Accepted Manuscript (Uncorrected Proof)

Title: Assessing the Perceived Impacts of Cyclone Remal on Households in Patuakhali District, Bangladesh

Authors: Tanvir Ahmed[1], Minhajul Islam Ove[1], Mohaiminul Islam Hasib[1], Abdul Hasib Mollah[1,*]

1. *Department of Economics, University of Barishal, Barishal, Bangladesh.*

To appear in: ***Health in Emergencies & Disasters Quarterly***

Received date: 2025/06/11

Revised date: 2025/10/06

Accepted date: 2025/10/11

First Online Published: 2025/11/10

Please cite this article as:

Ahmed T, Ove MI, Hasib MI, Mollah AH. Assessing the Perceived Impacts of Cyclone Remal on Households in Patuakhali District, Bangladesh. Health in Emergencies & Disasters Quarterly. Forthcoming 2026. Doi: http://dx.doi.org/10.32598/hdq.2026.690.1

ABSTRACT

Background: Cyclone Remal struck the coastal regions of Bangladesh in May 2024, causing widespread social, environmental, and economic disruptions. Patuakhali District, one of the most cyclone-prone regions in the country, experienced significant impacts, necessitating an in-depth assessment of community perceptions and vulnerabilities.

Materials and Methods: A quantitative research design was employed, using stratified random sampling to collect data from 468 households across four upazilas in Patuakhali District. An ordered logistic regression model was applied to examine factors influencing perceived disaster impact.

Results: The analysis revealed that households experiencing greater physical damage and cyclone-induced health problems were more likely to report higher perceived impacts (OR = 1.000 and 3.736, respectively, $p < 0.01$). Receipt of post-cyclone aid also contributed to higher perceived impact (OR = 2.049, $p < 0.05$), suggesting that assistance alone may not fully mitigate perceived vulnerability. The study also documented economic vulnerabilities, with average household income at 40,204 BDT and cyclone-related losses averaging 19,084 BDT.

Conclusion: Enhancing cyclone shelter infrastructure, improving healthcare services, and reforming disaster relief strategies are critical to strengthening community resilience in coastal Bangladesh. The insights from this study can inform more effective disaster risk reduction and recovery policies.

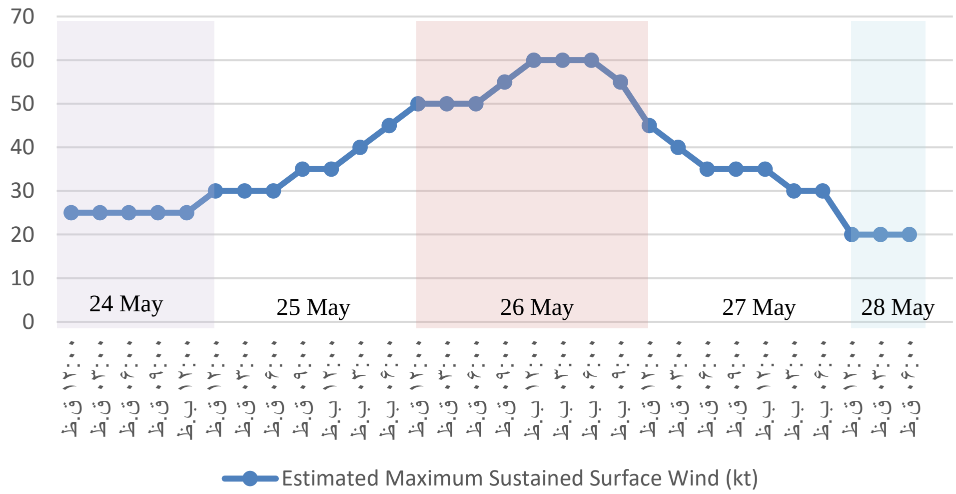
Keywords: Cyclone Remal, Perceived Disaster Impact, Ordered Logistic Regression, Household Vulnerability, Community Resilience, Coastal Bangladesh

INTRODUCTION

As Bangladesh is a low-lying deltaic region, it is one of the most cyclone prone regions in the world. The recently occured cyclone Remal is a severe cyclonic storm that swept over the coastal areas including Patuakhali district in the Barishal Division of Bangladesh on May 26, 2024 [1]. The cyclone led to severe infrastructural damage including a total of 40,246 houses that were completely destroyed with an additional 131,678 experiencing partial damages, disrupted the lives of local communities, displaced approximately 4.6 million people and caused significant environmental impacts destroying thousands of acres of different land area all over Bangladesh [2]. There were extreme rainfall and 8-12 feet large storm surge caused by the cyclone during the time being and with the rainfall continuing for 48 hours [3]. This worsened the flooding in many regions and Patuakhali is one the worst-hit districts experienced acute destruction. During this, over 30 villages in Patuakhali were severely flooded due to breaches in embankments [4]. As a result of these floods and severe gusts that accompanied the cyclone, an already difficult situation became even more difficult. Even beyond the immediate devastation, the cyclone has highlighted the ongoing challenges posed by climate change other way and thus there is need for effective disaster management strategies in that region. Although several coastal districts, including Khulna and Barguna, saw significant impact, Patuakhali's topographical and socio-economic characteristics render it particularly susceptible. The district's wide low-lying floodplains, significant reliance on agriculture and fisheries, and history of recurrent embankment failures distinguish it from other cyclone-prone regions [5]. These attributes validate its designation as an important case study for comprehending community-level perceptions of cyclones. The study aims to elucidate the environmental and infrastructural issues posed by the cyclone and to recognize insights for future preparedness and response initiatives.

According to the Bangladesh Red Crescent Society, cyclone Remal showed the maximum sustained wind speed of 117 km/h (60 kt) on May 27, when it was at its peak [6]. Making landfall on May 26, 2024, with wind speeds ranging from 92 to 117 km/h.

Figure 1: Estimated Maximum Sustained Surface Wind (kt)



Source: India Metrological Department [7]

Based on its maximum sustained wind speed, it can be categorized as Severe Cyclonic Storm (SCS) in the disturbance classification of both by the Bangladesh Meteorological Department (BMD) and the India Meteorological Department (IMD). Classification of tropical cyclones by IMD and BMD is mentioned in the following.

Table 1: Tropical Cyclone Intensity Scale

Category	Sustained winds	
	km/h	**knot**
Super Cyclonic Storm	≥222	≥120
Cyclonic Storm with a core of Hurricane Wind	118–221	64–119
Severe Cyclonic Storm	89–117	48–63
Cyclonic Storm	63–88	34–47
Deep Depression	52–61	28–33
Depression	41–51	17–21
Well-marked low	31-40	17-21
Low pressure area	<31	<17

Source: Bangladesh Meteorological Department [8]

Table 1 establishes the cyclone intensity categorization utilized by the Bangladesh Meteorological Department (BMD), whilst Table 2 illustrates the similar framework employed by the Indian Meteorological Department (IMD).

Table 2: Tropical Cyclone Intensity Scale

Category	Sustained winds	
	km/h	**knot**
Super Cyclonic Storm	≥221	≥120
Extremely Severe Cyclonic Storm	166–220	0–119
Very Severe Cyclonic Storm	118–165	64–89
Severe Cyclonic Storm	89–117	48–63
Cyclonic Storm	63–88	34–47
Deep Depression	51–62	28–33
Depression	31–50	17–27
Low Pressure Area	<31	<17

Source: Indian Meteorological Department [7]

Both approaches classify cyclones from Super Cyclonic Storms (≥221 km/h) to Low-Pressure Areas (<31 km/h), with minor discrepancies in intermediate classifications. These classifications are essential for evaluating cyclone severity and informing disaster preparedness strategies.

