaster vulnerability in coastal Bangladesh is well documented, there remains a critical gap in localized, multi-indicator assessments using standardized tools like the LVI and IPCC-VI. Many existing studies overlook the interaction between social vulnerability and environmental hazards at the micro level—particularly at the union level, where disaster impacts are most acutely felt. Furthermore, limited research has captured the perceptions of farmers and communities regarding disaster preparedness, shelter infrastructure, and institutional response, despite these being essential factors in designing effective and context-specific resilience strategies.

By filling these gaps, this study offers both academic value and practical relevance. It contributes to the literature on climate vulnerability assessment by applying globally recognized frameworks in a local setting and highlights the importance of combining quantitative indices with qualitative insights. For policymakers, disaster managers, and development practitioners, the findings provide actionable evidence to guide the formulation of targeted adaptation strategies, infrastructure investments, and community-based disaster risk reduction (DRR) programs. Ultimately, the study supports the broader goal of achieving climate-resilient development in one of the most vulnerable coastal regions of Bangladesh.

Materials and Methods

Selection of Study Area

KalaparaUpazila, located between 21°48' to 22°05' North latitude and 90°05' to 90°20' East longitude (BBS, 2021) (Figure 1), is a cyclone-prone coastal region in the Patuakhali district of southern Bangladesh. The upazila comprises nine union parishads, 58 mauzas, 217 villages, one paurashava, nine urban wards, and 24 mahallas (BBS, 2021). As per the Bangladesh Bureau of Statistics (2021), it has a population of 237,831 and an average literacy rate of 34.9%.

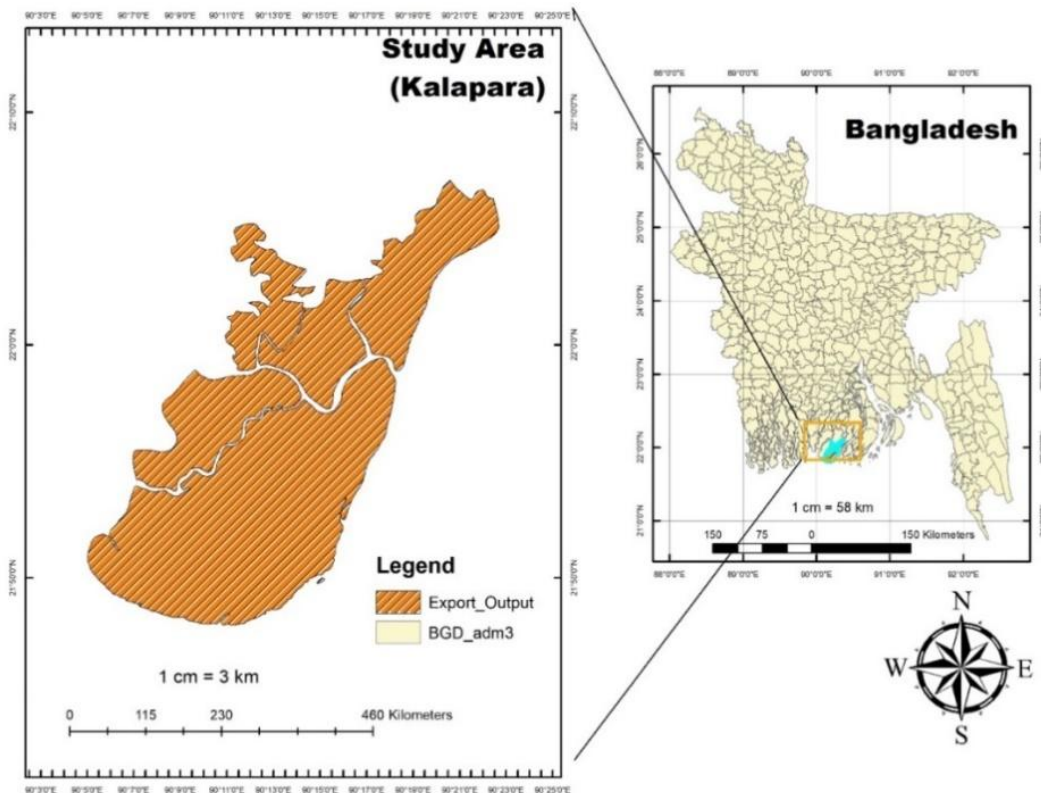


Figure 1. Study area of KalaparaUpazila

Description of the Study Area

The primary occupations in the region include agriculture and fishing, which are highly sensitive to climate and environmental changes. Kuakata Beach, a prominent tourist destination located in Kalapara, plays a crucial role in the local and national economy but is under constant threat from coastal erosion and tidal activity. The region's socio-economic vulnerability is exacerbated by environmental hazards, making it a relevant case study for cyclone-related risk assessment (Ahamed et al., 2012; CEGIS & GoB, 2013; Hasan & Akter, 2019).

