Economics of Disasters and Climate Change
https://doi.org/10.1007/s41885-024-00157-1

RESEARCH

Understanding Evacuation Behavior During Cyclones: Evidence from Bangladesh

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Received: 4 May 2024 / Accepted: 2 July 2024

Abstract

Due to its unique location, Bangladesh often faces devastating hydroclimatic shocks such as floods and cyclones. In the recent past, three major cyclones (Sidr in 2007, Aila in 2009, and Komen in 2015) claimed 3800 lives and damaged hundreds of thousands of houses with billions of dollars in property damages. In this paper, we focus on understanding people's evacuation behaviors in the face of approaching cyclones using survey data collected through face-to-face interviews with residents living in the coastal areas of Bangladesh. Through various statistical models, including probit, panel probit, bivariate probit, and multinomial logit models, we have explored the determinants of both past and future evacuation decisions, as well as the choice of evacuation destinations. Our findings reveal consistent patterns across different cyclone events, highlighting the significant roles played by warning time, proximity to the coast, property loss, shelter accessibility, housing structure, literacy, past evacuation experiences, and demographic factors such as age, gender, and employment status. Additionally, the analysis of evacuation destinations uncovers nuanced insights into the preferences and challenges faced by evacuees, including the need for improving shelter accessibility. With rising vulnerabilities in coastal areas in Bangladesh and worldwide, identifying what drives households' evacuation decisions and their destination choices can provide useful inputs for evacuation planning and effective disaster management.

Keywords Natural disasters · Evacuation decision · Cyclones

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Published online: 03 August 2024

JEL Classification D8 · Q54

Introduction

We have seen an increase in the frequency of natural disasters during the last three decades. We have also witnessed that developing countries are often the victims of these devastating events, and the macroeconomic impacts of natural disasters are relatively more substantial in developing countries (Strobl 2012). Bangladesh often faces devastating cyclones due to its unique location (Shamsuddoha and Chowdhury 2007). Climate change models predict that warmer and wetter weather will intensify the impacts of tropical cyclones in Bangladesh.

Cyclones have destroyed numerous assets and claimed over 1 million lives in Bangladesh since 1877 (Paul and Dutt 2010). Recently, three major cyclones (Sidr in 2007, Aila in 2009, and Komen in 2015) claimed 3800 lives and damaged thousands of houses, resulting in billions of dollars in property damage. About one million households were severely affected during Cyclone Sidr, causing a death toll of more than 3,500 (Mendelsohn et al. 2012). Cyclone Aila hit the west border of Bangladesh on May 25, 2009, causing 109 deaths, and affecting approximately 4 million people in 11 districts among 64 districts in Bangladesh. Cyclone Komen made landfall in Bangladesh on July 30, 2015. At least seven people lost their lives during the cyclone, and reportedly 30 more people were missing (Sanderson and Sharma 2016). More recently, Cyclone Amphan hit the coastal areas of Bangladesh in May 2020 and affected over a million people in Bangladesh across nine districts in the divisions of Khulna and Barisal, with the deaths of 26 people and heavy damage caused to properties.

After analyzing the cyclone activity of around 234 years, Haque et al (2012) showed a trend of around 2.5% decrease in death tolls due to cyclone activities in Bangladesh, possibly due to the emergency management efforts made by the government of Bangladesh and other concerned agencies. During a natural disaster, a large portion of people decide to stay home to protect their property and livestock. The agency can make evacuation easier by ensuring law and order in evacuation zones and protecting private property when people are gone. They can also ensure a better environment at the cyclone shelters. For example, authorities can take initiative and make accommodations for livestock in shelters. Ensuring services geared towards women, infants, and the elderly can be very useful. Arranging transportation to the shelter from vulnerable places can be instrumental. The government of Bangladesh has done a tremendous job during Cyclone Sidr in keeping the number of deaths relatively low. Most of their success is down to timely weather forecasting and warning systems. These have led to the successful evacuation of people (Paul and Dutt 2010). Disaster preparedness is now vital in emergency management plans in many countries, including Bangladesh (Halim et al. 2021; Meng and Mozumder 2021). In order to minimize losses, people are moved to a safer location temporarily (Saha and James 2017). However, making people respond to evacuation orders is still a significant challenge for disaster management agencies (Stein et al. 2013). It is recognized that the local institutions are learning a great deal from their experiences with recent cyclones. However, major constraints (e.g., resource constraints for the people who live in vulnerable coastal regions) can make evacuation very challenging even if the emergency management agencies are communicating the risk or danger effectively.

Aside from advanced warning, other factors such as gender, income, and other demographic variables may drive the household evacuation decision (Dash and Gladwin 2007; Jiang et al. 2023). For example, people rely more on radio messages to make evacuation decisions than on television and newspapers, as they are not readily available in countries like Bangladesh (Paul and Dutt 2010).

Recent data suggests that climate change might cause the sea level to rise, and significant portions of low-lying coastal areas will go underwater (Rotzoll and Fletcher 2013, Meng and Mozumder 2023). Using historical data from three coastal stations in Bangladesh (Hiron Point, Char Changa, and Cox's Bazaar), it was observed that the estimated rate of rise of water levels was 4, 6, and 7.8 mm per year for the three stations, respectively (Sarwar 2013). Moreover, many models predict that storm events will become more frequent and severe due to sea surface temperature rise (Webster et al. 2005; Bender et al. 2010). Major storms will create life-threatening conditions for the coastal population, where population density is several times higher than inland population densities (Hanson et al. 2011). This instantaneous increase in uncertainty and exposure emphasizes the significance of understanding the approach that can reduce the exposure and count of deaths in the face of rising vulnerability.

Evacuation is considered effective in saving lives if it is planned and coordinated effectively. Although there have been plenty of studies that focused on factors that influence evacuation behavior (Dow and Cutter 1998; Dash and Gladwin 2007; McCaffrey et al. 2018; Dixon et al. 2017; Jiang et al. 2023; Meng et al. 2024), researchers are still trying to learn different aspects regarding this crucial matter, especially in a developing country context.

This study analyzes the factors that affected the evacuation decision in a large, heterogeneous sample of three cyclones in Bangladesh. Based on the survey data collected through face-to-face interviews with residents living in the coastal areas of Bangladesh, we investigate the household's evacuation behavior and the choice of evacuation destination. We also examine how previous cyclone experiences influenced subsequent evacuation decisions using probit, panel probit, and biprobit regression analyses. In addition, multinominal panel logit regression analysis was employed to understand destination choices among evacuees.

This paper contributes to the literature by exploring cyclone evacuation in a developing country context. Our findings reveal consistent patterns across different cyclone events, highlighting the significant roles played by warning time, proximity to the coast, property loss, shelter accessibility, housing structure, literacy, past evacuation experiences, and demographic factors such as age, gender, and employment status. Additionally, the analysis of evacuation destinations uncovers nuanced insights into the preferences and challenges faced by evacuees, including the need for improving shelter accessibility. These analyses investigating the driving factors behind evacuation decisions can provide valuable inputs for future evacuation planning by emergency management agencies in a developing country context. With rising vulnerabilities in coastal areas in Bangladesh and worldwide, identifying what drives households' risk-averting behavior during natural disasters like cyclones can provide valuable inputs for evacuation planning and effective disaster management.

Literature Review

There is a growing body of research focusing on evacuation behaviors in response to natural hazards. When different people face climatic events, they behave in distinct ways. Their response to these events can be shaped by their cultural or social values. Mozumder et al. (2008) used survey data from New Mexico to investigate respondents' risk perceptions regarding wildfire risk and their intended evacuation decision in the face of wildfire risk. Even the intensity of the hazard event can have varying effects on evacuation decisions. Using a stated preference analysis, Mozumder and Vásquez (2018) analyzed the factors that individual households consider before evacuating during cyclones. They found that the cyclones' intensity was the main factor behind their evacuation decision. But even then, the correlation is not always linear. They also found that people are more likely to follow mandatory evacuation orders. Housing serves as a risk indicator for both households and emergency planners. For instance, occupants of multiunit residences tend to evacuate more frequently than those in single-family homes (Gladwin et al. 2001). Mobile homeowners also show higher evacuation rates compared to other housing types, leading to targeted evacuation messaging for this demographic (Baker 1991). Studies indicate that individuals weigh actual and perceived risks along with social and economic limitations when making evacuation decisions. While some research has explored factors influencing where evacuees go, this area remains less understood.

