



A Study on Prediction of Evacuation Preparation Time Based on Factors Affecting Households' Evacuation Decision in Response to Cyclone in angladesh

MD ATIKUR RAHMAN

(Degree)

博士 (学術)

(Date of Degree)

2022-03-25

(Date of Publication)

2024-03-25

(Resource Type)

doctoral thesis

(Report Number)

甲第8345号

(URL)

<https://hdl.handle.net/20.500.14094/D1008345>

※ 当コンテンツは神戸大学の学術成果です。無断複製・不正使用等を禁じます。著作権法で認められている範囲内で、適切にご利用ください。



Doctoral Dissertation

**A Study on Prediction of Evacuation Preparation Time Based on
Factors Affecting Households' Evacuation Decision in Response to
Cyclone in Bangladesh**

Bangladeshにおけるサイクロン災害時の世帯での避難意思決定
 要因に基づく避難準備時間の推定

January 2022

**Department of Architecture
Graduate School of Engineering
Kobe University**

MD ATIKUR RAHMAN

172T701T

Acknowledgments

I wish to express my most profound appreciation to my supervisor, Professor Akihiko HOKUGO, for his continued guidance and encouragement throughout my studies at Kobe University, Japan. His ideas, suggestions, and supports during field investigation and research were invaluable. Thanks for your kindness and patience. I would also like to thank professors from our seminar: Nobuhito OHTSU and Abel Táiti Konno PINHEIRO. Your tireless instruction and valuable comments have improved this study immensely and helped me grow as an excellent researcher. Thanks very much for your mentorship and friendship.

I acknowledge Ichikawa International Foundation Scholarship for their financial support during my doctoral study at Kobe University, Japan.

My gratitude is also to my wife, parents, and siblings for their moral support. I love them so much, and I would not have made it without their encouragement, help, and support. I know I always have my family to count on when times are rough.

Finally, I own sincerest appreciation and thanks to all the members of HOKUGO Lab, past and present. Thank you very much for your encouragement and friendship. Especially, I would like to thank Yuka Kumasaki, Kaiho Ryo, Taishu OMURA, Yegane Ghezelloo, Swarnali Chakma, and Yu Youngeon for their time and kind support: Thank you. I wish all the success to every one of you. I know you are the best.

Abstract

Bangladesh is one of the most disaster-prone countries worldwide. Every year, the country sees a small- or large-scale disaster, with past disaster history showing that cyclones have been a major phenomenon. The main purpose of this study is to investigate factors that are associated with households' safe and complete evacuation towards evacuation shelter during Cyclone. Therefore, considering three main objectives as 1) households' early and emergency evacuation decision influencing factors, 2) predict household evacuation preparation time through random forest simulation, and 3) factors influence households' decision of shelter and types of evacuation shelter to understand difficulties and complexities during evacuation better. To obtain the research goal, this study conducted a questionnaire survey of 413 households in Gabura, a union under Shyamnagar Upazila of Satkhira District, from mid-February to mid-March 2020 to investigate respondents' evacuation experience during Cyclone Bulbul. The questionnaire survey comprised qualitative and quantitative approaches that analyzed disaster preparedness levels, successful evacuation scenarios, and early evacuation decisions and their implementation in Gabura Union during Cyclone Bulbul.

In addition, this study provides details of the study objectives and their importance through several chapters. Chapter 1 presents this study's general introduction and essential motivation, including the research objectives. For instance, it gives an overview of natural disasters, especially Cyclone, concerning evacuation during an emergency. Chapter 2 represents a literature review of this research. This chapter contains a detailed overview of households' responses to evacuation warnings and their early and emergency evacuation

decision. Another significant component of households' evacuation is evacuation preparation and time before starting evacuation. Chapter 2 also provides details of households' preparation activities and the time and decision of shelter choice during the disaster.

Furthermore, chapter 3 represents and describes the study area, main core concept, and methodology of this study to gather and analyze data to investigate household evacuation scenarios during a Cyclone. In addition, this includes the proposed method of prediction of evacuation preparation time through the Random Forest algorithm. Following chapter 3, chapter 4 investigate in detail households' early and emergency evacuation decisions to check the possibility and consequence safe and complete evacuation towards shelter or safer place. Chapter 4 also shows the influence of evacuation preparation time and household demographic and socio-economic characteristics on early and emergency evacuation decisions. It is found that evacuation preparation time greatly influences households' early and emergency evacuation decisions. Therefore, chapter 5 further analyses households' evacuation preparation time and shows the relationship of demographic and behavioral factors to determine the importance of each factor that affects evacuation preparation time. In addition, Chapter 5 proposed a methodology that predicts households' evacuation preparation time concerning demographic and behavioral factors. It is found that type of shelter is one of the significant factors that influence households' starting time of evacuation and evacuation preparation time. Following this, chapter 6 try to investigate which factors are essential while households decide their evacuation shelter and types of shelter evacuated during a Cyclone. According to the results, chapters 3 to six analyze households' early and emergency evacuation decisions, prediction of preparation time and decision of shelter and, types of actual evacuation shelters. Chapter 7 investigates

and compares evacuation behavior concerning cyclones, typhoons, and hurricanes from Bangladesh, the Philippines, and the USA. The research results and findings are based on three objectives and show the relationship with existing research that distinguishes the current study. Finally, based on the research results, chapter 8 provides the necessary suggestion and recommendations, which is helpful for interested groups to make better and effective preparedness plans ahead of future disasters to reduce the disaster risk.

The comparison of evacuation behavior from three countries revealed that evacuation tendency is almost similar in Bangladesh cyclone and the Philippines typhoon cases. While the hurricane cases from the USA, the evacuation behavior is somehow little different in some specific aspects, such as traffic situation, warning receiving, and associated factors. The previous study distinguished the current research as it strongly correlated with evacuation decisions during a disaster. These findings could shed light on future research focusing on different disasters but similar nature.

Furthermore, concerning the first research objective, the survey results revealed that approximately 55% of the respondents evacuated during Cyclone Bulbul. Among them, 47% made early evacuation decisions, but an analysis of their evacuation starting time revealed that only 35.5% of them evacuated early before Cyclone Bulbul made landfall. Moreover, this research highlighted the importance of having adequate preparation time before starting evacuation. Most household respondents stated that they needed 2 hours before starting evacuation. However, the preparation time varied between 1 and 6 h depending on the evacuation stage, the type of preparation activities, and the presence of vulnerable members in the house. Both categories of respondents, those who made early evacuation decisions and those who followed through, cited evacuation companions, the presence of sick members in the house, distance from home to shelter, evacuation travel time, and socio-

economic characteristics as common influential factors. Respondents in the emergency evacuation category identified previous disaster experience, the presence of sick members in the house, and socio-economic aspects as the factors they considered while making evacuation decisions during Cyclone Bulbul. This analysis of factors influencing early evacuation decisions, early evacuation, and emergency evacuation helped shed light on people's perceptions about disasters. The results can guide authorities in taking policy actions to improve early evacuation possibility and issuing early evacuation orders to ensure safe and successful evacuation during cyclones or other disasters in the future.

Household evacuation preparation time is essential when ensuring safe and successful evacuations and is essential for estimating the total evacuation time during a disaster. Furthermore, concerning the second research objectives, this research proposes a methodology that predicts household evacuation preparation time following demographic and behavioral input variables based on the Random Forest algorithm focusing on cyclones. In addition, this research analyzes the variable importance and Partial Dependence Plot to identify the key influential factors that affect household evacuation preparation time. The prediction results showed high accuracy for household evacuation preparation time, which is credible and considerable for future disaster cases. Our results revealed that the most important factors that impact household evacuation preparation time are evacuation companions and age, followed by shelter distance, income, and shelter type. The results obtained from the prediction model can assist emergency response and evacuation planners and national disaster management authorities to demonstrate and improve effective evacuation plans considering household evacuation preparation time for future disaster cases.

Effective evacuation preparedness plan is the primary step in sending evacuees to safer places and ensuring their safety during a disaster. The decision of shelter choice and types of actual evacuation shelter during evacuation greatly influence evacuees' decision of evacuation, reflecting the total evacuation performance during a disaster. Finally, regarding the third research objective, this study investigated and analyzed households' data to distinguish households' preferences and behavior of evacuation decision for shelter choice and types of the evacuation shelter. In addition, focusing on household demographic characteristics, evacuation departure time, distance to shelter, evacuation travel time, and planning time and actual time to stay at the shelter for the coastal area in Bangladesh focusing Cyclone Bulbul. The result reveals that around 63 percent of households follow and depend on responsible authority's advice deciding their evacuation shelter. In addition, results indicate about 84 percent of households choose govt school/designated shelter as their evacuation destination. Moreover, it found that evacuation departure time, travel time, the actual time to stay at the shelter after evacuation, and household income are significant factors that influenced households' decisions while deciding evacuation shelter and types of shelter during evacuation. The findings of this study demonstrate households' preferences of choosing their evacuation shelter and types of shelter, especially in the coastal region during a cyclone.

Table of Contents

Acknowledgments	i
Abstract	ii
Table of Contents.....	vii
List of Figures	x
List of Tables	xii
Chapter 1 Introduction	1
1.1 Overview.....	1
1.2 Research Objectives	4
1.3 Organization of the Dissertation.....	7
1.4 References	8
Chapter 2 Literature Review	11
2.1 Households Evacuation Preparation Scenarios during Early and Emergency Evacuation	11
2.2 Household Evacuation Preparation Time During a Cyclone	13
2.2.1 Evacuation Preparation Time	14
2.3 Factors Influence Household Decision of Shelter and Types of Actual Shelter During Cyclone.....	16
2.4 References	17
Chapter 3 Methodology	23
3.1 Study Area.....	23
3.2 Data Collection	24
3.3 Prediction of Preparation Time Simulation	27
3.3.1 Data Processing.....	28
3.3.2 Simulation of Evacuation Preparation Time	28
3.3.3 Random Forest	29
3.3.4 Prediction of Preparation time Simulation Input Variable	30

3.3.5	Importance of Variables	32
3.3.6	Partial Dependence Plot (PDP)	33
3.4	References	33
Chapter 4	Household Evacuation Preparation Scenarios during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh	35
4.1	Introduction	35
4.2	Cyclone Primary Stage/ Warning Stage	35
4.3	Reasons for Non-evacuation During Cyclone Bulbul	36
4.4	Previous Disaster Experience	37
4.5	Evacuation During Cyclone Bulbul	38
4.6	Evacuation Preparation and Preparation Time	39
4.7	Early Evacuation Decision During Cyclone Bulbul	40
4.8	Early Evacuation Based on Starting Time of Evacuation During Cyclone Bulbul	41
4.9	Factors Prompting Early Evacuation Decision and Early Evacuation	42
4.9.1	Factors Prompting Early Evacuation Decision during Cyclone Bulbul .42	
4.9.2	Factors Prompting Early Evacuation Based on Evacuation Starting Time during Cyclone Bulbul	46
4.10	Factors Prompting Evacuation Response During Cyclone Bulbul	50
4.11	Summary	52
4.12	References	53
Chapter 5	Evacuation Preparation Time During a Cyclone: Random Forest Algorithm and Variable Degree Analysis	54
5.1	Introduction	54
5.2	Case Study	54
5.2	Data	55
5.2.1	Demographic Data	55

5.2.2	Behavioral Data.....	56
5.3	Implement the Model	58
5.4	Prediction of Preparation Time.....	59
5.7	Summary.....	64
5.8	References	64
Chapter 6	Relationship Between Household Decision of Shelter Choice and Types of Evacuation Shelter.....	66
6.1	Introduction.....	66
6.2	Questionnaire and Typical Response of Household to Cyclone Bulbul.....	66
6.3	Household Decision of Evacuation Shelter Choice	68
6.4	Types of Evacuation Shelter During Cyclone Bulbul.....	69
6.5	Test of Research Hypothesis	70
6.6	Summary.....	72
Chapter 7	Discussion	73
7.1	Comparison of Evacuation Behavior: Cases from Bangladesh, The Philippines, and the USA	73
7.1.1	Factors that Contribute to Evacuation Behaviors.....	77
7.2	Households Evacuation Preparation Scenarios during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh.....	79
7.3	Evacuation Preparation Time During a Cyclone: Random Forest Algorithm and Variable Degree Analysis.....	82
7.4	Relationship Between Household Decision of Shelter Choice and Types of Evacuation Shelter.....	84
7.5	References	86
Chapter 8	Conclusion.....	92
8.1	Conclusion	92
8.2	References	96

List of Figures

Figure 1.1 Schematic of the cyclone evacuation timeline (obtained from Rahman et al. (2021) [17])	5
Figure 1.2 Relationship between sheltering and demographic factors with associated influencing factors during Cyclone.....	6
Figure 1.3 Dissertation structure and outline	7
Figure 2.1 Schematic of the cyclone evacuation timeline (adapted from Rahman et al. 2021 [36]).....	15
Figure 3.1 (a) Cyclone Bulbul Impact Areas (Need Assessment Working Group Bangladesh, November 9, 2019 [1]), (b) Study area (obtained from Rahman et al. 2021 [5])	23
Figure 3.2 Data collection procedure and methods	26
Figure 3.3 Framework of evacuation preparation time simulation methodology (adapted from Chen et al. 2019 [9])	27
Figure 3.4 Random Forest classification principle.....	30
Figure 4.1 Reasons for non-evacuation during Cyclone Bulbul.....	36
Figure 4.2 Respondents' previous cyclone experience before Cyclone Bulbul	37
Figure 4.3 Respondents' activities before the start of the evacuation	39
Figure 4.4 Household preparation time before the start of evacuation during Cyclone Bulbul.....	40
Figure 4.5 Relationship between early evacuation decision and starting time of the evacuation of individual households before Cyclone Bulbul made landfall.....	41
Figure 4.6 Relationship between evacuation companions and early evacuation decision during Cyclone Bulbul.....	42
Figure 4.7 Relationship between preparation time before evacuation and early evacuation decision during Cyclone Bulbul	43
Figure 4.8 Relationship between the actual evacuation starting time and shelter type during cyclone Bulbul	47
Figure 4.9 Relationship between the actual evacuation starting time and evacuation companion during Cyclone Bulbul.....	48

Figure 4.10 Relationship between actual evacuation starting time and having a sick member in the house.....	48
Figure 4.11 Relationship between actual evacuation starting time and travel time to shelter.....	49
Figure 4.12 Relationship between actual evacuation starting time and preparation time	50
Figure 4.13 Relationship between previous disaster experience and evacuation during Cyclone Bulbul	50
Figure 5.1 Importance of variables	61
Figure 5.2 Partial Dependence Plot of all input variables	62

List of Tables

Table 3.1 Input variables to predict evacuation preparation time concerning cyclone Bulbul.....	31
Table 3.2 Example of input and output procedure of Random Forest.....	32
Table 4.1 Receipt of primary warning signal during Cyclone Bulbul	35
Table 4.2 Evacuation during Cyclone Bulbul	38
Table 4.3 Early evacuation decision during Cyclone Bulbul	41
Table 4.4 Factors prompting early evacuation decision during Cyclone Bulbul	44
Table 4.5 Respondent category based on their actual evacuation starting time.....	46
Table 4.6 Factors prompting evacuation during cyclone Bulbul.....	51
Table 5.1 Statistic of household demographic data	56
Table 5.2 Statistic of household behavioral data	57
Table 5.3 The prediction results of RF for input variables and the actual response of respondents	59
Table 5.4 Prediction and the actual response of household evacuation preparation time	60
Table 6.1 Summary of variables and response used in this research.....	67
Table 6.2 Evacuation shelter choice during cyclone Bulbul (multiple answers).....	69
Table 6.3 Types of shelter household evacuated during Cyclone Bulbul	70
Table 6.4 Intercorrelations among each variable to other variables	71
Table 7.1 Evacuation behavior during Cyclone, Typhoon, and Hurricane: Cases from Bangladesh, The Philippines, and The USA.....	76

Chapter 1 Introduction

1.1 Overview

Over the past decade, natural disasters have become more frequent in coastal regions around the world. Cyclones are common natural disasters that frequently occur in Bangladesh; the coastal area and its inhabitants are most affected by cyclones. It is evident that over the last two decades in Bangladesh, there has been a significant cyclone every two or three years: Sidr in 2007, Aila in 2009, Mahasen in 2013, Komen in 2015, Mora in 2017, Bulbul in 2019, Amphan in 2020, and Yaas in 2021. These frequent cyclones cause significant damage and destruction of life and properties. However, by ensuring effective planning, policy, and preparedness, losses and damage can be minimized. With national and local government authorities, disaster management authorities have tried to implement effective preparedness, policy, and planning during disasters to reduce damage and destruction. Evacuation plays a vital role in reducing disaster damage. The coastal areas in Bangladesh are vulnerable to cyclone disasters. As various factors, including evacuees' behavioral responses, pose challenges to successful evacuation, it is essential to evacuate early to reduce loss of life and damage to property [1]. People living in Bangladesh's coastal areas are at risk, but they usually decide to evacuate at the last minute; thus, it becomes challenging to complete the evacuation, especially given the weather conditions [2].

Additionally, over 90% of evacuees walk the evacuation routes in coastal areas. Still, poor road conditions and communication systems sometimes make traveling from their home to the shelter impossible. This state of affairs reasonably agrees with the conclusions of previous studies that acknowledged distance as an essential issue in evacuation decisions in coastal Bangladesh [3-8, 18]. Risk perceptions and previous cyclone experiences influence evacuation decisions [9-10]. Following the risk, Takagi et al. 2016 mentioned that it is difficult to evacuate during the storm surge and recommends evacuating before the storm surge [25].

Similarly, Walch 2018 revealed that prior experience of natural disasters is different for individual residents, increasing the resident's involvement in understanding the risk more clearly [22]. Distance of evacuation shelter and duration to reach evacuation shelter strongly correlated, which is essential for evacuation decision [26]. Many people could not

evacuate during Cyclone Sidr in 2007 because they delayed acting and eventually realized that time was not enough for evacuation because of the distance to evacuation shelters and inconvenient evacuation modes [6]. In the coastal area of Bangladesh at the community level, Cyclone Preparedness Program (CPP) volunteers disseminate cyclone warnings and other information among the communities through hand-mikes, megaphones, sirens, and individual house visits and help them to evacuate to shelters or safer places [11-13]. This research also investigated the involvement of CPP volunteers with local-level authorities and the dissemination of warning information during Cyclone Bulbul. People usually receive warning and evacuation information in Bangladesh coastal areas through radio and TV. However, no system has yet been developed to disseminate warnings through mobile phones. Besides, responsible local government authorities also disseminate the warning and other information directly to the community. Interviews with government representatives ensured that they gave warning dissemination and evacuation information through CPP volunteers to the individual community due to disruption of dissemination from the national government because of bad weather conditions. Interviews with CPP volunteers also noted that they went to respective communities to disseminate the information by megaphones, sirens, and sometimes individual households.

This study mainly focused on the early evacuation scenario and the possibility of early evacuation during future disasters, especially cyclone disasters. For the analysis, the study chose three wards in Gabura Union of Shyamnagar Upazila (sub-district) of Satkhira District, one of the worst-hit communities during Cyclone Bulbul struck the southwestern coast of Bangladesh on November 10, 2019. This study investigated early evacuation and behavior during the 2019 cyclone disaster to shed light on the conveniences or inconveniences faced during evacuation. This understanding can help inform policy to ensure safe evacuation and reduce damage during future disasters, especially physical damage. First, the study presents the findings related to the evacuation decision-making process, such as previous disaster experience, preparation type and time, household evacuation scenario, and demographic conditions. It outlines the factors influencing early evacuation and evacuation decisions. Second, the study reveals the percentage of people who evacuated early during Cyclone Bulbul. This was done by classifying the respondents into two categories based on their evacuation starting time before cyclone landfall to distinguish whether they evacuated early or not. The study presents the results of the analysis of factors that prompted an evacuation response in people, including household evacuation scenario, evacuation preparation

before the start of evacuation, the presence of vulnerable members in the house, distance to shelter, travel time, and demographic conditions during the disaster.

Although the disaster early warning process, emergency evacuation, and destination have improved, most people still cannot evacuate safely and on time during a cyclone disaster. This research emphasizes the prediction of evacuation preparation time and the importance of variables in understanding household factors promoting safe and successful evacuations. Household demographic and behavioral factors impact the delay in preparation time before starting an evacuation, hindering safe and successful evacuation to shelters or safer places. As evacuation plays a vital role in reducing disaster damage, a detailed investigation of the relative importance of the variables influencing preparation time during the evacuation phase is thus necessary to better ensure safe and complete evacuation by determining the preparations needed and time required before starting the evacuation. Previous studies of the evacuation decision-making process have focused on warning systems, cyclone shelters, information dissemination, route selection, destination, and evacuation behavior during a disaster [1-2, 14-16]. Huang et al. 2012 found that evacuees prefer to evacuate in the daytime instead of nighttime [23]. Another previous study found that, people want to evacuate during strong storm surge based on evacuation order from authority in the future [24]. Oikawa et al., 2016 found that a high level of disaster consciousness, such as disaster education, improving evacuation warning, and preparation of evacuation sites, leads to a smooth evacuation [19]. Similarly, another previous study found that better education and effective development strategies are essential to improve the resilience of local inhabitants in a specific region [21]. In this study, we focus on the preparation time, as it is essential to start evacuation at an appropriate time to ensure safe evacuation. This study proposes a simulation model of household evacuation preparation time prediction for coastal residents centering on cyclones based on previous research. In this study, an RF prediction model was built to predict household evacuation preparation time. The primary objective of this study is to develop a systematic prediction model of evacuation preparation time that can be used for effective evacuation preparedness plans to reduce disaster risk in specific areas.

Furthermore, the present study investigates in detail the degree of influence of each variable on household evacuation preparation time. It determines the relationship between demographic and behavioral factors and household preparation time during evacuations in coastal areas. This method of investigating the relative importance of variables in predicting

evacuation preparation time and relationships with independent variables better explains individual household evacuation decision-making processes during disasters, thus identifying consequences and factors that are important for evacuation preparation time, to assist the responsible authorities in understanding and establishing better preparations for future evacuations during similar types of disasters.

Furthermore, many previous studies investigated different aspects of household decisions regarding evacuation shelter choice, types of shelter identification maps, and destination choice models, rather than evacuees' preferences and risks. Furthermore, our past research revealed that types of shelter are an essential factor that should be considered during households' early and emergency evacuation, which ensures smooth evacuation to safe places during emergencies [17]. While staying at the shelter after evacuation, different aspects need to satisfy evacuees' perspective: internet access, privacy space, communication, disaster-related information, food, and hydration [20]. In this study, we deemed it an excellent initiative to assess and explore factors associated with household evacuation shelter preferences and types of shelter in the coastal area of Bangladesh, focusing on the November 2019 cyclone Bulbul. A detailed investigation of the associated factors is required to better understand the actual scenario during evacuation. Therefore, the findings of this study can help individual interested groups such as researchers, national and local level disaster management authorities, and government and non-government agencies to come up with new ideas, plans, and preparedness strategies to reduce disaster risk during evacuation in coastal areas. Therefore, disaster management planners and other interested agencies can understand the preferences of households regarding how and where to evacuate, which influences their shelter choice and shelter types, and the overall evacuation process. Considering the importance of households' evacuation shelter choice and their types of shelter, the evacuation plan and preparedness can be evaluated, and a better redesign plan helps to build safe evacuation completion.

1.2 Research Objectives

The objective of this study was to analyze people's perceptions of and experiences with evacuation decisions and preparation towards shelter preference during the evacuation, focusing on Cyclone. Therefore, this study's overall objectives and goals are addressed by three research objectives that describe specific perspectives to achieve the goals. The three research objectives of this study are given below in detail.

- Objective 1:** According to **Figure 1.1**, respondents decided to evacuate after receiving a cyclone warning. If they choose to evacuate, they then prepare for evacuation commencement. Following the cyclone warning signal, some respondents evacuated before the evacuation order, while others evacuated after the evacuation order. The evacuation starting time concerning evacuation orders identified who made early and emergency evacuations.

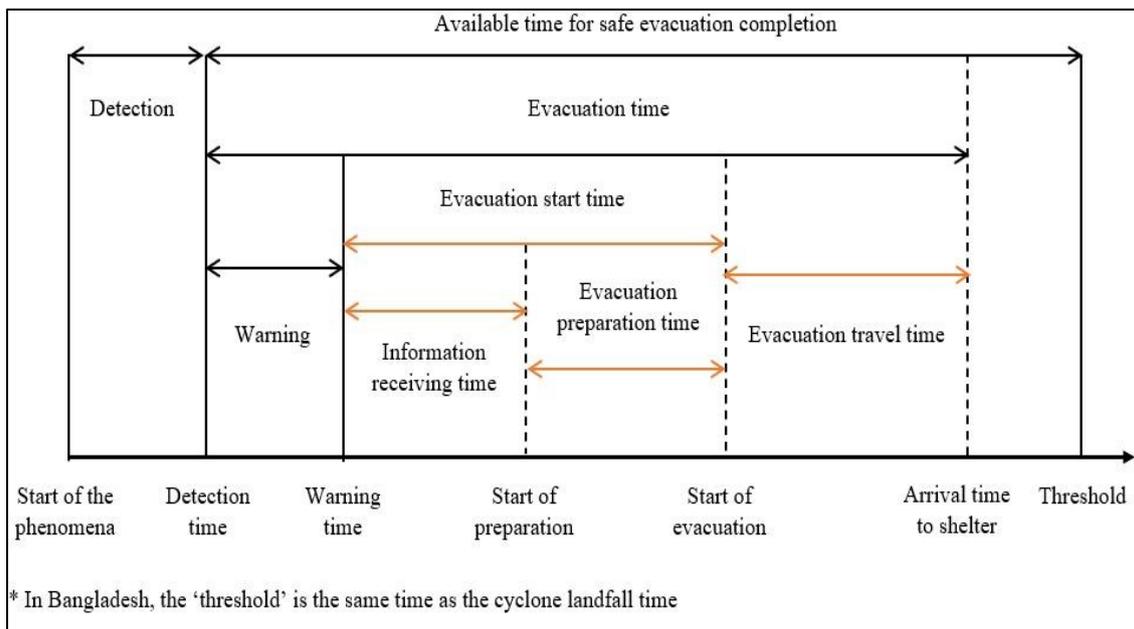


Figure 1.1 Schematic of the cyclone evacuation timeline (obtained from Rahman et al. (2021) [17])

The specific objectives based on starting time of evacuation are:

- To determine people's perception of weather conditions, the presence of vulnerable members in the house, previous disaster experiences, and demographic and socio-economic aspects affecting their evacuation decisions.
- To understand the consequences and complexities of early evacuation decisions for evacuees because of the different kinds of challenges they faced when attempting to come up with suitable solutions for the problems. Additionally, to determine the importance of household preparation time for safe and successful evacuation during a cyclone disaster, and
- To understand why few people evacuated early and many others did not during the cyclone, identify the critical factors that influenced people's early evacuation.