On May 24, the cyclone began as a low-pressure system in the Bay of Bengal near latitude 15.0° N and longitude 88.4° E, roughly 800 km south-west of Khepupara (Bangladesh) and 810 km south of Canning (West Bengal) [9].

Figure 2: Pathway of Cyclone Remal

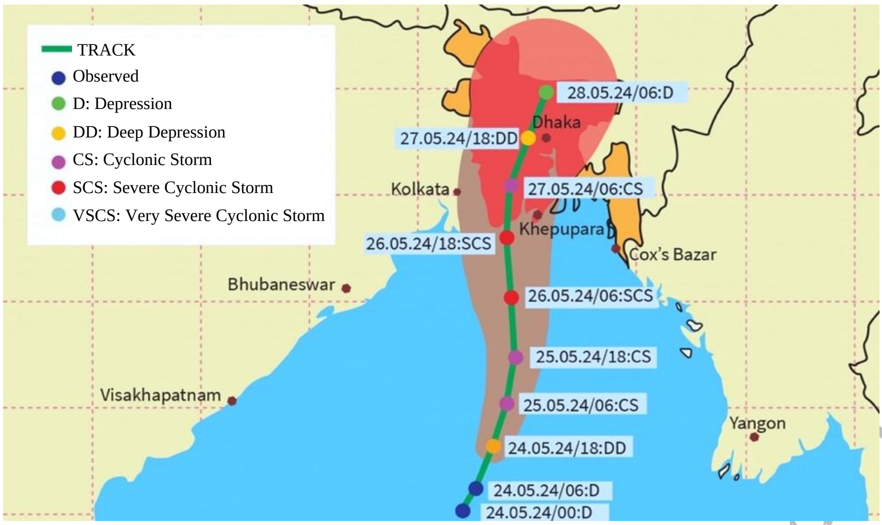


Illustration Source: [10]

Soon, because of the warm surface temperature of the sea which was around 30°C and low vertical wind shear, cyclone Remal started to rapidly intensify. It intensified and formed as severe cyclonic storm by May 25th evening. The cyclone was moving steadily towards the coast of southern Bangladesh directly in the path of Patuakhali and the surrounding coastal areas. This Cyclone made landfall near Kalapara, Patuakhali, around midnight on May 26, 2024 [6]. Its central pressure dropped significantly with intensification, reaching a low of about 978 hPa at its peak intensity before landfall [11]. Usually, there is a correlation that the lower the central pressure, the more intense the cyclone [12].

Figures 3 and 4, sourced from the Indian Meteorological Department (IMD), depict Cyclone Remal's central pressure dynamics. Figure 3 shows the estimated central pressure (hPa) during the cyclone's peak intensity, while Figure 4 illustrates the pressure drop at the cyclone's centre (hPa), highlighting its intensification before landfall.

Figure 3: Estimated Central Pressure (hPa)

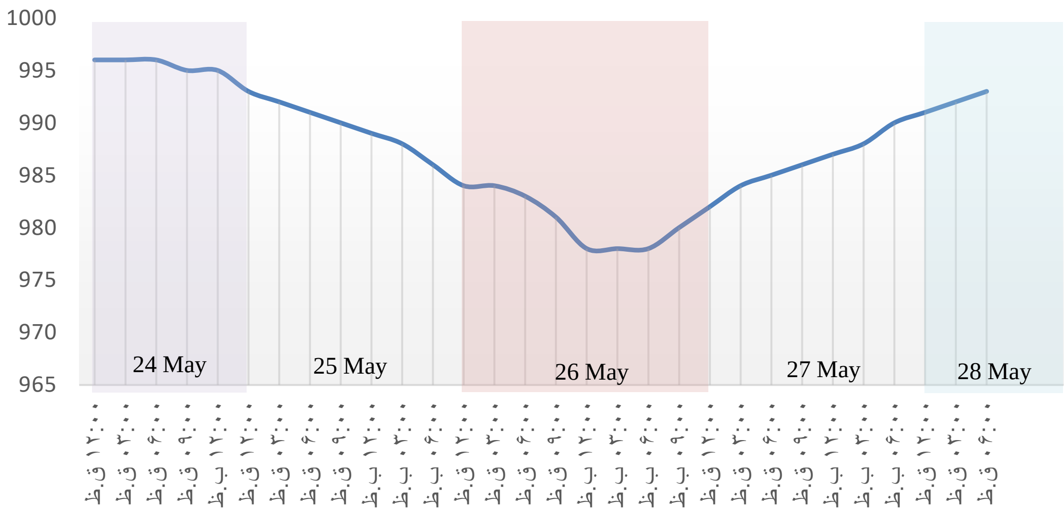
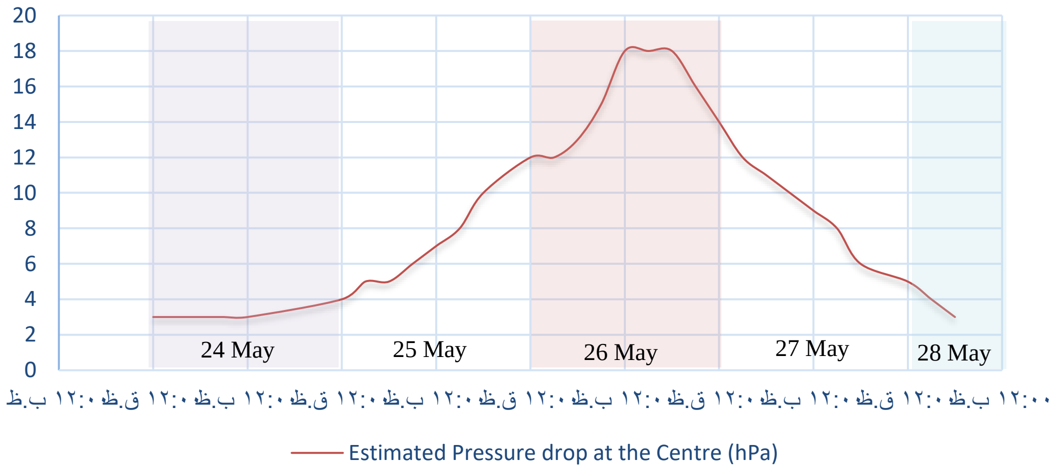


Figure 4: Estimated Pressure drop at the Centre (hPa)



Source: Indian Meteorological Department [7]

This decrease in pressure during its peak time suggests the strengthening of the cyclone because it leads to increase in the wind speed and severity of the weather. Pressure started to decrease after the landfall. Later, it started to proceed inland making itself weaker and weaker because of the harsher terrain and friction over land.

While previous studies have extensively examined cyclone exposure and damage assessment in Bangladesh, less attention has been paid to how households perceive cyclone impacts and which socioeconomic and disaster-related factors shape these perceptions [5]. Such insights are essential for designing community-centered disaster preparedness and response strategies. Therefore, this study focuses on Patuakhali District as a critical case study of Cyclone Remal's impacts. The objectives are twofold: (i) to document household perceptions of the cyclone's overall impact, and (ii) to identify key determinants—including income, damage, shelter use, health outcomes, and aid—that influence these perceptions. By analyzing household-level survey data using ordered logistic regression, this study contributes to a deeper understanding of disaster impact assessment and offers implications for strengthening cyclone preparedness in coastal Bangladesh.