In addition to socioeconomic and demographic factors, an individual's past evacuation experience can be crucial in evacuation decisions (Lazo et al. 2015). Previous evacuation experience allows people to make an informed evacuation decision during future cyclone events (Hasan et al. 2011; Vásquez et al. 2016; Jiang et al. 2022). When households have previous experience of dealing with a hazard, it is assumed that they will be more aware of the risk posed by hazard events, and this will motivate them to protect themselves. Some studies have found strong evidence in support of this hypothesis (Zhang et al. 2007; Morss et al. 2016), but several studies have found a negative or no significant relationship between past cyclone experience and evacuation behaviors (Dow and Cutter 1998; Lindell et al. 2005). Unnecessary evacuation experience might become a barrier for their future evacuation decision (Huang et al. 2012).

Despite increasing cyclone risks faced by the coastal communities, there is inadequate social science research addressing challenges in the evacuation process in developing country contexts. There are several studies that explored Bangladesh's susceptibility to different types of natural disasters (Saha and James 2017; Parvin et al. 2019; Shamsuddoha and Chowdhury 2007). However, they did not fully study how previous cyclone experience influences evacuation behavior.

Overall, the literature review suggests several generalizations about household behavior during a cyclone threat. Evacuation experience, as a measure of cyclone risk, is one of the best predictors of the evacuation decision. Some demographic and socioeconomic factors appear to affect evacuation decisions: however, it is unclear as to what extent these patterns might be related to objective and subjective risk.

Survey Design and Data Collection

Bangladesh is divided into eight administrative divisions. Among them, the coastal zones are mostly comprised of Khulna, Barisal and Chittagong. Each division is split into several districts and the total number of districts in Bangladesh is 64. The coastal

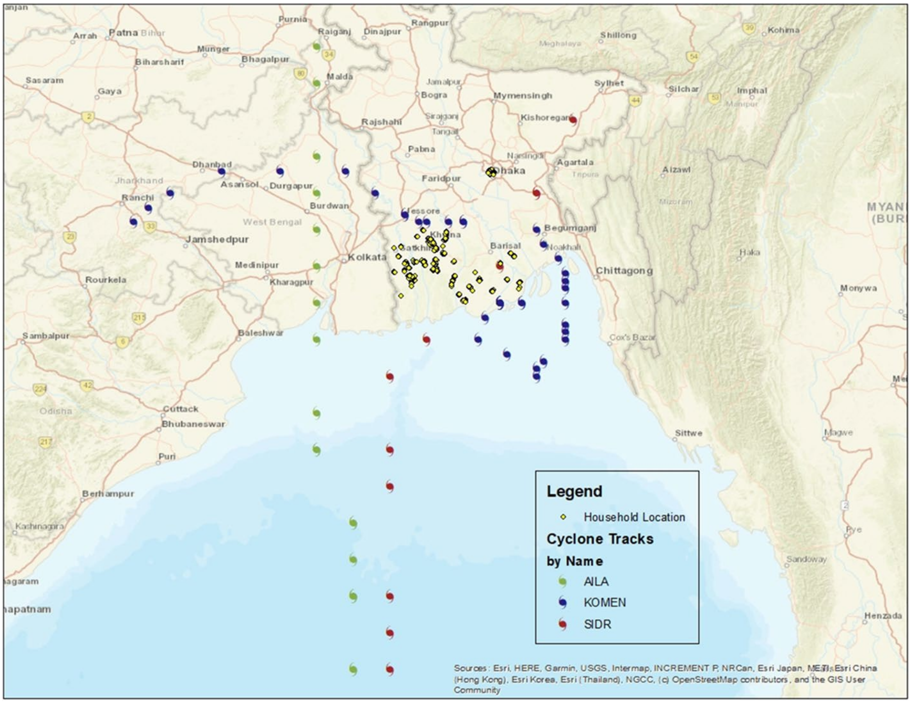

Fig. 1 Locations of surveyed respondents and the path of three cyclones (Aila, Komen and Sidr)

areas of Bangladesh comprise 19 districts along the Bay of Bengal (Dasgupta et al. 2014). The study sample covers households from two coastal divisions (Khulna and Barisal), which have been impacted during the cyclones Aila, Komen and Sidr in Bangladesh. The survey, conducted in 2015, engaged a total of 2,016 households within the specified region of Bangladesh. Of these, 1,418 households successfully completed the survey, with a completion rate of 70%.

Researchers from Florida International University (FIU) oversaw a face-to-face household survey conducted in Bangladesh by Evaluation and Consulting Services (ECONS) Limited. The survey aimed to uncover the connection between the severity of natural disasters and the patterns of recovery and resilience. The comprehensive questionnaire, divided into multiple sections, gathered data on various aspects, including the types and impacts of environmental shocks experienced by households, their evacuation practices, and their socio-demographic backgrounds (such as income, age, property ownership, literacy, housing conditions, and other socioeconomic attributes). Specifically, households were asked to share their experiences from each of the three cyclones, resulting in a comprehensive panel dataset that facilitates an in-depth understanding of evacuation behaviors.

We geocoded the household locations alongside with the cyclone track, which allows us to see their relative distance from the cyclone path in a geo-spatial platform (see Fig. 1). We also gathered demographic information about the household members (e.g., the number of family members, their ages, genders, marital status, etc.). Responses from the nine districts show a good deal of diversity in their sociodemographic

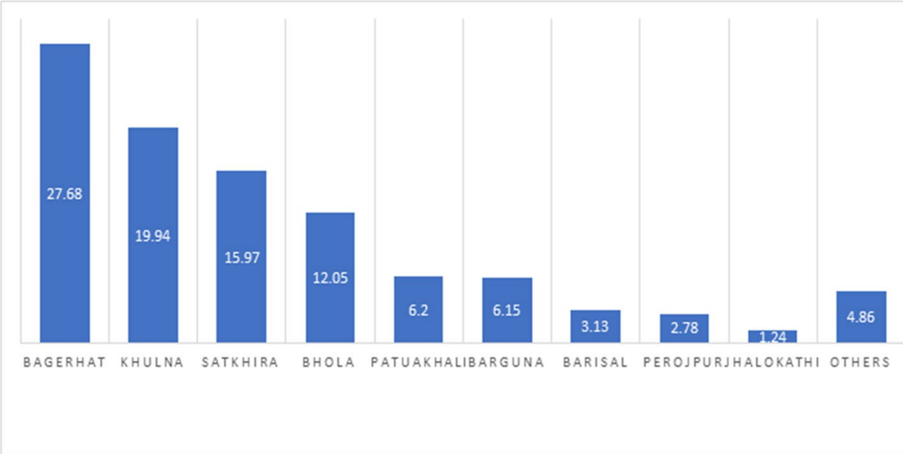

Fig. 2 Distribution of survey respondents (as % of total respondents)

characteristics, and the respondents seem to be generally representative of the region. The distribution of the sample respondents across the nine coastal districts of Bangladesh is presented in Fig. 2.

Respondents were first asked if they had been impacted by any of the three cyclones that struck the area over the last five years. Among the 1,418 respondents, 1,353 (95.4%) indicated they were affected by Cyclone Sidr (2007). Additionally, 1,406 respondents (99.2%) reported being impacted by Cyclone Aila (2009), and 1,199 respondents (84.6%) stated they were affected by Cyclone Komen (2015). Respondents were then asked whether or not they evacuated during these cyclones. Specifically, the evacuation questions were phrased as follows: Where were you along with your family during the disaster among the following options: 1) own house, 2) shelter, 3) relative's house, 4) on the dam, 5) school/college, 6) other. Their choices of past evacuation decisions and destinations are presented in Fig. 3.

This was followed by a similar question for a possible future evacuation, i.e., What would you do if the mentioned disaster appears at your locality this week? 1) stay at home, 2) go to your relative's home, 3) go to a high dam, 4) tie yourself with a tree, 5) go to the official shelter, 6) others. We categorized responses to this future evacuation decision question as "yes" if they would evacuate to a safe location, or "no" if they would choose to stay home during a cyclone in the future. We expect that people's past evacuation experience during a cyclone is likely to affect their future evacuation decision. Those who have previous evacuation experience will have greater probability of future evacuation during a cyclone. The future evacuation rate and the choices of hypothetical future evacuation destinations are presented in Fig. 4.

Furthermore, we asked several questions in order to assess various factors that might influence both past and future evacuation decisions, including warning time they received, distance to the nearest cyclone shelter, property damage, and location. In doing so, we aimed to capture the complexity of people's cyclone experience. We also expect that different socio-demographic factors, such as age, gender, marital status, family size, and housing conditions, will have a significant effect on their evacuation decisions.