- **Objectives 2:** Estimating household evacuation preparation time aims to better understand people’s starting evacuation time during a cyclone. Household evacuation preparation time is also essential when estimating the total evacuation time. The objectives based on household evacuation preparation time is to present the following:
 - A detailed investigation of household demographic and behavioral factors that affect evacuation preparation time, which need to be determined for the prediction of preparation time;
 - A presented prediction of household evacuation preparation time simulation based on RF during a cyclone;
 - Identifying major demographic and behavioral factors that influence household evacuation preparation time.

- **Objectives 3:** The research objectives based on the household decision of shelter choice and types of actual evacuation shelter are as follows (**Figure 1.2**):
 - Evacuation shelter choice will significantly relate to evacuation travel time, departure time, and shelter types.
 - Shelter type will be significantly related to distance to shelter, evacuation travel time, household primary plan to stay at the shelter before evacuation, and actual duration of stay at the shelter after evacuation.
 - Household demographic characteristics will be significantly related to evacuation travel time, departure time, types of shelter, and household primary plan to stay at the shelter before evacuation.

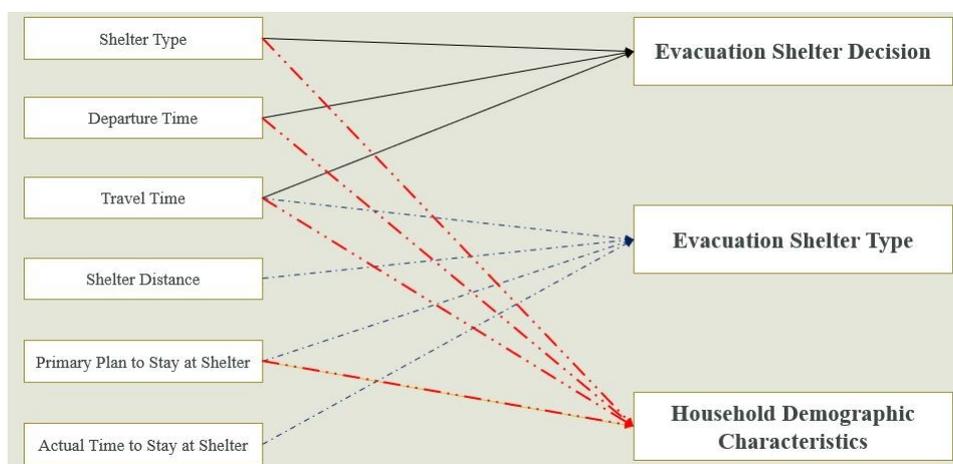


Figure 1.2 Relationship between sheltering and demographic factors with associated influencing factors during Cyclone

1.3 Organization of the Dissertation

This dissertation consists of eight chapters, as shown in Figure 1.3.

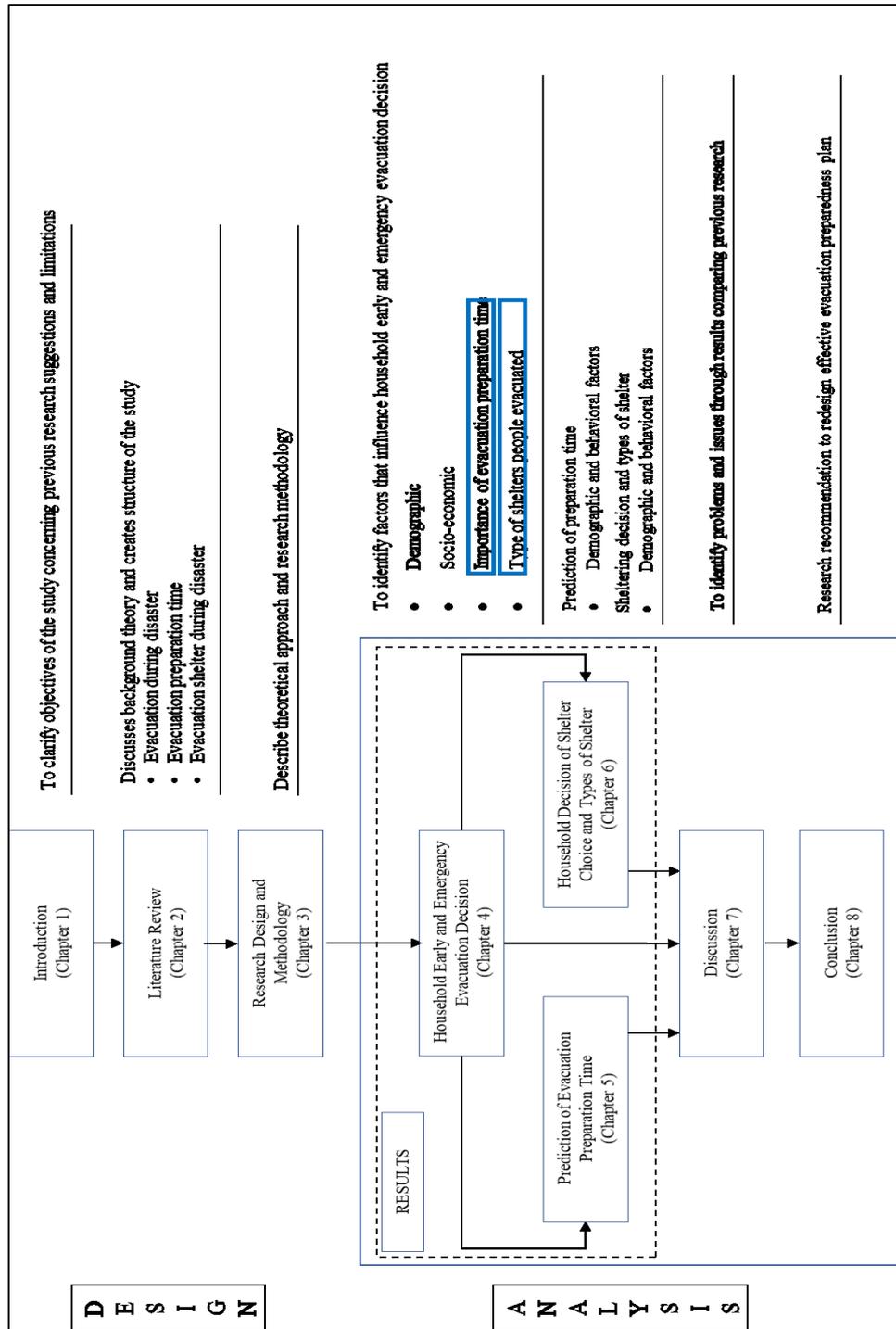


Figure 1.3 Dissertation structure and outline

Chapter 1 presents this study's general introduction and essential motivation, including the research objectives. In addition, chapter 2 represents a literature review of this research. This chapter contains a detailed overview of households' early and emergency evacuation decisions, evacuation preparation time, and shelter choice during the disaster. Furthermore, chapter 3 describes the data collection, sampling, processing, and analysis method. Following the methodology, chapters 4, 5, and 6 present the data analysis results based on three research objectives. Chapter 7 discusses the significant findings and links the findings with existing research findings. Chapter 8 concludes, which provides an overview of an effective evacuation preparedness plan for future disasters.

1.4 References

1. B. K. Paul, "Factors Affecting Evacuation Behavior: The Case of 2007 Cyclone Sidr, Bangladesh," *Prof. Geogr.*, 2012.
2. C. E. HAQUE and D. BLAIR, "Vulnerability to Tropical Cyclones: Evidence from the April 1991 Cyclone in Coastal Bangladesh," *Disasters*, vol. 16, no. 3, pp. 217–229, 1992.
3. A. M. R. Chowdhury, A. U. Bhuyia, A. Y. Choudhury, and R. Sen, "The Bangladesh Cyclone of 1991: Why So Many People Died," *Disasters*, vol. 17, no. 4, pp. 291–304, 1993.
4. K. Ikeda, "Gender Differences in Human Loss and Vulnerability in Natural Disasters: A Case Study from Bangladesh," *Indian J. Gend. Stud.*, vol. 2, no. 2, pp. 171–193, 1995.
5. B. Mallick, "Cyclone shelters and their locational suitability: An empirical analysis from coastal Bangladesh," *Disasters*, 2014.
6. B. K. Paul and S. Dutt, "Hazard warnings and responses to evacuation orders: The case of Bangladesh's cyclone Sidr," *Geogr. Rev.*, 2010.
7. B. K. Paul, H. Rashid, M. S. Islam, and L. M. Hunt, "Cyclone evacuation in bangladesh: Tropical cyclones gorky (1991) vs. sidr (2007)," *Environ. Hazards*, 2010.
8. S. K. Paul and J. K. Routray, "An Analysis of the Causes of Non-Responses to Cyclone Warnings and the Use of Indigenous Knowledge for Cyclone Forecasting in Bangladesh," in *Climate Change Management*, 2013.
9. M. N. Ahsan, K. Takeuchi, K. Vink, and J. Warner, "Factors affecting the evacuation decisions of coastal households during Cyclone Aila in Bangladesh," *Environ. Hazards*, vol. 15, no. 1, pp. 16–42, 2016.

10. T. Das, U. Barua, and A. Ansary, Mehedi, "A Review on Factors Affecting Cyclone Evacuation Decision and Behavioral Response," no. April, 2018.
11. B. K. Paul, "Why relatively fewer people died? The case of Bangladesh's cyclone sidr," *Nat. Hazards*, 2009.
12. U. Haque, M. Hashizume, K. N. Kolivras, H. J. Overgaard, B. Das, and T. Yamamoto, "Reduced death rates from cyclones in Bangladesh: What more needs to be done?," *Bull. World Health Organ.*, 2012.
13. M. Miyaji, K. Okazaki, and C. Ochiai, "A Study on the use of Cyclone Shelters in Bangladesh," *J. Archit. Plan. (Transactions AIJ)*, 2017.
14. M. N. Ahsan, K. Takeuchi, K. Vink, and M. Ohara, "A systematic review of the factors affecting the cyclone evacuation decision process in Bangladesh," *J. Disaster Res.*, vol. 11, no. 4, pp. 742–753, 2016.
15. C. E. Haque, "Climatic hazards warning process in Bangladesh: Experience of, and lessons from, the 1991 April cyclone," *Environ. Manage.*, 1995.
16. C. Roy, S. K. Sarkar, J. Åberg, and R. Kovordanyi, "The current cyclone early warning system in Bangladesh: Providers' and receivers' views," *Int. J. Disaster Risk Reduct.*, vol. 12, no. 12, pp. 285–299, 2015.
17. M. A. Rahman, A. HOKUGO, N. OHTSU, and S. Chakma, "Evacuation Preparation Scenarios of Households during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh," *IDRiM J.*, 2021.
18. S. K. Paul, "Determinants of Evacuation Response To Cyclone Warning in Coastal Areas of Bangladesh : a Comparative Study," *Orient. Geogr.*, vol. 55, no. 01, pp. 57–83, 2011.
19. Y. Oikawa, K. Sripramai, T. Katada, and Y. Ishii, "A Comparison of the Reasons for Evacuation Behavior during Floods: –Contrastive Effects of Disaster Consciousness–," *J. Nat. Disaster Sci.*, vol. 37, no. 2, pp. 35–47, 2016.
20. S. Choi, R. Maharjan, and S. Hanaoka, "Past evacuation behavior and intended shelter selection of Japanese considering presence of foreign tourists," 2021.
21. M. Esteban, V. P. Valenzuela, N. Y. Yun, T. Mikami, T. Shibayama, R. Matsumaru, H. Takagi, N. D. Thao, M. D. Leon, T. Oyama, and R. Nakamura, "Typhoon Haiyan 2013 Evacuation Preparation and Awareness", *J-Sustain*, vol. 3, no. 1, pp. 37-45, 2015.
22. C. Walch, "Evacuation ahead of natural disasters: Evidence from cyclone Phailin in India and typhoon Haiyan in the Philippines", *Geo: Geography and Environment*. 5. 10.1002/geo2.51, 2018.

23. S. K. Huang, M. K. Lindell, and C. S. Prater, "Household evacuation decision-making in response to Hurricane Ike", *Nat Hazards Rev*, 6 (4), 13:283-296, 2012.
24. M. A. Meyer, B. Mitchell, J. C. Purdum, K. Breen, and R. L. Iles, "Previous Hurricane Evacuation Decisions and Future Evacuation Intentions Among Residents of South Louisiana", *Int J Disaster Risk Reduct* 31:1231-1244, 2018.
25. H. Takagi, S. Li, M. E. Mario de Leon, T. Mikami, R. Matsumaru, T. Shibayama, and R. Nakamura "Storm Surge and Evacuation in Urban Areas during the Peak of a Storm", *Coast Eng* 108:1-9, 2016.

Chapter 2 Literature Review

2.1 Households Evacuation Preparation Scenarios during Early and Emergency Evacuation

Early evacuation decisions define whether households decide to evacuate before receiving the official evacuation order. Early evacuation decision means that after hearing the first warning signal, respondents decide their possible evacuation before they receive the official evacuation order—10 h before the predicted landfall of the cyclone. Similarly, if, in actual cases, households make their evacuation before they receive official evacuation orders from a responsible authority, this is distinguished as early evacuation. Issuing the official evacuation order is important to reduce the disaster risk during the evacuation phase. The local authorities should give a proper and timely evacuation order ahead of a strong typhoon concerning arrangements of vertical evacuation [40]. There is no official early evacuation order from the perspective of Bangladesh during cyclones. This research examined the possibility of early evacuation based on the current official evacuation order. Evacuation during a disaster facilitates successful and safe evacuation, which is essential for reducing physical damage. During the tsunami evacuation, evacuation is distinguished as the different stages which start from notification until evacuation movement. In the various stages of evacuation, people's evacuation behavior depends on different factors [48]. The Bangladesh Meteorological Department issued a cyclone warning at four stages: the first stage is the cyclone alert stage, 36 h before the predicted landfall; the second stage is the cyclone warning stage, 24 h before the predicted landfall; the third stage is the cyclone disaster stage, 18 h before the predicted landfall; and the last stage is the cyclone great-danger stage, 10 h before the predicted landfall [1]. These four stages of warning signals are the current organizational framework for the Bangladesh Government Disaster Management Ministry to disseminate the warning and evacuation orders during cyclones. The official evacuation order is given at the cyclone great-danger stage, 10 h before the predicted landfall. This research investigated the details of early evacuation decisions and early evacuation and the associated influential factors that affect the safe and successful evacuation.

Although the complexities and rules of early evacuation are different for different disasters, researchers agree that early evacuation is essential to mitigate damage during tsunami disasters [2]. However, that study focused only on the evacuation time during a tsunami disaster rather than determining the early evacuation time. Sun et al., 2016 found that resident actual evacuation behavior differs from evacuation plans prepared before for a specific area. Different factors are responsible for the sudden change of evacuation behavior during the evacuation of residents, for example, road conditions, confusion about safe evacuation, and diverse public opinion, leading to changes in evacuation behavior before starting evacuation [41]. In addition, Ohtomo et al., 2020 found that even though the residents were aware of the hazard map and evacuation plan, a small number tried to evacuate during the torrential rain in Okayama prefecture in 2018 [51]. An effective evacuation plan and timely evacuation are very important for safe evacuation—reducing casualties and property damage. Kruger *et al.* (2019) confirmed that successful evacuation involves various components, such as governmental and non-governmental organizations' participation, disaster response capabilities, sources of information, and aspects related to communication sources [3]. Local officials play a crucial role in disseminate warning information, which makes people evacuate during a hurricane [57-59]. Properly planning for evacuations is an essential assignment of reposing evacuees safe from the injuries and causalities from natural disasters. Evacuation planning and preparedness are influenced by prior behavior, which involves future evacuation intentions [50]. Planning for evacuations involves many things, for example, early evacuation and active involvement of local government and community people. The safe and successful evacuation dramatically depends on how quickly the people are transferred to a safe area from a risk area [43].

Furthermore, a safe evacuation place, disaster preparedness, and timely evacuation can reduce casualties during a disaster. A previous study revealed that useful information could help to mitigate disaster damage during the storm surge stage [54]. Following this, Leelawat 2014 found that despite people receiving the early warning, but did not evacuate during typhoon Haiyan in the Philippines [53]. In addition, another study found that underestimates the disaster damage; therefore, people failed to evacuate [55]. However, improving the warning dissemination process and disaster education throughout the communities can effectively increase natural disasters' evacuation and survival rates [42]. Dash and Gladwin 2007 suggested that the evacuation rates can be increased by improving communication of forecast and warning [56]. Bangladesh is recognized as one of the most

disaster-prone countries worldwide. It frequently experiences cyclones and other disasters. Therefore, many people are physically and economically vulnerable, leading their lives in danger. The coastal zones are low-lying areas situated on the deltas and floodplains of the three major rivers. Cyclones formed during the monsoon season from June to September are usually associated with storm surges. Because of such storm surges, high tides make the coastal land and embankments unstable, causing huge loss of life and property damage. Various governments and international organizations have reported that because of climate change-driven sea-level rise and cyclonic storm surges, around 20 million people in coastal districts are expected to be displaced [4]. Concerning the evacuation decision-making process, many previous studies have focused on warning systems, cyclone shelters, information dissemination, route selection, destination, and evacuation behavior during disasters [5-9, 51-52]. Furthermore, several studies have investigated the factors that affect people's evacuation decisions during emergencies.

2.2 Household Evacuation Preparation Time During a Cyclone

Methodologically, numerous previous studies have focused on evacuation and risk assessment models using the random forest (RF) algorithm based on natural disasters. Ghosh and Dey 2021, used four different prediction models, namely, frequency ratio, fuzzy logic, logistic regression, and RF, to investigate flood severity assessments, including eight conditioning factors in the coastal tract. They found that fuzzy logic and RF have significant potential for improved prediction results [10]. In addition, previous research found that random forests provide higher accuracy than multinomial logit and mixed logit models [18-19]. Similarly, another study that investigated the inpatient satisfaction of different public hospitals in China, considering the relationship between various influencing factors and overall satisfaction, found that the prediction accuracy of the RF is much higher than that of multiple regression and naïve Bayesian models [11]. Wang et al. 2015 found excellent efficiency over an extensive database using RF while analyzing flood risk assessment through various risk index variables. However, the error rate for both training and testing data can be improved by increasing the sample size and classification trees [12-13].

Few previous studies have investigated evacuation preparation time, as it is essential to estimate the total evacuation time for the evacuation process during an emergency. Considering the demographic characteristics, information sources and evacuation

inhibitors show more reliable correlations when estimating preparation time than other factors such as storm characteristics, personal impacts, and evacuation facilitators [13]. In addition, household activities such as travel from work to home, gathering all family members, packing essential things, and protecting houses and belongings are uncorrelated with household evacuation preparation time [37]. A recent study showed that evacuation preparation time is necessary for early and emergency evacuation during cyclones. Therefore, it is found that demographic and socioeconomic factors are significantly correlated with both early and emergency evacuation decisions [20]. Preparation is useful when residents want to evacuate in groups, manage important belongings, ensure measures to protect property, and identify safe places. However, few studies have characterized the factors that affect preparation time [14].

Only a few studies have focused on the prediction and importance of preparation time by performing degree analyses of different influential variables and the probability of the average preparation time that individual households need before starting to evacuate. A recent review of the estimation of pre-evacuation time focused on assessing the total evacuation time considering emergency evacuation in urban residential communities [15]. In addition, few studies have applied a partial dependence plot (PDP) to investigate the non-linear relationship between input and output variables for black-box machine learning tools based on the RF algorithm. However, there is no specific previous research considering the prediction of preparation time simulation based on RF during cyclones. Similarly, no previous study has analyzed the associated influential factors using demographic and behavioral characteristics of individual households through a PDP, which can distinguish the detailed relationship of each input variable to evaluate the influence on the output variable focusing on cyclones.

2.2.1 Evacuation Preparation Time

Evacuation preparation time plays a vital role in the safe and complete evacuation during the evacuation phase because evacuating at the right time depends on the evacuation preparation time before the start of an evacuation. Rahman et al. [20] proposed a cyclone evacuation timeline that involves (a) available time for safe evacuation, (b) detection, (c) evacuation time, (d) evacuation start time, (g) preparation time, and (h) evacuation travel time, as shown in **Figure 2.1**. However, this study modified the previous timeline by

including (e) authority decision time to disseminate warning and (f) information receiving and decision time. During the evacuation, one of the essential tasks of responsible authorities is to disseminate evacuation information or notices to ensure safe evacuation before the disaster [22, 38].

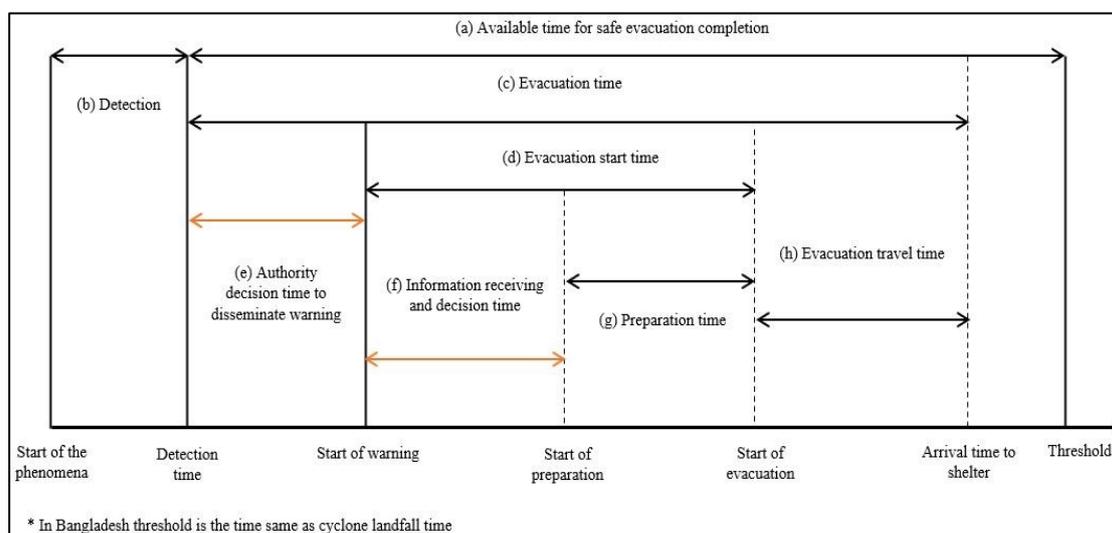


Figure 2.1 Schematic of the cyclone evacuation timeline (adapted from Rahman et al. 2021 [36])

According to **Figure 2.1**, the national disaster management authority detects the phenomenon and disseminates a warning to a specific area. Following this, people receive information regarding evacuation information and have an initial response as to whether to evacuate or not. From the perspective of Bangladesh facing a cyclone, this initial response is recognized as households' start of preparations for evacuation. If they decide to evacuate, they initiate the necessary preparations to start the evacuation from their homes to shelters. During the preparation time, some household members engage in information gathering, mediation, and appraisal of the risks of evacuation, which is called psychological preparation or social milling [21, 22, 38]. Nozawa et al., 2008 suggested that disaster education is essential for disaster preparedness concerning preparation and securing necessary equipment to form an effective network before the natural disaster occurs [39]. Some households also prepare necessities before starting evacuation for stays at evacuation shelters, such as packing bags, ensuring the safety of belongings from storms, and preparing family members, which is called logistical preparation [13, 21, 22]. Parvin et al. 2019 put forward a clear concept of the ideal time to issue an evacuation order and prepare to begin an evacuation. People's perceptions about the ideal time for an evacuation are based on the

time it takes to make evacuation preparations and leave their homes for shelters before a cyclone makes landfall and a storm surge occurs [1].

However, previous research determined that household evacuation preparation time starts after households decide upon evacuation during cyclones. In addition, during early and emergency evacuation, it has been found that during preparation, households engage in various activities such as organizing water and medicine, preparing food for use at the shelter, preparing family members, and ensuring house safety, which requires an average preparation time of approximately 2 h before the start of evacuation [20]. Following this, during the questionnaire survey, this study asked household respondents about their preparation time after they decided their evacuation and start of evacuation time under cyclone Bulbul in 2019. Therefore, the definition of evacuation preparation time indicates the time that starts just after they decide to evacuate and start to make the necessary preparations until they start their evacuation to shelters from their homes.

Furthermore, the pre-evacuation time included the evacuation decision and preparation times. Previous research focusing on pre-evacuation prediction models shows that social and environmental factors affect occupant evacuation decisions during building evacuation in the pre-evacuation stage [18-19]. However, this research focuses only on the household evacuation preparation time rather than the pre-evacuation time for the evacuation preparation time simulation model.