LITERATURE REVIEW

Cyclones are among the most devastating natural disasters, especially in coastal areas where inhabitants are often densely populated and rely on natural resources for a living [13]. Poverty, weak infrastructure, and environmental deterioration all contribute to the regions' susceptibility [14]. Cyclones, sometimes known as hurricanes or typhoons in various parts of the world, have caused widespread economic, social, and environmental destruction [15]. These theoretical lenses directly informed variable selection in this study. For example, PADM guided the inclusion of risk-related factors such as shelter use and past health impacts, while the social vulnerability paradigm shaped the choice of socioeconomic indicators such as income, education, and household size. Together, these frameworks provide a conceptual basis for interpreting how structural vulnerabilities and protective actions influence perceived cyclone impacts [16] [17]. The frequency and intensity of severe storms have grown in recent years, most likely due to climate change. For example, Emanuel (2005) and Webster (2005) found evidence of increased tropical storm intensity, which has been connected to rising sea surface temperatures. These developments are especially worrying for low-lying coastal communities, which are already prone to storm surges and flooding.

South Asia, particularly Bangladesh, is extremely vulnerable to cyclones due to its geographical location and socioeconomic characteristics [20]. Cyclones Sidr (2007) and Aila (2009) are two of the most destructive cyclones to hit the region, causing widespread destruction and loss of life [21]. Poverty, limited access to healthcare, and inadequate infrastructure all contribute to the vulnerability of Bangladesh's coastal communities [22]. An increasing database of literature establishes a correlation between climate change and an increase in the frequency and intensity of cyclones. According to the Intergovernmental Panel on Climate Change (IPCC), the frequency of severe tropical cyclones is expected to increase, which could devastate vulnerable regions such as South Asia [23]. Cyclone Remal has profoundly impacted coastal communities in Bangladesh, particularly in terms of environmental degradation, disaster preparedness, and recovery challenges [5]. Additionally, saltwater intrusion from storm surges rendered large tracts of agricultural land infertile, particularly affecting rice cultivation. This has had long-lasting impacts on the livelihoods of coastal farmers [24]. The biodiversity of the Sundarbans, the world's largest mangrove forest, was also adversely affected, with numerous endangered species suffering due to habitat loss [25]. Public health challenges have emerged as a critical concern in the aftermath of Cyclone Remal [26]. In the following days of Cyclone Remal, waterborne diseases such as cholera and diarrhea occurred due to the contamination of water supplies [27]. Mental health disorders were widespread, as numerous survivors encountered heightened anxiety and sadness resulting from insufficient post-disaster care services [28].

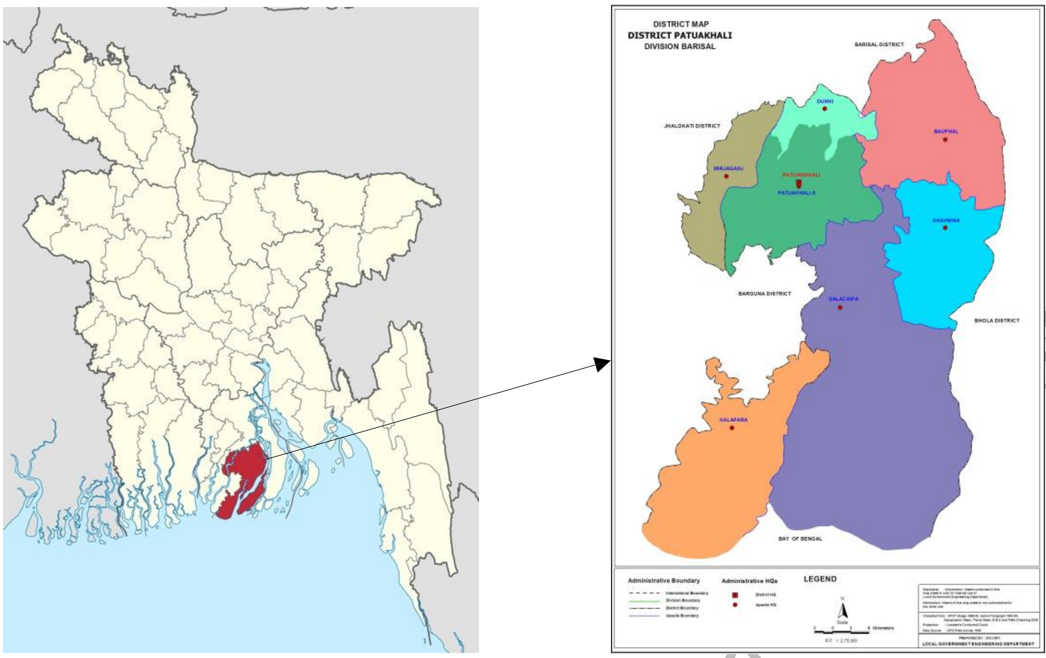
Education is essential in catastrophe preparedness and response. Higher levels of education are linked to greater understanding of disaster risks and more proactive behavior during calamities. This is supported by research such as [29], who discovered that communities with higher educational attainment were better prepared and more resilient to disasters. Income is another important driver of disaster impact. Poorer households frequently reside in more vulnerable places, such as floodplains or substandard buildings, and have fewer means to deal with the aftermath of a disaster. This has been well documented in the literature, including research by [30], that investigate the relationship between poverty and catastrophe susceptibility. Cyclones cause not just rapid physical destruction, but also long-term environmental and health effects. These impacts have the potential to worsen impacted populations' susceptibility, creating a vicious cycle of disaster-induced poverty and environmental degradation. The degradation of natural barriers like mangroves and coral reefs has made coastal regions more vulnerable to cyclones. According to [31], locations with intact mangrove forests receive less cyclone damage than those where mangroves have been removed. The response to Cyclone Remal revealed both strengths and weaknesses in Bangladesh’s disaster management framework. The country's early warning systems were effective in saving lives, as noted by the [32]. However, the evacuation and relief distribution procedures were problematic. Remote and vulnerable communities were frequently left behind during evacuations, and relief operations were impeded by logistical challenges and inconsistent resource allocation [5]. The recovery initiatives underscore the necessity of establishing durable resilience against future cyclones. Community-based disaster management strategies that engage local populations in disaster preparedness have effectively mitigated susceptibility [33]. Strategies like raised housing and accessible emergency shelters have improved disaster readiness [34].

Despite the abundance of knowledge regarding the impacts of cyclones, notable gaps persist, particularly for the Patuakhali District and similar regions in Bangladesh. One of these gaps is the necessity for supplementary regional research that considers the unique environmental conditions of various areas.

METHODOLOGY

This study adopted a quantitative research approach to assess the impacts of Cyclone Remal in Patuakhali District, located in the Barishal Division of Bangladesh, a region acutely vulnerable to cyclonic events due to its low-lying coastal geography [13]. A disproportionate stratified random sampling design was adopted. Four of the most cyclone-prone upazilas of Patuakhali—Patuakhali Sadar, Dumki, Galachipa, and Kalapara—were selected as strata based on their geographic location and exposure [35]. Household lists were obtained from local government authorities, and households were randomly selected within each stratum using a lottery method. To ensure balanced geographic representation, an equal number of 117 households was surveyed from each upazila, resulting in a total of 468 households. Although this equal allocation was not proportional to population size, it enhanced comparability across strata. In cases of non-response, replacement households were randomly selected to minimize bias. This design represents disproportionate stratification; therefore, sampling weights were applied for district-level inference. Within each selected household, the primary decision-maker was chosen as the respondent. Non-response was minimal (<5%), and replacement households were randomly chosen from the same list to minimize bias.