Based on our survey questionnaire, we test three hypotheses to determine the major factors that influence the evacuation decision:

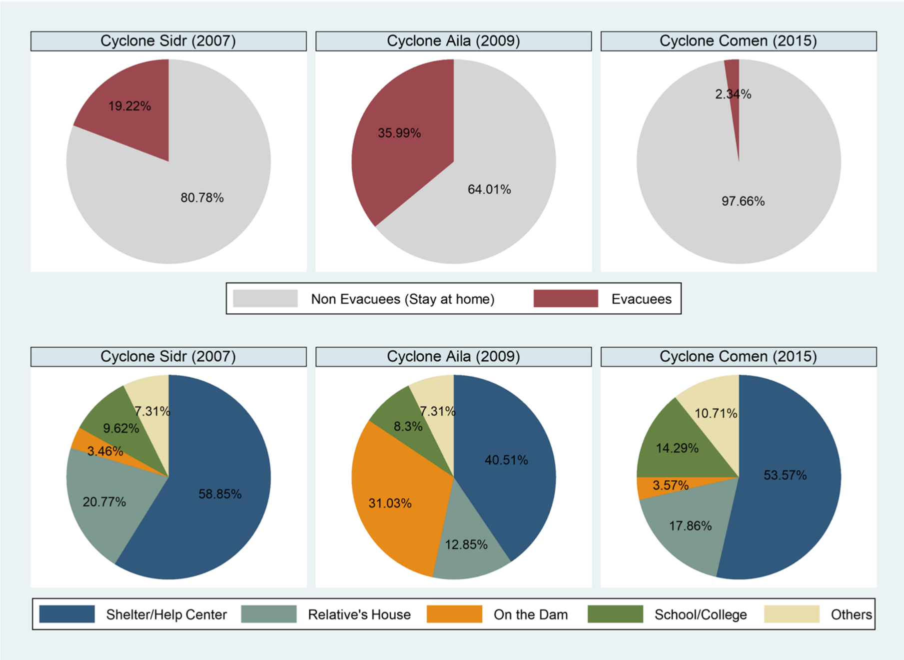

Fig. 3 Past evacuation rate and destination choices

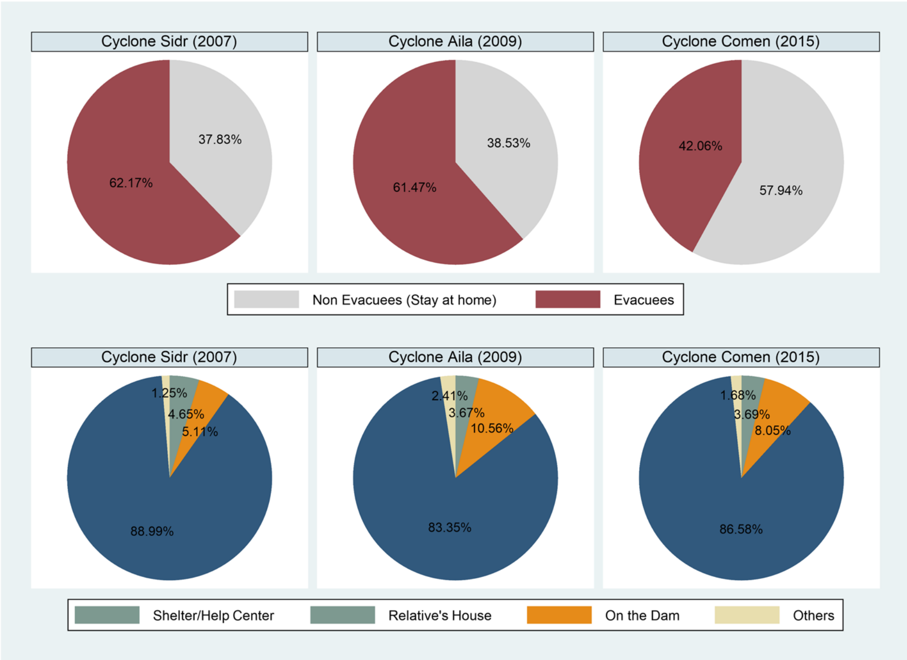

Fig. 4 Future evacuation rate and destination choices

Hypothesis 1: Increased warning and shelter services enhance evacuation rates, whereas inadequate services may hinder evacuation efforts.
Hypothesis 2: Socioeconomic and demographic factors will have a significant effect on evacuation decisions.
Hypothesis 3: Individuals with prior cyclone experience or those who have previously evacuated are likely to have a higher likelihood of evacuating for subsequent cyclones.

To test these hypotheses, we analyze two sets of data collected from the household survey. The first set includes cyclone-specific variables, such as past and future evacuation decisions, estimated warning time received, distance from cyclone tracks, and property loss incurred from each cyclone. These variables are based on responses specific to each cyclone and belong to a time-variant component when analyzed in a panel regression analysis. The second set includes variables that are not specific to cyclones, such as housing location and various socio-demographic factors. These variables are collected from the general survey section and do not vary across time or cyclones. Combined, these datasets enable us to examine evacuation behaviors for each cyclone individually and across a panel dataset. Definitions and descriptive statistics for the cyclone-specific variables and non-cyclone-specific variables used in the analysis are provided in Table 1 and Table 2, respectively.

Model Specification

To test our hypothesis and determine what factors influence people's past and future cyclone evacuation decision, we first implement a series of probit models by taking past evacuation decision (*EVAC*) and future evacuation decision (*EVAC_FUTURE*) as binary dependent variables. If the respondent indicated that they have evacuated before or will evacuate in the future, the dependent variables will take a value of 1; otherwise, their values will be 0.

Following Greene (2003), the probit models can be described as follows:

$$y^*_{1i} = \alpha z_i + \varepsilon_{1i} \tag{1}$$

$$y^*_{2i} = \beta x_i + \varepsilon_{2i} \tag{2}$$

where, y^*_{1i} and y^*_{2i} are latent variables and $y_{1i}(EVAC)$ and $y_{2i}(EVAC\_FUTURE)$ are dichotomous variables observed according to the following rule:

$$y_{li} = 1 \ if \ y^*_{1i} > 0$$

$$y_{li} = 0 \ if \ y^*_{1i} \leq \ 0; \ where, l = 1, 2$$

x_i and z_i are vectors of exogenous variables including previous cyclone experience, housing conditions, and socio-demographic factors, and α and β represent conformable vectors of relevant coefficients.

In addition to utilizing probit models, our analysis employed panel probit and bivariate probit models to comprehensively examine the factors influencing cyclone evacuation decisions. The panel probit model is an extension of the standard probit model designed to handle panel or longitudinal data, where observations are made over multiple time periods

Table 1 Descriptive statistics of cyclone-specific variables

Variable Name	Description	Cyclone Sidr (2007) $N=1353$		Cyclone Aila (2009) $N=1406$		Cyclone Komen (2015) $N=1199$	
		Mean	SD	Mean	SD	Mean	SD
EVAC	1 if the respondent indicates that they stayed at home during the mentioned disasters, 0 otherwise	0.19	0.39	0.36	0.48	0.02	0.15
EVAC_FUTURE	1 if the respondent indicates that they would stay at home during a similar disaster in the future, 0 otherwise	0.61	0.49	0.62	0.49	0.34	0.47
WARNING	The estimated time of the warning received before the cyclone (in hours)	8.32	12.00	6.88	10.74	9.56	8.11
DISTANCE	Distance between the respondent' house and the closest cyclone track (in km)	74.08	22.45	157.38	48.77	170.96	45.46
LOSS	1 if the respondent indicates any types of losses due to the disaster, 0 otherwise	0.68	0.47	0.64	0.48	0.10	0.29

Table 2 Descriptive statistics of non-cyclone-specific variables

Variable Name	Description	Mean	SD	Min	Max
SHELTER	The estimated time needed to go to the nearest shelter/help center (in hours)	0.34	0.28	0	4
COASTAL	1 if the respondent locates in coastal area, 0 if the respondent locates in costal far area	0.70	0.46	0	1
BRICK	1 if the respondent's house is built with bricks, 0 otherwise	0.22	0.41	0	1
OWNER	1 if the respondent is the owner of the house, 0 otherwise	0.96	0.19	0	1
AGE	Age of the respondent	42.74	14.35	18	96
GENDER	1 if the respondent is male, 0 if the respondent is female	0.47	0.50	0	1
MARRIED	1 if the respondent is married, 0 otherwise	0.89	0.31	0	1
LITERACY	1 if the respondent can read or write, 0 otherwise	0.62	0.49	0	1
WORK	1 if the respondent earns a daily wage, 0 otherwise	0.56	0.50	0	1
HHSIZE	Number of family members of the respondent's household	5.25	2.45	1	19
ELDERLY	1 if the household has a person older than 75 years old, 0 otherwise	0.36	0.48	0	1

for the same sample. In the context of cyclone evacuation in this study, panel probit models allow us to examine the three cyclones as a panel dataset and account for cyclone-specific characteristics that may influence both past and future evacuation decisions over time.