2.3 Factors Influence Household Decision of Shelter and Types of Actual Shelter During Cyclone

Evacuation is considered the primary possession to reduce risk towards a large-scale disaster, especially during a cyclone. Different variables or factors are consistent regarding their importance on safe and successful evacuation, like demographic characteristics of the household, evacuation shelter choice, types of shelter, the distance of shelter, and duration of stay at the shelter after evacuation. Previous research found that various demographic and socio-economic factors significantly influence evacuees deciding evacuation [44-47]. Although national and local level authorities responsible for disaster management had prepared an evacuation plan, there are still some problems during evacuation.

Evacuation shelter choice for evacuation is essential to ensure complete evacuation towards shelter or a safer place. Designated cyclone shelter is one of the essential essentials that coastal community people need to access for their safe stay before and after the cyclone landfall. According to previous research, during cyclone Sidr in 2007, Cyclone Preparedness Program (CPP) volunteers to assist nearly 1.5 million people in the coastal area of Bangladesh for their safe evacuation to shelter and safer place [22-23]. Furthermore, officials' late warning dissemination concerning sheltering advice can influence the household preference of shelter choice and smoothness of their evacuation. So, it is needed to investigate in detail about the involvement of officials' warning dissemination and sheltering advice towards the household preference of shelter choice [24]. According to previous research, socioeconomic characteristics, evacuees' purpose of the trip, evacuation time of the day, or evacuation mode can be affected while evacuees choose their evacuation destination for evacuation [25, 26, 27]. In addition, the existence of shelter close to the house, the geography of the area, and household risk attitude are considered as essential factors that affect evacuees' decisions to choose evacuation destination [1, 28-31]. Evacuees' evacuation decision during cyclones considerably relies on the evacuation place or destination where they want to evacuate and how long they want to stay there [32]. Hasan et al. (2013) have found that during Hurricane Ivan in 2004, households who chose public shelter for evacuation evacuated at a later stage revealed their preference to take the risk of staying at home longer than in a public shelter [33]. In addition, Sadri et al. (2013) found that during Hurricane Ivan, most evacuees wanted to evacuate earlier and determined to evacuating a public shelter took less time than others who chose other types of shelter [34].

2.4 References

1. G. A. Parvin, M. Sakamoto, R. Shaw, H. Nakagawa, and M. S. Sadik, "Evacuation scenarios of cyclone Aila in Bangladesh: Investigating the factors influencing evacuation decision and destination," *Prog. Disaster Sci.*, vol. 2, p. 100032, 2019.
2. N. Y. Yun and M. Hamada, "A Study on Evacuation Behaviors in the 2011 Great Japan Earthquake," *15th World Conf. Earthq. Eng.*, 2012.
3. J. Kruger, R. N. Avchen, and P. Purcell, "Preparing communities to evacuate for major hurricanes," *American Journal of Public Health*. 2019.

4. S. S. M. M. R. N. R. C. Ali, and N. R. Chowdhury, "Bangladesh : A Sustainable and Disaster Resilient Future Islamic Relief Worldwide-Bangladesh," Preventionweb 2012. https://www.preventionweb.net/files/27650_bookletstoryteller.pdf.
5. M. N. Ahsan, K. Takeuchi, K. Vink, and M. Ohara, "A systematic review of the factors affecting the cyclone evacuation decision process in Bangladesh," *J. Disaster Res.*, vol. 11, no. 4, pp. 742–753, 2016.
6. C. E. Haque and D. Blair, "Vulnerability to Tropical Cyclones: Evidence from the April 1991 Cyclone in Coastal Bangladesh," *Disasters*, vol. 16, no. 3, pp. 217–229, 1992.
7. C. E. Haque, "Climatic hazards warning process in Bangladesh: Experience of, and lessons from, the 1991 April cyclone," *Environ. Manage.*, 1995.
8. B. K. Paul, "Factors Affecting Evacuation Behavior: The Case of 2007 Cyclone Sidr, Bangladesh," *Prof. Geogr.*, 2012.
9. C. Roy, S. K. Sarkar, J. Åberg, and R. Kovordanyi, "The current cyclone early warning system in Bangladesh: Providers' and receivers' views," *Int. J. Disaster Risk Reduct.*, vol. 12, no. 12, pp. 285–299, 2015.
10. A. Ghosh and P. Dey, "Flood Severity assessment of the coastal tract situated between Muriganga and Saptamukhi estuaries of Sundarban delta of India using Frequency Ratio (FR), Fuzzy Logic (FL), Logistic Regression (LR) and Random Forest (RF) models," *Reg. Stud. Mar. Sci.*, vol. 42, p. 101624, 2021.
11. C. Li, C. Liao, X. Meng, H. Chen, W. Chen, B. Wei, and P. Zhu., "Effective analysis of inpatient satisfaction: The random forest algorithm," *Patient Prefer. Adherence*, vol. 15, pp. 691–703, 2021.
12. Z. Wang, C. Lai, X. Chen, B. Yang, S. Zhao, and X. Bai, "Flood hazard risk assessment model based on random forest," *J. Hydrol.*, vol. 527, pp. 1130–1141, 2015.
13. M. K. Lindell, J. H. Sorensen, E. J. Baker, and W. P. Lehman, "Community response to hurricane threat: Estimates of household evacuation preparation time distributions," *Transp. Res. Part D Transp. Environ.*, vol. 85, no. July, p. 102457, 2020.
14. M. K. Lindell and C. S. Prater, "Estimating Evacuation Time Components: Lessons from Nuclear Power Plants, Hurricanes, and the First World Trade Center Bombing," no. February 2014, p. 5, 2004.
15. J. Chen, J. Yu, J. Wen, C. Zhang, Z. Yin, J. Wu, and S. Yao, "Pre-evacuation time estimation based emergency evacuation simulation in urban residential communities," *Int. J. Environ. Res. Public Health*, vol. 16, no. 23, 2019.

16. D. F. D'Amico, S. M. Quiring, C. M. Maderia, and D. B. McRoberts, "Improving the Hurricane Outage Prediction Model by including tree species," *Clim. Risk Manag.*, vol. 25, no. June, p. 100193, 2019.
17. Q. Zhao and T. Hastie, "Causal Interpretations of Black-Box Models Qingyuan Zhao And Trevor Hastie Department of Statistics, Stanford University," 2016.
18. X. Zhao, R. Lovreglio, and D. Nilsson, "Modelling and interpreting pre-evacuation decision-making using machine learning," *Autom. Constr.*, vol. 113, no. November 2019, p. 103140, 2020.
19. X. Zhao, X. Yan, A. Yu, and P. Van Hentenryck, "Prediction and behavioral analysis of travel mode choice: A comparison of machine learning and logit models," *Travel Behav Soc*, 20, 2020.
20. M. A. Rahman, A. Hokugo, N. Ohtsu, and S. Chakma, "Evacuation Preparation Scenarios of Households during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh," *IDRiM J.*, 2021.
21. M. M. Wood, D. S. Mileti, H. Bean, B. F. Liu, J. Sutton, and S. Madden, "Milling and Public Warnings," *Environ. Behav.*, vol. 50, no. 5, pp. 535–566, 2018.
22. M. K. Lindell, S. Arlikatti, and S. K. Huang, "Immediate behavioral response to the June 17, 2013 flash floods in Uttarakhand, North India," *Int. J. Disaster Risk Reduct.*, vol. 34, no. August 2018, pp. 129–146, 2019.
23. B. K. Paul, "Why relatively fewer people died? The case of Bangladesh's cyclone Sidr," *Nat. Hazards*, 2009.
24. M. Nateque Mahmood, S. Prasad Dhakal, and R. Keast, "The state of multi-purpose cyclone shelters in Bangladesh," *Facilities*, vol. 32, no. 9/10, pp. 522–532, 2014.
25. M. Nagarajan and D. Shaw, "A behavioral simulation study of allocating evacuees to public emergency shelters," *Int. J. Disaster Risk Reduct.*, vol. 55, no. July 2020, p. 102083, 2021.
26. M. B. B. Lim, H. R. Lim, and J. M. L. Anabo, "Evacuation destination choice behavior of households in Eastern Samar, Philippines during the 2013 Typhoon Haiyan," *Int. J. Disaster Risk Reduct.*, vol. 56, no. February, p. 102137, 2021.
27. J. Molloy and R. Moeckel, "Improving Destination Choice Modeling Using Location-Based Big Data," *ISPRS Int. J. Geo-Information*, vol. 6, no. 9, p. 291, 2017.
28. F. Zong, Y. Tian, Y. He, J. Tang, and J. Lv, "Trip destination prediction based on multi-day GPS data," *Phys. A Stat. Mech. its Appl.*, vol. 515, pp. 258–269, 2019.

29. M. Janzen and K. . Auxhausen, "Destination and modal choice in agent-based simulation of Long-Distance Travel Demand," *ETH Libr.*, no. May, 2017.
30. G. Cheng, C. Wilmot, and E. J. Baker, "Development of a time-dependent disaggregate hurricane evacuation destination choice model," *Natural Hazards Review*, 14(3), 163-174, 2013.
31. G. Troncoso Parady and E. Hato, "Accounting for spatial correlation in tsunami evacuation destination choice: a case study of the Great East Japan Earthquake," *Nat. Hazards*, vol. 84, no. 2, pp. 797–807, 2016.
32. K. Xu, R. A. Davidson, L. K. Nozick, T. Wachtendorf, and S. E. DeYoung, "Hurricane evacuation demand models with a focus on use for prediction in future events," *Transp. Res. Part A Policy Pract.*, vol. 87, pp. 90–101, 2016.
33. Earl J. Baker, "Hurricane Evacuation Behavior," *International Journal of Mass Emergencies and Disasters* , vol. 9, no. 2. pp. 287–310, 1991.
34. S. Hasan, R. Mesa-Arango, and S. Ukkusuri, "A random-parameter hazard-based model to understand household evacuation timing behavior," *Transportation research part C: emerging technologies*, 27, 108-116, 2013.
35. A. M. Sadri, S. V. Ukkusuri, and P. Murray-Tuite, "A random parameter ordered probit model to understand the mobilization time during hurricane evacuation," *Transp. Res. Part C Emerg. Technol.*, vol. 32, pp. 21–30, 2013.
36. M.A Rahman, A. Hokugo, and N. Ohtsu, "Household evacuation preparation time during a cyclone: Random Forest algorithm and variable degree analysis," *Prog. Disaster Sci.*, 2019.
37. M.K. Lindell, J.C. Lu, and C.S. Prater, "Household decision making and evacuation in response to Hurricane Lili," *Nat Hazards Rev*, 6 (4), 2005.
38. M.K. Lindell, P. Murray-Tuite, B. Wolshon, and E.J. Baker, "Large-scale evacuation: the analysis, modeling, and management of emergency relocation from hazardous areas," *Routledge*, New York, 2019.
39. M. Nozawa, T. Watanabe, N. Katada, H. Minami, and A. Yamamoto, "Residents' awareness and behaviour regarding typhoon evacuation advice in Hyogo Prefecture, Japan," *Int. Nurs. Rev.*, vol. 55, no. 1, pp. 20–26, 2008.
40. T. Takabatake, M. Mäll, M. Esteban, R. Nakamura, T.O. Kyaw, H. Ishii, J.J. Valdez, Y. Nishida, F. Noya and T. Shibayama, "Field survey of 2018 Typhoon Jebi in Japan: Lessons for disaster risk management," *Geosci.*, vol. 8, no. 11, pp. 1–19, 2018.

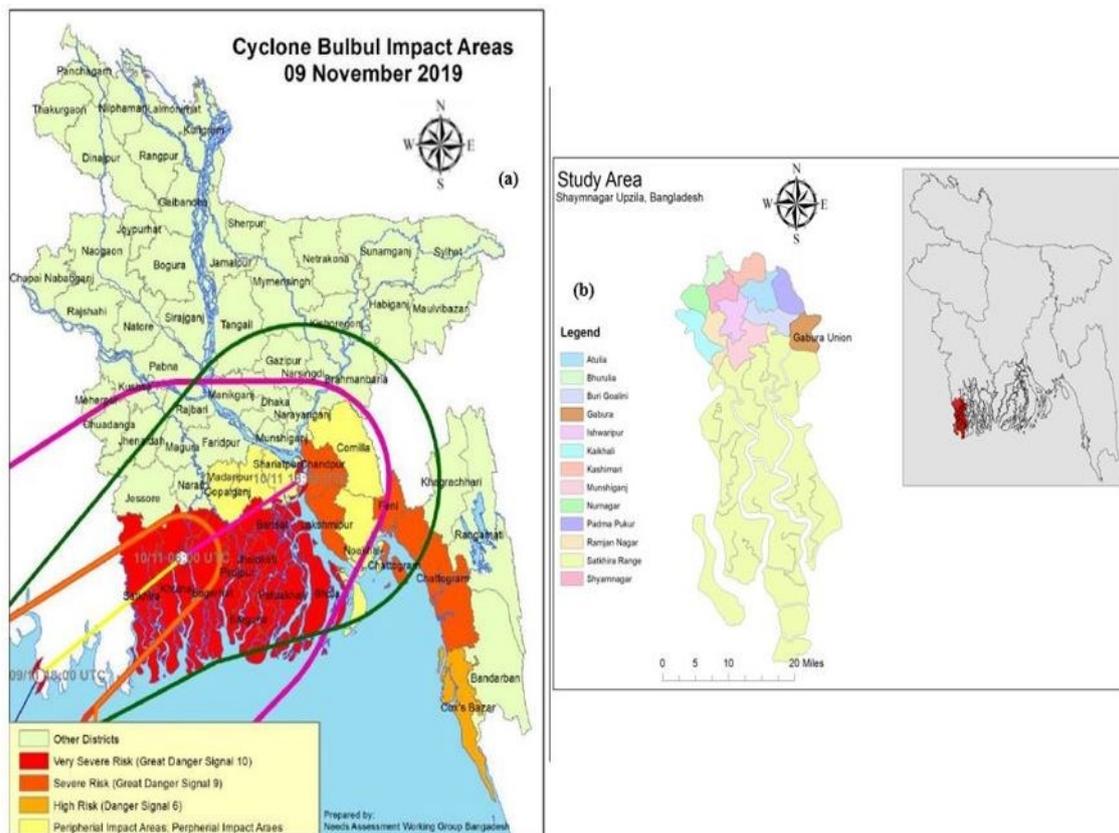
41. N. Y. Yun, F. Nakai, K. Yamori and M. Hatayama, "Tsunami evacuation behavior of coastal residents in Kochi Prefecture during the 2014 Iyonada Earthquake," *Geosci.*, vol. 37, no. 1, pp. 35–47, 2017.
42. N. Y. Yun and M. Hamada, "A Study on Evacuation Behaviors in the 2011 Great Japan Earthquake," 15th World Conf. Earthq. Eng., 2012.
43. J. Levinson, and H. Granot, "Transportation Disaster Response Handbook", Academic Press, an Elsevier Science Imprint, USA, 2002.
44. D. Lee, S. Yoon, E. S. Park, Y. Kim, and D. K. Yoon, "Factors contributing to disaster evacuation: The case of South Korea," *Sustain.*, vol. 10, no. 10, pp. 1–16, 2018.
45. S. K. Smith and C. Mccarty, "Fleeing the storm(s): An examination of evacuation behavior during florida's 2004 hurricane season," *Demography*, vol. 46, no. 1, pp. 127–145, 2009.
46. D. P. Eisenman, K. M. Cordasco, S. Asch, J. F. Golden, and D. Glik, "Disaster planning and risk communication with vulnerable communities: lessons from Hurricane Katrina," *Am. J. Public Health*, vol. 97 Suppl 1, 2007.
47. H. W. Fischer, G. F. Stine, B. L. Stoker, M. L. Trowbridge, and E. M. Drain, "Evacuation behaviour: Why do some evacuate, while others do not? A case study of the Ephrata, Pennsylvania (USA) evacuation," *Disaster Prev. Manag. An Int. J.*, vol. 4, no. 4, pp. 30–36, 1995.
48. F. Makinoshima, F. Imamura, and Y. Oishi, "Tsunami evacuation processes based on human behaviour in past earthquakes and tsunamis: A literature review," *Prog. Disaster Sci.*, vol. 7, p. 100113, 2020.
49. S. Ohtomo, R. Kimura, Y. Kawata, and K. Tamura, "The determinants of residents' evacuation behavior in the torrential rain in Western Japan in 2018: Examination of survey data of victims in Okayama prefecture," *J. Disaster Res.*, vol. 15, no. 7, pp. 1011–1024, 2020.
50. J. K. Lazo, A. Bostrom, R. E. Morss, J. L. Demuth, and H. Lazrus, "Factors Affecting Hurricane Evacuation Intentions", *Risk Anal.* 35(10):1837-1857, 2015.
51. B. K. Paul, "Hazard Warnings and Compliance with Evacuation Orders: The Case of Bangladesh's Cyclone Sidr. The Natural Hazards Center", University of Colorado at Boulder, Quick Response Report, 2008.
52. I. Matsuda, "Loss of Human Lives Induced by the Cyclone of 29-30 April, 1991 in Bangladesh", *Geo Journal*, V. 31, no 4, pp. 319-325, 1993.

53. N. Leelawat, C. M. R. Mateo, S. M. Gaspay, A. Suppasri, and F. Imamura, "Filipinos' views on the disaster information for the 2013 Super Typhoon Haiyan in the Philippines", *Int. J. Sustain. Future Hum. Sec. J. Sustain.* 2 (2), 16–28, 2014.
54. A. M. F. Lagmay, R. P. Agaton, M. A. C. Bahala, J. B. L. T. Briones, K. M. C. Cabacaba, C. V. C. Caro, L. L. Dasallas, L. A. L. Gonzalo, C. N. Ladiero, J. P. Lapidez, M. T. F. Mungcal, J. V. R Puno, M. M. A. C. Ramos, J. Santiago, J. K. Suarez, and J. Tablazon, "Devastating storm surges of Typhoon Haiyan", *Int. J. Disaster Risk Reduct*, 11, 1–12, 2015.
55. Y. Jibiki, S. Kure, M. Kuri, and Y. Ono, "Analysis of early warning systems: The case of super-typhoon Haiyan," *International Journal of Disaster Risk Reduction*, 15, 24–28, 2016.
56. N. Dash, and H. Gladwin, "Evacuation decision making and behavioral responses: Individual and household," *Natural Hazards Review*, 8(3):69–77, 2007.
57. F. Zhang, R. E. Morss, J. A. Sippel, T. K. Beckman, N. C. Clements, N. L. Hampshire, J. N. Harvey, J. M. Hernandez, Z. C. Morgan, R. M. Mosier, S. Wang, and S. D. Winkley SD, "An in-person survey investigating public perceptions of and responses to Hurricane Rita forecasts along the Texas coast. *Weather and Forecasting*", 22:1177–1190, 2007.
58. R. E. Morss, J. L. Demuth, J. K. Lazo, K. Dickinson, H. Lazrus, and B. H. Morrow, "Understanding public hurricane evacuation decisions and responses to forecast and warning messages," *Weather Forecast* 31(2):395–417, 2016.
59. R. E. Morss, and M. H. Hayden, "Storm surge and "certain death": interviews with Texas coastal residents following Hurricane Ike", *Weather, Climate, and Society* 2(3):174–189, 2010.
60. H. C. Wu, M. K. Lindell, and C. Prater C, "Logistics of Hurricane evacuation in Hurricanes Katrina and Rita," *Transportation Research Part F*, 15(4), 445-461, 2012.

Chapter 3 Methodology

3.1 Study Area

Cyclone Bulbul made landfall in Parsegonj, West Bengal, India, on November 9, 2019, between 8:30 pm and 11:00 pm, and hit Bangladesh on November 10, 2019, at around 1:00 am local time. The study area was Shyamnagar Upazila, Satkhira District, in Khulna, Bangladesh. Shyamnagar is located at 22.3306°N and 89.1028°E. It has 46,592 households and a total area of 1968.24 km². It comprises 12 union parishads, 127 Mouzas, and 216 villages. Among these 12 unions, Gabura was selected for this study, as this union (**Figure 3.1**) was the most severely affected community during Cyclone Sidr (2007) and Cyclone Aila (2009), as well as the recent Cyclone Bulbul.



Cyclone Bulbul directly affected 13 districts in Bangladesh's coastal region. The cyclone highly affected the coastal area because of high winds and heavy rainfall. Cyclone Bulbul—categorized as a “Category 2” cyclone—had an average wind speed of 130–148 km/h around the circulation center and average precipitation of approximately 100–200 mm/h. The cyclone lasted for approximately one-and-a-half days in Bangladesh, making it one of the longest-lasting cyclones that the country had witnessed in the last 52 years [1]. A *Daily Sun* news report (2019) quoted Md Shah Kamal, senior secretary at the Ministry of Disaster Management and Relief, as saying that nearly 0.3 million vulnerable people from Bhola, Barguna, Patuakhali, Barishal, Pirojpur, Jhalakathi, Bagherhat, Khulna, and Satkhira and their offshore islands and chars (smaller islands) had been moved to cyclone shelters or other safer places by noon [2]. Bulbul was expected to damage over 250,000 hectares of croplands and 150 households in the 13 districts, with at least 25 people killed during or shortly after the storm. Among these 13 districts, Barisal, Satkhira, and Khulna were reportedly the worst affected. In Satkhira, 25,000 hectares of paddy crops were fully or partially damaged, while 2,000 hectares of vegetables, betel leaf, mustard, and plums were destroyed [3].

3.2 Data Collection

In this study, qualitative and quantitative approaches were applied to achieve its objectives. A field survey was conducted between mid-February and mid-March 2020, three months after Cyclone Bulbul made landfall on November 10, 2019 (local time around 1:00 am in the targeted area), in Gabura Union of Shyamnagar Upazila in the Satkhira district of Bangladesh. According to Figure 3.2, a community-level structured questionnaire was used for the quantitative approach to conduct surveys in Gabura Union to understand people’s perceptions about early evacuation possibilities and emergency evacuation. This type of questionnaire survey of the affected community made it possible to comprehend evacuation behavior and identify the factors influencing early evacuation decisions. The questionnaire comprised different variables related to people’s perceptions about and the possibility of early evacuation, preparation, emergency response, evacuation order, and early evacuation decision-making issues. First, the author collected all household information from the local government office, such as house numbers. The primary data were collected via personal visits to the field from community members in the designated area using random sampling based on house numbers. If the randomly selected household respondents were absent

during the survey, the household respondents were interviewed later. Although we mentioned 413 households, each household's response to the questionnaire had one household head representative. Here, household respondents are the household heads responsible for household decision-making. Primary data were collected using questionnaires targeting 413 households from 1,971 households in one union in three wards or villages in the study area, most affected by cyclone Bulbul 2019. According to government representatives, these three wards are recognized as hard-to-reach areas, and internal communication is not good.

People face difficulties accessing social service facilities during the rainy season and disasters. The questionnaire comprised three sections and a total of 38 questions. The questionnaire sections used were 1. Early preparedness and warning for Cyclone Bulbul, 2. Evacuation decision, preparation time, and scenario information during Cyclone Bulbul and 3. General information about respondents and households before conducting the survey. The author tested the validity of the questionnaire through dummy data collection with several households and then modified the questionnaire again for the survey. For data collection, one college teacher and two former NGO members went to individual households to gather responses according to the questionnaire. The author also joined alternatively with each selected person during data collection. It took approximately 20 to 30 minutes to complete the questionnaire responses for each household. The original questionnaire survey was drafted in English and distributed in the selected area after being translated into Bengali.

The qualitative research approach was based on a literature review and the collected survey data analysis. The qualitative research approach focused on distinct threats, challenges, and problems prevalent in the early evacuation context. It also determined the relevant consequences for evacuees when they considered the possibility of early evacuation. To obtain precise information about particular problems and challenges, this study conducted interviews with four people to obtain qualitative data. People were selected based on their knowledge and involvement with the evacuation process during emergencies. The objective of each interview was to obtain information about each person's judgment about the evacuation process during a disaster. However, the interviews did not precisely follow the strict list of questions. Among the four persons, there was a chairman (head of the union) and a member (head of one ward in the union) local government representative, a college teacher, and a CPP unit team leader, respectively. The interview

with the chairman and CPP unit team leader took place at the local government office, while interviews with members and college teachers took place at community meetings.