Figure 5: Study Area



Source: Local Government Engineering Department (LGED)

Based on a 95% confidence level and a 5% error margin, the minimum sample size was calculated as 370 households [36]. However, to enhance the robustness and generalizability of the findings, data were collected from 468 households from June 1 to September 17, 2024, exceeding the recommended threshold. A standardized questionnaire was developed based on prior disaster perception studies [37] [5]. Content validity was assessed through expert review by one disaster management specialists, and a pilot survey with 20 households was conducted in Patuakhali. Enumerators received three days of training on questionnaire content, ethical protocols, and mock interviews. Paper-based surveys were used and later digitized into Stata for analysis. The overall response rate was 92.5%. Missing responses were rare (<3% per variable) and were handled through listwise deletion. Quality control procedures included daily review of completed questionnaires and random spot-checks by supervisors. The questionnaire captured demographic characteristics, household conditions, cyclone-related damages, income levels, and post-disaster experiences. This study did not involve medical or clinical trials and therefore did not require formal ethical clearance. Participation was voluntary, and informed consent (including parental/guardian consent for respondents under 18) was obtained. Confidentiality was strictly maintained. Descriptive statistics such as mean, median, and standard deviation were used to summarize continuous variables, while frequencies and percentages were reported for categorical variables. To identify the determinants of the perceived overall impact of Cyclone Remal, the study employed an Ordered Logistic Regression (OLR) model, appropriate for ordinal dependent variables with non-equidistant categories [38]. The regression model is specified as:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_5 + \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \varepsilon$$

The dependent variable was derived from the survey item: *'How would you describe the overall impact of Cyclone Remal on your household?'* (0=Low, 1=Medium, 2=High). As this was a single-item measure capturing direct household perceptions, no scale aggregation was applied; however, face validity was established through expert review during instrument development. $x_1 \ldots\ldots x_{10}$ are the independent variables encompassing socioeconomic indicators and cyclone-related experience. β_0 is the intercept term and β_1 to β_{10} are the coefficients associated with the

respective independent variables, x_1 to x_{10} while ε is the error term. These independent variables were carefully selected based on their relevance to disaster impact research and their ability to capture the multidimensional consequences of Cyclone Remal on households. Key variables include total damage, household income, health issues, aid received, cyclone shelter use, and demographic controls such as age, education, marital status, and place of residence. Among them, variables such as shelter use, health issues, aid received, marital status, and residence location were treated as dummy variables, while the rest were continuous. To improve interpretability and avoid rounding artifacts, continuous monetary variables (income and total damage) were rescaled in units of 10,000 BDT. As aid receipt is likely endogenous to impact severity, coefficients on this variable should be interpreted as associations rather than causal effects. The proportional odds assumption was assessed using the Brant test, indicating no significant violation ($x^2 = 12.34$, $p = 0.21$), supporting the use of the ordered logistic regression model. Model fit and diagnostics were evaluated using log-likelihood, likelihood-ratio (LR) chi-square, Akaike Information Criterion (AIC), and Bayesian Information Criterion (BIC) values. To enhance interpretability, average marginal effects and category-specific predicted probabilities were computed for key covariates, allowing for clear understanding of how changes in independent variables affect the probability of perceiving low, medium, or high cyclone impact. Findings are representative at the district level for Patuakhali when applying sampling weights, but not directly generalizable to other coastal districts.
Here, Table 3 indicates the key variables employed in the analysis and their descriptions. These variables encompass household characteristics, socioeconomic aspects, and the effects of Cyclone Remal, forming the basis for evaluating the perceived overall impact of the cyclone.

Table 3: Descriptions of the variables

Variables	Descriptions	Variables	Descriptions
x_1 =	Total amount of infrastructure and agricultural damage sustained by the household in BDT	x_6 =	Marital Status (0 = Unmarried, 1 = Married)
x_2 =	Households average monthly income in BDT	x_7 =	Years of Schooling
x_3 =	Indicating whether the household used cyclone shelter throughout the Remal's duration	x_8 =	Household Size
x_4 =	Indicating whether any household member experienced health issues due to the cyclone	x_9 =	Indicating if the household live in urban area or rural
x_5 =	Indicating whether the household received any form of aid or assistance after the cyclone	x_{10} =	Respondent's age

The Ordered Logistic Regression model was chosen over other models like multinomial logistic regression due to the ordinal nature of the dependent variable. While multinomial models treat outcome categories as nominal and unrelated, OLR respects the inherent order of impact perception (low to high) and provides more parsimonious and interpretable estimates. This approach allows for estimating how each independent variable influences the probability of a respondent perceiving the cyclone's impact as low, medium, or high. Model diagnostics assessed goodness-of-fit, with the pseudo R-squared statistic as a key indicator. Odds ratios were computed to interpret the direction and strength of the associations between predictor variables and the outcome. A significance threshold of 0.05 was adopted, with p-values used to evaluate the statistical significance of each coefficient.

This methodological framework ensures a robust and nuanced analysis of how various factors contribute to the perceived impacts of Cyclone Remal across diverse communities in Patuakhali District.

RESULTS AND FINDINGS

In the study, total observation is 468. In table 1 the descriptive summary of the variables is shown as mean, standard version deviation, minimum and maximum values.

Table 4: Descriptive statistics of household characteristics (N = 468)

Variable	Obs	Mean	Std. Dev.	Min	Max
Age	468	42.03	15.409	16	75
Years of Schooling	468	11.068	4.577	0	17
Household Size	468	5.53	1.775	2	12
Income	468	40204.06	20568.93	10000	160000
Total Damage	468	19084.59	26539.449	0	400000

The average age of the responders is 42.03 years, ranging from 16 to 75 years, indicating an extensive demographic. Respondents averaged 11 years of education, indicating diversified levels of educational achievement. The typical household size consists of five individuals, varying from two to twelve. The mean monthly income is 40,204 BDT, with a range of incomes from 10,000 to 160,000 BDT, reflecting considerable economic variation. The total total damage reported is 19,084 BDT, exhibiting significant variability, indicating heterogeneity in the impact of the cyclone among homes.

Tabulation of Dummy Variables

Five dummy variables are included in the research to assist in the explanation of the dependent variable which accepts the value of 0 or 1 to signify either the absence or presence of a particular category effect that would be anticipated to influence the outcome.

Table 5: Descriptive statistics of dummy variables

Variables	Responses	Freq.	Percent%
Marital status	Unmarried (0)	128	27.35
	Married (1)	340	72.65
Cyclone shelter usage	Didn't use (0)	259	55.34
	Used (1)	209	44.66
Health Issues Experienced During Cyclone	No (0)	299	63.89
	Yes (1)	169	36.11
Aid received following the cyclone	No (0)	302	64.53
	Yes (1)	166	35.47
Living status	Rural (0)	367	78.42
	Urban (1)	101	21.58

The sample includes married individuals (71%), while 29% are unmarried. Of the 468 households questioned, 209 used cyclone shelters, while 259 did not. 36.11% of households reported health difficulties related to Cyclone Remal, while 63.89% reported no health consequences. After the cyclone, 35.47% of homes received aid or assistance, leaving the remainder (64.53%) unsupported. Most responders (78.42%) live in rural regions, with only 21.58% living in cities, indicating that the cyclone had a primarily rural impact.

Table 6 presents the results of the ordered logistic regression model, which explores the factors influencing the perceived overall impact of Cyclone Remal in the Patuakhali District of

Bangladesh. The dependent variable, Overall Impa*ct*, is an ordinal variable with three categories: 0 (low impact), 1 (medium impact), and 2 (high impact). The model includes ten independent variables, and the results are assessed using various diagnostic metrics, including p-values, confidence intervals, and model fit indices.

