Research Paper

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

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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 (odds ratio [OR] = 1.000 and 3.736, respectively, $P<0.01$). Receipt of post-cyclone aid also contributed to higher perceived impact (odds ratios [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 for strengthening community resilience in coastal Bangladesh. The insights from this study can inform more effective disaster risk reduction and recovery policies.

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Introduction

As Bangladesh is a low-lying deltaic region, it is one of the most cyclone-prone regions in the world. The recently occurred cyclone Remal is a severe cyclonic storm (SCS) 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 40,246 houses that were completely destroyed, with an additional 131,678 experiencing partial damage, disrupted the lives of local communities, displaced approximately 4.6 million people, and caused significant environmental impacts, destroying thousands of acres of different land areas all over Bangladesh [2]. There was extreme rainfall and an 8-12 foot 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 of the worst-hit districts that experienced acute destruction. During this period, over 30 villages in Patuakhali were severely flooded due to breaches in the embankments [4]. As a result of these floods and the severe gusts accompanying 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 in other ways, and thus there is a need for effective disaster management strategies in that region. Although several coastal districts, including Khulna and Barguna, saw significant impact, Patuakhali's topographical and socioeconomic 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] a socioeconomic vulnerability index (SeVI). These attributes validate its designation as an important case study for comprehending community-level perceptions of cyclones. The study aimed 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 reached a maximum sustained wind speed of 117 km/h (60 kt) at its peak on May 27 [6]. Making landfall on May 26, 2024, with wind speeds ranging from 92 to 117 km/h.

Based on its maximum sustained wind speed, it can be categorized as SCS in the disturbance classification of both the Bangladesh Meteorological Department (BMD) and the India Meteorological Department (IMD). The classification of tropical cyclones by IMD and BMD is shown in Figure 1.

Table 1 compares the tropical cyclone intensity classification systems used by the BMD and IMD. While both systems classify cyclones based on sustained wind speed, differences exist in the intermediate intensity categories and threshold ranges.

On May 24, the cyclone developed 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]. The pathway of cyclone Remal is shown in Figure 2.

Soon, due to the warm sea surface temperature of approximately 30 °C and low vertical wind shear, cyclone Remal began to rapidly intensify. It intensified and formed as SCS 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 approximately 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].

Figure 3, sourced from the IMD, shows cyclone Remal's central pressure dynamics from 24 to 27 May 2024. Panel (A) presents the temporal variation in estimated central pressure (hPa), while Panel (B) shows the corresponding pressure drop at the cyclone center (hPa). Together, these trends highlight the cyclone's intensification prior to landfall and its subsequent weakening thereafter.

This decrease in pressure at its peak suggests the cyclone strengthening because it leads to an increase in wind speed and weather severity. The pressure began to decrease after landfall. Later, it began to move inland, growing weaker as it encountered harsher terrain and increased friction over land.