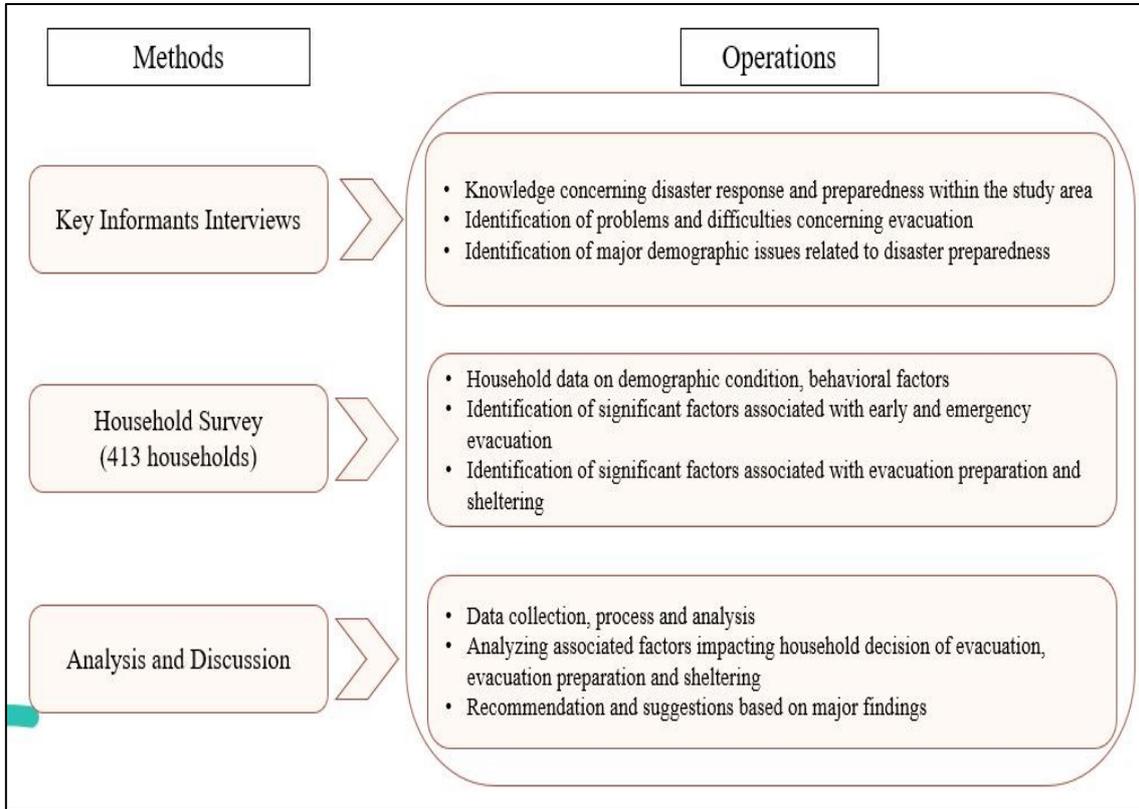


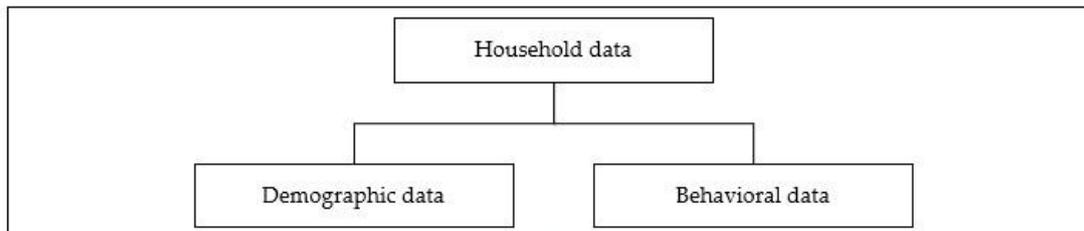
Figure 3.2 Data collection procedure and methods

By analyzing the results through descriptive statistics, this study examined the relationships among different variables, such as reasons for non-evacuation, preparation type and time, evacuation companions, livestock, evacuation mode, route selection, travel time from home to shelter, distance, and demographic characteristics to determine how they influenced early evacuation and evacuation decisions. Furthermore, the study analyzed factors that affected evacuation completion during Cyclone Bulbul based on the starting time of evacuation and the travel time to shelters for each household. In addition, the data were collected based on household demographic and behavioral and household evacuation preparation data and further analyzed to predict household evacuation time, focusing on future disasters. Finally, the questionnaire also comprised questions related to household departure time, house distance to shelter, evacuation travel time, the decision of evacuation shelter, types of shelter evacuated, time to stay at the shelter after evacuation, and demographic characteristics of each household and respondents.

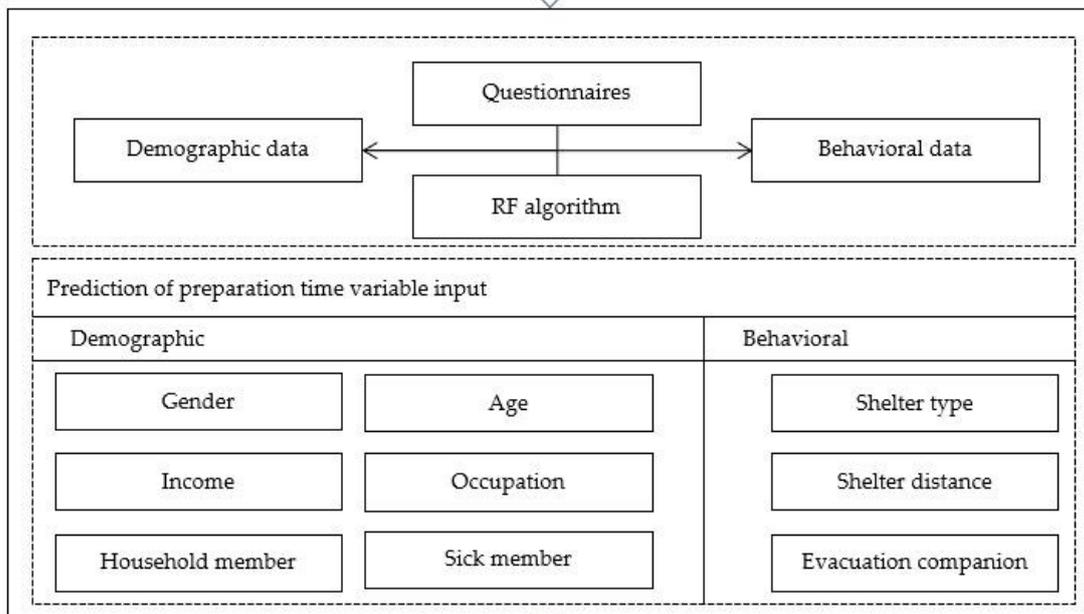
3.3 Prediction of Preparation Time Simulation

This research collected data from a questionnaire survey on preparations for Cyclone Bulbul for an evacuation preparation time simulation. **Figure 3.3** shows the framework of the proposed methodology for the preparation time simulation during a cyclone. This framework is based on the principles of RF (shown in **Figure 3.3**), structured by data acquisition, processing, simulation of evacuation preparation time, and simulation results.

1. Data acquisition and processing



2. Simulation of evacuation preparation time



3. Simulation result

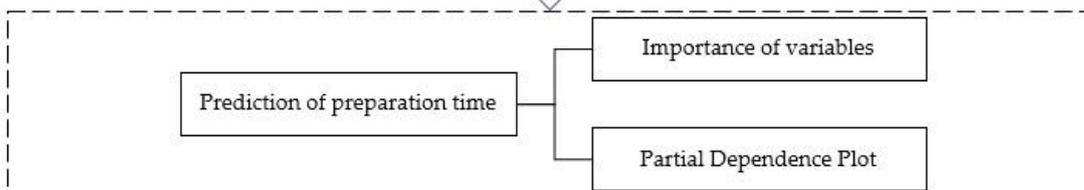


Figure 3.3 Framework of evacuation preparation time simulation methodology (adapted from Chen et al. 2019 [9])

In this study, the simulation model is based on household demographic and behavioral data to predict the evacuation preparation time. In addition, the demographic and behavioral data gathered by the questionnaire were used as input data for a mathematical model (Eq. 2), which was divided into training and test data. Based on Eqs. 2 and 3, the mathematical model analyzes the data to output the results reported in the results section of this study, which is interpreted to assess the simulation model.

3.3.1 Data Processing

The importance of the variables indicates the significance of each variable concerning its influence on the predicting variable. Two different approaches were used to assess the significance of factors using RF. One approach proposed by Breiman, called the out-of-bag (OBB) method, is used to analyze the individual variable prediction strength [4]. Another approach is splitting each variable and computing the mean decrease in node impurities considering the Gini index classification value. According to the Gini index classification, the values from highest to lowest reveal the importance of each individual factor over the predicting factor. In the OBB method, the importance of variables is measured as an average between the correct classification OBB rate and values of all trees that were replaced randomly. Each tree measured and ranked the Gini index classification, and each variable from the paired node was averaged across the trees. Thus, the Gini Index analysis better indicates the relative importance of variables and their significance over dependent variables [5]. This study uses the Gini index classification to evaluate the significance of factors and predict household evacuation preparation times.

3.3.2 Simulation of Evacuation Preparation Time

There are two types of simulation methods: one is through evacuation drills, and the other is computer-based simulation. This study conducts a household evacuation preparation time simulation using a computer-based simulation model. Based on warning dissemination, the household respondent's reaction and the start of evacuation can be used to identify individual household evacuation preparation times. Therefore, household respondents mentioned how much time they needed or took to prepare before starting the evacuation. After identifying all essential parameters of household data, an estimation of the preparation time simulation is conducted.

3.3.3 Random Forest

Random Forest is a high-accuracy prediction algorithm and a combination of trees proposed by Breiman. An RF is a classifier consisting of a collection of tree-structured classifiers $\{h(\mathbf{x}, \theta_k), k = 1, \dots\}$, where the $\{\theta_k\}$ is independent identically distributed random vectors, and each tree casts a unit vote for the most popular class at input \mathbf{x} [6]. The RF classifier method was used to construct different training datasets and finally fit the multiple classifier combination models to avoid the local maximum [7]. The RF algorithm model is used to calculate preparation time through computer-based simulation. The RF algorithm simulation for preparation time prediction uses questionnaire results of household demographic and behavioral data and secondary data from previous research. The following RF algorithm and steps were used to simulate the prediction result:

- 1) The bootstrap method was used to take samples for N times from the training set to generate N datasets after dividing the original dataset into training and test sets [8].
- 2) According to [9], N decision trees are constructed as classification models $\{h_1(\mathbf{x}), h_2(\mathbf{x}), \dots, h_N(\mathbf{x})\}$ to classify N datasets. For the nth tree, a random vector θ_n was generated. Under the condition of sufficient trees, $h_n(\mathbf{x}) = h(\mathbf{x}, \theta_n)$. A set of models that depend on the values of θ_n can be presented as follows:

$$h(\mathbf{x}, \theta_n), n = 1, 2, \dots, N \quad (1)$$

Where n is the nth tree, N is the number of trees, and θ_n is the random vector that is independently distributed with $\theta_1, \dots, \theta_{n-1}$ but with the same distribution. The N classification results are generated in this step.

- 3) Voting the N classification results and using the most frequently predicted class as the final output without pruning the decision trees. The voting decision is shown in Equation (2) [9]:

$$H(\mathbf{x}) = \underset{y \in Y}{\operatorname{argmax}} \sum_{n=1}^N I(h_n(\mathbf{x}) = y) \quad (2)$$

where $H(\mathbf{x})$ is an ensemble classification model, which represents the most frequently predicted class; $h_n(\mathbf{x}) = y$ is the prediction of the variable y using the nth tree with the variable x, and $I(\cdot)$ is the indicator function.

In a Random Forest, N decision trees train each subset of the original training set derived by bootstrapping the original dataset. Therefore, draw N decision trees (n_{tree})

bootstrap samples from the original dataset. Furthermore, it is possible that the input of each node from different trees can be different, which is the subset feature M (m_{try}) of the original set. At each node, instead of picking the best split predictors, the m_{try} is randomly selected the predictors which are considered as best split among all variables [7]. Finally, it counted majority votes to produce the output (**Figure 3.4**).

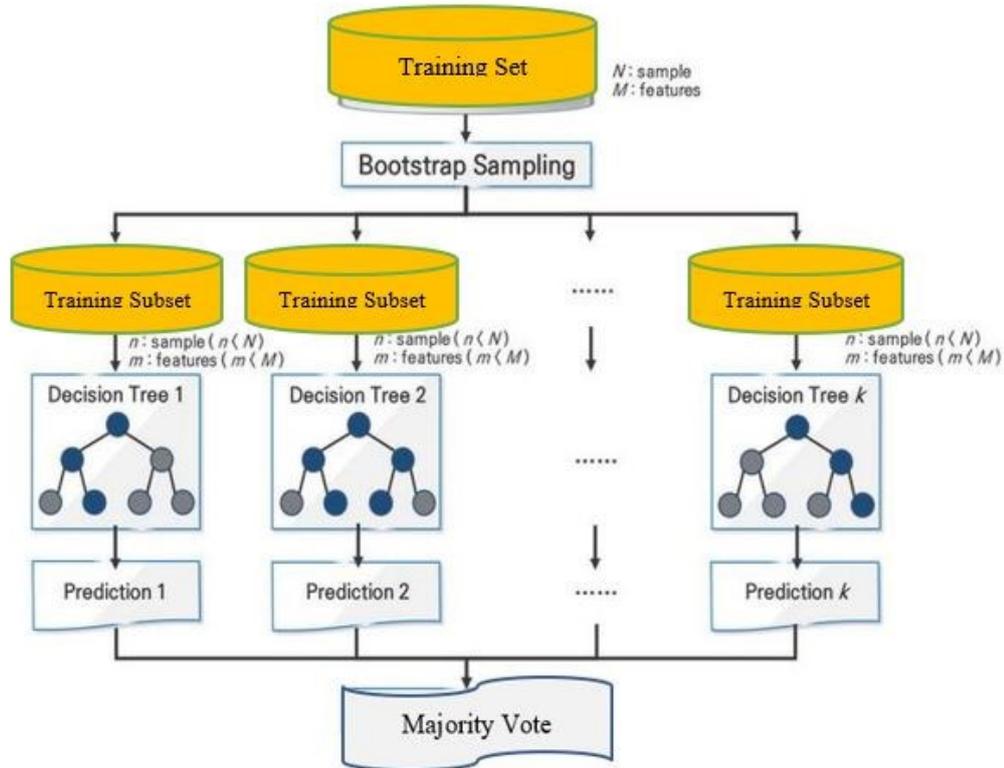


Figure 3.4 Random Forest classification principle

3.3.4 Prediction of Preparation time Simulation Input Variable

During cyclone Bulbul, individual household respondents were asked about their evacuation preparation time before evacuating. They were also asked about different demographic and behavioral factors that are important for early evacuation, emergency evacuation, and household evacuation preparation time. This study used ten variables (demographic and behavioral) as input variables to predict household evacuation preparation time (**Table 3.1**).

Table 3.1 Input variables to predict evacuation preparation time concerning cyclone Bulbul

<i>Variable</i>	<i>Category response</i>
<i>Gender</i>	0=Male, 1=Female
<i>Age</i>	Actual age of the respondent
<i>Income</i>	Actual household monthly income in Bangladeshi Taka (BDT)
<i>Occupation</i>	0=Housewife, 1=Day laborer, 2=Job, 3=Business, 4=Retired, 5=Agriculture, 6=Mechanic, 7=Very Poor
<i>Household member</i>	Total number of members in the house
<i>Sick member in house</i>	0=No, 1=Yes
<i>Shelter type</i>	1=Govt. school, 2=Other Govt. buildings, 3=Rich people's houses, 4=Relative's house, 5=Mosque
<i>Shelter distance</i>	Actual distance of individual houses from shelters in meters
<i>Evacuation companion</i>	1=with children, older people, others, and relatives 2=with children, relatives, and others 3=with children, older people, and relatives 4=with children, older people, and persons with disabilities 5=with children and relatives, 6=with children and older people 7=with children and others 8=with children and persons with disabilities 9=with older people and relatives 10=with children 11=with relatives
<i>Preparation time</i>	Households' evacuation preparation time before start evacuation

To construct the prediction model, first data was gathered and processed, obtained through a questionnaire. After that, the answers to each individual question were then set as a binary value. **Table 3.2** shows how Random Forest classification works and finally generates the output results. Here, the first ten cases of households' input variable and output results presented followed the binary coding of Table 1.

Table 3.2 Example of input and output procedure of Random Forest

Sample No.	Input									Output
	Gender	Age	Income	Occupation	Household member	Sick member in the house	Shelter type	Shelter distance	Evacuation companion	Preparation time
1	1	34	4000	1	5	0	1	2000	5	2
2	0	48	8000	1	7	1	1	2000	11	6
3	1	55	3000	0	4	0	1	2000	5	1
4	0	28	9000	1	3	1	1	2000	11	2
5	0	53	6000	1	4	0	1	2000	6	2
6	0	70	6000	1	6	0	1	2000	6	2
7	0	53	6500	1	7	0	1	2000	6	2
8	0	37	6500	1	4	0	1	2000	6	2
9	0	78	5000	1	5	0	1	2000	6	2
10	0	38	3000	1	5	0	4	1500	7	3

3.3.5 Importance of Variables

The importance of the variables measures the significance of each variable concerning their influence on the predicting variable. There are two different approaches to assess the significance of factors using RF. One approach proposed by Breiman, called the out-of-bag (OBB) method, is used to analyze the individual variable prediction strength [6]. Another approach is splitting each variable and computing the mean decrease in node impurities considering the Gini Index Classification value. According to the Gini Index Classification, values from highest to lowest reveal the importance of each individual factor over the predicting factor. In the OBB method, variables' importance is measured as an average between correct classification OBB rate and values of all trees that are replaced randomly.

In comparison, the Gini Index Classification was measured and ranked by each tree and each variable from pair node, which is average across the trees. So, analysis through Gini Index presents better relative importance of variables and their significance over

dependent variables [10]. This study uses the Gini Index Classification to evaluate the significance of factors and predict household evacuation preparation time.

3.3.6 Partial Dependence Plot (PDP)

The Partial Dependence Plot (PDP) is one of the essential interpretational tools and models that can produce graphical relationships between input variables and the output predicted class probabilities [11]. Through the PDPs, it is useful to identify whether the relationship is positive or negative and non-linear. Moreover, PDP can measure the influence of a particular predictor variable over the response variable; therefore, the effects of other variables remain constant [12]. PDP shows the influence of a particular covariate on the response variable, while the impact of the rest of the covariates is averaged out. This is calculated as shown in equation (3), where X_s denotes the covariate for which the PDP is being calculated, x_{ic} denotes the other remaining covariates in the training dataset other than X_s , and N is the total number of records [11]:

$$f_s(X_s) = \frac{1}{N} \sum_{i=1}^N f(X_s, x_{ic}) \quad (3)$$

The PDP illustrates the marginal effect of X_s on the response variable of f_s , while the marginal influences of f_s and x_{ic} are accounted for [11].

3.4 References

1. J. Iqbal, Needs Assessment Working Group Bangladesh, "Cyclone Bulbul 2019, Joint Rapid Assessment," no. October, 2019. https://www.researchgate.net/publication/344951112_Cyclone_Bulbul_2019_Joint_Rapid_Assessment?channel=doi&linkId=5f9abb2a299bf1b53e4efad5&showFulltext=true
2. "Bulbul' hits coastal belt", 2019, The Daily Sun. <https://www.daily-sun.com/arcprint/details/437677/%E2%80%98Bulbul%E2%80%99-hits-coastal-belt/2019-11-10>.

3. "Cyclone Bulbul: Early estimates suggest extensive damage," 2019 Dhaka Tribune. <https://www.dhakatribune.com/bangladesh/2019/11/12/cyclone-bulbul-early-estimates-suggest-extensive-damage>.
4. M. K. Lindell, J. H. Sorensen, E. J. Baker, and W. P. Lehman, "Community response to hurricane threat: Estimates of household evacuation preparation time distributions," *Transp. Res. Part D Transp. Environ.*, vol. 85, no. July, p. 102457, 2020.
5. M. A. Rahman, A. Hokugo, N. Ohtsu, and S. Chakma, "Evacuation Preparation Scenarios of Households during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh," *IDRiM J.*, 2021.
6. L. Breiman, "Random forests," *Random For.*, pp. 1-122, 2001.
7. L. Breiman, "Classification and Regression Trees," *Encycl. Ecol. Five-Volume Set*, vol. 2, no. October, pp. 582-588, 1984.
8. L. Breiman, "Bagging predictors," *Risks*, vol. 8, no. 3, pp. 1-26, 1996.
9. J. Chen, J. Yu, J. Wen, C. Zhang, Z. Yin, J. Wu, and S. Yao, "Pre-evacuation time estimation based emergency evacuation simulation in urban residential communities," *Int. J. Environ. Res. Public Health*, vol. 16, no. 23, 2019.
10. C. C. M. Chen, H. Schwender, J. Keith, R. Nunkesser, K. Mengersen, and P. MacRossan, "Methods for identifying SNP interactions: A review on variations of logic regression, Random Forest and bayesian logistic regression," *IEEE/ACM Trans. Comput. Biol. Bioinforma.*, vol. 8, no. 6, pp. 1580-1591, 2011.
11. J. H. Friedman, "1999 Reitz Lecture," *Statistics (Ber.)*, vol. 29, no. 5, pp. 1189-1232, 2001.
12. R. Nateghi, S. Guikema, and S. M. Quiring, "Power Outage Estimation for Tropical Cyclones: Improved Accuracy with Simpler Models," *Risk Anal.*, vol. 34, no. 6, pp. 1069-1078, 2014.

Chapter 4 Household Evacuation Preparation Scenarios during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh

4.1 Introduction

In this chapter, the researcher has illustrated the efforts to present the importance of households' evacuation preparation time before starting evacuation. The relationship of household evacuation preparation time and decision of evacuation strongly correlated with each other concerning safe and successful evacuation. In addition, early evacuation is a key important factor of evacuation decision which ensures evacuees' safe and complete evacuation to shelter or safer place during a disaster. This research investigated the possibility of early evacuation based on the individual household starting time of evacuation and key influential factors that affect evacuation decisions. Furthermore, this research also analyzed data to present the difficulties households face during emergency evacuation and specific reasons for their non-evacuation.

4.2 Cyclone Primary Stage/ Warning Stage

The cyclone warning stage, occurring between 10 hours and 36 hours before the predicted landfall of a cyclone, defines the cyclone primary stage. When people receive the first warning signal, they consider or start making evacuation plans. They begin preparations for evacuation and plan when to evacuate. All survey respondents said they received a warning about Cyclone Bulbul.

Table 4.1 Receipt of primary warning signal during Cyclone Bulbul

Gender	Yes (%)	No (%)	Total (%)
Male	324 (100)	0 (0)	324 (100)
Female	89 (100)	0 (0)	89 (100)
Total	413 (100)	0 (0)	413 (100)

The questionnaire survey revealed that all respondents (100%), both men and women, received the prior warning signal (**Table 4.1**). The results confirmed the success of local and national authorities in disseminating the prior warning, but the communication did not happen simultaneously in the same area.

4.3 Reasons for Non-evacuation During Cyclone Bulbul

There are different reasons why respondents did not evacuate during Cyclone Bulbul. Of the 413 respondents, 185 did not evacuate during Cyclone Bulbul, with these respondents citing 16 reasons for not evacuating. Among the reasons mentioned, the main reasons for non-evacuation varied for men and women.

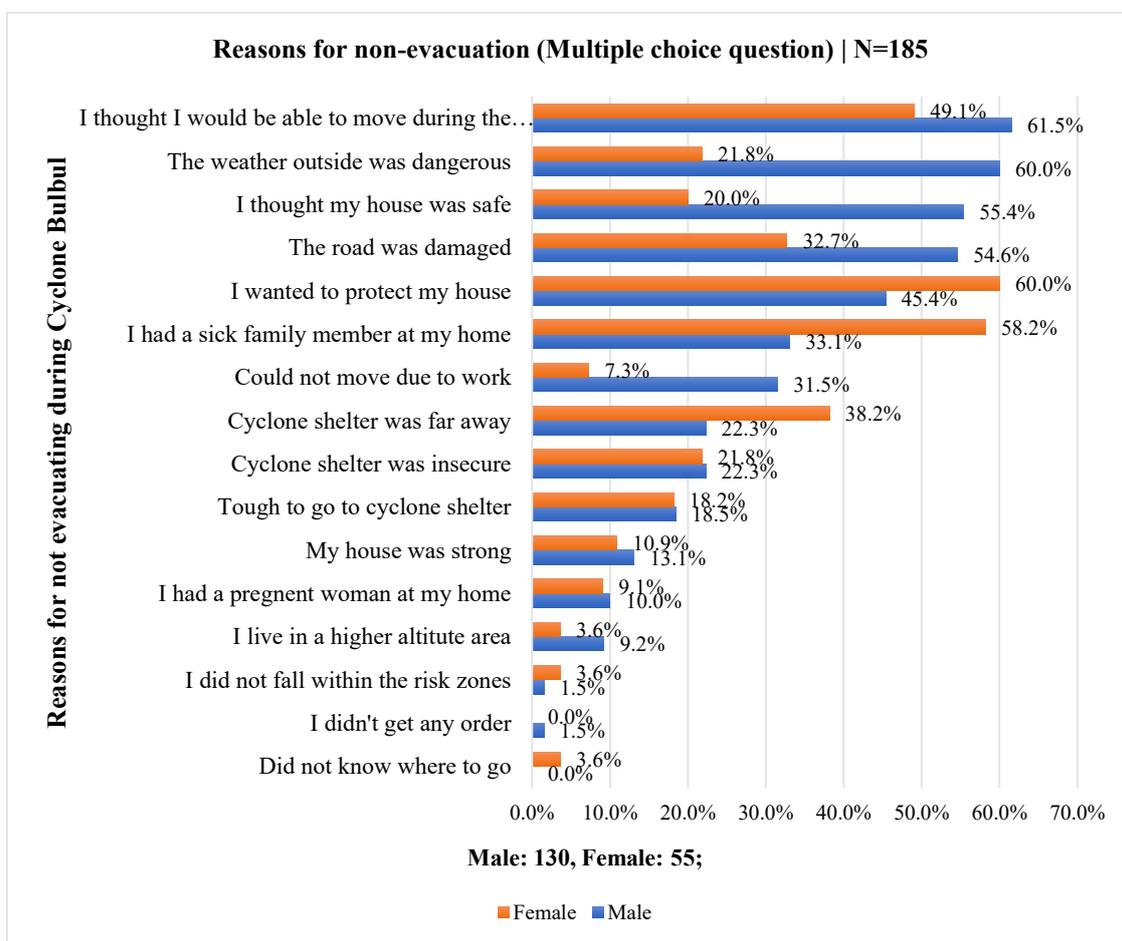


Figure 4.1 Reasons for non-evacuation during Cyclone Bulbul

As shown in **Figure 4.1**, male respondents had five main reasons, with 61.5% of respondents saying, “I thought I would be able to move during the cyclone,” followed by

60% who said, “the weather outside was dangerous.” Approximately 55% of respondents said they could not move because the road was damaged, 45% said they wanted to protect their home by not evacuating, and 55% reported feeling that their house was safe to stay. Although the percentages were not very high, the presence of a sick member in the house (33%), work (31.5%), a distance of the cyclone shelter from home (22%), and unsafe cyclone shelters (22%) were also cited as reasons for not evacuating.