Table 6: Results of Ordered Logistic Regression Estimating Determinants of Perceived Cyclone Impact

Variables	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
x_{10}	-.019	.013	-1.50	.133	-.044	.006	
x_7	-.055	.031	-1.80	.072	-.115	.005	*
x_6	-.05	.352	-0.14	.886	-.74	.639	
x_8	-.093	.084	-1.12	.264	-.257	.071	
x_2	0	0	-0.91	.365	0	0	
x_3	-.235	.24	-0.98	.328	-.706	.236	
x_1	0	0	11.17	0	0	0	***
x_4	1.318	.283	4.66	0	.763	1.873	***
x_5	.717	.331	2.17	.03	.068	1.366	**
x_9	-.545	.285	-1.91	.056	-1.103	.014	*
Constant	-1.526	.719	.b	.b	-2.936	-.117	
Constant	2.874	.745	.b	.b	1.415	4.334	

Mean dependent var	1.094	SD dependent var	0.752
Pseudo r-squared	0.482	Number of obs	468
Chi-square	483.104	Prob > chi2	0.000
Akaike crit. (AIC)	544.037	Bayesian crit. (BIC)	593.819

**** p<.01, ** p<.05, * p<.1*

The logistic regression results reveal several significant determinants of household outcomes following Cyclone Remal. The level of damage sustained (x1) is strongly and positively associated with the dependent variable (Coef. = 0.000, $p < 0.01$), indicating that higher infrastructure and agricultural losses substantially increased the likelihood of being affected. Health-related issues (x4) also exerted a large positive effect (Coef. = 1.318, $p < 0.01$), suggesting that households experiencing cyclone-induced health problems were over one unit higher on the log-odds scale of the adverse outcome. Similarly, receiving aid or assistance (x5) increased the probability of being affected (Coef. = 0.717, $p < 0.05$). On the other hand, years of schooling (x7) had a negative and marginally significant effect (Coef. = –0.055, $p < 0.10$), implying that better-educated respondents were slightly less likely to experience adverse consequences. Residence in urban areas (x9) also showed a negative association (Coef. = –0.545, $p < 0.10$), indicating lower vulnerability relative to rural households. In contrast, respondent's age (x10, Coef. = –0.019, p = 0.133), marital status (x6, Coef. = –0.050, p = 0.886), household size (x8, Coef. = –0.093, p = 0.264), average monthly income (x2, Coef. = 0.000, p = 0.365), and use of cyclone shelters (x3, Coef. = –0.235, p = 0.328) did not demonstrate statistically significant relationships. Overall, the model fit was robust (Pseudo R^2 = 0.482; x^2 = 483.104, $p < 0.01$), highlighting the central role of cyclone-related damage, health impacts, and aid provision in shaping household vulnerability, while education and urban residence offered modest protective effects. The model has an overall strong fit, as indicated by the Pseudo R-squared value of 0.482, which suggests that nearly 48% of the variance in perceived impact can be explained by the independent variables included in the model. The likelihood ratio test (Chi-square = 483.104, $p < 0.001$) confirms that the model is statistically significant. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) further support the validity of the model fit.

Table 7 presents the ordered logistic regression analysis results in terms of odds ratios, which help interpret the likelihood of experiencing a higher perceived impact of Cyclone Remal based on various factors. Each odds ratio is reported along with its standard error, t-value, p-value, and 95% confidence interval.

Table 7: Odds Ratios from Ordered Logistic Regression on Perceived Cyclone Impact Determinants

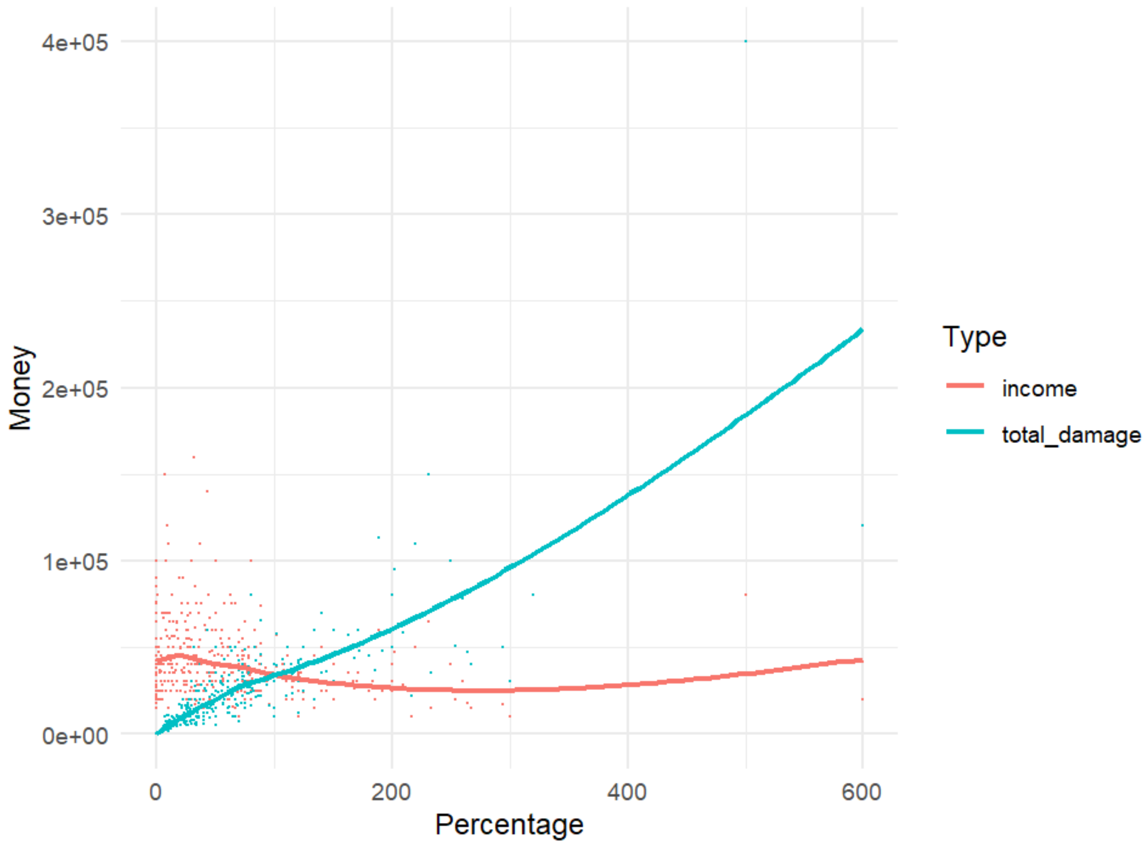
Overall Impact	**Odds ratio.**	**St.Err.**	**t-value**	**p-value**	**[95% Conf**	**Interval]**	**Sig**
x_{10}	.981	.012	-1.50	.133	.957	1.006	
x_7	.946	.029	-1.80	.072	.891	1.005	*
x_6	.951	.335	-0.14	.886	.477	1.895	
x_8	.911	.076	-1.12	.264	.773	1.073	
x_2	1	0	-0.91	.365	1	1	
x_3	.79	.19	-0.98	.328	.493	1.266	
x_1	1	0	11.17	0	1	1	***
x_4	3.736	1.058	4.66	0	2.145	6.507	***
x_5	2.049	.678	2.17	.03	1.071	3.92	**
x_9	.58	.165	-1.91	.056	.332	1.014	*
Constant	-1.526	.719	.b	.b	-2.936	-.117	
Constant	2.874	.745	.b	.b	1.415	4.334	
Mean dependent var	1.094		SD dependent var				0.752
Pseudo r-squared	0.482		Number of obs				468
Chi-square	483.104		Prob > chi2				0.000
Akaike crit. (AIC)	544.037		Bayesian crit. (BIC)				593.819

**** p<.01, ** p<.05, * p<.1*

The ordered logistic regression results indicate that households' perceived cyclone impact was most strongly influenced by damage sustained (x1) and health-related issues (x4), with odds ratios of 1.000 ($p < 0.01$) and 3.736 ($p < 0.01$), respectively, showing that greater damage and cyclone-induced health problems substantially increased the likelihood of perceiving higher impact. Receiving aid or assistance (x5, Odds Ratio = 2.049, $p < 0.05$) also raised the odds, while education (x7, Odds Ratio = 0.946, $p < 0.10$) and urban residence (x9, Odds Ratio = 0.580, $p < 0.10$) slightly reduced them. Age, marital status, household size, income, and cyclone shelter use were not significant. Overall, the model demonstrates strong explanatory power (Pseudo $R^2 = 0.482$), highlighting the key roles of physical damage, health vulnerabilities, and post-disaster support in shaping perceived impact.