Methods of Data Collection

Primary and Secondary Data Collection

This study is based on both primary and secondary data sources. Primary data were gathered through household surveys, informal interviews, and focus group discussions (FGDs). A total of 180 households, comprising approximately 540 adult individuals, were selected using a random sampling technique. Given the large population size, the use of Cochran's sample size formula (1977) is appropriate and therefore justified for determining the required sample of 540 individuals. The structured questionnaire was pre-tested and revised with expert input before final implementation.

The questionnaire comprised seven thematic sections that addressed various dimensions of vulnerability. These included (i) demographic characteristics, (ii) socio-economic status, (iii) livelihood strategies, (iv) disaster vulnerability, (v) water usage, (vi) sanitation conditions, and (vii) access to healthcare. Respondents represented a range of occupations, including farmers, day laborers, business owners, service workers, housewives, teachers, and fishermen.

Secondary data were obtained from government and non-governmental organizations, research publications, and institutional reports. Key sources included the Bangladesh Bureau of Statistics, Disaster Management Bureau, Upazila Disaster Management Committee, Patuakhali Zila Parishad, and local NGOs. Data analysis was conducted using ArcGIS (v10.5) and Microsoft Excel (2007).

Vulnerability Assessment Approaches

To measure vulnerability, this study employed the indicator-based approach, which is more adaptable and less statistically demanding than econometric techniques (Deressa et al., 2009). This approach allows tracking of changes in vulnerability across space and time, aiding in both diagnosis and policy planning (Adger et al., 2009).

Two established frameworks were applied: the Livelihood Vulnerability Index (LVI) (Hahn et al., 2009) and the IPCC Vulnerability Index (IPCC-VI) (IPCC, 2001). These frameworks use multiple indicators to capture dimensions of exposure, sensitivity, and adaptive capacity in the context of cyclone hazards.

Livelihood Vulnerability Index (LVI)

The Livelihood Vulnerability Index (LVI) developed by Hahn et al. (2009) was used to assess the multidimensional aspects of vulnerability in the study area. The LVI framework is built on seven major components: Socio-Demographic Profile (SDP), Livelihood Strategies (LS), Health (H), Food (F), Water (W), Natural Disaster & Climate Variability (ND), and Social Networks (SN). These components are organized under three contributing factors aligned with the IPCC vulnerability framework: Exposure, Sensitivity, and Adaptive Capacity.

All indicators were normalized using min–max normalization:

$$X_{ij}^{norm} = \frac{X_{ij} - \min(X_i)}{\max(X_i) - \min(X_i)} \quad (1)$$

(Hahn et al., 2009).

Where:

- X_{ij}^{norm} = normalized value of the j-th observation for the i-th variable
- X_{ij} = actual value of the i-th indicator for the j-th unit
- $\min(X_i)$ = minimum value of the variable i
- $\max(X_i)$ = maximum value of the variable i

Each component index M_j was calculated by averaging the normalized values of its indicators:

$$M_j = \frac{\sum X_{ij}}{n} \quad (2)$$

(Hahn et al., 2009).

Where:

- M_j = the component index for component j
- X_{ij} = the normalized value of the i-th indicator within component j
- n = the number of indicators within that component
- $\sum X_{ij}$ = the sum of all normalized indicator values for component j

Then, the Contributing Factor Score (CF) for each of the three dimensions (Exposure, Sensitivity, and Adaptive Capacity) was calculated:

$$CF_k = \frac{1}{m} \sum_{j=1}^m M_j \quad (3)$$

(Hahn et al., 2009).

Where:

- CF_k = Contributing Factor Score for factor k (e.g., Socio-demographic Profile, Livelihood Strategies, Health, etc.)
- M_j = Component index within contributing factor k
- m = Number of components that make up the contributing factor

- $\sum M_j$ = Sum of component indices under the contributing factor

Finally, the overall LVI was calculated as a weighted average of the three contributing factors. For the LVI-IPCC format, the vulnerability score is computed as:

$$\text{LVI-IPCC} = (E+S) - A \quad (4)$$

(Hahn, et al., 2009)

Where:

- E, S, and A represent the composite scores for Exposure, Sensitivity, and Adaptive Capacity, respectively

The final LVI scores range from 0 (least vulnerable) to 1 (most vulnerable). Spatial units (e.g., unions) are ranked based on their LVI scores to identify areas requiring urgent intervention and adaptation planning. Higher scores indicate greater livelihood vulnerability to climate variability and natural disasters.