Female respondents cited four main reasons, as shown in **Figure 4.1** Sixty percent of the respondents said, “I wanted to protect my house,” followed by 58% who claimed that they had a sick member in the house, which is not surprising as women are usually responsible for taking care of family members. Like male respondents, around 49% of female respondents said, “I thought I would be able to move during the cyclone.” Furthermore, around 38% of respondents mentioned that the shelter was far away, and 33% said the road was damaged, making it difficult to go to cyclone shelters. Although the percentages were not very high, the dangerous weather outside (22%), unsafe cyclone shelters (22%), and their belief that their house was safe to stay in (20%) were also cited as reasons for not evacuating.

4.4 Previous Disaster Experience

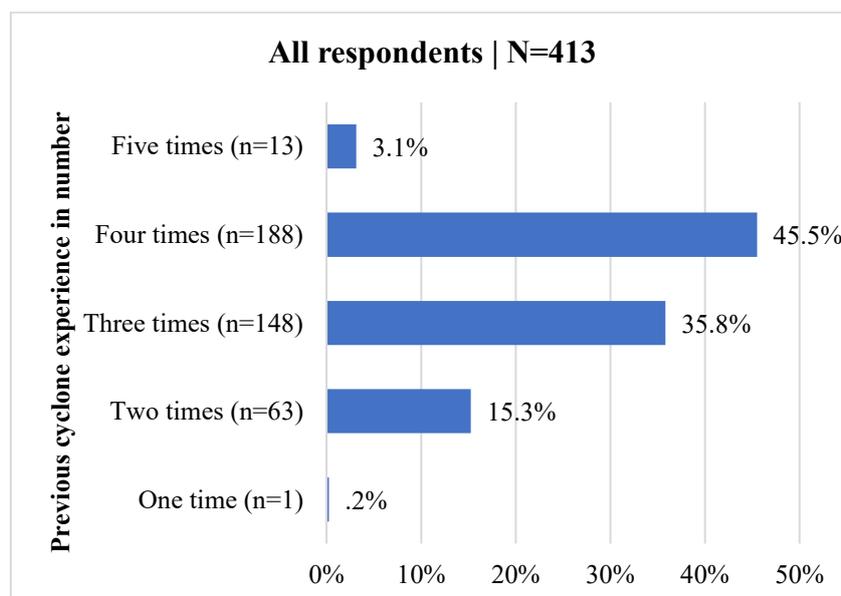


Figure 4.2 Respondents’ previous cyclone experience before Cyclone Bulbul

Previous disaster experience is an essential factor in making more effective decisions during future emergencies. **Figure 4.2** shows people’s past experiences of a super-cyclone before Cyclone Bulbul. The survey results showed that of the 413 respondents, 188 (45.5%) had experienced a cyclone four times in the past, followed by 148 respondents (35.8%) who had experienced a cyclonic disaster three times, and 63 respondents (15.3%) had experienced a cyclone twice. Thirteen respondents (3.1%) had experienced a cyclone five times, and one respondent had experienced a cyclone once in the past.

4.5 Evacuation During Cyclone Bulbul

In Bangladesh, males are generally the head of the household and make household decisions. Those households representing female respondents mean that they are divorced, widowed, or the male stays outside the village due to work or other reasons. Thus, those females are now responsible for taking care of households and households’ decisions on different issues. **Table 4.2** shows the percentage of respondents who evacuated during Cyclone Bulbul by gender. Of the 324 male respondents, 194 (59.9%) said they had evacuated. Only 34 of the 89 female respondents (38.2 percent) said they had evacuated. The evacuation rate is lower among women than men because the latter is usually the head of the household and responsible for making decisions and executing them, while women are more likely to be involved in caring for family members and managing household activities.

Table 4.2 Evacuation during Cyclone Bulbul

Gender	Yes (%)	No (%)	Total (%)
Male	194 (59.9)	130 (40.1)	324 (100)
Female	34 (38.2)	55 (61.8)	89 (100)
Total (%)	228 (55.2)	185 (44.8)	413 (100)

4.6 Evacuation Preparation and Preparation Time

People prepare for evacuation after receiving a cyclone warning by organizing things they will need before or just after the cyclone makes landfall. According to Parvin et al. (2019), the preparation process from the time of receipt of warning to cyclone landfall and the prioritization of activities ahead of evacuation vary from person to person depending on individual considerations. Most people prioritize organizing emergency goods that they would need at the shelter. They also consider the safety of domestic animals and want to bring their animals along with them when evacuating to shelters or other safer places. Thus, evacuation preparation and preparation time depend on people's perceptions of the type of preparation needed for either emergency evacuation or early evacuation [1].

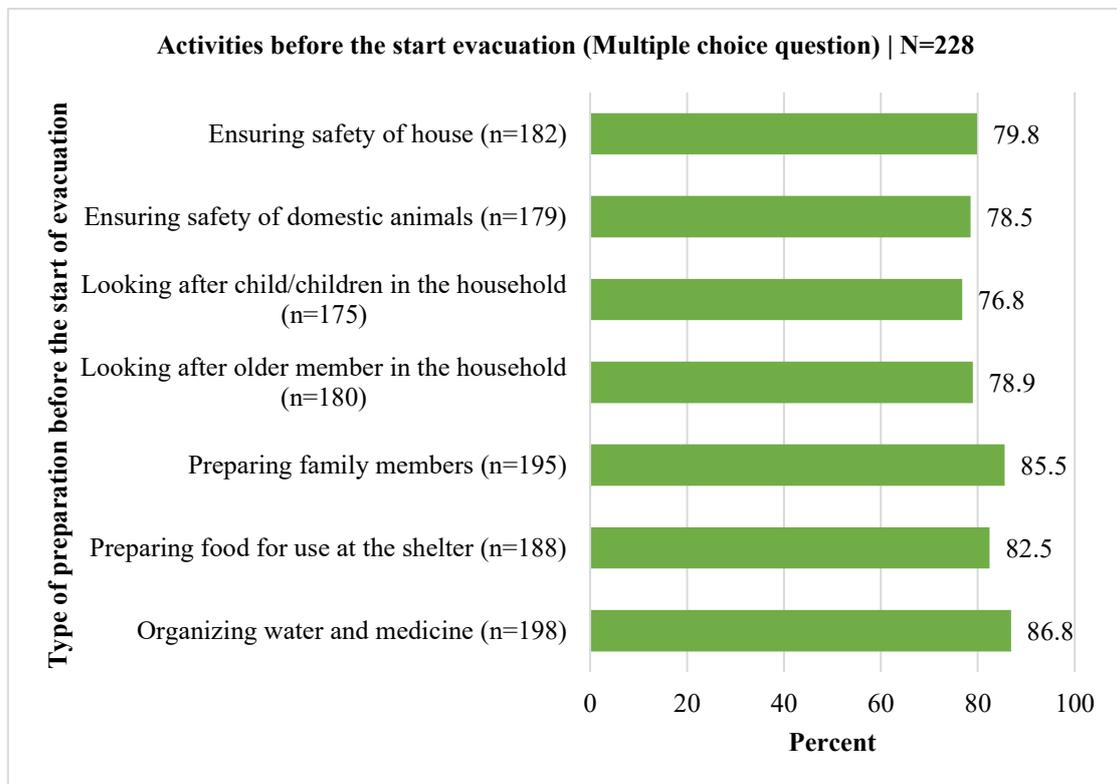


Figure 4.3 Respondents' activities before the start of the evacuation

People were involved in various activities before the start of the evacuation during Cyclone Bulbul, and they believed that all of those activities were important. As shown in **Figure 4.3**, people prioritized activities such as organizing drinking water and medicine (87%), preparing all family members (85.5%), and preparing food for use at the shelter (82.5%). They were also engaged in other similarly essential activities, such as ensuring the

safety of the house (80%) and attending to children (77%) and older members (79%) who needed special care before evacuation. Therefore, if there are children or older members in the house, a longer preparation time is required for evacuation.

Figure 4.4 shows the respondents' responses regarding individual household preparation time before the evacuation commencement during Cyclone Bulbul. Most respondents (73%) said their preparation time ahead of evacuation was 2 hours. Very few respondents (18%) said they only took one hour, while about 9% of the respondents took between 3 and 6 hours to prepare for evacuation.

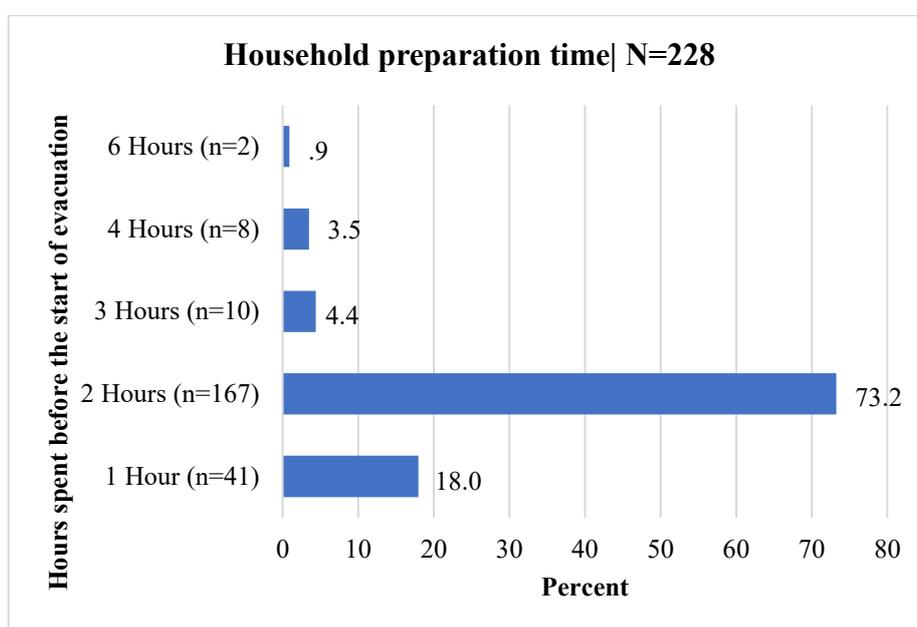


Figure 4.4 Household preparation time before the start of evacuation during Cyclone Bulbul

4.7 Early Evacuation Decision During Cyclone Bulbul

Table 4.3 shows the percentage of respondents who made an early evacuation decision during Cyclone Bulbul by gender. Of the 324 male respondents, 171 (52.8%) decided to evacuate early, while only 23 (25.8%) of the 89 female respondents made an early evacuation decision.

Table 4.3 Early evacuation decision during Cyclone Bulbul

Gender	Yes (%)	No (%)	Total (%)
Male	171 (52.8)	153 (47.2)	324 (100)
Female	23 (25.8)	66 (74.2)	89 (100)
Total (%)	194 (47.0)	219 (53.0)	413 (100)

4.8 Early Evacuation Based on Starting Time of Evacuation During Cyclone Bulbul

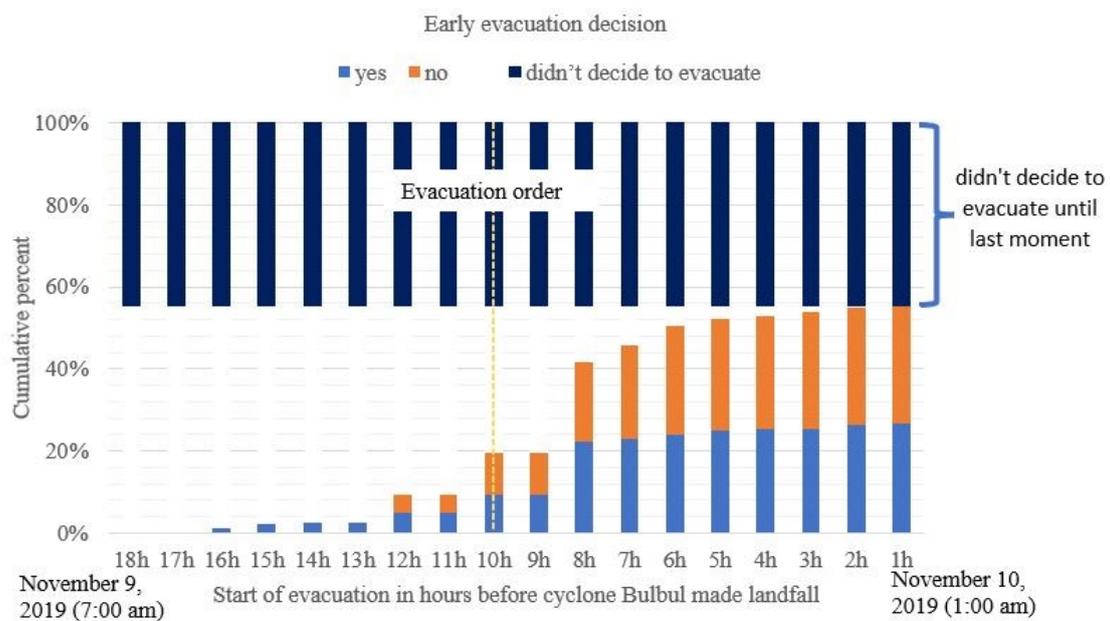


Figure 4.5 Relationship between early evacuation decision and starting time of the evacuation of individual households before Cyclone Bulbul made landfall

This research analyzed the target population’s starting time of evacuation from their house based on the time Cyclone Bulbul made landfall on November 10, 2019 (local time 1:00 am in the targeted area). The starting time of evacuation before cyclone landfall depended on various factors associated with household characteristics, risk perception, and the overall situation. As seen in **Figure 4.5**, the resulting cumulative distribution graph confirms that most began evacuating 8 to 12 hours before landfall among the respondents

who evacuated during Cyclone Bulbul. Approximately 40% of household respondents started their evacuation 8 h before landfall—categorized as emergency evacuation. Around 33% started evacuating 10 to 18 hours before landfall—classified as early evacuation. Only 20% started their evacuation 1 to 7 h before the cyclone made landfall.

4.9 Factors Prompting Early Evacuation Decision and Early Evacuation

This research analyzed the factors that influenced early evacuation decisions and actual early evacuation during Cyclone Bulbul and the relationship between those factors and the actual evacuation commencement.

4.9.1 Factors Prompting Early Evacuation Decision during Cyclone Bulbul

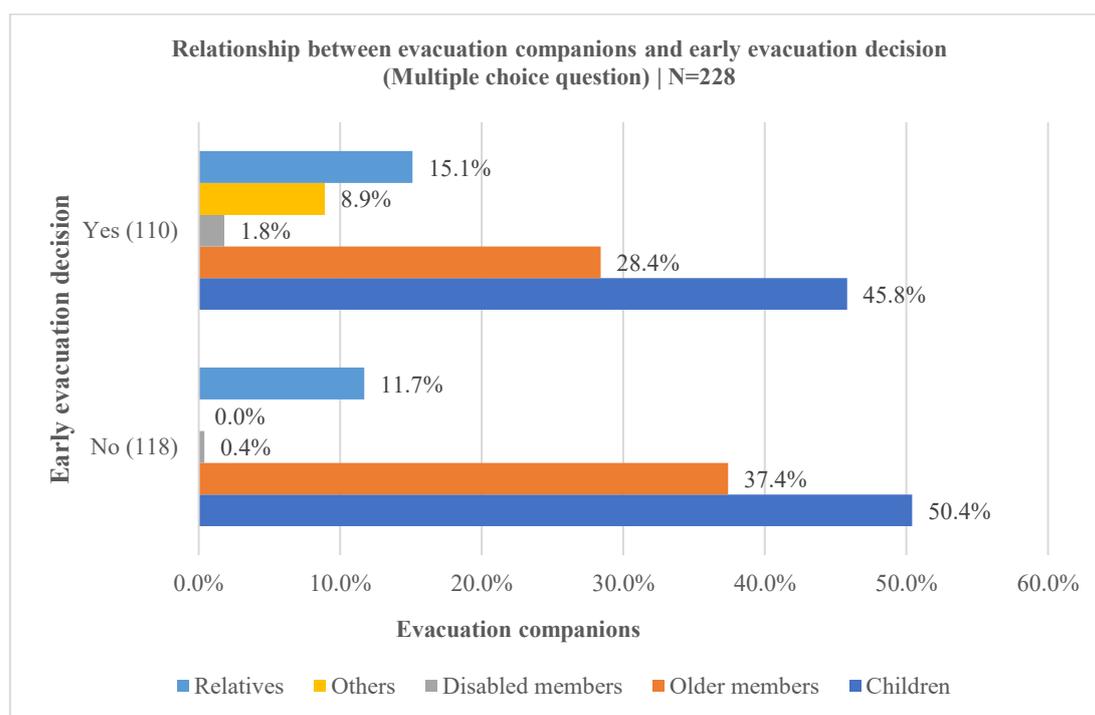


Figure 4.6 Relationship between evacuation companions and early evacuation decision during Cyclone Bulbul

As part of the questionnaire survey, respondents were asked whether they evacuated family members individually or together, with 100% saying they evacuated all members together, showing great concern for the family during a disaster. Here, the household members are categorized as relatives, disabled members, older members, and others.

Notably, disabled members are those who cannot move alone and therefore need assistance from other members during evacuation. While categorizing others, they mention their neighbors or surrounding households who are not well-known to each other. **Figure 4.6** reveals the relationship between evacuation companions and early evacuation decisions during Cyclone Bulbul. The survey results indicated a significant correlation between evacuation companions and early evacuation decisions. Approximately 46% and 28% of respondents with children and older members in their household, respectively, decided to evacuate early. Conversely, around 50% and 37% of respondents with children and older members in their household, respectively, did not make early evacuation decisions.

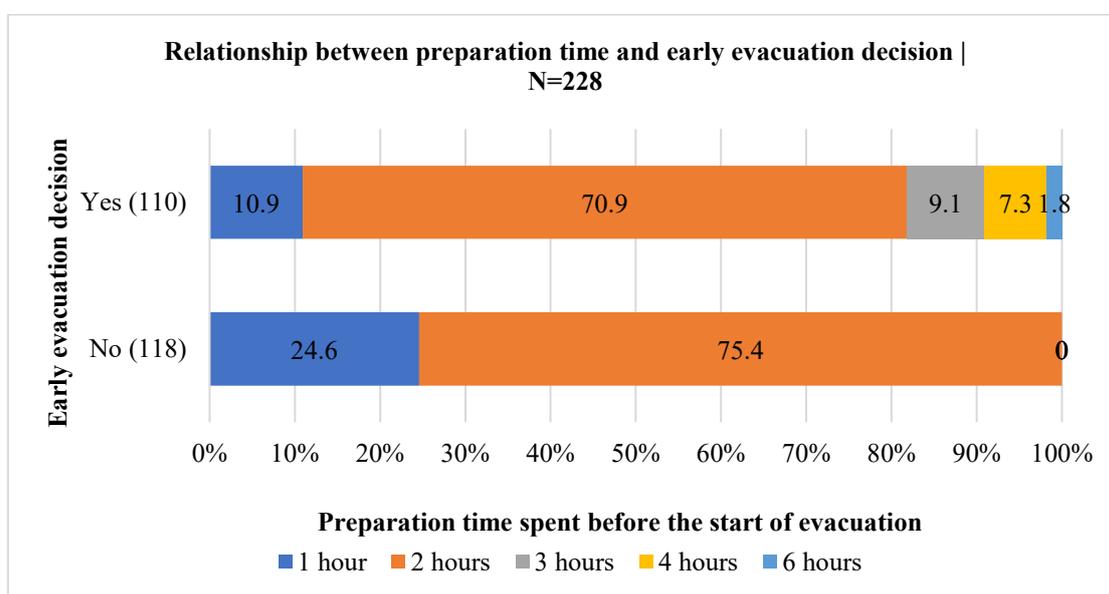


Figure 4.7 Relationship between preparation time before evacuation and early evacuation decision during Cyclone Bulbul

Respondents were asked about their preparation time before evacuation to determine the relationship between preparation time and early evacuation decisions. **Figure 4.7** illustrates that around 71% took 2 hours as preparation time among respondents who made an early evacuation decision, while around 11%, 9%, and 7% took 1 h, 3 h, and 4 h, respectively before evacuation. Conversely, among those who did not make an early evacuation decision, the majority (75%) took two hours, while only around 25% took one hour.

Table 4.4 Factors prompting early evacuation decision during Cyclone Bulbul

		Early evacuation decision during Cyclone Bulbul					
		Yes		No		Total	
Respondent gender P=.000*	Male	171	52.8%	153	47.2%	324	100.0%
	Female	23	25.8%	66	74.2%	89	100.0%
Age Group P=.632	18-40	77	46.1%	90	53.9%	167	100.0%
	41-60	85	48.6%	90	51.4%	175	100.0%
	>60	32	45.1%	39	54.9%	71	100.0%
Occupation Category P=.847	Housewife	7	36.8%	12	63.2%	19	100.0%
	Farmer/Daily Worker	174	47.2%	195	52.8%	369	100.0%
	Retired	4	66.7%	2	33.3%	6	100.0%
	Business/Job	9	47.4%	10	52.6%	19	100.0%
Income Group P=.000*	500-5000 BDT	180	52.9%	160	47.1%	340	100.0%
	>5000 BDT	14	19.2%	59	80.8%	73	100.0%
Household Size P=.663	<=5	138	46.3%	160	53.7%	298	100.0%
	>5	56	48.7%	59	51.3%	115	100.0%
Sick Member P=.000*	No	168	53.8%	144	46.2%	312	100%
	Yes	26	25.7%	75	74.3%	101	100%
Shelter Distance Group P=.000*	100-1000 m	68	40.2%	101	59.8%	169	100.0%
	>1000 m	42	71.2%	17	28.8%	59	100.0%
Travel Time to Shelter P=.000*	2-30 min	50	35.7%	90	64.3%	140	100.0%
	31-60 min	59	72.0%	23	28.0%	82	100.0%
	>60 min	1	16.7%	5	83.3%	6	100.0%

* The chi-square test statistic is significant at the 0.05 level

This study also adopted demographic and socio-economic approaches to determine the relationship between factors that prompted an early evacuation response (based on people's perception) among the respondents during Cyclone Bulbul. Eight factors were considered in this study. **Table 4.4** shows that of the eight factors, four are demographic variables, namely respondent gender, age group, household size, and the presence of a sick member in the house. Only two of these four demographic variables, respondent gender and the presence of a sick member in the house, were found to have a significant correlation with early evacuation decisions. Approximately 53% of male respondents made early evacuation decisions. Then again, only around 26% of the female respondents made early evacuation decisions, indicating that women are less likely to be involved in the decision-making process and more likely to take care of family members during a disaster. A relatively high percentage of respondents with a sick member at home (approximately 74%) did not make an early evacuation decision, indicating that having a sick member in the house makes it difficult to evacuate because the travel time and shelter distance pose a significant challenge. Age group and household size had no significant influence on the early evacuation decisions.

Concerning the two socio-economic variables, occupation category and income group, occupation category had no significant correlation with early evacuation decisions. The survey results showed that most respondents in the study area were farmers or daily workers. All occupation category respondents indicated similar trends in early evacuation decisions. However, the income group significantly influenced the early evacuation decisions. Around 81% of the respondents whose income was higher than 5,000 BDT (around \$59) and about 47% of those whose income was less than 5,000 BDT did not make an early evacuation decision.

Table 4.4 also shows that the early evacuation decision rate was higher among respondents whose houses were far from shelters than those near shelters. This difference confirmed a significant correlation between the shelter distance and early evacuation decisions. Approximately 71% of respondents for whom the distance from their house to the shelter was over 1000 meters made an early evacuation decision. In contrast, the corresponding rate was around 40% for respondents for whom the distance was 100–1000 meters. Similarly, travel time to the shelter also showed a significant influence. According to the survey results, most respondents (140 out of 228) took less than 30 minutes to travel from home to the shelter suggesting the distance to the shelter was 100–1000 meters for

most of them. The evacuation decision rate was higher for those who took 31–60 min to evacuate at 72%. Conversely, the percentage was much lower among the other groups; six respondents (17%) took over 60 minutes to evacuate.

4.9.2 Factors Prompting Early Evacuation Based on Evacuation Starting Time during Cyclone Bulbul

According to the Bangladesh Meteorological Department (BMD), a cyclone evacuation order is given at the cyclone great-danger stage or 10 h before the cyclone landfall time. Based on this evacuation order time, this study divided respondents into two groups considering the actual time they began evacuation during Cyclone Bulbul. One group evacuated 10 hours or more before the cyclone made landfall, while the other group evacuated less than 10 hours before the cyclone made landfall. Respondents who evacuated 10 hours or more before landfall were categorized into the early evacuation group, and the other group was classified as the general or emergency evacuation group. **Table 4.5** shows the distribution of respondents based on the starting time of evacuation to a safer place during Cyclone Bulbul. The percentage of respondents who carried out emergency evacuation (147 of 228 [64.5%]) was higher than that of early evacuees (81 228 [35.5%]).

Table 4.5 Respondent category based on their actual evacuation starting time

Starting time of evacuation (before cyclone landfall)	Number	Percent
Less than 10 hours	147	64.5
10 hours or more	81	35.5
Number of evacuated people	228	100

Respondents were asked about the types of shelter that they evacuated during Cyclone Bulbul. **Figure 4.8** shows the relationship between the actual evacuation start time and shelter type chosen by the respondents. Among respondents who evacuated less than 10 hours before the cyclone made landfall, the majority (92.5%) chose a government school as

the designated cyclone shelter. In contrast, 3.4% and 2% chose other government buildings and rich people’s houses, respectively, as their evacuation places. The survey results revealed more variation in the choice of cyclone shelter when respondents carried out an early evacuation. Nearly 68% of the respondents chose a government school, around 25% chose other government buildings, and some 6% chose rich people’s houses as their evacuation place.