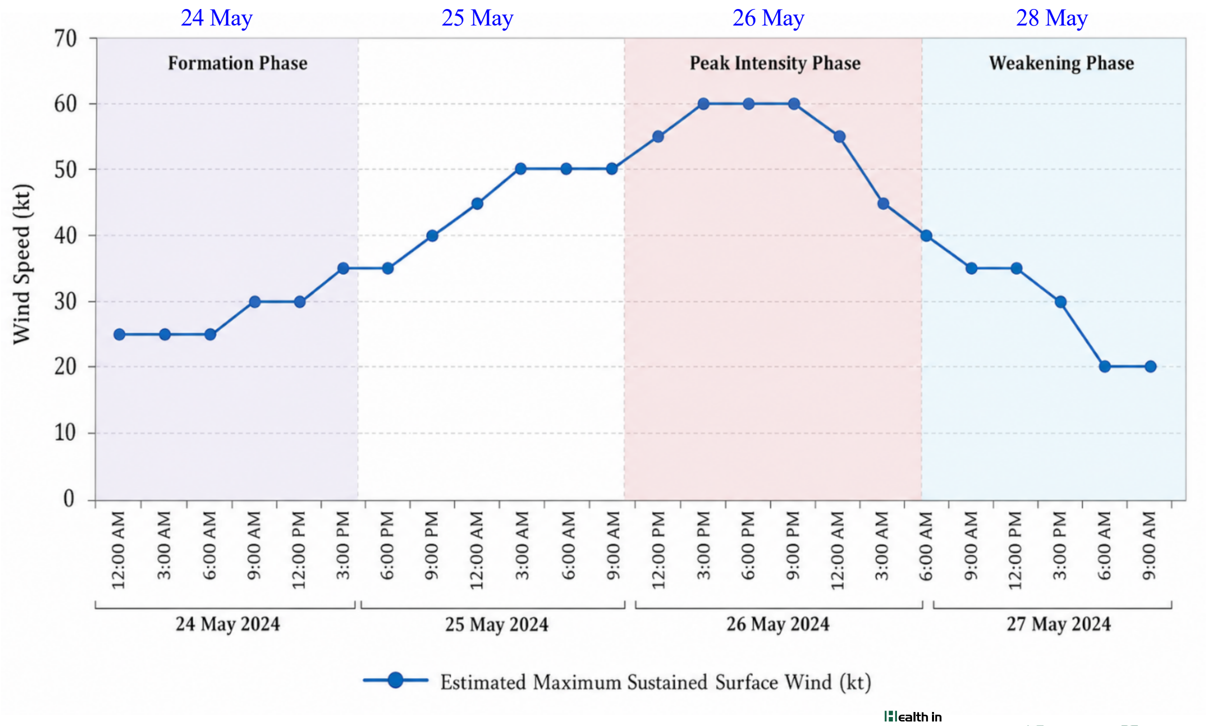

Figure 1. Temporal variation in estimated maximum sustained surface wind speed (kt) of Cyclone remal (source: India Meteorological Department [7])

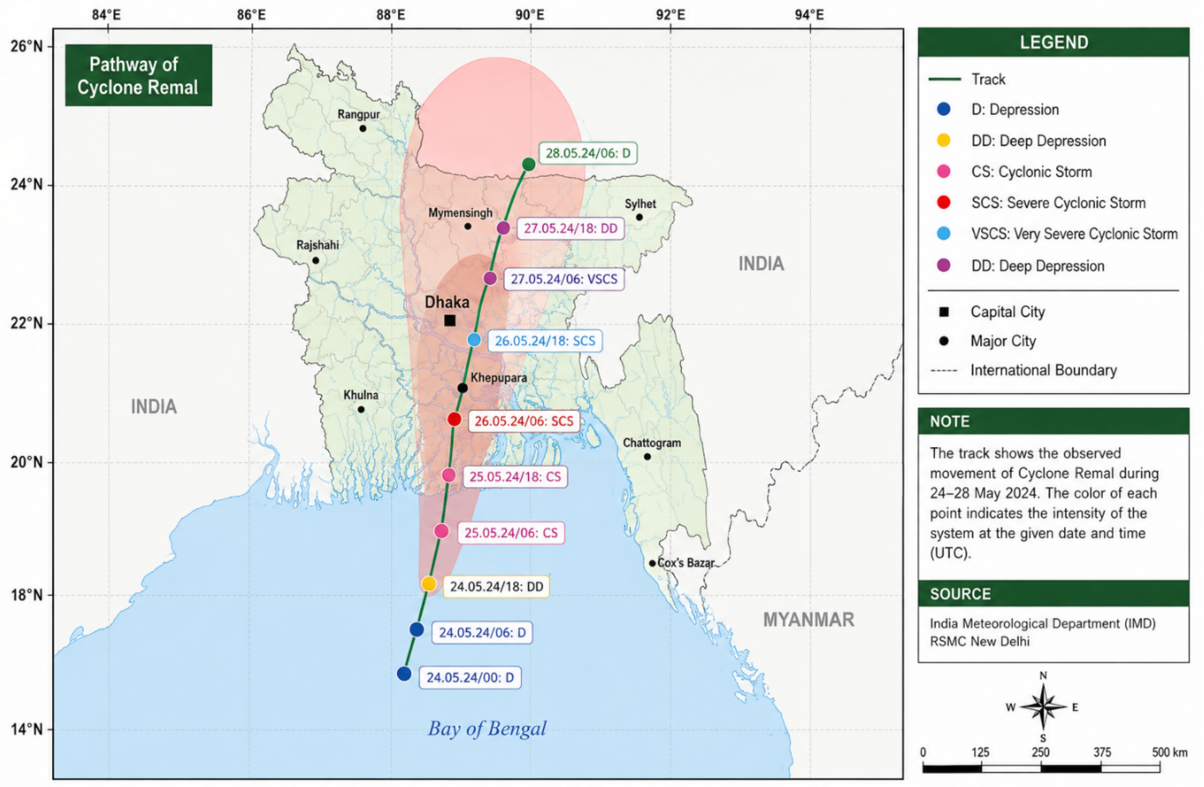

Figure 2. Pathway of cyclone Remal [10]