IPCC Vulnerability Index (IPCC-VI)

The assessment of vulnerability in this study follows the Intergovernmental Panel on Climate Change (IPCC) vulnerability framework, which conceptualizes vulnerability as a function of three main components: Exposure (E), Sensitivity (S), and Adaptive Capacity (A). According to the IPCC (2007), vulnerability is defined as:

$$\text{Vulnerability} = (\text{Exposure} + \text{Sensitivity}) - \text{Adaptive Capacity} \quad (5)$$

Each component was constructed from normalized indicators using the same min-max scaling approach. The average of normalized indicators was used to derive the respective scores for Exposure, Sensitivity, and Adaptive Capacity:

$$CF_k = \frac{1}{m} \sum_{j=1}^m M_j \quad (6)$$

(Hahn et al., 2009).

Where M_j represents the normalized indicator values under each component. Once calculated, the IPCC-VI score was used to rank administrative units (e.g., unions) in terms of their relative vulnerability to climate-related hazards. Higher scores indicate greater vulnerability.

Social Vulnerability Mapping Criteria

Eight socio-demographic criteria were selected for spatial vulnerability mapping, based on their relevance to cyclone exposure and community fragility. These criteria include population density, dependent population (children and elderly), disabled population, female-headed households, wooden housing, household's dependent on ponds or other informal water sources, absence of sanitation facilities, and agriculture-dependent households. Population density data were obtained from the 2011 national census. Higher values across these criteria indicate greater vulnerability.

Results and Discussion

Assessment of the Level of Social Vulnerability Using LVI and IPCC-VI

Assessing social vulnerability requires a multidimensional approach that captures both environmental exposure and socio-economic sensitivity. The Livelihood Vulnerability Index (LVI) and IPCC Vulnerability Index (IPCC-VI) frameworks provide standardized tools for quantifying community-level vulnerability to climate-induced hazards such as cyclones. In this study, these indices were applied to evaluate and compare the vulnerability status of different unions within KalaparaUpazila, identifying areas most at risk and the underlying drivers of that vulnerability.

Vulnerability Assessment Using LVI

The Livelihood Vulnerability Index (LVI) results show variation in vulnerability across unions in Kalapara (Table 1).

Table 1. LVI Scores for Different Unions in KalaparaUpazila

Union	LVI Score	Rank
Latachapli	0.37	1
Khaprabhanga	0.37	1
Lalua	0.37	1
Tiakhali	0.34	2
Nilganj	0.34	2
Mithaganj	0.32	3
Dhulasar	0.30	5
Dhankhali	0.32	3
Chakamaiya	0.31	4

The Livelihood Vulnerability Index (LVI) from equation, as proposed by Hahn et al. (2009), is a composite index that captures the vulnerability of communities to climate-related hazards based on a range of contributing factors, including socio-demographic characteristics, livelihood strategies, health, food, water, and natural disaster exposure. Table 1 presents the LVI scores for various unions in KalaparaUpazila, revealing notable variations in vulnerability levels across the region. The unions of Latachapli, Khaprabhanga, and Lalua exhibit the highest vulnerability, each with an LVI score of 0.37, and are jointly ranked first. This indicates that these areas face the most significant livelihood challenges and are potentially the most exposed and least adaptive to climate-induced stresses, likely due to factors such as high population density, dependence on climate-sensitive occupations, and poor access to basic services.

The second tier of vulnerability includes Tiakhali and Nilganj, both with an LVI score of 0.34, suggesting moderate but still significant levels of risk. Mithaganj and Dhankhali follow closely with scores of 0.32, ranked third, indicating a slightly lower level of vulnerability but still

necessitating targeted interventions. Chakamaiya, with a score of 0.31, is ranked fourth, while Dhularsar, with the lowest LVI score of 0.30, is ranked fifth, suggesting relatively better resilience compared to other unions. This distribution of LVI scores underscores the importance of localized policy responses. While all unions show some degree of vulnerability, those ranked highest—particularly Latachapli, Khaprabhanga, and Lalua—should be prioritized in terms of livelihood support programs, infrastructure development, and disaster preparedness initiatives. The LVI approach thus provides a practical tool for identifying spatial inequalities in vulnerability and guiding resource allocation for climate adaptation planning.

Vulnerability Assessment using IPCC-VI

The IPCC-VI approach confirmed findings from the LVI. Latachapli, Khaprabhanga, and Lalua emerged as the most vulnerable unions, primarily due to high exposure and low adaptive capacity (Table 2).