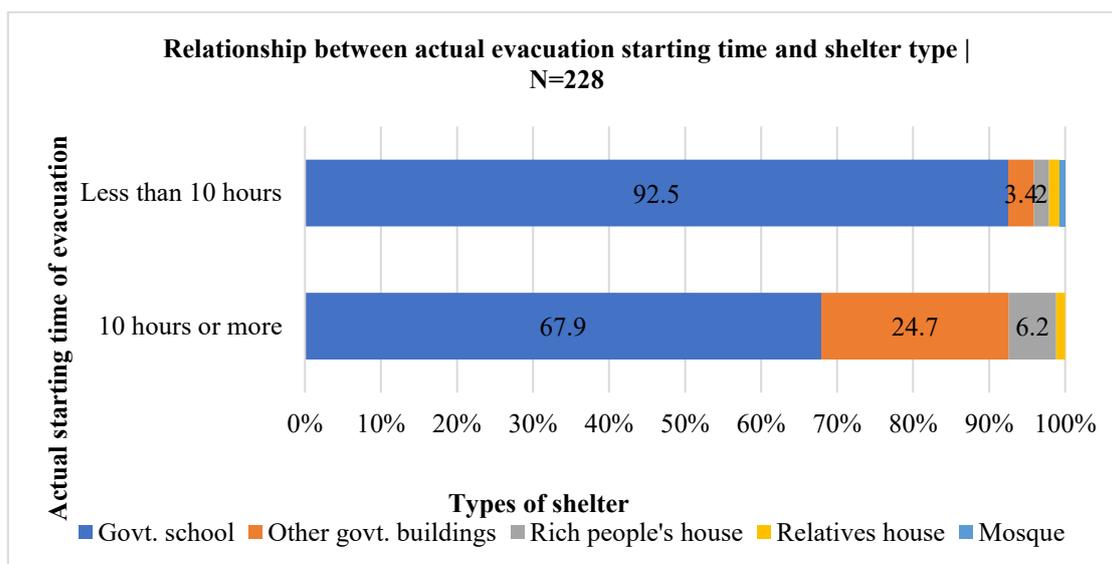


Figure 4.8 Relationship between the actual evacuation starting time and shelter type during cyclone Bulbul

Figure 4.9 shows the relationship between evacuation companions and early evacuation during Cyclone Bulbul. The results indicated a significant correlation between evacuation companions and early evacuation. Among respondents who did not evacuate early, around 49% said they evacuated with children, and 40% evacuated with older members. A significantly lower percentage of respondents evacuated with others and relatives at approximately 2.1% and 8.3%, respectively. Similarly, among respondents who carried out early evacuations, about 47% said they evacuated with children. A relatively lower percentage of respondents confirmed that they evacuated with older members, with others, and with relatives at around 21%, 8%, and 22%, respectively. Households with older members tend to evacuate early because they already know the consequences of evacuation, such as longer preparation times and longer travel times. Considering these difficulties, they are more likely to evacuate early for their safe and complete evacuation.

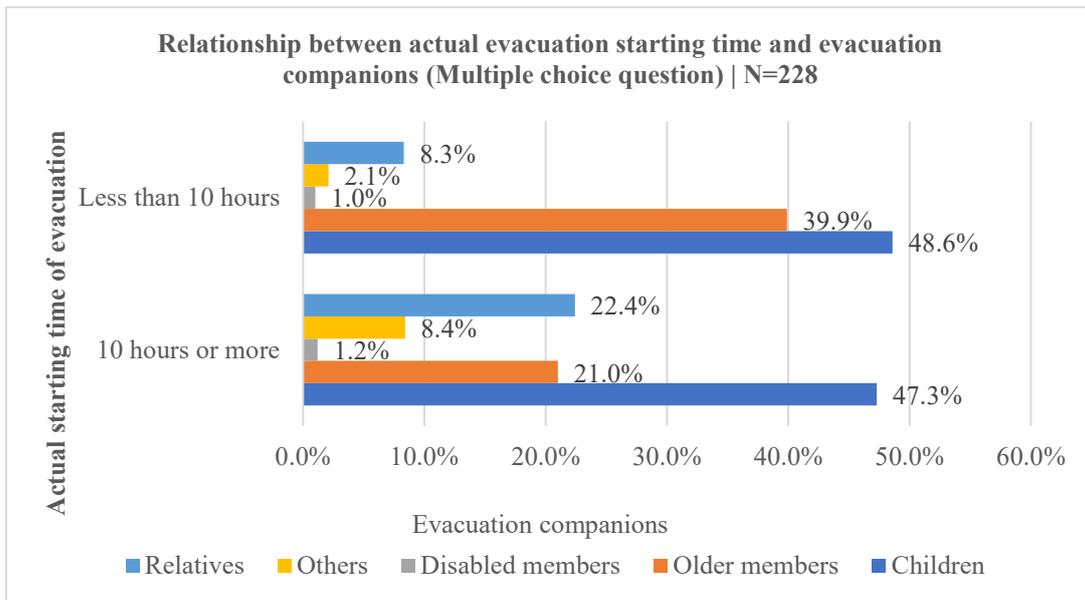


Figure 4.9 Relationship between the actual evacuation starting time and evacuation companion during Cyclone Bulbul

The survey results showed that only 24.5% of households had sick members at home. **Figure 4.10** shows that only around 12% said they had a sick member among respondents who did not evacuate early. In comparison, the percentage was much higher at about 32% among early evacuees during Cyclone Bulbul if sick members in the house were also intended to evacuate early because of longer preparation and travel times.

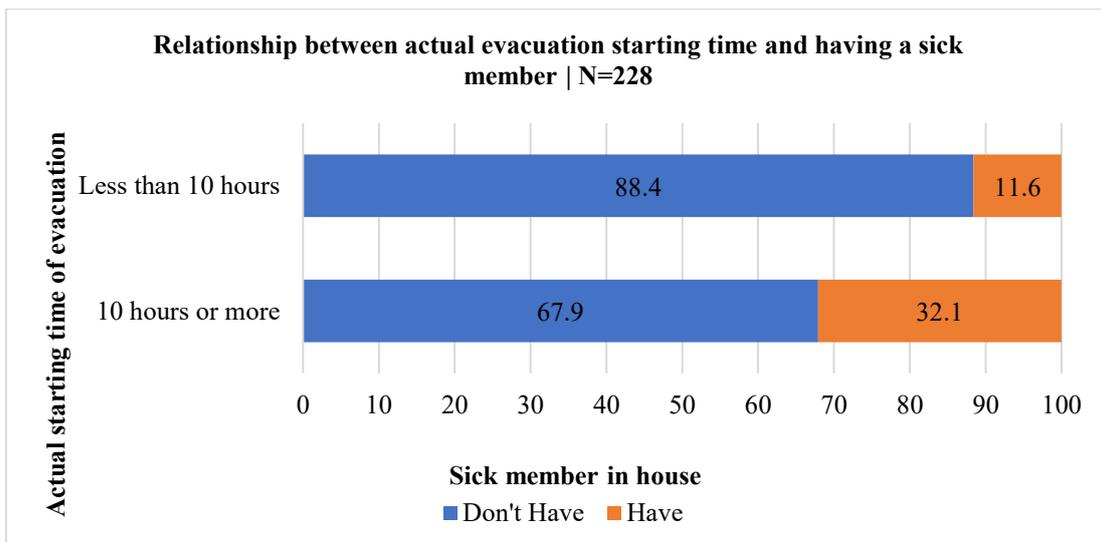


Figure 4.10 Relationship between actual evacuation starting time and having a sick member in the house

The travel time from home to shelter is also an essential factor influencing evacuation decisions. **Figure 4.11** suggests that most household respondents in both groups took 10–60 minutes of evacuation travel time. Among respondents who did not evacuate early, nearly 43% took 10 to 30 minutes, and 46% took 31 to 60 minutes in evacuation travel time. Among respondents who were early evacuees, the majority (73%) took 10 to 30 minutes, while only around 17% took 31 to 60 minutes in evacuation travel time during Cyclone Bulbul. For respondents in both groups, the distance from their house to the shelter was between 100 and 1000 m, explaining why they took a similar time even though the percentage differed.

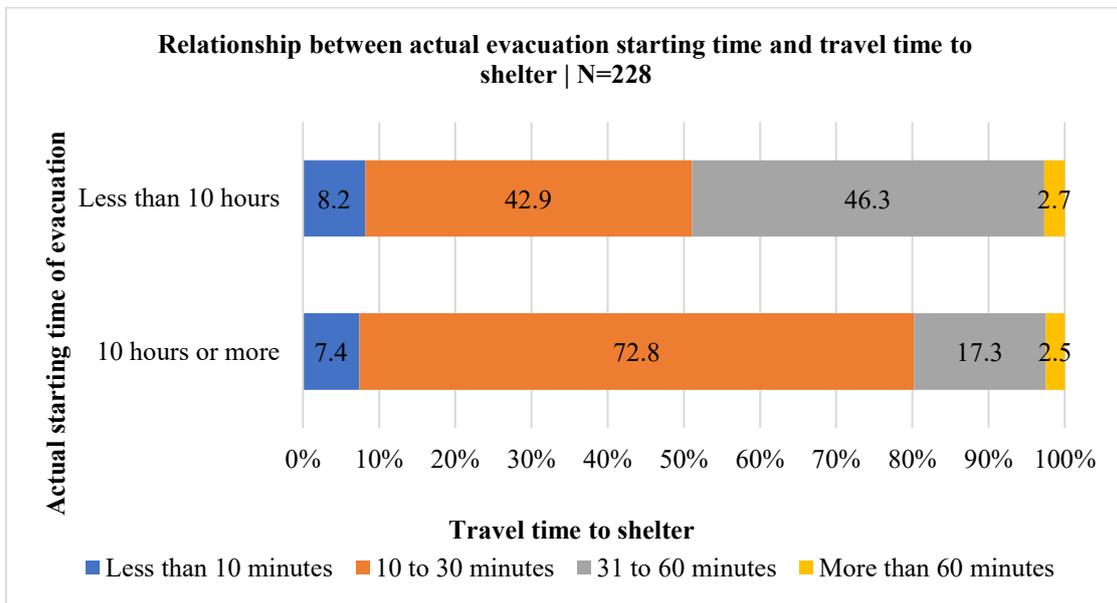


Figure 4.11 Relationship between actual evacuation starting time and travel time to shelter

Respondents were asked about their preparation time before starting the evacuation to determine the relationship between the preparation time and actual evacuation starting time. **Figure 4.12** shows that a little over half of the early evacuees (51%) took 2 h in preparation time, while approximately 28%, 11%, and 9% took 1 h, 3 h, and 4 h, respectively. Among those who did not evacuate early, the majority (86%) took two hours, while only around 12% took one hour. Earlier evacuation shows a variation in preparation time—ensuring sufficient time for preparation before starting evacuation.

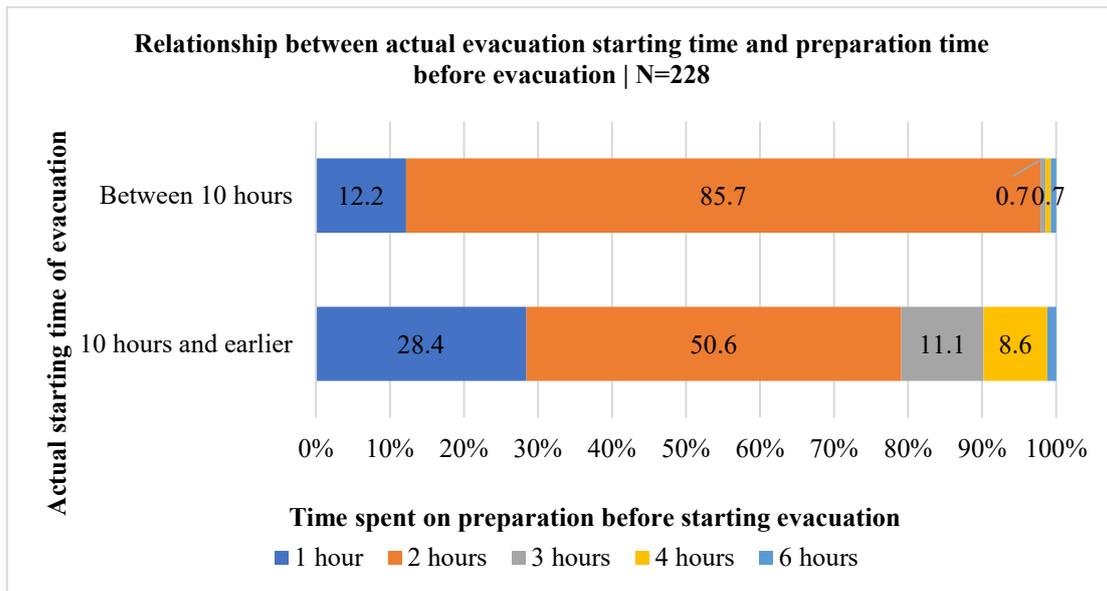


Figure 4.12 Relationship between actual evacuation starting time and preparation time

4.10 Factors Prompting Evacuation Response During Cyclone Bulbul

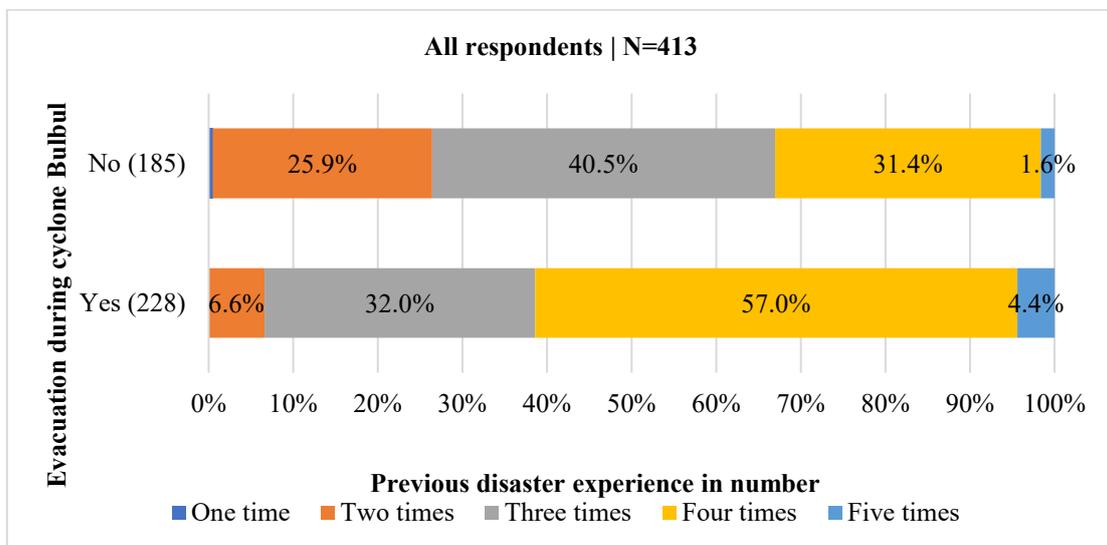


Figure 4.13 Relationship between previous disaster experience and evacuation during Cyclone Bulbul

Figure 4.13 shows that among respondents who were not driven to take steps to evacuate during Cyclone Bulbul, around 26% had experienced a disaster two times in the past, 40.5% three times, 31% four times, and 2% five times. Among those prompted to evacuate, nearly 7% had experienced a disaster twice in the past, 32% three times, 57%

four times, and 4% five times. The result indicated that those who had experienced disasters more times took effective evacuation decisions compared to those who had less experience, showing their effectiveness during an emergency.

Table 4.6 Factors prompting evacuation during cyclone Bulbul

		Evacuation during Cyclone Bulbul					
		Yes		No		Total	
Respondent gender P=.000*	Male	194	59.9%	130	40.1%	324	100.0%
	Female	34	38.2%	55	61.8%	89	100.0%
Age Group P=.179	18-40	83	49.7%	84	50.3%	167	100.0%
	41-60	103	58.9%	72	41.1%	175	100.0%
	>60	42	59.2%	29	40.8%	71	100.0%
Occupation Category P=.004*	Housewife	3	15.8%	16	84.2%	19	100.0%
	Farmer/Daily Worker	212	57.5%	157	42.5%	369	100.0%
	Retired	4	66.7%	2	33.3%	6	100.0%
	Business/Job	9	47.4%	10	52.6%	19	100.0%
Income Group P=.000*	500-5000 BDT	172	50.6%	168	49.4%	340	100.0%
	>5000 BDT	56	76.7%	17	23.3%	73	100.0%
Household Size P=.579	<=5	162	54.4%	136	45.6%	298	100.0%
	>5	66	57.4%	49	42.6%	115	100.0%
Sick Member P=.003*	No	185	59.3%	127	40.7%	312	100.0%
	Yes	43	42.6%	58	57.4%	101	100.0%

* The chi-square test statistic is significant at the 0.05 level

This study used demographic and socio-economic approaches to determine the relationship between factors that prompted an evacuation response among respondents during Cyclone Bulbul in the same way it did for early evacuation decisions. Six factors were considered in this study. **Table 4.6** shows that of these six factors, four are demographic variables, namely respondent gender, age group, household size, and the presence of a sick member in the house. Only two of the four demographic variables, respondent gender and the presence of a sick member in the house, had a significant correlation with evacuation. Approximately 60% of the male respondents evacuated during Cyclone Bulbul. Only 38% of the female respondents evacuated. The results also showed that the evacuation rate was higher among respondents who did not have a sick member in the house (59%) than among those who had (43%), suggesting that it was difficult and unsafe to evacuate with a sick member. Age and household size had no significant influence on evacuation.

Table 4.6 shows that both the socio-economic variables, occupation category, and income group significantly influenced evacuation during Cyclone Bulbul. Respondents from all occupational categories had almost similar trends for evacuation except housewives as they are more likely involved in taking care of family members and related things than in managing evacuation during a disaster. Similarly, the income group also had a significant influence on evacuation. The evacuation rate was around 77% among those whose income was higher than 5,000 BDT and about 51% among respondents whose income was less than 5,000 BDT. An informal conversation during the questionnaire survey confirmed that low-income people always want to protect their house during a disaster, they are therefore reluctant to evacuate and want to stay home during an emergency.

4.11 Summary

This study analyzed survey data to evaluate perceptions about the early evacuation and emergency evacuation during Cyclone Bulbul, including the factors that influenced evacuation decisions and the reasons for non-evacuation. The survey results revealed that evacuation with all family members was a significant concern in early and emergency evacuations. The findings of this study are important as they shed light on the reasons for non-evacuation and people's evacuation behavior. This understanding can contribute to a safe and successful evacuation during a cyclone or related disaster. The key findings of this study are explained in detail.

Based on the results presented in this chapter, we can draw some essential concluding remarks as follows:

- All household respondents mentioned that they received a primary warning of the cyclone. However, only about half (55.2%) of the respondents evacuate during cyclone Bulbul.
- There are different types of preparation needed before starting evacuation. However, the type of preparation they mentioned here is equally important, while their top priority is water and medicine and preparing family members. The preparation of necessary things before starting evacuation, which needs around two hours to manage well.
- Like the evacuation decision and evacuation, households are still not interested in making early evacuation decisions. About 47 percent of households took early evacuation decisions before the official evacuation order during cyclone Bulbul. However, is actual case based on the starting time of individual household evacuation during cyclone Bulbul, only about 33 percent of household respondents made early evacuation.
- Specific vulnerable members in the house are a significant concern while respondents consider early evacuation and emergency evacuation.
- Evacuation companion, evacuation preparation time, travel time, gender, income, and sick member in the house are common factors that affect early and emergency evacuation decisions during a cyclone.

4.12 References

1. G. A. Parvin, M. Sakamoto, R. Shaw, H. Nakagawa, and M. S. Sadik, "Evacuation scenarios of cyclone Aila in Bangladesh: Investigating the factors influencing evacuation decision and destination," *Prog. Disaster Sci.*, vol. 2, p. 100032, 2019.

Chapter 5 Evacuation Preparation Time During a Cyclone: Random Forest Algorithm and Variable Degree Analysis

5.1 Introduction

Cyclones are frequent global occurrences, especially in Bangladesh. They cause casualties and injuries that need to be considered for future disaster cases to reduce the risk to inhabitants and the risk area. In this chapter, this research proposed a computer-based simulation method to predict individual household evacuation preparation time before starting an evacuation using the RF algorithm. The prediction of household evacuation time based on household demographic and behavioral characteristics was derived from a questionnaire survey considering cyclone Bulbul in 2019. In addition, the proposed methodology also investigated the importance of variable degree analysis to identify individual variable impacts while predicting evacuation preparation time. Finally, it shows the detailed relationship between household evacuation preparation time and all individual input variables to understand the specific issues responsible for varying preparation times before starting an evacuation.

5.2 Case Study

A questionnaire survey was conducted in Gabura union, Shaymnagar Upazila, Bangladesh, three months after cyclone Bulbul occurred on November 10, 2019. A total of 413 households out of 1971 households in 3 villages between 9 villages (most affected by cyclone Bulbul) were chosen to collect demographic and behavioral data through a questionnaire survey. First, the author collected household information from local government offices. Random sampling was then used based on house numbers to select the individual house for the questionnaire survey. A questionnaire survey was administered to measure the impact of different factors that influenced household evacuation preparation time during cyclone Bulbul. One respondent represented an individual household to answer the questionnaire. The selected respondents were the heads of the households and were also responsible for making decisions for the whole household. The original questionnaire survey was drafted in English and distributed in the selected area after being translated into

Bengali. Questionnaire responses were gathered through visits to individual households, informal interviews with key informants, Cyclone Preparedness Program (CPP) unit team leaders, and local government representatives. The key informants were college teachers, former NGO members, ward members, and a Union Parishad chairman. The data were collected based on household demographic and behavioral and household evacuation preparation data and further analyzed to predict household evacuation time, focusing on future disasters.

5.2 Data

5.2.1 Demographic Data

The questionnaire gathered demographic data, including respondent age, gender, household members, income, occupation, and sick members in the household during cyclone Bulbul. A total of 413 households were investigated for the questionnaire survey, and 228 households confirmed that they evacuated during cyclone Bulbul. Therefore, we used the data from 228 individual households for this study of the simulation process; their answers were used as input variables. Here, respondents represent individual households and are responsible for making decisions during disasters.

Furthermore, age and gender represent the age and gender of the head of the household. Data on household members, income, occupation, and sick members during cyclone Bulbul were also collected for each household. **Table 5.1** shows the overall statistic of the household demographic condition obtained from the questionnaire survey. About 79 percent of the household respondents (head of household) are male. In Bangladesh's perspective, males are the household head and responsible for making household decisions. About 40 percent of the respondents identified as young people between 18-40 years while only 17 percent are aged people. People in this area are mostly low to middle-income groups, and their main occupation is day labor. Concerning the family size, more than half (about 60 percent) are medium-level households having 4-6 members. During the evacuation stage, about 25 percent of households have sick members in the house who need help while moving from one place to another.

Table 5.1 Statistic of household demographic data

Variable	Categories of response	of Distribution of responses (%)
Gender	Male	324 (78.5)
	Female	89 (21.5)
Age	18 – 40 years	165 (40)
	41 – 60 years	174 (42)
	over 60 years	70 (17)
	No response	2 (1)
Monthly family income (BDT)	500 - 2000	48 (11.62)
	2500 - 7000	350 (84.74)
	7500 - 10000	12 (2.91)
	12000 – 20000	3 (.73)
Occupation of household head	Day labor	369 (89.35)
	Business	17 (4.12)
	Housewife	19 (4.60)
	Retired	5 (1.22)
	Permanent job	2 (.48)
	Unemployed	1 (.24)
Family members	1 - 3 persons	99 (23.97)
	4 – 6 persons	253 (61.26)
	7 – 9 persons	50 (12.11)
	10 and above	11 (2.66)
Sick member in the house	No	312 (75.5)
	Yes	101 (24.5)

5.2.2 Behavioral Data

After hearing the warning signal for cyclone Bulbul, the household respondent decided to evacuate. Furthermore, if they decided to evacuate, they needed some preparations before starting the evacuation. Different factors influence household evacuation

preparation time. Therefore, it is necessary to investigate the relationship between basic household information and behavioral activities during the evacuation procedure. Thus, during the questionnaire survey focusing on cyclone Bulbul, respondents were asked questions about their households, such as evacuation companions, shelter distance, and shelter type, to determine their behavioral activities during the evacuation.

Table 5.2 Statistic of household behavioral data

Variable	Categories of response	Distribution of responses (%)
Type of evacuation shelter	Government school	191 (83.8)
	Other govt. building	25 (11)
	Rich peoples' house	8 (3.5)
	Relative's house	3 (1.3)
	Mosque	1 (.4)
Shelter distance	100 – 500 m	104 (39)
	600 – 1000 m	65 (25)
	1100 – 1500 m	50 (19)
	1600 – 2000 m	45 (17)
Evacuation companion (multiple answers)	Alone	0
	With children	219 (48.1)
	With elder	150 (33.0)
	With disable	5 (1.1)
	With others	20 (4.4)
Preparation time spent before starting evacuation	1 hour	41 (18)
	2 hours	167 (73.2)
	3 hours	10 (4.4)
	4 hours	8 (3.5)
	6 hours	2 (.9)

Table 5.2 presents the overall statistics of household behavioral data during the evacuation stage, obtained through the actual response of household respondents. The majority of household respondents (83.8%) evacuated the Government school/designated shelter, and about 64 percent of the total household respondents' house distance to shelter is ranges between 100 to 1000 meters. During the evacuation time, all households had someone with them and half of the household respondents evacuated with children and about 33 percent with older. Finally, household respondents were asked about their preparation time during and future concerning similar cases. About 73 percent among 228 household respondents mentioned needing 2 hours as preparation time before starting evacuation. While only 18 percent mentioned it as 1 hour, the rest of them said it was 3 or 4 or 6 hours.