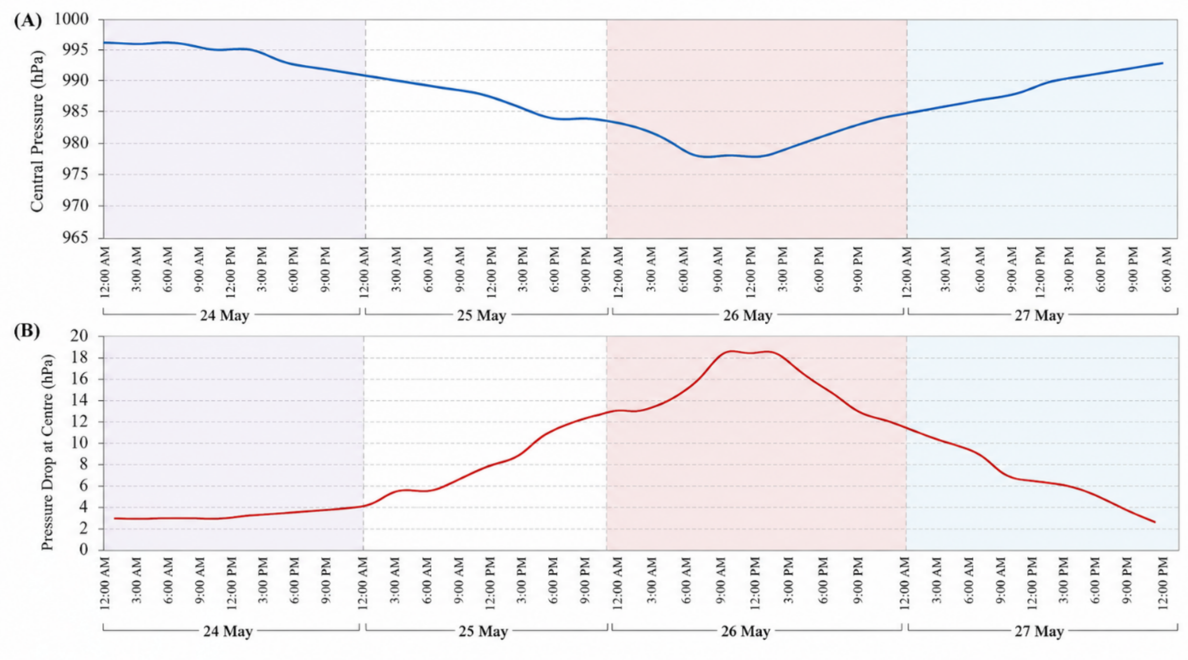

Figure 3. Temporal variation in cyclone Remal's central pressure (A) and pressure drop at the cyclone centre (B) from 24 to 27 May 2024 [7]

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,

Table 1. Comparison of tropical cyclone intensity classifications used by BMD and IMD [7, 8]

Category	BMD (km/h)	BMD (kt)	IMD (km/h)	IMD (kt)
Super cyclonic storm	≥222	≥120	≥221	≥120
Cyclonic storm with a core of hurricane winds	118–221	64–119	—	—
Extremely severe cyclonic storm	—	—	166–220	90–119
Very severe cyclonic storm	—	—	118–165	64–89
Severe cyclonic storm	89–117	48–63	89–117	48–63
Cyclonic storm	63–88	34–47	63–88	34–47
Deep depression	52–61	28–33	51–62	28–33
Depression	41–51	22–27	31–50	17–27
Well-marked low	31–40	17–21	—	—
Low pressure area	<31	<17	<31	<17

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BMD: The Bangladesh Meteorological Department; IMD: The India Meteorological Department.