Table 2. IPCC-VI Scores and Rankings

Union	Exposure (EI)	Sensitivity (SI)	Adaptive Capacity (AI)	IPCC-VI	Rank
Latachapli	0.417	0.335	0.342	0.410	1
Khaprabhanga	0.418	0.342	0.350	0.410	1
Lalua	0.410	0.342	0.343	0.409	3
Nilganj	0.340	0.400	0.289	0.451	4
Tiakhali	0.336	0.389	0.286	0.439	5
Dhularsar	0.319	0.325	0.270	0.374	6
Mithaganj	0.310	0.385	0.277	0.418	7
Dhankhali	0.316	0.370	0.285	0.401	8
Chakamaiya	0.310	0.345	0.279	0.376	9

Table 2 presents the vulnerability scores of nine unions in KalaparaUpazila using the IPCC-VI framework. The analysis reveals that Latachapli and Khaprabhanga share the highest vulnerability score (0.410), placing them jointly at Rank 1. These unions are located in coastal zones that are highly exposed to tropical cyclones, storm surges, and salinity intrusion. Both have relatively high exposure (0.417 and 0.418) and moderate sensitivity scores, but their adaptive capacities (0.342 and 0.350) are not strong enough to offset their exposure to climate-related hazards. This reflects challenges such as dependence on fishing and agriculture, weak infrastructure, and insufficient access to early warning systems. Lalua, with a nearly equivalent vulnerability score (0.409), is ranked third. It also shows a high combination of exposure and sensitivity, and only modest adaptive capacity. These unions illustrate the classic case where high environmental exposure and socio-economic fragility compound climate risks, especially in low-lying, hazard-prone areas.

Nilganj and Tiakhali follow with scores of 0.451 and 0.439, respectively. These unions have higher sensitivity indices (0.400 and 0.389), indicating significant social and economic

fragility—such as poor access to healthcare, education, and clean water. Their adaptive capacities (both below 0.290) suggest that while they may not be the most exposed, they are highly sensitive and poorly equipped to cope with climate shocks.

The unions of Dhularsar, Chakamaiya, Mithaganj, and Dhankhali exhibit comparatively lower vulnerability scores (ranging from 0.374 to 0.401). These areas demonstrate a more balanced profile, where moderate exposure and sensitivity are somewhat mitigated by better adaptive capacities (0.270–0.285). Although still vulnerable, these unions show greater relative resilience compared to their more exposed coastal counterparts.

The findings clearly show that vulnerability is multi-dimensional, driven not only by environmental exposure but also by socio-economic fragility and institutional limitations. Latachapli, Khaprabhanga, and Lalua should be prioritized for targeted interventions including infrastructure improvements, livelihood diversification, and community-based disaster risk reduction. Meanwhile, moderate- and lower-vulnerability unions should receive sustained support to further strengthen their resilience.

Identifying the Most Vulnerable Unions and Analyze Key Contributing Factors

Understanding which areas are most vulnerable to climate-induced hazards is critical for targeted intervention and resource allocation. By identifying unions with the highest levels of social and environmental vulnerability, planners and policymakers can prioritize adaptation measures where they are needed most. This section analyzes the unions in KalaparaUpazila with the highest vulnerability scores and examines the socio-economic and infrastructural factors—such as livelihood dependency, access to services, and disaster preparedness—that contribute to their heightened risk.

Analysis of Major Drivers of Vulnerability in Kalapara

Based on Table 2 and the IPCC-VI vulnerability assessment framework, the major drivers of vulnerability in KalaparaUpazila can be systematically analyzed under the three core dimensions of Exposure (EI), Sensitivity (SI), and Adaptive Capacity (AI). The following discussion integrates quantitative index values with contextual socio-environmental realities, identifying four critical factors that contribute to the region's overall vulnerability.

Heavy Reliance on Natural Resources for Livelihood

One of the most prominent drivers of vulnerability in Kalapara is the community's dependence on natural resource-based livelihoods, particularly in coastal unions such as Latachapli (EI = 0.417), Khaprabhanga (EI = 0.418), and Lalua (EI = 0.410). These areas rely heavily on climate-sensitive sectors like fishing, shrimp farming, and subsistence agriculture. Despite moderately high adaptive capacity scores ranging from 0.342 to 0.350, the combined effect of high exposure and moderate sensitivity results in significant vulnerability, with IPCC-VI scores of 0.410 and 0.409, placing these unions at the top of the vulnerability rankings. Their geographical location and livelihood dependency leave them particularly susceptible to cyclones, tidal surges, and salinity intrusion.