5.3 Implement the Model

The efficiency of an RF model greatly depends on the statistical validation of the original dataset. The training dataset is employed to fit the model. At the same time, the validation dataset was used to produce a biased evaluation over the training dataset to fit the model. The test dataset was used to produce an unbiased assessment to fit the final model over the training dataset. However, defining the dataset and ratio to fit the model mainly depends on the database. Suppose the database is small, for example, 100 or less, in this case, better to use cross-validation to find out the best fit ratio of the model. The training dataset ratio should be higher for the larger database to get a better machine learning rate. Furthermore, previous studies mentioned concerning the RF model for large databases, the best fit for training data ranges between 70-90% and for test data between 10-30% [1] [2] [3] [4]. In this study, the dataset (over 200) was taken and divided into training and test data, where the training and test data were 70% and 30%, respectively. Training data were used to build the model, and the test set was used to test the generalization ability of the simulation process. Furthermore, for the prediction of input data to set out the best fit for m_{try} and n_{tree} for the training and testing data analysis, the estimated error rate was determined. Therefore, the system checked the best m_{try} , n_{tree} , and number of nodes for each variable and tried to split at each step. The classification of the RF of m_{try} , n_{tree} , and node sizes were 6, 500, and 3, respectively. We then analyzed the variable of importance and checked the detailed relationships of input variables and the predictor (preparation time) variable through the significance of variable commands and PDP.

5.4 Prediction of Preparation Time

After the simulation process, the classification accuracy of the RF model was found to be 85.71%. This high accuracy indicates the great practicability of the model, which is reliable for considering analysis results. Even though the RF simulation results produced high precision, the prediction accuracy can be increased by using a larger database and increasing the training data ratio by 90 percent. This is one possible way to reduce the error rate of prediction results. The dependent variable 'preparation time' has six categories of responses based on the actual responses of individual household respondents. Based on the classification results from the prediction simulation, which was gathered from the questionnaire survey, the prediction of preparation time was produced. Firstly, the individual respondent's responses against individual questions were imported into the prediction model as an input parameter to generate the output to predict preparation time.

Table 5.3 The prediction results of RF for input variables and the actual response of respondents

Case No	Gender	Age	Income	Occupation	Household member	Sick member in house	Shelter type	Shelter distance	Evacuation companion	Preparation time (actual response)	Preparation time (predicted)
4	0	28	9000	1	3	1	1	2000	11	2	1
6	0	70	6000	1	6	0	1	2000	6	2	2
7	0	53	6500	1	7	0	1	2000	6	2	2
15	0	46	2500	1	3	1	1	1500	6	4	2
17	0	40	3000	1	5	0	2	1500	6	2	3
18	1	42	3000	1	3	0	2	1500	9	2	2
20	0	69	2500	1	5	0	3	1500	6	4	3
21	0	49	6000	1	8	0	1	1500	6	6	2
29	1	68	1000	1	1	1	1	1500	4	1	1
35	1	38	3000	1	3	0	1	1500	3	2	2

Table 5.3 shows the predicted results where preparation time (actual response) was the response obtained from individual respondents during the questionnaire survey. While

preparation time (predicted) was generated through simulation. There is the total of 228 households' data where 170 are training data (70%) of original data to be considered for prediction. **Table 5.3** represents the first 10 cases of randomly selected households and compares them with actual and predicted results.

Table 5.4 shows the comparison results of the actual and predicted responses for each category of preparation time. The prediction results for 1 hour, 2 hours, 3 hours, 4 hours, and 6 hours are 8, 60, 2, 0, and 0, respectively. In contrast, the actual results for 1 hour, 2 hours, 3 hours, 4 hours, and 6 hours are 7, 57, 3, 2, and 1, respectively.

Table 5.4 Prediction and the actual response of household evacuation preparation time

Prediction of preparation time	Actual case of preparation time					
	1 hour	2 hours	3 hours	4 hours	6 hours	Total
1 hour	5	1	2	0	0	8
2 hours	2	55	1	1	1	60
3 hours	0	1	0	1	0	2
4 hours	0	0	0	0	0	0
6 hours	0	0	0	0	0	0
Total	7	57	3	2	1	70

5.5 Importance of Variables

The RF model also helps to detect relative importance among the variables using the mean decrease in Gini. This indicates the influence of individual variables on the predictive model performance.

Figure 5.1 shows that out of nine evacuation preparation time influencing variables, evacuation companion (17.37%) and age (13.31%) during cyclone Bulbul had the most significant influence on household evacuation preparation time. Shelter distance (7.6%), income (7.50%), shelter type (7.22%), and household members (6.49%) were also essential variables with higher impact, while gender (5.40%) and sick member (5.06%) had little effect on evacuation preparation time; occupation (3.18%) had almost no impact on evacuation preparation time.

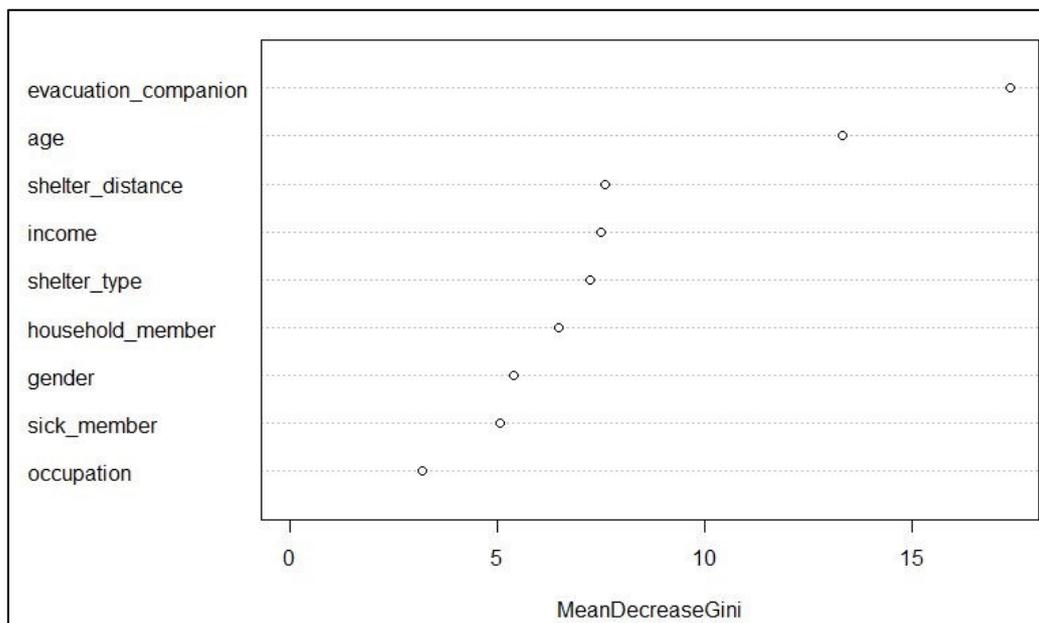


Figure 5.1 Importance of variables

5.6 Partial Dependence Plot

The Partial Dependence Plot (PDP) for all input variables is shown in **Figure 5.2**. It shows the relationships between the independent (demographic and behavioral) variables and the dependent variable (preparation time). It should be noted that in **Figure 5.2**, the y -axis does not indicate the actual responses of individual household preparation times; instead, the y -axis shows the average probability of preparation time for individual households, except for those on the x -axis, that differed from one, and therefore average the responses listed in **Table 3.1** across the cells.

The PDP for shelter type shows that when people choose evacuation shelters other than government schools and buildings, they take a longer time for preparations before starting their evacuation. When respondents chose a relative's house or mosque (religious place) as evacuation places, the average preparation time was approximately 1.95 h, while choosing designated evacuation shelters or rich people's houses required less than 1.90 h. According to **Figure 5.2** (2 Gender), the probability of the average preparation time for male respondents was higher than that for female respondents. Male respondents needed approximately 1.94 h, while female respondents needed about 1.77 h. Similarly, if there were sick members in the household, they required less time than households without sick

members: The average preparation time was about 1.93 h if there is a sick member in the house versus about 1.85 h for without sick member (**Figure 5.2** [3 Sick member]).

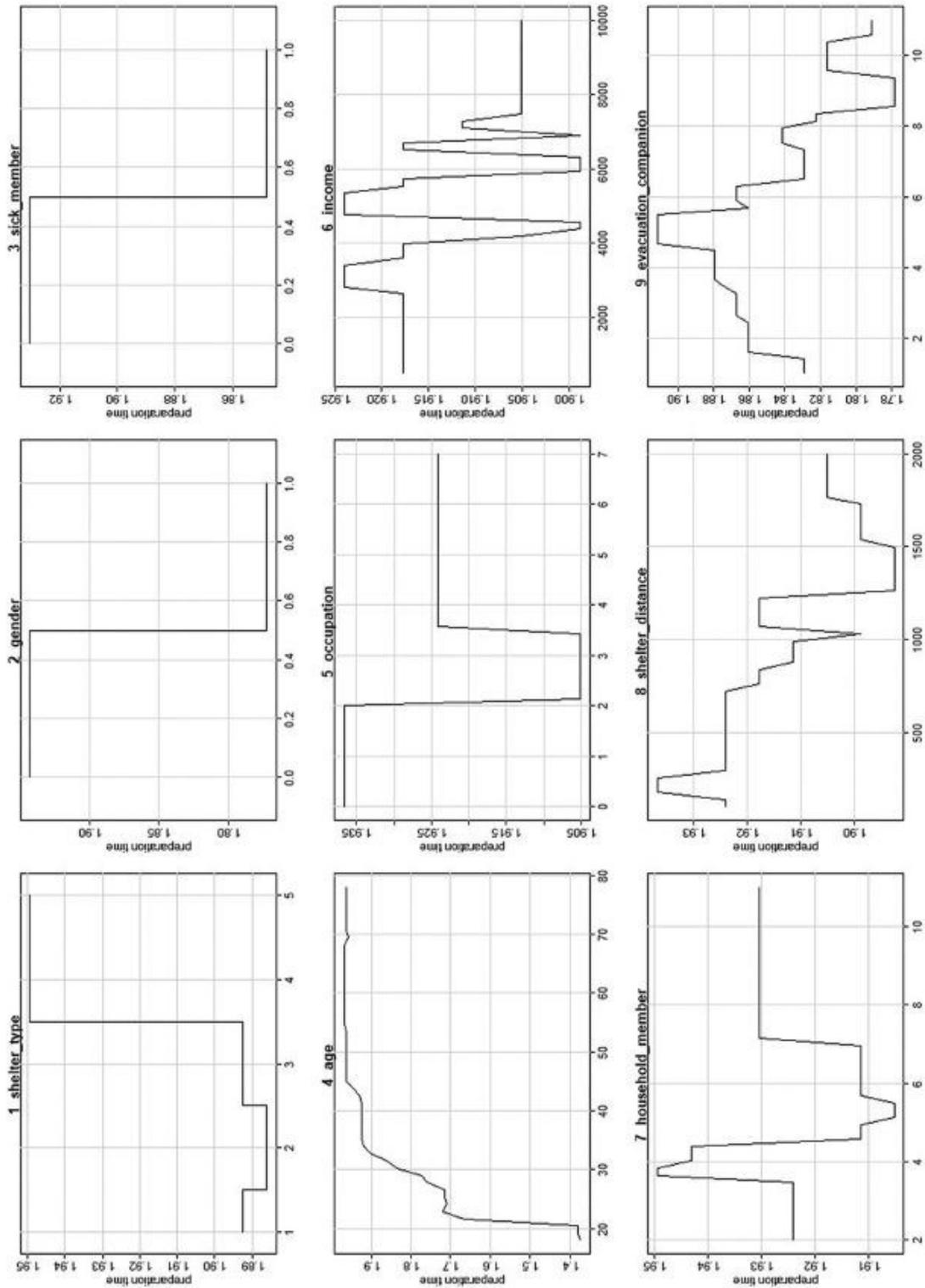


Figure 5.2 Partial Dependence Plot of all input variables

Furthermore, the PDP for age (**Figure 5.2** [4 Age]) shows that younger people needed less time to prepare before starting to evacuate. Respondents over the age of 45 needed an average of 1.97 h of evacuation preparation time, while very young respondents aged between 18 and 20 took only around 1.35 h for preparation. Similarly, respondents aged 22 and 27 years and 33–41 years took an average preparation time of about 1.71 h and 1.93 h, respectively. According to **Figure 5.2** (5 Occupation), among the different occupations, housewives and day laborers required longer preparation times (around 1.94 h). In comparison, people with jobs or who worked in business needed shorter preparation times than other occupations (1.90 h). In addition, monthly household income from 500 BDT to 12,000 BDT showed little difference when considering household evacuation preparation time, varying from 1.89 to 1.92 h. Furthermore, **Figure 5.2** (6 Income) shows that monthly household income of about 500–2500 BDT, 4000 BDT, 6000 BDT, and 6500 BDT needed an average preparation time of approximately 1.91 h, while households with monthly incomes around 3000 BDT and 5000 BDT needed a slightly longer preparation time of about 1.93 h. The PDP for household members (**Figure 5.2** [7 Household_members]) shows that those who had four household members needed the most time (around 1.95 h), while those who had five members needed the shortest preparation time (1.90 h). On the other hand, households with seven or more members needed an average preparation time of 1.93 h. Moreover, when the distance between the shelter and the individual household was shorter, they required more time than those sheltered further away.

Figure 5.2 (8 Shelter_distance) shows that if the shelter distance from individual houses was less than 300 m, those households took a longer preparation time than other households. In contrast, if the shelter distance was 1300–1500 m, these households spent the least amount of time preparing (about 1.89 h), while if the shelter distance was between 300 and 900 m and 1600–2000 m, the household evacuation preparation time was 1.92–1.91 h and 1.90–1.91 h, respectively. Regarding evacuation companions (**Figure 5.2** [9 Evacuation_companion]), when evacuating with children and relatives, the preparation time was approximately 1.91 h; in contrast, preparing to evacuate with older people and relatives took less time (around 1.77 h). In comparison, while evacuating with children, relatives, and others or with children, older people, and relatives or with children, older people, and persons with disabilities, the preparation time varied between 1.86 and 1.88 h. Similarly, if they evacuated with children and others, with children and persons with

disabilities, with older people and relatives, or with children or relatives, then preparation time varied between 1.79 and 1.83 h.

5.7 Summary

This study represents the first approach to predict household evacuation preparation time using Random Forest (RF) for a cyclone disaster focusing on the coastal community in Bangladesh. Furthermore, the detailed analysis of the importance of variable and Partial Dependence Plot (PDP) revealed the essential factors that affect and distinguish the household evacuation preparation time either longer or shorter before starting evacuation. Based on the results presented in this chapter, we can draw some essential concluding remarks as follows:

- The random forest to predict the household evacuation preparation time showed about 86 percent accuracy over the actual results of preparation time.
- The importance of variable analysis showed evacuation companion and age are the most important factors that affect the household evacuation preparation time. The Gini Index Classification values of evacuation companion and age are 17.37 and 13.31 percent, respectively.
- Similar to the importance of variables, the Partial Dependence Plot (PDP) found a significant correlation between household evacuation preparation time with evacuation companion and age. It revealed that household respondents evacuate with children and relatives take longer preparation time, around 1.91 hours. On the other hand, evacuating with older people and relatives took less time to prepare before starting evacuation. Age showed that younger people need less preparation time than older people. It showed that respondents aged over 45 years need 1.97 hours as preparation time while respondents need 1.35 hours only as preparation time whose age is between 18 to 20 years old.

5.8 References

1. A. Ghosh and P. Dey, "Flood Severity assessment of the coastal tract situated between Muriganga and Saptamukhi estuaries of Sundarban delta of India using

- Frequency Ratio (FR), Fuzzy Logic (FL), Logistic Regression (LR) and Random Forest (RF) models,” *Reg. Stud. Mar. Sci.*, vol. 42, p. 101624, 2021.
2. C. Li, C. Liao, X. Meng, H. Chen, W. Chen, B. Wei, and P. Zhu., “Effective analysis of inpatient satisfaction: The random forest algorithm,” *Patient Prefer. Adherence*, vol. 15, pp. 691–703, 2021.
 3. X. Zhao, R. Lovreglio, and D. Nilsson, “Modelling and interpreting pre-evacuation decision-making using machine learning,” *Autom. Constr.*, vol. 113, no. November 2019, p. 103140, 2020.
 4. J. Chen, J. Yu, J. Wen, C. Zhang, Z. Yin, J. Wu, and S. Yao, “Pre-evacuation time estimation based emergency evacuation simulation in urban residential communities,” *Int. J. Environ. Res. Public Health*, vol. 16, no. 23, 2019.

Chapter 6 Relationship Between Household Decision of Shelter Choice and Types of Evacuation Shelter

6.1 Introduction

This chapter comprises details of household respondents' responses by individual questions from the questionnaire survey. Furthermore, it presented the relationship of each variable, in particular, to test and support the research hypothesis. This section aimed to determine households' preferences and behavior regarding the selection of evacuation shelters and the actual evacuation shelters provided, focusing on Cyclone Bulbul and the households in the coastal area in Bangladesh. The results showed that most households choose an evacuation shelter based on the responsible authority's advice, and most choose government school/designated shelter as their evacuation destination. In addition, evacuation departure time, travel time, the actual time of stay at the shelter after evacuation, and household income significantly influence households' choice of evacuation shelter and the actual types of shelter during the evacuation, especially in coastal regions, during cyclones.

6.2 Questionnaire and Typical Response of Household to Cyclone Bulbul

According to the questionnaire analysis, out of 413 households, 228 households confirmed evacuation during Cyclone Bulbul. Household respondents were asked about their gender, age, household size, and average monthly income. Similarly, respondents were asked about their departure time before cyclone landfall, house distance to the nearest shelter, evacuation travel time from home to shelter, initial plan of how long they want to stay at a shelter before evacuation, and actual time to remain in a shelter after evacuation. In addition, respondents were asked about their evacuation shelter choice based on how to decide the way they selected and the type of shelter evacuated. The types of shelter are categorized as 1. Government school or designated cyclone shelter, 2. Other government buildings, 3. Rich people's house, 4. Relative's house and 6. Mosque (religion place).

Table 6.1 Summary of variables and response used in this research

Variable	N	M	SD	Variable Description
Gender	413	1.22	.41	Household respondents' gender
Age	413	45.95	13.77	Household respondents' actual age
Household Size	413	4.82	1.85	Total number of members in the household
Income	413	4201.69	1914.88	Monthly household income in BDT (Bangladesh Taka)
Evacuation Departure time	228	8.58	2.72	Household evacuation start time from home before cyclone landfall in hour
House Distance	228	840.20	490.79	House distance to shelter in meter
Travel Time	228	33.20	24.14	Evacuation travel time from home to shelter in minutes
Plan of shelter stay time	228	11.51	3.49	Plan to stay at the shelter before evacuation in hours
Actual Shelter stay time	228	14.93	3.47	Actual time to stay at the shelter after evacuation in hours
Shelter types	228	1.24	.62	Types of shelter
Shelter choice decision	258	1.59	.83	The household decision of evacuation shelter choice

Similarly, the evacuation shelter selection was categorized as 1. Responsible authority's advice, 2. Decide my own, 3. Discuss with relatives, 4. Decide by a shelter near to house, 5. Consider road condition, and 6. Concerning high place. **Table 6.1** shows the typical response of each variable followed by the number of household respondents' responses (N), mean (M), and standard deviation (SD) concerning their experience during Cyclone Bulbul

in November 2019. Here gender, age, household size, and income were consistent with demographic characteristics. On average, the household respondents' age was around 46 years and in the study area majority of the household size was between 4 and 5 (M=4.2). Households in this area are mainly distinguished as low-income households, and the monthly average income was 4200 BDT (Bangladeshi Taka). According to **Table 6.1**, around 46 percent of household evacuees started their evacuation 10 to 12 hours before the cyclone landfall.

On the other hand, about 31 percent of evacuees started evacuation just 1 to 10 hours before, and around 24 percent started 12 to 18 hours before the cyclone landfall. On an average of 8.58 hours per household, that started evacuation before cyclone landfall. More than half of the households who evacuated, around 53 percent household distance to shelter was between 500 m to 1000 m, while the average distance per household was about 840 m. Following the average house distance to shelter, which is around 840 m, per household took on an average of 33.20 minutes for their evacuation travel time from home to shelter. In addition, before evacuation, the household plan for stay at the shelter was an average of around 11 hours, while after evacuating to shelter per household stay at the shelter was an average of about 15 hours.

Table 6.1 indicates the majority of the household, around 83 percent, choose government schools or designated cyclone shelters for evacuation place. On the other hand, only about 11 percent went to other government buildings while only around 6 percent took shelter at rich people's houses, relatives' houses, or mosques (religious places). Around one-third, 69 percent of the household choose the evacuation route following by responsible authority's advice. In comparison, only around 25 and 17 percent prefer the evacuation route by themselves or by discussing it with relatives.

6.3 Household Decision of Evacuation Shelter Choice

According to **Table 6.2**, the majority of the household, about 70 percent, decide their evacuation shelter based on responsible authority's advice followed by deciding by own, discuss with relatives, deciding by a house near to shelter, considering road condition and, considering the high place and the percentage is 21.5, 19.7, 0.9, 0.0 and 0.4, respectively. Furthermore, from Ward 2 (Gabura and Gabura Dakshin Para) majority (about 67 percent) of the household choose the evacuation shelter by themselves. Around 29 percent were

chosen by discussing with relatives. In comparison, only around 7 percent and 2.2 percent of household evacuees followed responsible authority's advice and considered road conditions, respectively, choosing their evacuation shelter. Households from Ward 3 (Jeliakhali and Lebubunia) all households (around 99 percent) followed the authority's advice while choosing their evacuation shelter. Less than 2 percent of the household choose their evacuation shelter considering the nearest shelter from their home. On the other hand, in households from Ward 4 (Lakshmikhali and Kholishabunia), 73 percent of household evacuees chose their evacuation shelter both decide by themselves and discuss with relatives. In contrast, only around 24 percent were followed by the responsible authority's advice to choose their evacuation shelter for evacuation.

Table 6.2 Evacuation shelter choice during cyclone Bulbul (multiple answers)

Ward No. (Village Name)	Responsible authority's advice (%)	Decide by own (%)	Discuss with relatives (%)	Decide by a house near to shelter (%)	Decide by a road condition (%)	Consider high place (%)	Total (N)
Ward 2 (Gabura and Gabura Dakshin Para)	6.7	66.7	28.9	0.0	2.2	0.0	45
Ward 3 (Jeliakhali and Lebubunia)	98.6	0.0	0.0	1.4	0.0	0.0	146
Ward 4 (Lakshmikhali and Kholishabunia)	24.3	73.0	73.0	0.0	0.0	0.0	37
Total	69.7	21.5	19.7	0.9	0.0	0.4	228

$X^2 = 223.47, p = .000$; (Chi-square statistic is significant at 0.05 level)

6.4 Types of Evacuation Shelter During Cyclone Bulbul

According to **Table 6.3**, the majority of the household, about 84 percent, evacuated at govt. School/designated shelter during Cyclone Bulbul. Only about 11 percent took shelter at other govt. buildings while the rest of them took shelter at rich people's houses or

relatives' houses or Mosques (religious places). Furthermore, from Ward 2 (Gabura and Gabura Dakshin Para) and Ward 3 (Jeliakhali and Lebubunia), most of the households evacuated at govt. school/designated shelter, which is about 80 and 99 percent respectively. On the other hand, from Ward 4 (Lakshmikhali and Kholishabunia), more than 50 percent of households were evacuated at other govt. buildings, while only around 27 and 13.5 percent people took shelter at govt. school/designated shelter and rich people's house, respectively.

Table 6.3 Types of shelter household evacuated during Cyclone Bulbul

Ward No. (Village Name)	Govt. school (%)	Other Govt. buildings (%)	Rich people's house (%)	Relative's house (%)	Mosque (religion place) (%)	Total (N)
Ward 2 (Gabura and Gabura Dakshin Para)	80.0	11.1	6.7	2.2	0.0	45
Ward 3 (Jeliakhali and Lebubunia)	99.3	0.0	0.0	0.7	0.0	146
Ward 4 (Lakshmikhali and Kholishabunia)	27.0	54.1	13.5	2.7	2.7	37
Total	83.8	11.0	3.5	1.3	0.4	228

X² = 120.56, p = .000; (Chi-square statistic is significant at 0.05 level)

6.5 Test of Research Hypothesis

Table 6.4 presents the correlations among variables used in this research. During cyclone Bulbul evacuation, shelter choice was partially supported by some significant correlations with different factors. According to **Table 6.4**, households' shelter choice and travel time negatively correlated with each other. Households took longer evacuation travel time while following responsible authority's advice, choosing evacuation shelter for evacuation. Notably, evacuation shelter choice and evacuation departure time were positively correlated with each other. Households who followed responsible authority's advice while choosing evacuation shelter tended to start their evacuation from home to

shelter earlier. In addition, household evacuees tended to choose government buildings or designated shelters for evacuation, while most of the following responsible authorities advise choosing their evacuation shelter.