Figure 6 represents the comparison of monthly household income (red line, BDT) and total cyclone damage incurred (blue line, BDT) across sampled households.

Figure 6: Comparison of Income and Damage from Cycone Remal



The graph clearly illustrates that the total damage consistently exceeds income levels across the distribution. As damage rises sharply, especially beyond the lower income brackets, it reveals a growing disparity between financial capacity and losses endured. This disproportionate burden is particularly severe for low-income households, emphasizing the cyclone's role in deepening existing economic vulnerabilities. The pattern supports broader research findings on how natural disasters exacerbate poverty and contribute to prolonged financial instability in affected communities.

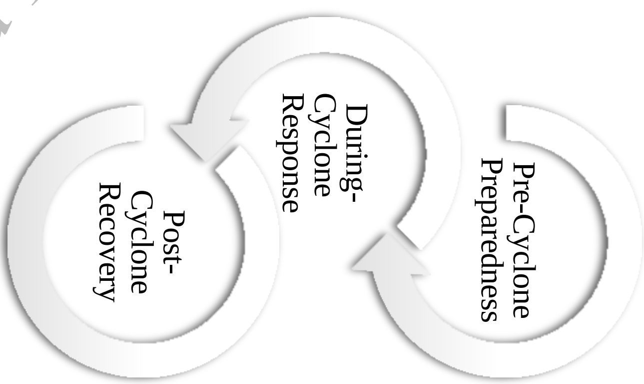
DISCUSSION

This study demonstrates the multifaceted vulnerabilities faced by communities affected by Cyclone Remal. These findings align with prior research emphasizing the disproportionate impact of cyclones on coastal areas due to poverty, inadequate infrastructure, and environmental fragility [39]. Environmental repercussions, including saltwater intrusion that rendered agricultural fields unproductive, support previous work highlighting the vulnerability of agricultural livelihoods to storm surges [40]. Similarly, the degradation of biodiversity in the Sundarbans reflects global concerns about the loss of natural protective barriers, consistent with research linking intact mangrove ecosystems to reduced cyclone damage [41]. Public health issues emerged as a significant concern, with outbreaks of waterborne diseases and increased mental health challenges. These findings echo studies documenting the health impacts of inadequate disaster preparedness and response [42]. Furthermore, households that perceived higher impacts were also more likely to report receiving aid. This association likely reflects selection effects where aid is directed toward the most affected rather than a causal relationship of aid increasing vulnerability [43]. The results also align with the Protective Action Decision Model (PADM), in which prior disaster experiences, health consequences, and warning reception shape perceptions and protective responses, such as shelter use. Similarly, social vulnerability theory helps explain the gradient of impacts across education, income, and urban–rural divides, emphasizing how structural inequalities mediate disaster outcomes. While early warning systems played a crucial role in saving lives, ongoing inefficiencies and inequities persist in disaster response. One limitation of this study is its lack of direct quantification of socioeconomic consequences, which other researchers have identified as critical to comprehensive disaster assessment [44, 24]. Future research should consider incorporating quantitative measures of economic and social disruption. Although the findings are context-specific to Patuakhali, similar vulnerability dynamics particularly those related to health, aid distribution, and education may apply to other cyclone-prone deltaic regions such as the Indian Sundarbans, Myanmar's Ayeyarwady delta, or Pacific island nations. Explicitly testing these associations across regions would strengthen external validity and refine theoretical applications of PADM and social vulnerability frameworks in disaster contexts.

POLICY RECOMMENDATION

Effective cyclone management requires an integrated approach encompassing preparedness, emergency response, and long-term recovery. The findings of this study highlight several policy gaps in Patuakhali, particularly regarding rural vulnerabilities, infrastructure resilience, and disaster communication. Strengthening early warning systems is critical, with localized and accessible communication channels designed for communities with limited media access and lower educational levels. Preparedness measures should focus on increasing the availability of cyclone shelters and enhancing the structural resilience of dwellings and vital infrastructure [45]. Community-based education initiatives can promote proactive evacuation behavior and improve risk awareness. During the response phase, improved coordination between governmental and non-governmental actors is essential. Mobile medical teams, water purification units, and targeted rescue operations can ensure that isolated communities receive timely assistance, while logistical preparedness can minimize delays in evacuation and relief delivery [46].

Figure 7: Policy Recommendations Process Flow



Long-term recovery strategies should prioritize livelihood restoration, agricultural support, and financial assistance for households experiencing high damage-to-income ratios, reflecting the study's finding that low-income families face disproportionate impacts. Ecosystem-based interventions, such as wetland protection and mangrove reforestation, can further reduce environmental vulnerability and buffer against future storm surges [47]. Although these recommendations are tailored to the specific conditions of Patuakhali, they may provide guidance for similar low-lying coastal regions, provided that local ecological, social, and infrastructural contexts are considered. By linking empirical insights from this research to policy actions, decision-makers can develop more targeted strategies to reduce both the immediate and long-term impacts of cyclones on vulnerable communities.

CONCLUSION

This study offers valuable insights into how Cyclone Remal was perceived and impacted by the communities in four upazilas of Patuakhali District. The results underscore the significance of socio-demographic and ambient factors influencing the perceived impact, including income level, education, and housing quality. While these results are specific to Patuakhali, the findings regarding income-loss disparities, health vulnerabilities, and shelter effectiveness may inform disaster management in other low-lying coastal regions. For example, targeted aid distribution and strengthening community-based evacuation strategies could be prioritized in similar deltaic environments globally, with adjustments for local socioeconomic and ecological conditions. Consequently, future research must be conducted in additional coastal districts to verify and contrast these discoveries. Nevertheless, this localized evidence can be used as a basis for disaster management planning that is more community-sensitive and tailor-made in similar vulnerable coastal environments.

LIMITATIONS

This study is limited to the Patuakhali District, so the findings may not be generalizable to other cyclone-affected regions of Bangladesh or beyond. The regression model explains 48.2% of the variation in perceived impact, suggesting that important factors like psychological resilience and access to resources were not captured due to data constraints. Future studies should address these gaps by including additional variables, longitudinal data, and a broader geographic scope. Self-reported perceptions may lead to recall bias, potentially inflating the reported impacts of Cyclone Remal. Social desirability bias might result in underreporting health issues or overstating compliance with evacuation. Additionally, selecting respondents based on availability may have overrepresented male or older individuals, which could skew perceived impact estimates. Future studies could implement stratified household-level random selection and triangulate survey responses with objective damage records to reduce these biases. While perceptions are inherently subjective, they remain valuable, especially where objective data are limited.