and aid—that influence these perceptions. By analyzing household-level survey data using ordered logistic regression (OLR), this study deepens 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 populations are often densely concentrated and rely on natural resources for their livelihoods [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, the protective action decision model (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 [18, 19]. 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 expanding body of literature establishes a correlation between climate change and increased cyclone frequency and intensity. According to the Intergovernmental Panel on Climate Change, the frequency of severe tropical cyclones is expected to increase, potentially devastating vulnerable regions, such as South Asia [23]. Cyclone Remal has profoundly impacted coastal communities in Bangladesh, particularly regarding 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 days following Cyclone Remal, waterborne diseases, such as cholera and diarrhea, occurred due to contaminated 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 for 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 [29], which 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 resources to cope with the aftermath of a disaster. This has been well documented in the literature, including research by [30], which investigates the relationship between poverty and catastrophe susceptibility. Cyclones cause not only rapid physical destruction but also long-term environmental and health effects. These impacts can worsen the susceptibility of affected populations, creating a vicious cycle of disaster-induced poverty and environmental degradation. The degradation of natural barriers, such as 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 [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, such as 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 in 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.

Materials and Methods

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] (Figure 4). 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 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.

Based on a 95% confidence level and a 5% error margin, the minimum sample size was calculated to be 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]. Content validity was assessed through expert review by one disaster management specialist, 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 reviews of completed questionnaires and random spot checks by supervisors. The questionnaire captured demographic

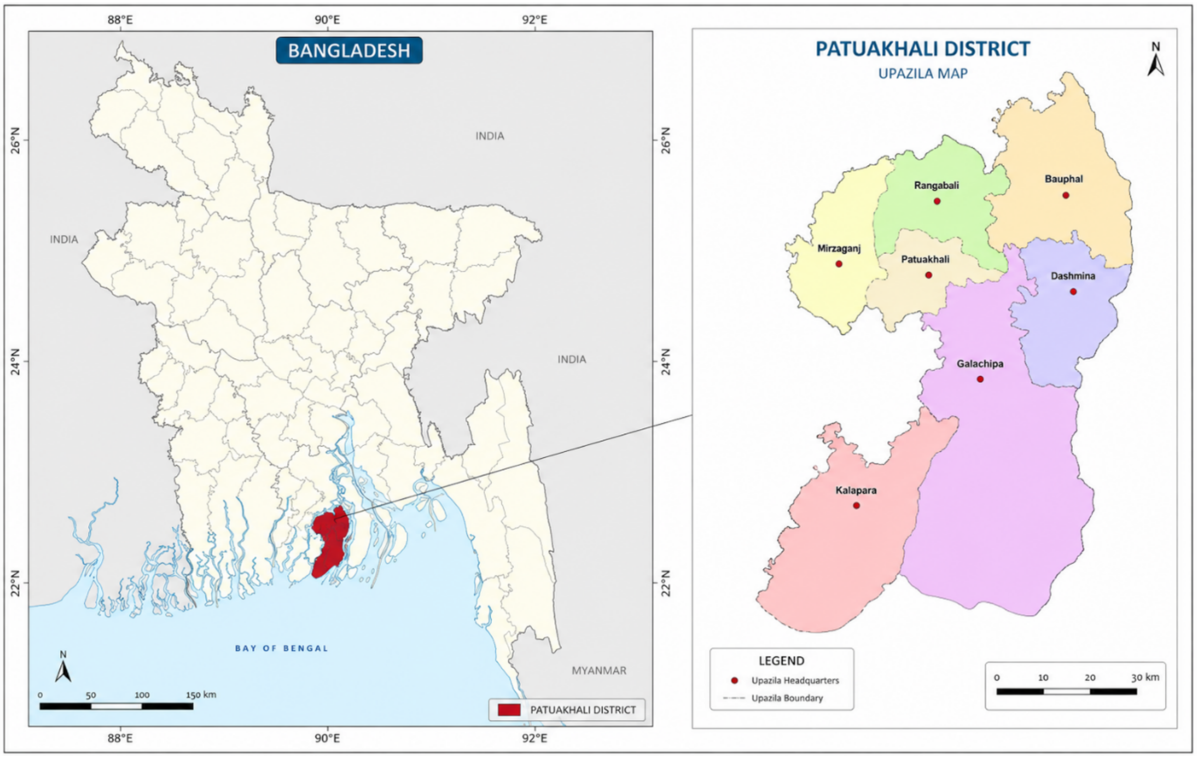

Figure 4. Study area

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 OLR model, appropriate for ordinal dependent variables with non-equidistant categories [38]. The regression model is specified as Equation 1:

$$1.\ y=\beta_0+\beta_{1x1}+\beta_{2x2}+\beta_{3x3}+\beta_{4x4}+\beta_{5x5}+\beta_{6x6}+\beta_{7x7}+\beta_{8x8}+\beta_{9x9}+\beta_{10x10}+\varepsilon$$