The bivariate probit model is employed to jointly examine two binary dependent variables, that is, past and future cyclone evacuation decisions. Unlike the panel probit model, which considers the longitudinal nature of data, the bivariate probit model focuses on the correlation between two binary outcomes within the same sample. In the context of cyclone evacuation, the bivariate probit model allows us to examine how various factors may influence both past and future evacuation decisions, while accounting for potential interdependencies between the two.

Estimation Results on Evacuation Decisions

Results from the Probit Models on Past Evacuation Decisions

Table 3 presents the estimation results concerning past evacuation decisions. The dependent variable, *EVAC*, is assigned a value of 1 if respondents evacuated and 0 if they opted to stay at home, indicating no evacuation. Models (1)-(6) report the results for each of the three cyclones separately using probit models, while Models (7) and (8) present the results by considering the three cyclones as a panel data structure, employing a panel probit model.[1]

For each cyclone, we run two regression models to estimate the probability of past evacuation: a basic model that does not include socio-demographic factors and an extended model that accounts for socio-demographic factors. First, we found that the proximity of the cyclone's path to a household's location (*DISTANCE*) impacts the decision to evacuate, with its effect being negatively significant at the 1% level for cyclones Sidr and Aila. Households located further from the cyclone's projected path were less likely to evacuate. This is expected as households farther from the threat perceive a lower risk and, consequently, exhibit a reduced urgency to evacuate. However, this distance factor did not significantly influence evacuation decisions for cyclone Komen. Given that Komen was less powerful compared to Sidr and Aila (Desportes 2019), and its path was more distant for the respondents, this lack of significance likely reflects the diminished perceived risk from Komen.

Additionally, the experience of loss during the cyclone (*LOSS*) significantly affects the likelihood of evacuation for cyclones Sidr and Aila at the 1% level and for cyclone Komen at the 5% level. This indicates that households that suffered significant losses were more likely to reside in the areas that were harder hit by the cyclone, and thus, were more inclined to evacuate. The accessibility of cyclone shelters (*SHELTER*) has a notable impact on evacuation decisions, with a significant negative effect observed at the 1% level. Essentially, the closer a household is to a cyclone shelter, the more likely they were to evacuate.

[1] Another approach is the linear probability model, which estimates the probability of a binary outcome using a linear regression framework. While this model offers straightforward interpretations of the impact of independent variables on the probability of occurrence, it is less preferred than probit models because its predicted probabilities can fall outside the 0–1 range. Therefore, our main analysis will focus on probit models, but results from the linear probability model are provided in the Online Supplementary Material.

Table 3 Estimation results on past evacuation decisions (Dep Var = *EVAC*)

	Probit Model						Panel Probit Model	
	Cyclone Sidr (2007)		Cyclone Aila (2009)		Cyclone Komen (2015)		Panel Data	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
WARNING	-0.0138***	-0.0132***	-0.0480***	-0.0421***	-0.0387**	-0.0356**	-0.0413***	-0.0404***
	(0.005)	(0.004)	(0.015)	(0.014)	(0.017)	(0.015)	(0.009)	(0.008)
DISTANCE	-0.0164***	-0.0167***	-0.00567***	-0.00407***	0.00167	0.00161	-0.00980***	-0.00959***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.001)	(0.001)
LOSS	0.536***	0.582***	1.489***	1.422***	0.335	0.538**	1.416***	1.396***
	(0.110)	(0.112)	(0.123)	(0.130)	(0.226)	(0.218)	(0.119)	(0.117)
SHELTER	-1.595***	-1.765***	-0.711***	-0.679***	-1.495***	-1.679**	-1.317***	-1.324***
	(0.268)	(0.286)	(0.206)	(0.210)	(0.565)	(0.657)	(0.279)	(0.277)
COASTAL	0.279***	0.386***	0.521***	0.360***	0.404	0.500*	0.693***	0.576***
	(0.107)	(0.120)	(0.113)	(0.118)	(0.252)	(0.260)	(0.122)	(0.126)
BRICK	-0.559***	-0.539***	-0.656***	-0.544***	-0.320	-0.264	-0.954***	-0.856***
	(0.144)	(0.149)	(0.114)	(0.120)	(0.259)	(0.258)	(0.144)	(0.144)
OWNER	0.197	0.313	0.376*	0.314	-0.748***	-0.630**	0.0883	0.0618
	(0.245)	(0.237)	(0.194)	(0.206)	(0.266)	(0.260)	(0.284)	(0.278)
AGE		-0.00732**		0.000461		-0.00491		-0.00398
		(0.004)		(0.003)		(0.007)		(0.004)
GENDER		0.0149		0.0335		-0.120		0.0310
		(0.095)		(0.090)		(0.185)		(0.095)
MARRIED		-0.151		-0.0282		0.0923		-0.0769
		(0.142)		(0.149)		(0.289)		(0.163)
LITERACY		-0.175*		-0.281***		-0.403**		-0.342***
		(0.098)		(0.095)		(0.173)		(0.099)
WORK		-0.00590		0.183*		0.312		0.110
		(0.099)		(0.094)		(0.198)		(0.100)
HHSIZE		-0.0471*		0.000398		-0.00961		-0.0419
		(0.025)		(0.025)		(0.051)		(0.027)
ELDERLY		0.429***		-0.743***		0.478**		-0.216
		(0.128)		(0.132)		(0.217)		(0.133)
KOMEN							-1.435***	-1.406***
							(0.157)	(0.156)
SIDR							-1.589***	-1.550***
							(0.147)	(0.147)
_CONS	0.113	0.580	-0.773***	-0.585	-1.209***	-1.352**	0.168	0.882**
	(0.334)	(0.414)	(0.296)	(0.377)	(0.456)	(0.672)	(0.360)	(0.444)
Pseudo R^2	0.202	0.216	0.352	0.390	0.138	0.184		
AIC	1072.3	1068.4	1206.2	1150.0	245.0	246.9	2506.9	2488.7
N	1353	1353	1406	1406	1199	1199	3958	3958

Robust standard errors in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

This finding underscores the importance of shelter accessibility in facilitating timely and efficient evacuations.

The probability of evacuation is significantly higher for cyclones Sidr and Aila if the house is located in the coastal area (*COASTAL*). In rural Bangladesh, wealthier households typically reside in brick houses, which are more secure compared to the houses made of mud or wood. So, it is expected that households in brick houses have a lower probability of evacuation. The structure of the house (*BRICK*) played a significant role in evacuation decision. If the household lives in a brick-built house, they were less likely to evacuate (significant at 1% levels) during cyclones Sidr and Aila. However, this factor was not significant for cyclone Komen. While factors such as distance to the cyclone and living in brick houses were not significant for evacuation during Cyclone Komen, we found ownership to be a significant factor (*OWNER*). During relatively smaller-scale cyclones like Komen, homeowners have a lower probability of evacuating. This could be attributed to households preferring to stay at home to protect their properties, especially when the situation was not perceived as life-threatening.

It is interesting that the warning time received (*WARNING*) before the cyclone was consistently found to be significant and negative across all three cyclones. Respondents who received early warnings were actually less likely to evacuate. This finding could be explained by the possibility that a shorter warning time creates a heightened sense of immediate danger, prompting a quicker decision to evacuate. In contrast, a longer warning time might diminish the perceived urgency, leading some individuals to underestimate the threat and choose to stay put. Moreover, longer warning times may provide households with the opportunity to fortify their homes and make preparations to weather the cyclone, thus believing that taking shelter at home is a viable option compared to evacuating. However, it is plausible that the effects of warning time are not linear, thus necessitating further investigation.

Regarding socio-demographic factors, we found age (*AGE*) to be a significant factor for evacuation during cyclone Sidr, with older respondents being less likely to evacuate. Gender of the respondent (*GENDER*) and marital status (*MARRIED*) were not significant predictors of past evacuation for any of the cyclones. Being able to read and write (*LITERACY*) emerged as a significant factor influencing past evacuation decisions. Specifically, it was significant at the 10% level for Sidr and at the 1% level for Aila and Komen. Furthermore, we observed relatively weak relationships between employment status (*WORK*) and evacuation decisions during Cyclone Aila, as well as weak relationships between family size (*HHSIZE*) and evacuation decisions during Cyclone Sidr.