Poor Access to Healthcare and Clean Water

A second major driver is the limited access to basic services, including healthcare, clean drinking water, and sanitation, which is reflected in the high sensitivity scores of unions like Nilganj (SI = 0.400), Tiakhali (SI = 0.389), and Mithaganj (SI = 0.385). These elevated sensitivity scores indicate a lack of adequate social infrastructure, which significantly reduces the community's ability to withstand and recover from climate-related shocks. For instance, Nilganj, despite a moderate exposure score of 0.340, remains highly vulnerable due to weak adaptive capacity (AI = 0.289). This demonstrates how service deficiencies—particularly in health and water sectors—intensify vulnerability by exacerbating disease outbreaks, economic hardship, and food insecurity during and after disasters.

Inadequate Disaster Preparedness and Early Warning Systems

The lack of effective disaster preparedness and limited reception of early warning information is another major factor increasing vulnerability in several unions. Adaptive capacity scores across Kalapara are generally low, ranging from 0.270 in Dhularsar to 0.350 in Khaprabhanga, indicating institutional weaknesses, inadequate training, and low public awareness of cyclone preparedness protocols. For example, Dhularsar, although having relatively lower exposure (EI = 0.319) and sensitivity (SI = 0.325), records a notable vulnerability score (IPCC-VI = 0.374) due to its very low adaptive capacity (AI = 0.270). This highlights the critical role of institutional readiness and community awareness in reducing vulnerability, even in less exposed areas.

Poor Condition of Infrastructure, Including Cyclone Shelters

Lastly, the degraded condition of critical infrastructure—such as cyclone shelters, embankments, and evacuation routes—remains a fundamental challenge. In highly exposed unions like Latachapli and Lalua, insufficient or poorly maintained cyclone shelters and embankments fail to provide adequate protection during extreme weather events. Even in moderately exposed unions like Tiakhali (EI = 0.336), low adaptive capacity (AI = 0.286) reflects the limitations of physical infrastructure in mitigating disaster risks. The lack of resilient infrastructure not only hinders timely evacuation and relief efforts but also prolongs recovery periods, intensifying both immediate and long-term socio-economic impacts.

The vulnerability of KalaparaUpazila is shaped not only by its geographic exposure to climate hazards but also by entrenched socio-economic and institutional weaknesses. High exposure in coastal regions, combined with poor access to essential services, limited disaster preparedness, and deficient infrastructure, results in a complex and multidimensional vulnerability profile. Addressing these challenges requires a comprehensive, context-specific approach that includes livelihood diversification, health and WASH improvements, investment in resilient infrastructure, and strengthened local disaster management systems. Strategic and coordinated action across these domains is essential for enhancing resilience in one of Bangladesh's most climate-vulnerable coastal regions.

Evaluating Farmers’ Perceptions of Cyclone Impacts on Livelihoods and Services

Understanding farmers’ perceptions is crucial for capturing the real-life consequences of cyclones on rural communities. Perception-based assessments offer valuable insights into how local populations experience and respond to disruptions in livelihoods, agriculture, health, education, and infrastructure. This section explores the perspectives of farmers in KalaparaUpazila regarding the extent and nature of cyclone-induced damages, complementing quantitative vulnerability indices with community-level experiences.

Cyclone Impacts in the Study Area

KalaparaUpazila experiences frequent cyclones of varying intensities. The region’s poor economic conditions exacerbate the social and environmental consequences of these events. Notable cyclones such as Sidr (2007), Aila (2009), and Mahasen (2013) have caused significant damage to lives, livelihoods, and infrastructure (Table 3).

Table 3. Comparative Impacts of Major Cyclones on Kalapara Upazila

Impact Indicator	Sidr (2007)	Aila (2009)	Mahasen (2013)
Affected unions	9	9	9
Affected paurashavas	1	1	1
Affected population	210,000	93,675	87,614
Destroyed/semi-destroyed houses	27,895	18,128	218
Deaths	94	0	3
Injured	1,678	152	136
Crop damage	45%	38%	41%
Damaged educational institutions	195	68	11
Damaged religious institutions	886	285	0

Source: Field Survey Report, 2014

Table 3 provides a comparative overview of the impacts of three major cyclones—Sidr (2007), Aila (2009), and Mahasen (2013)—on KalaparaUpazila, highlighting the scale of damage across key indicators. Notably, all three cyclones affected the same administrative areas, with nine unions and one paurashava impacted in each event, indicating the geographical consistency of cyclone vulnerability in this coastal region.