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 OLR model. Model fit and diagnostics were evaluated using log-likelihood, likelihood-ratio chi-square (χ^2), 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, enabling a clear understanding of how changes in independent variables affect the probability of perceiving a low, medium, or high cyclone impact. Findings are representative at the district level in Patuakhali when sampling weights are applied, but are not directly generalizable to other coastal districts.

Table 2 presents 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 cyclone's perceived overall impact.

The OLR model was chosen over other models, such as 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 perceived impact (low to high) and yields more parsimonious and interpretable estimates. This approach allows estimation of how each independent variable influences the probability that a respondent perceives the cyclone's impact as low, medium, or high. Model diagnostics assessed goodness-of-fit, with the pseudo R-squared (R^2) statistic as a key indicator. ORs 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

In the study, the total number of observations is 468. Table 3 presents the descriptive summary of the variables as Mean ± standard deviation, minimum, and maximum values.

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

Table 2. 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 lives in an urban area or a rural area
x_5	Indicating whether the household received any form of aid or assistance after the cyclone	x_{10}	Respondent's age

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Tabulation of dummy variables

Five dummy variables are included in the research to help explain the dependent variable, which takes the value 0 or 1 to indicate the absence or presence of a particular category effect expected to influence the outcome (Table 4).

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, 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 5 presents the results of the OLR model, which explores the factors influencing the perceived overall impact of Cyclone Remal in the Patuakhali District of Bangladesh. The dependent variable, Overall Impact, 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.

The logistic regression results reveal several significant determinants of household outcomes following Cyclone Remal. The level of damage sustained (x_1) 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 (x_4) 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 (x_5) increased the probability of being affected (Coef. = 0.717, P<0.05). On the other hand, years of schooling (x_7) 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 (x_9) was also negatively associated (Coef. = –0.545, P<0.10), indicating lower vulnerability relative to rural households. In contrast, respondent's age (x_{10}, Coef. = –0.019, P=0.133), marital status (x_6, Coef. = –0.050, P=0.886), household size (x_8, Coef. = –0.093, P=0.264), average monthly income (x_2, Coef.

Table 3. Descriptive statistics of household characteristics (n=468)

Variables	Obs	Mean±SD	Min	Max
Age (y)	468	42.03±15.409	16	75
Years of schooling	468	11.068±4.577	0	17
Household size (persons)	468	5.53±1.775	2	12
Income (BDT/month)	468	40204.06±20568.93	10000	160000
Total damage (BDT)	468	19084.59±26539.449	0	400000

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Table 4. Descriptive statistics of dummy variables

Variables	Responses	No. (%)
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)

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Table 5. Results of ordered logistic regression estimating determinants of perceived cyclone impact

Variables	Coef.	St.Err.	t	P	95% CI
x_{10}	-0.019	0.013	-1.50	0.133	-0.044, 0.006
x_7	-0.055	0.031	-1.80	0.072*	-0.115, 0.005
x_6	-0.05	0.352	-0.14	0.886	-0.74, 0.639
x_8	-0.093	0.084	-1.12	0.264	-0.257, 0.071
x_2	0	0	-0.91	0.365	0, 0
x_3	-0.235	0.24	-0.98	0.328	-0.706, 0.236
x_1	0	0	11.17	0.00***	0, 0
x_4	1.318	0.283	4.66	0.00***	0.763, 1.873
x_5	0.717	0.331	2.17	0.03**	0.068, 1.366
x_9	-0.545	0.285	-1.91	0.056*	-1.103, 0.014
Constant	-1.526	0.719	.b	.b	-2.936, -0.117
Constant	2.874	0.745	.b	.b	1.415, 4.334
Mean dependent var		1.094	SD dependent var		0.752
Pseudo R^2		0.482	Number of obs		468
χ^2		483.104	Prob > χ^2		0.000
AIC		544.037	Bayesian crit. (BIC)		593.819

$^{***}P<0.01$, $^{**}P<0.05$, $^{*}P<0.1$.