We observed mixed effects of having elderly members in the household (*ELDERLY*) on evacuation decisions. Specifically, households with elderly members were more likely to evacuate during cyclones Sidr and Komen, but less likely to evacuate during cyclone Aila. One possible explanation could be due to the previous experiences of households with elderly members during cyclone Sidr in 2007. If these households encountered negative evacuation experiences during Sidr, such as difficulties in transportation or discomfort in shelters, they might develop a reluctance to evacuate during subsequent events, such as cyclone Aila in 2009. This reluctance could stem from a desire to avoid repeating past negative experiences and to ensure the comfort and safety of the elderly members by staying at home. Additionally, the decision to evacuate or stay during a cyclone may also depend on the perceived severity of the storm and the level of preparedness of the household. If households believe that the cyclone poses a significant threat, they may prioritize evacuation regardless of the presence of elderly members. Conversely, if the cyclone is perceived as less severe or if households feel adequately prepared to weather the storm at home, they may opt to stay rather than evacuate, especially if they have concerns about the well-being of elderly members during evacuation.

Finally, we examine past evacuation decisions by treating the three cyclones as panel data to explore further and conduct robustness tests. Our panel probit models revealed

Table 4 Marginal effects of estimated models on past evacuation decisions

	Probit Model						Panel Probit Model	
	Cyclone Sidr (2007)		Cyclone Aila (2009)		Cyclone Komen (2015)		Panel Data	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
WARNING	-0.003***	-0.003***	-0.015***	-0.013***	-0.001**	-0.001**	-0.041***	-0.040***
DISTANCE	-0.004***	-0.003***	-0.002***	-0.001***	0.000	0.000	-0.010***	-0.010***
LOSS(d)	0.103***	0.107***	0.388***	0.369***	0.013	0.021	1.416***	1.396***
SHELTER	-0.341***	-0.365***	-0.223***	-0.210***	-0.043***	-0.038***	-1.317***	-1.324***
COASTAL(d)	0.056***	0.073***	0.150***	0.105***	0.010*	0.009*	0.693***	0.576***
BRICK(d)	-0.100***	-0.094***	-0.176***	-0.148***	-0.008	-0.005	-0.954***	-0.856***
OWNER(d)	0.038	0.054	0.102**	0.087*	-0.048*	-0.029	0.088	0.062
AGE		-0.002**		0.000		-0.000		-0.004
GENDER(d)		0.003		0.010		-0.003		0.031
MARRIED(d)		-0.033		-0.009		0.002		-0.077
LITERACY(d)		-0.037*		-0.089***		-0.010**		-0.342***
WORK(d)		-0.001		0.056**		0.007		0.110
HHSIZE		-0.010*		0.000		-0.000		-0.042
ELDERLY(d)		0.095***		-0.209***		0.013**		-0.216
KOMEN(d)							-1.435***	-1.406***
SIDR(d)							-1.589***	-1.550***
N	1353	1353	1406	1406	1199	1199	3958	3958

Marginal effects; (d) for discrete change of dummy variable from 0 to 1; * $p<0.10$, ** $p<0.05$, *** $p<0.01$

consistent results with the probit models. We found that warning time before the cyclone, distance from the cyclone path, property loss, accessibility to cyclone shelters, the location and structure of the house, and the literacy level of the respondents significantly affect past evacuation decisions. These findings align with earlier studies focusing on evacuation. For instance, Paul (2014) identified cyclone distance from the home, distance from the coast, and literacy as significant predictors of evacuation decisions. Overall, our results strongly support the first and second hypotheses that evacuation services and socio-demographic factors strongly influence evacuation decisions.

The marginal effects calculated from the estimation results are reported in Table 4, revealing the size and magnitude of various factors influencing household evacuation decisions during three cyclones. Given the better goodness of fit, we will report the results based on the full model controlling for socio-demographic factors. For Cyclone Sidr (2007), a one hour increase in warning time reduces the likelihood of evacuation by 0.3%, and a one km increase in distance from the cyclone track decreases it by 0.3%. Households experiencing property loss are 10.7% more likely to evacuate, while inadequate access to shelter decreases the likelihood by 36.5%. Coastal households are 7.3% more likely to evacuate, and those living in brick houses are 9.4% less likely to evacuate. Furthermore, for Cyclone Aila (2009), a one hour increase in warning time reduces the likelihood of evacuation by 1.3%, and a one km increase in distance decreases it by 0.1%. Property loss significantly increases the likelihood of evacuation by 36.9%, while inadequate access to shelter decreases it by 21%. Coastal location increases the likelihood of evacuation by 10.5%, and living in a brick house decreases it by 14.8%. Homeowners are more likely to evacuate by 8.7%. For Cyclone Komen (2015), an increase in warning time (by 1 h) reduces the likelihood of evacuation by 0.1%. Inadequate access to shelter decreases the likelihood by 3.8%, and coastal location increases it by 0.9%.

Demographic variables show that age has a small negative effect on evacuation probability for Cyclone Sidr. Literacy (can read or write) reduces the likelihood of evacuation by 3.7% for Cyclone Sidr, 8.9% for Cyclone Aila, and 1.0% for Cyclone Komen. Employment status increases the likelihood of evacuation by 5.6% for Cyclone Aila. Household size negatively affects evacuation likelihood by 1.0% for Cyclone Sidr, and having elderly members increases it by 9.5% for Cyclone Sidr and decreases it by 20.9% for Cyclone Aila.

In the panel data analysis, an increase in warning time (by 1 h) and distance from the cyclone track (by 1 km) results in a 4% and 1% decrease in the likelihood of evacuation, respectively. Property loss significantly increases the likelihood of evacuation by 139.6%, while low access to shelter decreases it by 132.4%. Coastal households are 57.6% more likely to evacuate, and those living in brick houses are 85.6% less likely to evacuate. Overall, these results highlight the varying magnitudes of some key factors that influence evacuation decisions, emphasizing the need for targeted disaster management strategies.

Results from the Probit Models on Future Evacuation Decisions

We also examine if past experience has a significant effect on future evacuation decision by exploring the factors influencing these decisions, and the estimation results are presented in Table 5. The dependent variable, *EVAC_FUTURE*, is assigned a value of 1 if respondents indicate they would evacuate for a similar cyclone in the future, and 0 if they would stay at home.

The results revealed a notable aspect where the variable representing past evacuation decisions (*EVAC*) from Table 3, when included as an explanatory variable in the estimation of future evacuation decisions, showed a positive and statistically significant impact at the 1% level across all three cyclones examined. The finding implies that past evacuation decision positively affects the future evacuation decision. This indicates that people learn from their past evacuation decision and update their belief about future risk and their evacuation behavior. If a household had evacuated previously, they now have more familiarity and experience with the evacuation process and thus, they are more comfortable making evacuation decision. Therefore, we find evidence in support of our third hypothesis that past evacuation experience plays a crucial positive role in promoting evacuation in the future.

In examining the factors that influence future evacuation decisions, several variables demonstrated consistent trends with those observed in past evacuation behaviors. Specifically, factors such as the distance to the cyclone's path, property loss, access to cyclone shelters, residing in coastal areas, and living in brick-built houses maintained similar effects on both past and future evacuation decisions. In line with the literature, these factors consistently influence individuals' risk perceptions and their subsequent decisions to evacuate across different cyclone events.

However, discrepancies also emerged in the effects of various factors between past and future evacuation decisions. First, an extended warning period showed a positive and significant influence on future evacuation decisions specifically for Cyclone Aila yet exhibited a negative significance across the panel dataset comprising three cyclones. This divergence underscores the complex role that warning time plays in evacuation decision-making. This can be an important topic for future research.

Table 5 Estimation results on future evacuation decisions (Dep Var = *EVAC_FUTURE*)