AUTHOR CONTRIBUTION

Md. Tanvir Ahmed conceptualized and supervised the investigation. Minhajul Islam Ove conducted the formal data analysis, while Md. Mohaiminul Islam Hasib contributed to the data compilation and preliminary analysis. Additionally, Abdul Hasib Mollah served as the corresponding author and authored the initial manuscript draft. All authors reviewed and revised the manuscript, and the final version was approved for submission.

ACKNOWLEDGEMENT

The authors respectfully thank Mr. Saikat Hossen, Department of Soil and Environmental Sciences, University of Barishal, for his great help in designing and preparing the figure used in this work.

ETHICAL STATEMENT

This research did not involve medical or clinical trials and therefore did not require formal ethical clearance from an institutional review board. The study adhered to ethical principles for social science research. Participation was entirely voluntary, and verbal informed consent was obtained from all respondents prior to survey administration. In cases where respondents were under 18 years of age, consent was obtained from parents or household heads. Participants were assured that their responses would remain confidential and that no identifying information would be published.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no competing interests or conflicts of interest related to this research.

DATA AVAILABILITY STATEMENT

The data used in this study are available upon reasonable request. Researchers interested in accessing the dataset can contact the corresponding author at ahasib20.eco@bu.ac.bd.

FUNDING STATEMENT

No external funding was received for this research. The study was conducted using the authors' resources.

REFERENCES

[1] United Nations Bangladesh, “On the frontline of climate change – WFP responds to Cyclone Remal, the first cyclone of 2024 in Bangladesh | United Nations in Bangladesh.” Accessed: Jan. 18, 2025. [Online]. Available: https://bangladesh.un.org/en/273038-frontline-climate-change-%E2%80%93-wfp-responds-cyclone-remal-first-cyclone-2024-bangladesh, https://bangladesh.un.org/en/273038-frontline-climate-change-%E2%80%93-wfp-responds-cyclone-remal-first-cyclone-2024-bangladesh

[2] ECHO, “European Civil Protection and Humanitarian Aid Operations.” Accessed: Jan. 18, 2025. [Online]. Available: https://civil-protection-humanitarian-aid.ec.europa.eu/index_en

[3] BRAC, “Cyclone Remal | Latest Updates.” Accessed: Jan. 18, 2025. [Online]. Available: https://www.brac.net/latest-news/item/1417-cyclone-remal-latest-updates

[4] ReliefWeb, “Cyclone Remal | BRAC teams prepare for response in Bangladesh - Bangladesh | ReliefWeb.” Accessed: Jan. 18, 2025. [Online]. Available: https://reliefweb.int/report/bangladesh/cyclone-remal-brac-teams-prepare-response-bangladesh

[5] A. H. Mollah, H. H. Shovon, and A. Roy, “Assessing socioeconomic vulnerability of cyclone remal-affected coastal communities in Bangladesh,” *Nat Hazards*, Dec. 2024, doi: 10.1007/s11069-024-07058-2.

[6] BDRCS, “Cyclone Remal - May 2024,” BDRCS. Accessed: Jan. 18, 2025. [Online]. Available: https://bdrcs.org/cyclone-remal/

[7] IMD, “Home | India Meteorological Department.” Accessed: Jan. 18, 2025. [Online]. Available: https://mausam.imd.gov.in/

[8] BMD, “Bangladesh Meteorological Department.” Accessed: Jan. 18, 2025. [Online]. Available: https://live8.bmd.gov.bd/

[9] Hindustan Times, “Remal likely to cross Bengal coast around Sunday midnight as severe cyclonic storm,” Hindustan Times. Accessed: Jan. 18, 2025. [Online]. Available: https://www.hindustantimes.com/india-news/remal-likely-to-cross-bengal-coast-around-sunday-midnight-as-severe-cyclonic-storm-101716530185695.html

[10] TBS, “Cyclone Remal hits Bangladesh coasts,” The Business Standard. Accessed: Jan. 18, 2025. [Online]. Available: https://www.tbsnews.net/bangladesh/cyclone-remal-mongla-payra-hoist-great-danger-signal-10-chattogram-9-860421

[11] Wikipedia, “Cyclone Remal,” *Wikipedia*. Dec. 20, 2024. Accessed: Jan. 18, 2025. [Online]. Available: https://en.wikipedia.org/w/index.php?title=Cyclone_Remal&oldid=1264088331

[12] N. Sparks and R. Toumi, “The Dependence of Tropical Cyclone Pressure Tendency on Size,” *Geophysical Research Letters*, vol. 49, no. 19, p. e2022GL098926, 2022, doi: 10.1029/2022GL098926.

[13] S. K. Sarkar, R. R. Rudra, and Md. M. H. Santo, “Cyclone vulnerability assessment in the coastal districts of Bangladesh,” *Heliyon*, vol. 10, no. 1, p. e23555, Jan. 2024, doi: 10.1016/j.heliyon.2023.e23555.

[14] S. Rahman and M. A. Rahman, “Climate extremes and challenges to infrastructure development in coastal cities in Bangladesh,” *Weather and Climate Extremes*, vol. 7, pp. 96–108, Mar. 2015, doi: 10.1016/j.wace.2014.07.004.

[15] UNDRR, “Impacts of super typhoons and climate change | PreventionWeb.” Accessed:

Jan. 18, 2025. [Online]. Available: https://www.preventionweb.net/news/impacts-super-typhoons-and-climate-change

[16] M. K. Lindell and R. W. Perry, "The protective action decision model: theoretical modifications and additional evidence," *Risk Anal*, vol. 32, no. 4, pp. 616–632, Apr. 2012, doi: 10.1111/j.1539-6924.2011.01647.x.

[17] K. Kim, J.-Y. Kang, and C. Hwang, "Identifying Indicators Contributing to the Social Vulnerability Index via a Scoping Review," *Land*, vol. 14, no. 2, Art. no. 2, Feb. 2025, doi: 10.3390/land14020263.

[18] K. Emanuel, "Increasing destructiveness of tropical cyclones over the past 30 years," *Nature*, vol. 436, no. 7051, pp. 686–688, Aug. 2005, doi: 10.1038/nature03906.

[19] P. J. Webster, G. J. Holland, J. A. Curry, and H.-R. Chang, "Changes in tropical cyclone number, duration, and intensity in a warming environment," *Science*, vol. 309, no. 5742, pp. 1844–1846, Sep. 2005, doi: 10.1126/science.1116448.

[20] M. S. Islam Arif, I. Mahdi, M. A. Rafi, S. J. Khan, and M. M. Rahman, "Cyclone exposure mapping in coastal Bangladesh: A multi-criteria decision analysis," *Heliyon*, vol. 9, no. 10, p. e21259, Oct. 2023, doi: 10.1016/j.heliyon.2023.e21259.

[21] M. Abbas, "Cyclone Amphan in Bangladesh: Strongest storm ever recorded in Bay of Bengal amid a pandemic | undefined," May 19, 2020. Accessed: Jan. 18, 2025. [Online]. Available: https://www.thedailystar.net/cyclone-amphan-in-bangladesh-strongest-storm-ever-recorded-in-bay-bengal-amid-pandemic-1904173

[22] B. K. Paul, "Why relatively fewer people died? The case of Bangladesh's Cyclone Sidr," *Nat Hazards*, vol. 50, no. 2, pp. 289–304, Aug. 2009, doi: 10.1007/s11069-008-9340-5.