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Table 6. Odds ratios from ordered logistic regression on perceived cyclone impact determinants

Overall Impact	Odds Ratio	St.Err.	t	P	95% CI
x_{10}	0.981	0.012	-1.50	0.133	0.957, 1.006
x_7	0.946	0.029	-1.80	0.072*	0.891, 1.005
x_6	0.951	0.335	-0.14	0.886	0.477, 1.895
x_8	0.911	0.076	-1.12	0.264	0.773, 1.073
x_2	1	0	-0.91	0.365	1, 1
x_3	0.79	0.19	-0.98	0.328	0.493, 1.266
x_1	1	0	11.17	0.00***	1, 1
x_4	3.736	1.058	4.66	0.00***	2.145, 6.507
x_5	2.049	0.678	2.17	0.03**	1.071, 3.92
x_-	0.58	0.165	-1.91	0.056*	0.332, 1.014
Constant	-1.526	0.719	.b	.b	-2.936, -0.117
Constant	2.874	0.745	.b	.b	1.415, 4.334
Mean dependent var		1.094	SD dependent var		0.752
Pseudo R^2		0.482	Number of obs		468
χ^2		483.104	Prob > χ^2		0.000
AIC		544.037	Bayesian crit. (BIC)		593.819

***P<0.01, **P<0.05, *P<0.1.

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= 0.000, P=0.365), and use of cyclone shelters (x_3, 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^2 value of 0.482, which suggests that nearly 48% of the variance in perceived impact is explained by the independent variables. The likelihood ratio test (χ^2= 483.104, P<0.001) confirms that the model is statistically significant. The AIC and BIC further support the validity of the model fit.

Table 6 presents the OLR analysis results in terms of OR, which helps interpret the likelihood of experiencing a higher perceived impact of Cyclone Remal based on various factors. Each OR is reported along with its standard error, t, P, and 95% confidence interval (CI).

The OLR results indicate that households' perceived cyclone impact was most strongly influenced by damage sustained (x_1) and health-related issues (x_4), with ORs 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 (x_5, OR=2.049, P<0.05) also raised the odds, while education (x_7, OR=0.946, P<0.10) and urban residence (x_9, OR=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 5 shows the comparison of monthly household income (red line, BDT) and total cyclone damage incurred (blue line, BDT) across sampled households.

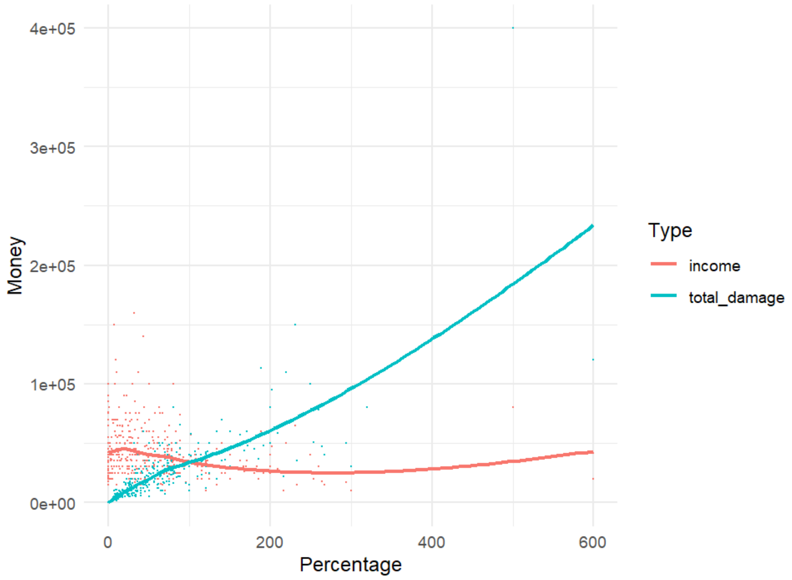

Figure 5. Comparison of income and damage from cycone Remal

Figure 5 shows the relationship between monthly household income (BDT) and total cyclone-related damage incurred across the sampled households in Patuakhali District. The figure shows considerable variation in both income and damage levels across observations. Cyclone-induced losses are observed among households across all income groups, indicating that disaster impacts are not confined to any specific income category. While higher-income households tend to report larger absolute losses in some cases, lower-income households are likely to experience more severe economic pressure due to their limited financial capacity to absorb such shocks. Overall, the pattern highlights the widespread nature of cyclone impacts and underscores the economic vulnerability of coastal households, particularly those with lower income levels.