	Probit Model						Panel Probit Model	
	Cyclone Sidr (2007)		Cyclone Aila (2009)		Cyclone Komen (2015)		Panel Data	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EVAC	1.210***	1.266***	1.969***	1.849***	1.253***	1.375***	3.015***	2.959***
	(0.156)	(0.160)	(0.162)	(0.167)	(0.314)	(0.323)	(0.323)	(0.317)
WARNING	0.00351	0.00352	0.00805**	0.00733**	0.00407	0.00312	-0.0197***	-0.0201***
	(0.003)	(0.003)	(0.004)	(0.004)	(0.005)	(0.005)	(0.005)	(0.005)
DISTANCE	-0.0198***	-0.0189***	-0.00879***	-0.00817***	0.00947***	0.00858***	-0.00536***	-0.00548***
	(0.003)	(0.003)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
LOSS	0.0850	0.0577	0.602***	0.594***	0.0308	0.00683	0.601***	0.576***
	(0.083)	(0.085)	(0.095)	(0.097)	(0.131)	(0.135)	(0.097)	(0.096)
SHELTER	-0.755***	-0.760***	-0.690***	-0.729***	-0.685***	-0.684***	-1.473***	-1.388***
	(0.192)	(0.192)	(0.160)	(0.163)	(0.217)	(0.215)	(0.352)	(0.339)
COASTAL	0.627***	0.620***	0.219**	0.101	0.292***	0.182*	1.190***	0.868***
	(0.085)	(0.091)	(0.095)	(0.099)	(0.092)	(0.096)	(0.161)	(0.158)
BRICK	-0.217**	-0.284***	-0.167	-0.103	-0.192*	-0.168	-0.429***	-0.353**
	(0.095)	(0.099)	(0.103)	(0.107)	(0.099)	(0.103)	(0.165)	(0.162)
OWNER	-0.0511	-0.151	-0.491**	-0.511**	-0.976***	-1.056***	-1.320***	-1.506***
	(0.205)	(0.207)	(0.216)	(0.234)	(0.203)	(0.206)	(0.424)	(0.415)
AGE		0.00788**		0.00400		0.00272		0.00945*
		(0.003)		(0.004)		(0.003)		(0.005)
GENDER		0.130		0.0761		0.0444		0.151
		(0.084)		(0.094)		(0.086)		(0.139)
MARRIED		0.110		-0.0594		0.107		0.201
		(0.136)		(0.141)		(0.146)		(0.224)
LITERACY		0.202**		0.151		0.187**		0.345**
		(0.087)		(0.102)		(0.089)		(0.147)
WORK		-0.148*		0.163*		0.0438		0.127
		(0.085)		(0.095)		(0.088)		(0.140)
HHSIZE		0.0144		-0.0238		0.000413		-0.0289
		(0.020)		(0.023)		(0.022)		(0.035)
ELDERLY		-0.229**		-0.522***		-0.446***		-1.024***
		(0.112)		(0.119)		(0.118)		(0.187)
KOMEN							-0.625***	-0.652***
							(0.083)	(0.082)
SIDR							-0.246**	-0.267**
							(0.114)	(0.113)
_CONS	1.491***	1.025***	1.466***	1.499***	-1.164***	-1.083***	1.759***	1.753***
	(0.309)	(0.369)	(0.290)	(0.399)	(0.288)	(0.377)	(0.493)	(0.594)
Pseudo R^2	0.235	0.249	0.405	0.431	0.124	0.143		
AIC	1401.1	1390.8	1128.6	1095.5	1363.8	1348.4	3456.0	3401.7
N	1353	1353	1406	1406	1199	1199	3958	3958

Robust Standard errors in parentheses* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Second, literate respondents displayed a lower likelihood of evacuating during past cyclones but a higher propensity to evacuate in future scenarios. Individuals with greater ability to read and write are more adept at assimilating new information and adjusting their behaviors based on past experiences. They often have broader access to social networks and communities, facilitating a shared learning process. This communal exchange of information, resources and experiences may allow to overcome the constraints and better position them to evaluate the benefits of evacuating in forthcoming cyclones, contrasting with their past decisions.

Third, the impact of having an elderly household member on evacuation decisions was mixed for past events but showed consistency for future decisions. Households with elderly members were found to be less likely to evacuate in anticipation of future events. This finding corroborates our hypothesis that previous negative evacuation experiences can diminish the willingness to evacuate again. It also underscores the critical need for policies that specifically cater to assisting vulnerable groups, such as the elderly, during evacuations. The potential challenges they face in evacuation scenarios highlight an area requiring targeted support and intervention to ensure their safety and well-being during extreme weather events.

The marginal effects of the estimation results on future evacuation decisions are presented in Table 6. Across all three cyclones, households that previously evacuated are 34.1–50.3% more likely to evacuate in the future. An increase in distance from the cyclone track decreases the likelihood of future evacuation by 0.7% for Sidr and Aila, and increases it by 0.3% for Komen. Inadequate access to shelter reduces the likelihood by 22.4–27.5%, while living in coastal areas increases it by 6.3–23.5%. Households in brick houses are 5.7–10.6% less likely to evacuate in the future. Homeowners are 13.7% less likely to evacuate in the future in scenarios like Aila, but 40.2% less likely in situations akin to Komen, where the cyclone intensity is less severe.

Demographic variables show that age has a small positive effect (0.3%) on future evacuation probability for Cyclone Sidr. Literacy increases the likelihood of future evacuation by 7.4% for Cyclone Sidr, 6.5% for Cyclone Komen, and 34.5% in the panel data. Employment status slightly increases the likelihood of future evacuation for Cyclone Sidr and Cyclone Komen. Household size has a negligible effect, while having elderly members decreases future evacuation likelihood by 8.4% for Cyclone Sidr, 17.5% for Cyclone Aila, and 15.1% for Cyclone Komen. Overall, these results highlight the significant and varied effects of past experiences, warning times, distances, property losses, and socio-demographic factors on future evacuation decisions, underscoring the importance of tailored disaster preparedness and response strategies.

Results from the Bivariate Probit Models on Joint Evacuation Decisions

In further exploring the dynamics of evacuation decision-making, we simultaneously estimate the past evacuation decision and future evacuation decision using the bivariate probit modeling approach. The Bivariate probit models allow the flexibility of including a variable as both a dependent and independent variables, which has particular relevance in exploring how preferences evolve. Also, the revealed preference evacuation data are endogenous. The bivariate formulation, however, can address endogeneity of one of the dependent variables (revealed evacuation) that appears in another equation (stated preference evacuation) (Greene 2003; Landry et al. 2021). The functional form of the bivariate probit model is sufficient to address endogeneity (Freedman and Sekhon 2010; Greene

Table 6 Marginal effects of estimated models on future evacuation decisions

	Probit Model						Panel Probit Model	
	Cyclone Sidr (2007)		Cyclone Aila (2009)		Cyclone Komen (2015)		Panel Data	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
EVAC(d)	0.341***	0.349***	0.497***	0.471***	0.467***	0.503***	3.015***	2.959***
WARNING	0.001	0.001	0.003**	0.002**	0.001	0.001	-0.019***	-0.020***
DISTANCE	-0.007***	-0.007***	-0.003***	-0.003***	0.003***	0.003***	-0.005***	-0.005***
LOSS(d)	0.031	0.021	0.203***	0.199***	0.011	0.002	0.601***	0.576***
SHELTER	-0.274***	-0.275***	-0.224***	-0.235***	-0.243***	-0.241***	-1.473***	-1.388***
COASTAL(d)	0.235***	0.231***	0.073**	0.033	0.100***	0.063*	1.190***	0.868***
BRICK(d)	-0.081**	-0.106***	-0.056	-0.034	-0.066**	-0.057*	-0.429***	-0.353**
OWNER(d)	-0.018	-0.053	-0.133***	-0.137***	-0.374***	-0.402***	-1.320***	-1.506***
AGE		0.003**		0.001		0.001		0.009*
GENDER(d)		0.047		0.025		0.016		0.151
MARRIED(d)		0.040		-0.019		0.037		0.201
LITERACY(d)		0.074**		0.049		0.065**		0.345**
WORK(d)		-0.053*		0.053*		0.015		0.127
HHSIZE		0.005		-0.008		0.000		-0.029
ELDERLY(d)		-0.084**		-0.175***		-0.151***		-1.024***
KOMEN(d)							-0.625***	-0.652***
SIDR(d)							-0.246**	-0.267**
N	1353	1353	1406	1406	1199	1199	3958	3958

Marginal effects; (d) for discrete change of dummy variable from 0 to 1; * $p<0.10$, ** $p<0.05$, *** $p<0.01$

2003; Li et al. 2019). The estimation results from the bivariate probit models are presented in Table 7.

Table 7 Panel A and Panel B look into the analysis of various explanatory variables and their impact on the probability of past and future evacuation decisions, respectively. The findings demonstrate consistency in terms of significance and direction of effect when compared to the results from probit models across three cyclone events. A noteworthy aspect of the analysis is the significance and positivity of the Rho obtained from the estimation results across all six models. The positive Rho indicates a statistically significant and positive correlation between the decision-making processes for past and future evacuations. This implies that factors influencing the likelihood of evacuating in the past were not only relevant but also influenced future evacuation decisions. The significance of rho underscores the interdependent nature of these decisions, suggesting that an individual's experience with past evacuations directly informs their approach and attitude towards future evacuation actions.