Among the three, Cyclone Sidr (2007) had the most devastating impact. It affected approximately 210,000 people, more than double the population affected by Aila and Mahasen combined. Sidr also caused significant structural damage, destroying or partially destroying 27,895 houses, compared to 18,128 in Aila and only 218 in Mahasen. The human toll was also far greater during Sidr, with 94 deaths and 1,678 injuries, making it the deadliest of the three events. In contrast, Aila recorded no fatalities and 152 injuries, while Mahasen resulted in 3 deaths and 136 injuries, reflecting improved early warning systems and evacuation efforts in later years. In terms of agricultural impact, all three cyclones caused substantial crop damage,

with Sidr again being the most destructive (45%), followed by Mahasen (41%) and Aila (38%). This consistent damage highlights the region's dependence on climate-sensitive agriculture and its vulnerability to saline water intrusion and storm surges. The destruction of social infrastructure also varied significantly. Sidr caused the most extensive damage, destroying 195 educational institutions and 886 religious' institutions. Aila's toll was also severe but lower, with 68 schools and 285 religious establishments affected. In stark contrast, Mahasen had a minimal impact on such infrastructure, damaging only 11 schools and no religious institutions—a likely outcome of its relatively weaker intensity and improved disaster preparedness measures.

Overall, the data clearly indicate a trend of decreasing mortality and structural damage over time, suggesting progress in disaster management, early warning dissemination, and community-level preparedness. However, the persistent impact on crops and housing even in more recent events like Mahasen underscores the ongoing need for resilient infrastructure, agricultural adaptation, and community-based risk reduction strategies in Kalapara's cyclone-prone areas.

Community Perceptions of Cyclone Impacts

Understanding how local communities perceive the impacts of cyclones is crucial for assessing their lived experiences and adaptive responses. This section captures farmers' and residents' observations of cyclone-related effects on livelihoods, infrastructure, health, and essential services in Kalapara Upazila. A survey of 180 households identified agriculture, food security, and the local economy as the most adversely affected sectors (Table 4).

Table 4. Community-Perceived Impacts of Cyclones across Socio-Economic and Environmental Sectors in Kalapara Upazila

Impact Category	Frequency	% of Respondents	Severity Rating
Agriculture	180	100%	+++
Local Economy	180	100%	+++
Food Security	180	100%	+++
Livelihood	171	95%	+++
Health	158	88%	+++
Education	151	84%	+++
Infrastructure	140	78%	++
Transportation	138	77%	++
Gender-based Violence	119	66%	++
Saline Water Intrusion	119	66%	++
Biodiversity Loss	84	47%	+
Migration	36	20%	+

Note: Severity ratings are based on respondent percentages: + = Low Impact (<50%), ++ = Moderate Impact (50–80%), +++ = High Impact (>80%)

Table 4 presents the perceived impacts of cyclones across various socio-economic and environmental categories in KalaparaUpazila, based on community-level responses. The frequency, percentage of respondents, and severity ratings provide insight into the multidimensional consequences of recurring cyclone events.

Agriculture, the local economy, and food security were reported as the most severely affected sectors, with 100% of respondents identifying these as major impact categories and assigning the highest severity rating (+++). This underscores the heavy reliance of the community on climate-sensitive livelihoods such as farming and fishing. Cyclones disrupt agricultural production, damage crops, and degrade soil quality through waterlogging and salinity intrusion, which in turn destabilizes the local economy and exacerbates food insecurity. Livelihood impacts were reported by 95% of respondents, also with a high severity rating. This reflects widespread income loss due to damage to natural resources, infrastructure, and productive assets. The high impact on health (88%) and education (84%), both rated as highly severe (+++), highlights how repeated disasters strain healthcare systems and interrupt schooling, especially when health centers and educational institutions are physically damaged or repurposed as cyclone shelters. Infrastructure (78%) and transportation (77%) impacts were noted as significant, with a severity rating of ++, indicating physical damage to roads, embankments, and public facilities, which affects mobility, service delivery, and post-disaster response. Social and environmental issues were also notable. Gender-based violence and saline water intrusion were each reported by 66% of respondents, both with a moderate severity rating (++), suggesting that cyclones not only cause physical damage but also exacerbate underlying social vulnerabilities and environmental degradation. Biodiversity loss (47%) and migration (20%) were reported less frequently and with lower severity ratings (+), but their presence indicates longer-term ecological and demographic shifts caused by repeated disasters. Biodiversity decline may result from habitat loss, while migration often reflects a last-resort adaptation strategy. Overall, the data reflect a highly interconnected and systemic pattern of vulnerability, where environmental shocks impact every aspect of local life—from food and income to infrastructure, health, education, and social stability.