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, in which aid is directed toward the most affected, rather than a causal relationship in which aid increases vulnerability [43]. The results also align with the 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 [24, 44]. 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].

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 study to policy actions, decision-makers can develop more targeted strategies to reduce the immediate and long-term impacts of cyclones on vulnerable communities (Figure 6).

Conclusion

This study offers valuable insights into how Cyclone Remal was perceived and impacted 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. Although 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 of community-based evacuation strategies could be prioritized in similar deltaic environments globally, with adjustments to local socioeconomic and ecological conditions. Consequently, future research must be conducted in additional coastal districts to verify and contrast these dis-

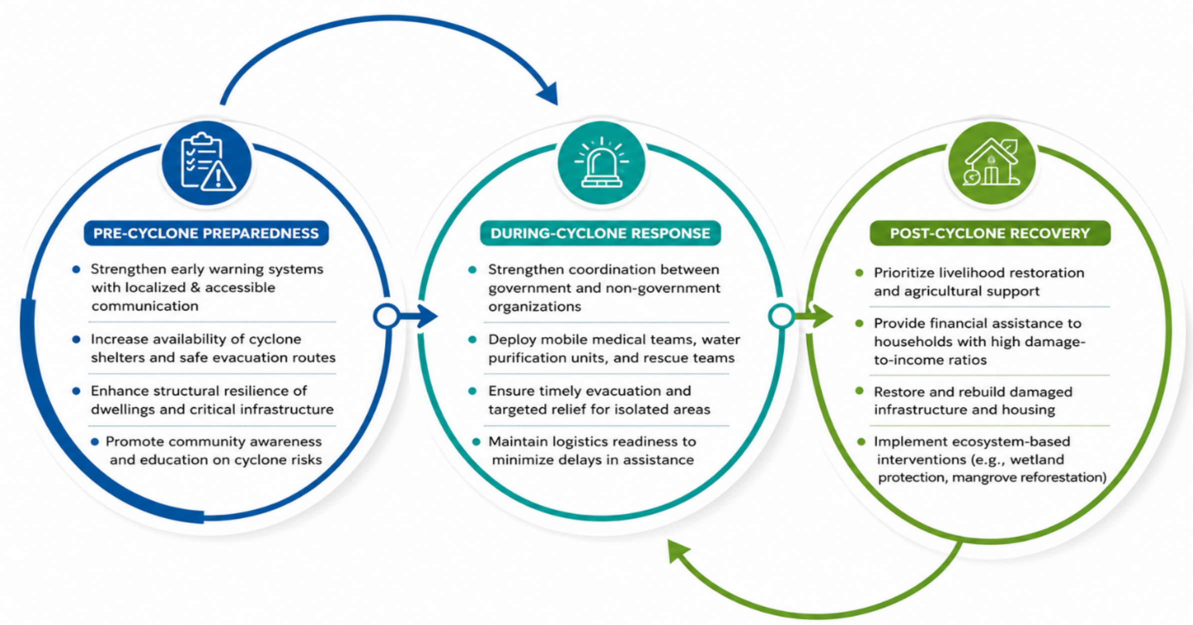

Figure 6. Framework for cyclone risk management and recovery policies

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coveries. Nevertheless, this localized evidence can serve as a basis for disaster management planning that is more community-sensitive and tailored to 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 explained 48.2% of the variation in perceived impact, suggesting that important factors, such as 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 of 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. Although perceptions are inherently subjective, they remain valuable, especially where objective data

Ethical Considerations

Compliance with ethical guidelines

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.

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Authors' contributions

Conceptualization and supervision: Md. Tanvir Ahmed; Data analysis: Minhajul Islam Ove; Data compilation and preliminary analysis: Mohaiminul Islam Hasib; writing the original draft: Abdul Hasib Mollah; Review, editing and final approval: All authors.

Conflict of interest

The authors declared no conflict of interests.

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