Furthermore, we introduced a squared term for warning time in the biprobit analysis, allowing us to explore the nonlinear effects of warning time on evacuation probability. The results indicated a non-linear relationship between warning time and the likelihood of evacuation: as warning time increases, the probability of evacuation initially decreases, followed by an increase. This pattern was observed for past evacuation decisions for cyclone Aila and future evacuation decisions for both cyclone Sidr and Aila. The findings suggest

Table 7 Estimation results on joint evacuation decisions

	Cyclone Sidr (2007)	Cyclone Sidr (2007)	Cyclone Aila (2009)	Cyclone Aila (2009)	Cyclone Komen (2015)	Cyclone Komen (2015)
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A Past Evacuation Decisions						
WARNING	-0.0132***	-0.00960	-0.0323***	-0.0859***	-0.0334**	-0.0134
	(0.004)	(0.010)	(0.011)	(0.013)	(0.013)	(0.042)
WARNINGSQ		-0.0000811		0.000983***		-0.000911
		(0.000)		(0.000)		(0.002)
DISTANCE	-0.0169***	-0.0169***	-0.00435***	-0.00379***	0.00222	0.00237
	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)
LOSS	0.601***	0.600***	1.367***	1.270***	0.544***	0.559***
	(0.112)	(0.112)	(0.123)	(0.124)	(0.211)	(0.211)
SHELTER	-1.524***	-1.531***	-0.590***	-0.547***	-1.305**	-1.305**
	(0.264)	(0.266)	(0.171)	(0.168)	(0.593)	(0.595)
COASTAL	0.380***	0.384***	0.411***	0.423***	0.455*	0.456*
	(0.118)	(0.119)	(0.113)	(0.114)	(0.256)	(0.254)
BRICK	-0.480***	-0.479***	-0.521***	-0.526***	-0.323	-0.330
	(0.147)	(0.147)	(0.115)	(0.115)	(0.250)	(0.251)
OWNER	0.296	0.300	0.297	0.234	-0.628**	-0.647**
	(0.245)	(0.245)	(0.200)	(0.188)	(0.261)	(0.270)
AGE	-0.00719**	-0.00721**	0.00137	0.00119	-0.00524	-0.00511
	(0.004)	(0.004)	(0.003)	(0.003)	(0.008)	(0.008)
MALE	0.0287	0.0290	0.0299	0.0516	-0.107	-0.110
	(0.093)	(0.093)	(0.087)	(0.089)	(0.180)	(0.178)
MARRIED	-0.159	-0.161	0.0114	0.00389	0.0254	0.0216
	(0.138)	(0.138)	(0.145)	(0.148)	(0.289)	(0.287)
LITERACY	-0.147	-0.147	-0.233**	-0.223**	-0.367**	-0.362**
	(0.097)	(0.097)	(0.091)	(0.093)	(0.168)	(0.167)
WORK	0.0221	0.0235	0.217**	0.206**	0.309	0.323*

Table 7 (continued)

	Cyclone Sidr (2007)	Cyclone Sidr (2007)	Cyclone Aila (2009)	Cyclone Aila (2009)	Cyclone Komen (2015)	Cyclone Komen (2015)
	(0.097)	(0.097)	(0.091)	(0.093)	(0.192)	(0.192)
HHSIZE	-0.0438*	-0.0436*	0.00447	0.00674	-0.00166	0.000952
	(0.024)	(0.024)	(0.022)	(0.023)	(0.045)	(0.043)
ELDERLY	0.409***	0.413***	-0.713***	-0.694***	0.389**	0.394**
	(0.123)	(0.123)	(0.123)	(0.124)	(0.196)	(0.194)
_CONS	0.482	0.468	-0.749**	-0.543	-1.489**	-1.596**
	(0.415)	(0.418)	(0.367)	(0.364)	(0.733)	(0.744)
Panel B Future Evacuation Decisions						
WARNING	0.00119	-0.0152*	-0.000522	-0.0659***	0.00156	0.00589
	(0.003)	(0.009)	(0.004)	(0.011)	(0.005)	(0.011)
WARNINGSQ		0.000314**		0.00123***		-0.000114
		(0.000)		(0.000)		(0.000)
DISTANCE	-0.0217***	-0.0216***	-0.00862***	-0.00821***	0.00860***	0.00869***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
LOSS	0.156*	0.167**	0.997***	0.891***	0.0431	0.0482
	(0.081)	(0.081)	(0.088)	(0.090)	(0.131)	(0.131)
SHELTER	-0.959***	-0.944***	-0.874***	-0.824***	-0.731***	-0.723***
	(0.196)	(0.195)	(0.169)	(0.164)	(0.219)	(0.219)
COASTAL	0.657***	0.644***	0.180*	0.194**	0.204**	0.203**
	(0.088)	(0.088)	(0.093)	(0.095)	(0.096)	(0.096)
BRICK	-0.350***	-0.343***	-0.288***	-0.294***	-0.181*	-0.182*
	(0.097)	(0.097)	(0.101)	(0.102)	(0.103)	(0.103)
OWNER	-0.0733	-0.0866	-0.357	-0.478**	-1.098***	-1.098***
	(0.195)	(0.194)	(0.239)	(0.244)	(0.202)	(0.202)
AGE	0.00625**	0.00618**	0.00324	0.00312	0.00230	0.00224

Table 7 (continued)

	Cyclone Sidr (2007)	Cyclone Sidr (2007)	Cyclone Aila (2009)	Cyclone Aila (2009)	Cyclone Komen (2015)	Cyclone Komen (2015)
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
MALE	0.132	0.131	0.0826	0.111	0.0388	0.0399
	(0.081)	(0.081)	(0.085)	(0.086)	(0.085)	(0.085)
MARRIED	0.0613	0.0564	-0.0744	-0.0596	0.113	0.114
	(0.132)	(0.133)	(0.132)	(0.132)	(0.145)	(0.144)
LITERACY	0.166^{**}	0.168^{**}	-0.00216	0.0437	0.161^{*}	0.160^{*}
	(0.084)	(0.084)	(0.090)	(0.091)	(0.089)	(0.089)
WORK	-0.140^{*}	-0.149^{*}	0.190^{**}	0.163^{*}	0.0597	0.0611
	(0.082)	(0.082)	(0.085)	(0.086)	(0.087)	(0.087)
HHSIZE	0.00468	0.00304	-0.0187	-0.0182	-0.000382	-0.000548
	(0.020)	(0.020)	(0.021)	(0.021)	(0.022)	(0.022)
ELDERLY	-0.140	-0.151	-0.735^{***}	-0.729^{***}	-0.404^{***}	-0.401^{***}
	(0.108)	(0.108)	(0.112)	(0.113)	(0.116)	(0.116)
_CONS	1.476^{***}	1.574^{***}	1.822^{***}	2.164^{***}	-0.988^{***}	-1.029^{***}
	(0.349)	(0.352)	(0.386)	(0.396)	(0.373)	(0.384)
Rho	0.652^{***}	0.648^{***}	1.025^{***}	0.984^{***}	0.563^{***}	0.565^{***}
	(0.079)	(0.079)	(0.097)	(0.097)	(0.133)	(0.132)
AIC	2466.9	2466.1	2273.5	2214.7	1599.5	1603.0
N	1353	1353	1406	1406	1199	1199

Robust standard errors in parentheses * $p<0.10$, ** $p<0.05$, *** $p<0.01$

an inverted U-shaped curve, indicating a critical threshold of warning time beyond which the likelihood of evacuation begins to rise after initially declining. Based on the calculated coefficients, the thresholds were found to range between 24 and 40 h.

Intuitively, when individuals first receive a warning, having a longer response time might lead to complacency or a perception that the urgency to evacuate is low, hence the initial decrease in evacuation probability. However, within the 24 to 40 h preceding an approaching cyclone, receiving a warning in advance increases the likelihood of evacuation. This finding highlights the complex interplay between human perception of risk, the timing of warnings, and the decision-making process related to evacuation. It is crucial to optimize the timing of evacuation warnings to ensure they are issued in a manner that maximizes compliance and enhances the effectiveness of evacuation orders**.**

Estimation Results on Evacuation Destinations

In addition to understanding the binary decision of whether to evacuate or not, the destination of evacuation offers valuable insights into evacuation behavior. To delve deeper into this aspect, we employed multinomial logit models to investigate the factors influencing the choice of evacuation destination. Given the number of responses for each destination choice, we categorized them into three groups: staying at their own house (the base group), seeking shelter or evacuation help centers (one alternative group), and evacuating to all other destinations (the other alternative group). Building on insights from previous findings, we employed multinomial panel logit models to examine the overall panel data, while also considering the non-linear impact of warning time on evacuation decisions. The estimation results on evacuation destinations from past cyclones and future cyclones are provided in Table 8.

Models (1) and (2) present the estimation results for two alternative evacuation destinations during the three past cyclones, while Models (3) and (4) present the outcomes considering a future evacuation scenario. With the base outcome being staying at home, i.e., not evacuating, the factors significantly shaping evacuation decisions consistently displayed similar trends. For instance, factors such as proximity to the coast, experiencing property loss, living in coastal areas, residing in non-brick houses, and literacy were positively associated with a higher probability of evacuation, regardless of the chosen destination. Meanwhile, past evacuation experiences, coastal proximity, property loss, and literacy increased the likelihood of future evacuation, whereas homeownership and having elderly household members decreased the probability of future evacuation, regardless of destination choice. The influence of warning time consistently exhibited a nonlinear effect across the models.