Investigating the effectiveness of existing disaster management systems

Evaluating the effectiveness of disaster management systems is essential for understanding gaps in preparedness, response, and recovery, particularly in cyclone-prone coastal regions. In areas like KalaparaUpazila, where communities face recurrent storm events, the quality and functionality of cyclone shelters, early warning dissemination, and institutional coordination play a critical role in reducing vulnerability. This section explores local perceptions of these systems to identify structural, operational, and communication-related weaknesses in current disaster risk reduction efforts.

Inadequacies in Existing Cyclone Management

Despite ongoing efforts in disaster risk reduction, several critical inadequacies persist within the existing cyclone management framework in KalaparaUpazila, as revealed by community

perceptions and field-level assessments. These shortcomings span across infrastructure, governance, early warning systems, and preparedness planning, ultimately hindering the effectiveness of cyclone response and resilience-building efforts, as outlined in Table 5.

Table 5. Perceived Management Gaps in Cyclone Risk Reduction in Kalapara Upazila

Management Gap	Frequency (n=180)	Percentage
Poor condition of cyclone shelters	180	100%
Inefficiencies in relief distribution	171	95%
Lack of housing guidelines	162	90%
Weak coordination between GoB and NGOs	157	87%
Inadequate training and public awareness	153	85%
Cyclone warning system limitations	142	79%
Deteriorating coastal embankments	140	78%
Lack of land use planning	137	76%
Deficient disaster action plans	137	76%

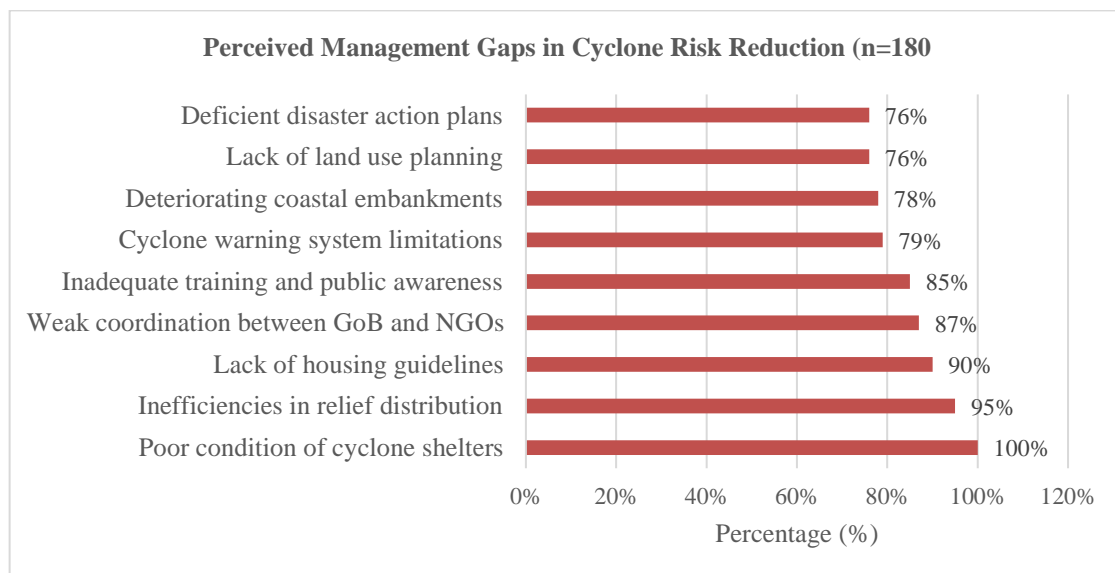


Figure 2. Perceived Management Gaps in Cyclone Risk Reduction among Households in Kalapara (n = 180)

Table 5 and Figure 2 together present a comprehensive overview of the key management gaps in cyclone disaster preparedness and response as perceived by 180 households in Kalapara Upazila. The data reveal a consistent and widespread recognition of critical vulnerabilities across both structural and institutional domains. The most prominently cited issue, reported by 100% of respondents, is the poor condition of cyclone shelters, underscoring the urgent need for upgrading and maintaining protective infrastructure in the

region. This is followed by inefficiencies in relief distribution (95%) and the lack of housing guidelines for disaster-prone areas (90%), reflecting significant weaknesses in post-disaster logistics and resilient urban planning. Further concerns include weak coordination between the Government of Bangladesh (GoB) and NGOs (87%) and inadequate public training and awareness (85%), which point to institutional fragmentation and gaps in community-level disaster preparedness. Technological and structural issues are also evident, with limitations in the cyclone warning system (79%) and deteriorating coastal embankments (78%) raising alarms over the effectiveness of early warning dissemination and physical defenses. Additionally, lack of land use planning and absence of disaster action plans (each reported by 76%) highlight the pressing need for strategic foresight and integrated disaster risk reduction frameworks.