[23] M. Collins *et al.*, "SPM6 Extremes, Abrupt Changes and Managing Risks," 2019, [Online]. Available: https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/10_SROCC_Ch06_FINAL.pdf

[24] Y. Lam, P. J. Winch, F. A. Nizame, E. T. Broaddus-Shea, Md. G. D. Harun, and P. J. Surkan, "Salinity and food security in southwest coastal Bangladesh: impacts on household food production and strategies for adaptation," *Food Sec.*, vol. 14, no. 1, pp. 229–248, Feb. 2022, doi: 10.1007/s12571-021-01177-5.

[25] S. F. ALIM, "How much damage Remal did to Sundarbans' ecology?," *The Financial Express*, Jun. 03, 2024. Accessed: Jan. 18, 2025. [Online]. Available: https://thefinancialexpress.com.bd/views/opinions/how-much-damage-remal-did-to-sundarbans-ecology

[26] K. A. Hoque, "Cyclone Remal gives a stark reminder of our crisis protection gap," *The Daily Star*, Jun. 10, 2024. Accessed: Jan. 18, 2025. [Online]. Available: https://www.thedailystar.net/opinion/views/news/cyclone-remal-gives-stark-reminder-our-crisis-protection-gap-3630711

[27] IFRC, "Bangladesh | Cyclone Remal - Operation Update #2 Emergency appeal No: MDRBD035 - Bangladesh | ReliefWeb." Accessed: Jan. 18, 2025. [Online]. Available: https://reliefweb.int/report/bangladesh/bangladesh-cyclone-remal-operation-update-2-emergency-appeal-no-mdrbd035

[28] M. Sharmin, "The untold agony of Cyclone Remal," *The Daily Star*, Jun. 03, 2024. Accessed: Jan. 18, 2025. [Online]. Available: https://www.thedailystar.net/opinion/views/news/the-untold-agony-cyclone-remal-3625116

[29] S. L. Cutter, B. J. Boruff, and W. L. Shirley, “Social Vulnerability to Environmental Hazards,” *Social Science Quarterly*, vol. 84, no. 2, pp. 242–261, 2003, doi: 10.1111/1540-6237.8402002.

[30] S. Hallegatte, “Open Knowledge Repository,” 2017. Accessed: Jan. 18, 2025. [Online]. Available: https://openknowledge.worldbank.org/entities/publication/25ab6845-b9d1-56dc-9ee9-95ee78ea5d40

[31] S. Das and J. R. Vincent, “Mangroves protected villages and reduced death toll during Indian super cyclone,” *Proc Natl Acad Sci U S A*, vol. 106, no. 18, pp. 7357–7360, May 2009, doi: 10.1073/pnas.0810440106.

[32] BMD, “Bangladesh Meteorological Department.” Accessed: Jan. 18, 2025. [Online]. Available: https://live8.bmd.gov.bd/

[33] R. Šakić Trogrlić, M. Duncan, G. Wright, M. van den Homberg, A. Adeloye, and F. Mwale, “Why does community-based disaster risk reduction fail to learn from local knowledge? Experiences from Malawi,” *International Journal of Disaster Risk Reduction*, vol. 83, p. 103405, Dec. 2022, doi: 10.1016/j.ijdrr.2022.103405.

[34] L. Zhao, “Planning Emergency Shelters for Urban Disaster Resilience: An Integrated Location-Allocation Modeling Approach,” *Sustainability*, vol. 9, no. 11, 2017, doi: https://doi.org/10.3390/su9112098.

[35] R. Sarmin, S. Akther, and T. Yasmin, “A Geospatial Analysis to Assess Risks of Extreme Events in Low Lying Delta Environment: A Case Study of the Patuakhali District in Bangladesh,” Nov. 30, 2021, *Social Science Research Network, Rochester, NY*: 3972017. doi: 10.2139/ssrn.3972017.

[36] J. E. Bartlett, J. W. Kotrlik, and C. C. Higgins, “Organizational research: Determining appropriate sample size in survey research - ProQuest,” *Information Technology, Learning, and Performance Journal*, vol. 19, no. 1, pp. 43–50, 2001, Accessed: Jan. 27, 2025. [Online]. Available: https://www.proquest.com/openview/968e6436885222038106d874c370feaa/1?pq-origsite=gscholar&cbl=9497

[37] M. M. Rahman, N. J. Chaity, Md. T. Hossain, and E. Alam, “Exploring factors affecting disaster risk perception in ethnic minority: A case study in Garo community, Bangladesh,” *Progress in Disaster Science*, vol. 26, p. 100424, Apr. 2025, doi: 10.1016/j.pdisas.2025.100424.

[38] P. Bhandari, “Ordinal Data | Definition, Examples, Data Collection & Analysis,” Scribbr. Accessed: May 19, 2025. [Online]. Available: https://www.scribbr.com/statistics/ordinal-data/

[39] Md. M. Rahman, Md. A. Hossain, Md. R. Ali, Z. Ahmed, and A. H. M. Hedayutul Islam, “Assessing vulnerability and adaptation strategy of the cyclone affected coastal area of Bangladesh,” *Geoenvironmental Disasters*, vol. 9, no. 1, p. 6, Feb. 2022, doi: 10.1186/s40677-022-00209-2.

[40] P. Tarolli, J. Luo, E. Park, G. Barcaccia, and R. Masin, “Soil salinization in agriculture: Mitigation and adaptation strategies combining nature-based solutions and bioengineering,” *iScience*, vol. 27, no. 2, p. 108830, Feb. 2024, doi: 10.1016/j.isci.2024.108830.

[41] H. Mahmood, M. Ahmed, T. Islam, M. Z. Uddin, Z. U. Ahmed, and C. Saha, “Paradigm shift in the management of the Sundarbans mangrove forest of Bangladesh: Issues and challenges,” *Trees, Forests and People*, vol. 5, p. 100094, Sep. 2021, doi:

10.1016/j.tfp.2021.100094.

[42] R. Dasgupta and M. Basu, “Mental health and socio-psychological manifestations of cyclone-induced water insecurity in the Indian Sundarban delta,” *International Journal of Disaster Risk Reduction*, vol. 98, p. 104085, Nov. 2023, doi: 10.1016/j.ijdrr.2023.104085.

[43] I. Ahmed, “The national plan for disaster management of Bangladesh: Gap between production and promulgation,” *International Journal of Disaster Risk Reduction*, vol. 37, p. 101179, Jul. 2019, doi: 10.1016/j.ijdrr.2019.101179.

[44] R. Subhani and M. M. Ahmad, “Socio-Economic Impacts of Cyclone Aila on Migrant and Non-Migrant Households in the Southwestern Coastal Areas of Bangladesh,” *Geosciences*, vol. 9, no. 11, Art. no. 11, Nov. 2019, doi: 10.3390/geosciences9110482.

[45] E. Alam, “Reasons for non-evacuation and shelter-seeking behaviour of local population following cyclone warnings along the Bangladesh coast,” *Progress in Disaster Science*, vol. 21, p. 100307, Jan. 2024, doi: 10.1016/j.pdisas.2023.100307.

[46] Md. T. Islam *et al.*, “Revisiting disaster preparedness in coastal communities since 1970s in Bangladesh with an emphasis on the case of tropical cyclone Amphan in May 2020,” *International Journal of Disaster Risk Reduction*, vol. 58, p. 102175, May 2021, doi: 10.1016/j.ijdrr.2021.102175.

[47] A. Chausson *et al.*, “Harnessing nature-based solutions for economic recovery: A systematic review,” *PLOS Climate*, vol. 3, no. 10, p. e0000281, Oct. 2024, doi: 10.1371/journal.pclm.0000281.