Several nuanced findings emerged from our examination of destination choices. First, we found a positive relationship between shelter accessibility and the likelihood of choosing to evacuate to a shelter. Conversely, longer travel times required to reach the nearest shelter were associated with a higher probability of opting for other destinations for future evacuations. This underscores the importance of proximity to shelters in influencing evacuation decisions and highlights the need to enhance shelter accessibility during emergencies. Second, the age of respondents played a significant role in destination choices. Older individuals were less likely to seek shelter during past cyclone evacuations but showed a higher probability to do so for future events. This underscores the heightened demand for sheltering services among aging populations and addressing their specific needs during evacuation planning. Third, male respondents and those who were employed were found to

Table 8 Estimation results on past and future evacuation destinations

	Evacuation Destination from Past Cyclones		Evacuation Destination for Future Cyclones	
	(1)	(2)	(3)	(4)
Base Group = Stay at Home				
	Go to Shelter/Help Center	Go to All Other Destinations	Go to Shelter/Help Center	Go to All Other Destinations
EVAC			6.103***	4.518***
			(0.705)	(0.618)
WARNING	-0.0841**	-0.214***	-0.223***	-0.104***
	(0.035)	(0.030)	(0.031)	(0.034)
WARNINGSQ	0.000311	0.00272***	0.00358***	0.00184***
	(0.001)	(0.000)	(0.001)	(0.001)
DISTANCE	-0.0241***	-0.0139***	-0.0111***	-0.0101***
	(0.005)	(0.003)	(0.002)	(0.002)
LOSS	2.614***	2.459***	1.117***	0.858***
	(0.366)	(0.274)	(0.188)	(0.311)
SHELTER	-9.951***	-0.429	-6.372***	1.948***
	(1.547)	(0.314)	(1.217)	(0.556)
COASTAL	1.961***	0.421*	2.357***	0.517
	(0.496)	(0.244)	(0.357)	(0.408)
BRICK	-2.674***	-1.237***	-1.013***	0.0863
	(0.556)	(0.269)	(0.312)	(0.391)
OWNER	-0.696	0.700	-3.022***	-2.345***
	(0.822)	(0.568)	(0.703)	(0.810)
AGE	-0.0259**	0.00174	0.0316***	-0.0115
	(0.012)	(0.008)	(0.010)	(0.014)
GENDER	0.442	-0.227	0.0626	0.816**
	(0.312)	(0.198)	(0.272)	(0.360)
MARRIED	-0.625	0.176	0.442	0.554
	(0.523)	(0.312)	(0.439)	(0.675)
LITERACY	-0.706**	-0.687***	0.615**	0.703*
	(0.334)	(0.205)	(0.292)	(0.383)
WORK	-0.219	0.169	-0.220	0.922**
	(0.325)	(0.207)	(0.267)	(0.390)
HHSIZE	-0.0486	-0.0815	-0.0620	0.0352
	(0.093)	(0.053)	(0.066)	(0.105)
ELDERLY	-0.417	-0.361	-2.384***	-1.602***
	(0.452)	(0.267)	(0.426)	(0.531)
KOMEN	-3.551***	-2.288***	-0.960***	-1.051***
	(0.775)	(0.324)	(0.187)	(0.242)
SIDR	-3.036***	-2.744***	-0.191	-1.418***
	(0.465)	(0.298)	(0.240)	(0.342)
_CONS	2.930**	-0.400	4.237***	-2.619*
	(1.471)	(0.857)	(1.135)	(1.398)
AIC	3264.2		4458.7	
N	3958		3958	

Robust standard errors in parentheses * $p<0.10$, ** $p<0.05$, *** $p<0.01$

be more likely to go to alternative destinations for future evacuations. This may be attributed to factors such as employment obligations, greater access to resources and options, or preferences for alternative sheltering arrangements.

Overall, exploring evacuation destinations in addition to evacuation decisions provides valuable insights into the complexities of evacuation behavior during cyclone events in Bangladesh. Analyzing evacuation destinations allows policymakers and emergency responders to identify potential challenges in evacuation decision-making, assess the adequacy of sheltering facilities, and tailor evacuation plans to meet the diverse needs of communities. Moreover, studying evacuation destinations enables the identification of vulnerable populations who may face challenges in accessing shelters or choosing alternative destinations, thus informing targeted interventions to enhance their safety and well-being during disasters. Our findings shed light on the diverse considerations influencing evacuation destination choices and underscore the importance of addressing various demographic and situational factors in evacuation planning and emergency response efforts.

Discussion and Conclusion

Drawing upon extensive cross-sectional and panel data, our research investigated the determinants influencing evacuation decisions and destination selections among individuals affected by cyclones Sidr, Komen, and Aila. We analyzed the factors impacting evacuation behavior, risk perception, and the considerations guiding the selection of evacuation destinations.

This paper provided a comprehensive analysis of the determinants of households' evacuation decisions during three cyclone occurrences in Bangladesh. In this study, we investigated three hypotheses regarding evacuation behavior. Our first hypothesis posited that effective evacuation services contribute to higher evacuation rates, whereas ineffective or inadequate services may impede evacuation efforts. The second hypothesis suggested that socioeconomic and demographic factors play a significant role in evacuation decisions. Lastly, the third hypothesis proposed that individuals with prior cyclone experience or those who have previously evacuated are more likely to evacuate for subsequent cyclones. Our results robustly supported all three hypotheses.

Specifically, we found that various factors related to evacuation services, such as warning time before the cyclone, accessibility to cyclone shelters, housing location and structure, and respondents' literacy levels significantly influenced past evacuation decisions. Furthermore, beyond factors directly related to cyclone risks, household-specific characteristics and demographic attributes—including housing structure, literacy, age, gender, and employment status—exerted notable influence on evacuation behavior.

Moreover, we observed strong evidence indicating that past evacuation experience positively influenced future evacuation decisions. Additionally, location-related variables, such as proximity to coastal areas and distance from the cyclone trajectory, emerged as pivotal determinants of evacuation choices. Furthermore, we also explored how the influence of different factors change based on the evacuation destination choice. These findings offer valuable insights for targeted policy interventions during natural disasters.

Crucially, our study meets criteria for external validity, providing insights relevant to regional and global scenarios. Through the inclusion of relevant socioeconomic and demographic variables, we establish the reproducibility of our findings across various contexts. These empirical insights into evacuation behavior hold potential for guiding policy interventions and strategic investments aimed at alleviating the socioeconomic repercussions of disasters and preserving lives.

We recognize several constraints within our study. Firstly, while we attempted to gauge individuals' risk perception through various socioeconomic and demographic factors, we encountered a deficiency in crucial variables necessary for a comprehensive assessment. Secondly, our dataset solely comprises information regarding whether respondents suffered losses during the preceding cyclone, without detailing the magnitude or value of these losses. Thirdly, we lack precise location data concerning the evacuation destinations of respondents. Future research endeavors could focus on devising strategies to gather additional data and rectify these limitations inherent in our study.

In summary, this study utilizes both revealed preference (RP) and stated preference (SP) data gathered through surveys to assess household evacuation decisions. Various statistical models, including univariate and bivariate probit models, alongside panel probit and multinomial panel logit models, are employed to examine hypotheses concerning the determinants of evacuation behavior. Despite its limitations, our analysis and findings align with existing literature, emphasizing the significant impact of past evacuation experiences on future intentions. Additionally, we explore the factors influencing the selection of evacuation destinations. Our research demonstrates external validity and can be replicated at both regional and global levels by integrating relevant socioeconomic and demographic variables, thereby enhancing comprehension of evacuation decision-making amidst risk.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s41885-024-00157-1.

Acknowledgements We would like to thank the reviewers and the editor for their valuable comments, as well as the U.S. National Science Foundation for their support. We would also like to thank all the survey respondents who participated in this study.

Author contributions "M.K. and S.M. wrote the main manuscript text, prepared the tables and ran the data analysis and P.M. and N.H. wrote part of the manuscript, collected data for the research and reviewed the manuscript. All authors reviewed the manuscript."

Funding We acknowledge the support from the National Science Foundation [Award # 1832693: CRISP 2.0 Type 2: Collaborative Research: Organizing Decentralized Resilience in Critical Interdependent-infrastructure Systems and Processes (ORDER-CRISP) and Award # 2122135: EAGER-SAI: Exploring Pathways of Adaptive Infrastructure Management with Rapidly Intensifying Hurricanes].

Data Availability The data will be provided upon request.

Code availability Code will be made available upon request.

Declarations

Ethics Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Consent to Participate Informed consent to participate was obtained from all authors included in the study.

Consent for Publication Informed consent for publication was obtained from all authors included in the study.

Competing Interests The authors declare no competing interests.

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