The bar chart in Figure 2 visually reinforces these findings, illustrating the relative severity and frequency of each management gap. The uniformity of high response rates across nearly all indicators reveals a strong consensus among respondents about systemic shortcomings in cyclone risk governance. Together, Table 5 and Figure 2 offer a powerful diagnostic of the existing challenges, emphasizing the need for comprehensive reforms in infrastructure development, institutional coordination, community engagement, and long-term planning to enhance cyclone resilience in coastal Bangladesh.

Comparison with Other Cyclone-Affected Areas in Bangladesh

In comparison with other cyclone-affected areas of Bangladesh, the findings from Kalapara Upazila reveal both consistent patterns and distinct differences in vulnerability dynamics. Similar to studies in Barguna and Bhola (Paul & Routray, 2011; Shameem et al., 2015), the unions of Latachapli (EI = 0.417) and Khaprabhanga (EI = 0.418) show high exposure due to their proximity to the Bay of Bengal. However, unlike broader upazila-level analyses, this study provides a union-level perspective, offering more spatial precision for vulnerability mapping. Sensitivity in Nilganj (SI = 0.400) and Tiakhali (SI = 0.389) mirrors that found in Satkhira and Khulna, where salinity intrusion and poor access to healthcare drive community fragility (Mallick & Vogt, 2014). Nevertheless, the perception of agricultural and livelihood impacts appears even more severe in Kalapara, with 100% of respondents reporting negative effects on agriculture, food security, and the local economy, compared to 85–90% in similar studies in the southwest coastal belt (Rana & Ghosh, 2018).

In terms of adaptive capacity, Kalapara unions such as Dhularsar (AI = 0.270) and Tiakhali (AI = 0.286) show low institutional resilience, consistent with findings from Patharghata (Barguna) and Shyamnagar (Satkhira) (Islam et al., 2013). However, community-reported gaps in disaster training and early warning awareness are more pronounced in Kalapara, with 85% identifying inadequate preparedness, suggesting a greater knowledge and capacity gap than in neighboring districts. Additionally, respondents in Kalapara expressed unanimous dissatisfaction with the condition of cyclone shelters (100%) and raised high concern over inefficiencies in relief distribution (95%)—figures that surpass the 70–80% dissatisfaction

levels reported in Khulna and Patuakhali (UNDP, 2014). These findings suggest that, while early warning systems and evacuation efforts have improved nationally—as evidenced by the reduction in cyclone-related fatalities from 94 during Cyclone Sidr in 2007 to just 3 during Cyclone Mahasen in 2013 (GoB, 2008; UN OCHA, 2013)—the continued livelihood disruption, housing damage, and weak institutional coordination observed in Kalapara reveal a persistent gap between national-level progress and local-level implementation.

Conclusion and Recommendations

Conclusion

This study reveals that KalaparaUpazila faces significant cyclone vulnerability, driven by high exposure levels, socio-economic sensitivity, and limited adaptive capacity. According to the IPCC-VI analysis, the unions of Latachapli (EI = 0.417, IPCC-VI = 0.410), Khaprabhanga (EI = 0.418, IPCC-VI = 0.410), and Lalua (EI = 0.410, IPCC-VI = 0.409) were identified as the most vulnerable areas. Community survey data show that 100% of respondents reported severe impacts on agriculture, food security, and the local economy, while 95% reported damage to livelihoods, and 88% cited health-related disruptions. Additionally, 84% of respondents identified cyclone-related interruptions to education.

Management-related challenges were also prominent. All respondents (100%) highlighted the poor condition of cyclone shelters, while 95% cited inefficiencies in relief distribution. Other critical gaps included lack of housing guidelines (90%), weak coordination between GoB and NGOs (87%), and inadequate public awareness and training (85%). These quantitative findings clearly demonstrate that cyclone vulnerability in Kalapara is not only a function of physical exposure but is compounded by institutional and infrastructural inadequacies. Addressing these issues will require evidence-based, area-specific interventions that enhance infrastructure, strengthen coordination, and build adaptive capacity at the community level.

Recommendations

To strengthen cyclone resilience in KalaparaUpazila, several key actions are recommended. Cyclone shelters should be urgently renovated and equipped to accommodate vulnerable populations. Relief distribution systems must be improved for efficiency, transparency, and speed. The government should implement clear housing and land use guidelines to reduce exposure in high-risk areas. Coordination between government and NGOs needs to be enhanced through joint planning and communication platforms. Community-based training and public awareness campaigns should be expanded to improve early warning response. Lastly, long-term planning must include embankment maintenance and updated disaster action plans to ensure sustainable disaster risk management.

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