Table 6.4 Intercorrelations among each variable to other variables

	Gender	Age	Household size	Income	Evacuation departure time	House distance	Travel time	Plan of shelter stay time	Actual shelter stay time	Shelter types	Shelter choice decision
Gender	1	-.161*	-.123	-.196**	-.135*	.001	-.185**	-.108	-.119	.098	.203**
Age	-.161*	1	.074	-.118	.067	.046	.072	.121	.040	-.012	-.064
Household size	-.123	.074	1	.309**	.063	.048	.013	.053	-.026	.035	.077
Income	-.196**	-.118	.309**	1	-.104	-.129	-.088	-.165*	.135*	-.165*	-.155*
Evacuation departure time	-.135*	.067	.063	-.104	1	.022	-.144*	.117	-.253**	.206**	.321**
House distance	.001	.046	.048	-.129	.022	1	.631**	.011	-.046	-.106	.029
Travel time	-.185**	.072	.013	-.088	-.144*	.631**	1	-.131*	.466**	-.328**	-.459**
Plan of shelter stay time	-.108	.121	.053	-.165*	.117	.011	-.131*	1	-.046	.186**	.118
Actual shelter stay time	-.119	.040	-.026	.135*	-.253**	-.046	.466**	-.046	1	-.438**	-.623**
Shelter types	.098	-.012	.035	-.165*	.206**	-.106	-.328**	.186**	-.438**	1	.352**
Shelter choice decision	.203**	-.064	.077	-.155*	.321**	.029	-.459**	.118	-.623**	.352**	1

* Correlations is significant at the 0.05 level (2-tailed)

** Correlations is significant at the 0.01 level (2-tailed)

Table 6.4 indicates a negative correlation of types of shelter that households evacuated with their evacuation travel time. It revealed that if households choose evacuation shelter other than govt. building or designated shelter like different types of govt. building, or rich people's house, or relatives house or Mosque (religion place) they took less time for evacuation from home to shelter. Notably, it shows a statistically significant correlation with types of shelter households evacuated with households' primary plan to stay at evacuation shelter just after they decided to evacuate. Households who chose designated shelter for

evacuation, primarily those determined to stay at the shelter less time than those who chose other types of shelter. On the other hand, types of shelter and actual time to stay at the shelter were negatively correlated. In genuine cases, households spent longer staying at the shelter after evacuation, evacuating to a shelter that is govt. building or designated shelter.

Furthermore, **Table 6.4** indicates a significant correlation between gender and evacuation departure time of households. The tendency revealed that males wait for a long time compared with females to start their evacuation from home to shelter. Similarly, males took a long time evacuating from their homes to shelter. Low-income households plan to stay at the shelter longer while deciding evacuation and choosing the designated shelter following the responsible authority's advice.

6.6 Summary

Based on the results presented in this chapter, we can draw some essential concluding remarks as follows:

- Household choice of evacuation shelter greatly influences the ward's location or community. However, most (about 70%) household respondents choose evacuation shelters following the responsible authority's advice.
- Similarly, as evacuation shelter choice, around 84 percent of the household took shelter in a designated shelter during cyclone Bulbul.
- The types of shelter households evacuated during cyclone Bulbul significantly influenced by evacuation departure time, plan to stay at the shelter, and household choice of the evacuation shelter.
- Furthermore, household choice of evacuation shelter is also significantly influenced by gender, evacuation departure time, and types of the evacuation shelter.

We believe that our analyzed results from this chapter makes a significant contribution to the literature because the findings can act as a reference for researchers, disaster management authorities, governments, and non-government agencies to come up with new ideas, plans, and preparedness strategies for reducing disaster risk during evacuation in coastal areas. Further, we believe that the findings will be of interest to the readership of your journal because they can refer to it in studying coastal evacuees' behavior and preferences in deciding on the type of shelter to which they can be evacuated.

Chapter 7 Discussion

7.1 Comparison of Evacuation Behavior: Cases from Bangladesh, The Philippines, and the USA

This section aims to identify the evacuation tendency during cyclones from Bangladesh, typhoons from the Philippines, and hurricanes from the USA. The Philippines is a Southeast Asian country situated in the Pacific Ocean and has more than seven thousand islands. In addition, the Philippines is located at the Pacific typhoon belt, where natural disasters, especially typhoons, happen often. In 2013 the typhoon Haiyan caused massive damage over the Philippine coastal area. The USA is situated in North America and becoming more vulnerable to natural disasters. Due to climate change, sea-level rise, and weather-associated change in the atmosphere, several significant hurricane events occurred in the USA over the last two decades, which caused severe damage to both property and lives. On the other hand, Bangladesh is situated in South Asia, having a long coastal belt beside the Bay of Bengal. The coastal belt is prone to natural disasters, especially cyclones, which cause severe damage to the coastal area's residents' property and lives. The nature and condition of cyclones in Bangladesh and typhoons in the Philippines are similar considering their nature, situation, and demography over the coastal area. Considering the hurricane cases in the USA, the character and condition are also related to cyclones and typhoons from Bangladesh and the Philippines, respectively, but the demography is different. So, the main purpose of this section is to identify evacuees' cause of non-response with evacuation behavior towards evacuation response and obtain a comparative overview of cyclones in Bangladesh, typhoons in the Philippines, and hurricanes in the USA as these disasters have similarities concerning situation and condition in the evacuation stage. This comparative analysis will help understand the evacuation situation during a similar disaster, even from different countries. Therefore, the findings provide necessary insight and guidelines for future interventions to develop better preparedness to make evacuation more participable among people during natural disasters from different perspectives.

Based on the review of existing literature, evacuation cases from natural disasters, this section tries to compare the evacuation behavior between Bangladesh, the Philippines, and

the USA. To detail analysis of evacuation behavior from the typhoon in the Philippines, secondary data was gathered from Leelawat et al. 2014, Esteban et al. et al. 2015, Lagmay et al. 2015, Jibiki et al. 2016, Takagi et al. 2016 and Walch 2018. Similarly, concerning the USA, data were collected from Lindell et al. 2005, Dash and Gladwin 2007, Zhang et al. 2007, Morss and Hayden 2010, Huang et al. 2012, Lazo et al. 2015, Morss et al. 2016 and Meyer et al. 2018. While in case of Bangladesh collected data from this research (Rahman et al. 2021) including Haque and Blair 1992, Matsuda 1993, Choudhury et al., 1993, Ikeda 1995, Paul 2008, Paul and Dutt 2010, Paul et al., 2010, Paul 2011, Paul 2012, Paul and Routray 2013, Roy et al., 2015 and Ahsan et al., 2016. **Table 7.1** presented the evacuation tendency associated with the warning, weather, socio-demographic, shelter, and evacuees' perspective reason for non-evacuation during cyclones from Bangladesh, typhoons from the Philippines, and hurricanes from the USA.

According to **Table 7.1**, a warning is an essential issue during natural disasters, which is essential for an effective preparedness plan focusing evacuation to a safer place. Previous research revealed that people mentioned important factors associated with the warning during a disaster. In the case of Bangladesh, false warning signals, incomplete warning signals related to evacuation information, lack of understanding of warning receiving, late warning, and sudden change of warning are the main reasons people did not consider evacuation during a disaster. Haque and Blair 1992, found that distrust of warning was the main reason residents stayed at home instead of evacuation [33]. Previous studies found that people did not receive the warning or lately recognize the warning during cyclones [26, 31]. During the evacuation stage, late warning, change of warning signal suddenly and the evacuation order was not issued timely some other significant reasons that people did not evacuate [26, 31-32]. On the other hand, in the Philippines, Esteban et al. 2015 found that residents mentioned the information regarding typhoon Haiyan, especially information related to storm surges, which was moderately useful they received from different sources [36]. However, Leelawat 2014 found that the majority of the people received the warning, but half of them did not evacuate during typhoon Haiyan [44]. Following these previous studies revealed that residents got an unclear evacuation message, and some did not get any evacuation order from officials, complicating evacuation [36-37]. Previous studies revealed that residents did not trust the hurricane warning and forecast [38-39]. Dash and Gladwin 2007 showed that most people get the warning from family members, friends, and relatives [48]. In comparison, most people received hurricane Rita forecasts and warning from

television [49-50]. In addition, Lindell et al. 2005 found that during hurricane Lili in 2005, there was an evacuation recommendation from officials, but residents did not follow the evacuation recommendation [38-39]. Morss and Hayden 2010 presented that half of the respondents received the mandatory evacuation order during Hurricane Ike [50].

Bad weather conditions during the emergency period make it difficult for evacuation. In addition, following the bad weather condition, the storm surge is a significant problem that makes it difficult to evacuate cases from all three countries. In Bangladesh, people think the cyclone would not be severe and less possibility to occur the storm surge [32]. At the same time, the majority mentioned that it is difficult for evacuation due to bad weather conditions outside [25, 32, 34]. In the case of the Philippines, Esteban et al., 2015 found that residents know about the storm surge possibility but ignore the strong impact of storm surge [36]. Similarly, previous studies found the strong possibility of storm surge and flooding caused by storm surges during Typhoon Haiyan [44-45, 47]. In contrast, residents from the USA mentioned that they were aware of storm surge and believed that their house was vulnerable due to storm surge and later flooding during the hurricane event [38-40, 51].

Furthermore, socio-demographic issues also found strong relationship with residents' non-evacuation reason during natural disasters. The most important common socio-demographic reason for all three countries was cited as vulnerable member in the house, which hinders evacuation during disasters. Many people did not evacuate as they faced difficulties moving with vulnerable members who needed special assistance. For example, moving with an infant, children, disabled person makes it difficult to complete the evacuation [25, 29-30, 32, 37-38, 41, 43-44, 48]. In addition, people are engaged with activities like preparing all household members, house belongings, and related issues and sometimes run out of time and finally cannot move [25, 30-32]. However, residents from the Philippines, instead of the vulnerable member, residents are anxious that their house is vulnerable because of flooding resulting from storm surge [36]. Following the similarities, residents also mentioned that they were at work and could not move timely [25, 32, 36, 39]. Concerning the hurricane cases, preparing early could be safe to start evacuation at the right time [48] while around ninety percent of respondents said did necessary preparation before storm surge [50]. But Lindell et al. 2005 found evacuation preparation is not essential for the decision of evacuation [39].

Table 7.1 Evacuation behavior during Cyclone, Typhoon, and Hurricane: Cases from Bangladesh, The Philippines, and The USA

Variable	Bangladesh	Philippines	USA
	Sources		
Warning Information	Haque and Blair 1992, Ikeda 1995, Paul and Dutt 2010, Paul 2012, Paul and Routray 2013, Roy et al. 2015, Ahsan et al. 2016	Leelawat et al. et al. 2014, Lagmay et al. 2015, Esteban et al. 2015	Lindell et al. 2005, Dash and Gladwin 2007, Zhang et al. 2007, Morss and Hayden 2010, Lazo et al. 2015
Evacuation message/ order	Paul 2008, Paul and Dutt 2010	Esteban et al. 2015, Walch 2018	Lindell et al. 2005, Morss and Hayden 2010, Lazo et al. 2015
Storm surge/ weather	Ikeda 1995, Rahman et al. 2021	Leelawat et al. 2014, Esteban et al. 2015, Lagmay et al. 2015, Takagi et al. 2016	Lindell et al. 2005, Zhang et al. 2007, Huang et al. 2012, Lazo et al. 2015, Morss et al. 2016
Vulnerable member/ house is vulnerable	Matsuda 1993, Ikeda 1995, Paul and Routray 2013, Rahman et al. 2021	Leelawat et al. 2014, Esteban et al. 2015	Dash and Gladwin 2007, Lazo et al. 2015, Mayer et al. 2018
Evacuation preparation	Ikeda 1995, Paul 2011, Paul and Dutt 2010, Paul and Routray 2013, Rahman et al. 2021	Leelawat et al. 2014, Esteban et al. 2015	Dash and Gladwin 2007, Lindell et al. 2005, Morss and Hayden 2010
Shelter accessibility/ facilities	Matsuda 1993, Ikeda 1995, Paul and Dutt 2010, Paul et al. 2010, Paul 2011, Paul 2012, Paul and Routray 2013, Roy et al. 2015, Ahsan et al. 2016, Rahman et al. 2021	Leelawat et al. 2014, Esteban et al. 2015, Walch 2018	Lindell et al. 2005, Huang et al. 2012, Wu et al. 2012, Mayer 2018
Safety of house and property	Haque and Blair 1992, Chowdhury et al. 1993, Ikeda 1995, Paul and Dutt 2010, Paul et al. 2010, Paul and Routray 2013, Ahsan et al. 2016, Rahman et al. 2021	Leelawat et al. 2014, Esteban et al. 2015, Walch 2018	Lindell et al. 2005, Huang et al. 2012, Lazo et al. 2015
Hazard knowledge	Chowdhury et al. 1993, Paul and Dutt 2010, Paul 2012	Esteban et al. 2015, Jibiki et al. 2016, Walch 2018	Lazo et al. 2015

Furthermore, Table 7.1 revealed shelter as the main issue concerning evacuation during a disaster based on previous research. In cyclone cases from Bangladesh, previous studies revealed that access to nearby shelters is sometimes difficult as the situation outside was not safe for evacuation [25, 30, 32]. In addition, people were unaware of the nearby shelter and accessibility route, and also the distance hinders evacuation for both Bangladesh and the Philippines evacuation cases [25-30, 34]. Many previous research also mentioned one particular reason: the lack of facilities in the shelter was not good, so people consider staying at their own house. People mentioned lack of facilities as drinking water, electricity, toilets, and separate space for gender, the shelter was vulnerable to collapse the main reason [26, 28, 31]. While in the Philippines, it was cited as it was hard to get to the shelter area [36] and feel insecure to stay at the shelter due to the poor maintenance and facilities in the shelter [37, 44]. In contrast, in hurricanes evacuation cases from the USA, residents mentioned it took longer to reach the destination [39-40, 52]. At the same time, Meyer et al. 2018 found that residents feel insecure about staying at their own home due to storm surge [41].

Finally, **Table 7.1** presented evacuees' perception of evacuation behavior during a disaster. In all three countries, the common tendency among people tried to ensure the safety of the house and household belongings from disaster damage is one of the major concerns for people during a disaster [25, 36, 39-40, 44]. Similarly, house and household belongings from fear of theft or looting during their stay at the shelter is another important reason people stay at home during a disaster [28, 33, 35-37, 39-40, 44]. Following this, people thought their house was safe and out of risk area, so it was better to stay at home [25-26, 30-38, 41]. Another important reason from countries is that people ignore the severity of cyclones, typhoons, or hurricanes and therefore do not feel the real danger, leading to less participation in the evacuation decision-making process [26, 31, 35-40, 44, 46].

7.1.1 Factors that Contribute to Evacuation Behaviors

Analyzing the evacuation behavior from three countries during disaster warning and evacuation order dissemination is one of the most important and common aspects that hinder smooth evacuation. Many vulnerable residents mentioned receiving false or no warning and no evacuation order or late evacuation from the authority in Bangladesh before approaching the event. While in The Philippines, it is found that residents did not

get any evacuation warning or order in some areas. Compared to hurricane evacuation cases from the USA, residents have received strong evacuation recommendations. So, ensuring warning and evacuation orders must be carefully addressed to the risk area from responsible authorities could be a significant initiative for smooth evacuation in Bangladesh and the Philippines. Before starting the evacuation, one of the major concerns is vulnerable members in the house make it difficult to complete the evacuation in Bangladesh. Therefore, it is needed to identify those households regularly and prioritize those households' assisting evacuation during a disaster. However, in Philippine's people are worried about flooding their houses resulting from a strong storm surge. So, better to identify risk areas concerning storm surge and flooding and provide necessary information to the specific location. For example, people should not ignore storm surge and flooding and take initiatives for evacuation. In addition, shelter-related issues are also essential and common factors that residents did not evacuate during a disaster in Bangladesh and The Philippines. Accessing the shelter and the shelter's facilities is not good enough. That is why people want to stay at home instead of a shelter. So, maintaining shelter and improving the facilities is essential to satisfy people that shelter is reasonable for stay during a disaster. Also, it is needed to make residents aware of the access of nearby shelters. On the other hand, it found that it takes a longer time to reach the destination in the USA because of traffic. So, in that case, multiple access route information will be helpful considering the circumstances in the USA. Therefore, they can quickly decide and evacuate before the situation outside goes worst. These initiatives can help overcome challenges and risks for future disaster cases, even in Bangladesh or the Philippines.

According to the comparative analysis of evacuation behavior from different countries, this research is essential considering the evacuation preparation time which is associated with successful evacuation. Previous studies mentioned evacuation preparation, cases from cyclone and typhoon events from Bangladesh and the Philippines, mainly different evacuation activities. On the other hand, previous studies said preparation activities and time during hurricane cases did not significantly correlate with evacuation decisions and behavior. Following this, the current research found a significant correlation of evacuation preparation and time with evacuation decision and behavior, ensuring effective evacuation participation. This finding can be a considerable factor associated with the evacuation decision-making process for future research to reduce the disaster risk during a similar type of disaster.

7.2 Households Evacuation Preparation Scenarios during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh

Regarding people's response to an evacuation order and reasons for not evacuating during a cyclone, many previous studies conducted in the last two decades have focused on different perspectives. This research acknowledges the reasons for non-evacuation during cyclone disasters identified in earlier research. According to Bern et al. (1993), trust in warning signals/evacuation orders is essential, as most of the respondents did not follow the evacuation order during the 1991 cyclone because of their previous experience of receiving a false warning [1]. The lack of cyclone shelters and facilities and the distance to shelters are also important reasons for non-evacuation during a cyclone [2] [3]. During Cyclone Bulbul, all respondents admitted that they received an early warning, but half of them did not follow evacuation orders (**Table 4.2**). For male respondents, the four main reasons for non-evacuation were "I thought I would be able to move during the cyclone," "the weather outside was dangerous," "I thought my house was safe," and "the road was damaged." For female respondents, the three main reasons for non-evacuation were "I wanted to protect my house," "I had a sick family member in my house," and "I thought I would be able to move during the cyclone" (**Figure 4.1**). Therefore, it is essential to understand the reasons for non-evacuation from both male and female perspectives, which will make it easier to address gender-specific causes carefully. The analysis of the survey results showed that the reasons for non-evacuation during Cyclone Bulbul were mostly related to weather conditions and shelter characteristics. Because of the bad weather conditions before the cyclone made landfall, the condition of the roads deteriorated and made it difficult to travel to shelters. Furthermore, shelter distance and lack of proper facilities were significant reasons for non-evacuation.

After receiving the warning, it is necessary to make evacuation decisions at the right time to ensure safe evacuation, given the risks involved. With early evacuation, the risk of property damage could be minimized by sending vulnerable members to the shelter earlier and having the household head stay at home and evacuating later [4]. The present study acknowledges previous research by focusing on early evacuation decisions during Cyclone Bulbul. Early evacuation during cyclones could be beneficial for household evacuation. People who consider early evacuation during a disaster have specific priorities. For most respondents, the safe passage for specific members in the house, like children or seniors, is

the main concern. After making an early evacuation decision, people undertake various activities and preparations before starting an evacuation. The decision to evacuate early gives people enough time for preparation. The questionnaire survey showed that households that made an early evacuation decision took 1 to 6 hours for preparation, with most respondents in this group taking two hours for preparation before evacuation.

Conversely, households that did not make an early evacuation decision spent either 1 or 2 hours for preparation time, with the majority taking two hours for preparation. Demographic and socio-economic characteristics play a key role in early evacuation decisions. There was a significant difference between male and female involvement in early evacuation decisions. People along the coastal regions of Bangladesh are very poor and always evacuate since their houses are not strong enough to protect them during a disaster. The rate of early evacuation decisions among households with sick members was relatively low, given the difficulties in moving them from home to shelters. Inadequate access roads because of weather conditions and shelter-related aspects were cited as the main reasons for an early evacuation decision. People who lived far from the shelter thought it would take around 30 to 60 minutes to cover the distance, it would be better to evacuate early before the weather worsened.

Early evacuation ensures effective disaster preparedness and completion of evacuation to a safer place during a tsunami disaster [5]. However, a cyclone does not strike as quickly as a tsunami; consequently, there is enough time to evacuate during a cyclone, but the consequences and complexities of evacuation are comparable. This research identified factors that influence early evacuation—a key concern for safe and successful evacuation during a cyclone disaster. The survey results indicated that around 47% of respondents made early evacuation decisions, but only about 35% followed up with their decisions during Cyclone Bulbul. Although most of the respondents who evacuated early chose a government school or designated shelter for evacuation, they had enough time to choose from different options. Among those who did not evacuate early, over 90% had to choose the designated shelter even when they did not know if the shelter was already full (**Figure 4.8**). This sometimes made some shelters overcrowded, but evacuees could not move to other places because of bad weather conditions. It is challenging to make evacuation decisions when there are children and elderly members in the house who need special care during evacuation [6] [7] [8]. Households with children, seniors, or sick members were

sometimes unable to decide whether to evacuate early because they thought it would be safer to stay at home with them.

In contrast, other households thought if they reached the shelter at any cost, they would be safe. The preparation time and evacuation travel time also significantly impacted early evacuation. Half of the households that evacuated early took two hours for preparation, while the remaining half took one hour or two to six hours. Among households that did not evacuate early, most took two hours (**Figure 4.12**). Respondents who evacuated early could choose any shelter regardless of the distance and faced relatively fewer difficulties as the weather was not as bad as it was just before the cyclone landfall. Concerning evacuation preparation time, female respondents took a longer time than male respondents for evacuation at different warning stages [9]. Therefore, to ensure safe evacuation, coastal residents must be made aware of the severity of a cyclone and have enough time for preparation before evacuation. According to the survey results, people need a longer preparation time and evacuation travel time if a vulnerable member is present in the house (**Table 4.4, Table 4.6, and Figure 4.11**).

Recently, technological advancements in natural disasters have enabled significant initiatives to reduce disaster risk in various sectors. Disasters such as cyclones, typhoons, hurricanes, floods, disaster preparedness, early warning mechanisms, evacuation, and recovery after a disaster have become more systematic and effective. Despite the improvements in warning dissemination and evacuation order mechanisms, many people still did not evacuate to cyclone shelters or other safer places during Cyclone Bulbul. This study analyzed evacuation behavior during a cyclone and the factors influencing evacuation behavior. Previous disaster experience plays an essential role in guiding an individual or household to better prepare for a disaster (**Figure 4.13**). According to Lindell and Perry (2000), people who have previous disaster experience are aware of the risks and effects of the different stages of a disaster—helping them handle the situation more effectively [10]. The analysis of the survey results found that respondents' previous disaster experiences had a significant impact on evacuation during Cyclone Bulbul. Respondents who did not evacuate had less experience with disasters than those who did. This research found that demographic and socio-economic characteristics influence people's evacuation decisions. Gender is an essential issue in the evacuation decision-making process. Ikeda (1995) noted that women are vulnerable in different ways during a disaster in terms of disaster preparedness, evacuation decisions, and sheltering stages [11]. This study found that female

respondents faced difficulties when evacuating with a sick or other vulnerable member and sometimes felt unsafe evacuating alone. Most respondents cited the presence of a sick member in the house as an important factor influencing their evacuation decisions during the disaster. People who are poor and struggle to survive daily were more concerned with protecting their properties than with evacuation, which significantly impacted their evacuation decisions.

7.3 Evacuation Preparation Time During a Cyclone: Random Forest Algorithm and Variable Degree Analysis

According to previous studies, using RF for prediction models can provide better predictive results over large databases compared to other machine learning models [12] [13] [14]. The results revealed that the RF simulation to predict household evacuation preparation time shows that the accuracy result is approximately 86%, which can produce efficient accuracy and realistic compared to the traditional method. Based on the prediction results, responsible government authorities, policymakers, and key stakeholders can better understand the valuable insights of individual household evacuation preparation times and, therefore, better preparedness plans for safe evacuations. Rahman et al. (2021) found that evacuation preparation time is essential and significantly influences households' early and emergency evacuation decisions during cyclones [15]. Huang et al. (2016) found that the demographic characteristics are less impact over evacuation while "homeownership" is the only demographic characteristic that found a somewhat reliable correlation with evacuation [16]. This is inconsistent with previous research that found the strong impact of demographic and behavioral factors on household evacuation preparation time before starting an evacuation. **Figure 5.1** shows that evacuation companions and age are the most important variables affecting household evacuation preparation time. It seems that preparation time can change if specific vulnerable members (children, people with disabilities) and elderly people in the household. Therefore, it is necessary to prepare different things to stay in shelters after evacuations. Moreover, age can be a significant concern when considering evacuation preparation time since younger people are generally more active in the act of early preparation. In addition, the results show that shelter distance, monthly household income, types of shelter for evacuations, and household members are also important when considering the prediction of evacuation preparation time.

Furthermore, demographic and behavioral factors are essential to estimate preparation time; therefore, the impact of each individual factor on preparation time needs to be investigated [17]. Similarly, Lindell and Prater (2004) found that when people evacuate with groups of people, preparation is essential to manage things and household belongings; thus, evacuating to a safe place is associated with different factors [18]. In this research, we investigated the complex non-linear relationship between household evacuation preparation time and other input variables, and the results revealed that several demographic and behavioral factors showed significant positive relationships with household evacuation preparation time. According to **Figure 5.2 (1 shelter_type)**, when people choose shelters for evacuations, their evacuation preparation time also changes following designated and other types of evacuation shelters. Households who want to evacuate to government-related shelters and rich people's houses require relatively short preparation times compared to other shelter types, such as relatives' houses or mosques (religious places). It seems that most people want to evacuate to government-related shelters, but sometimes those shelters are full; therefore, people need to change their evacuation destination. Male respondents need more time than female respondents since male respondents are generally responsible for preparing various things before the evacuation (**Figure 5.2 (2 gender)**). While evacuating, if there are sick people in the house, those households spend less time preparing before starting their evacuation. It seems that people are aware of the consequences while evacuating with sick members and take longer to reach evacuation shelters (**Figure 5.2 (3 sick_member)**). Age is one of the most considerable factors affecting household evacuation preparation time. According to **Figure 5.2 (4 age)**, respondents younger than 25 years are considered the most energetic and thus need the shortest amount of preparation time; preparation time increases with age. In addition, after around 45 years of age, households need almost similar preparation times. Household respondents' occupations had no impact on the evacuation preparation time, as the individual occupation group needed a nearly similar amount of time to prepare to evacuate. **Figure 5.2 (5 occupation)** shows that household respondents who have jobs and businesses need less preparation time (1.905 hours) compared to other occupation groups; housewives and day laborers required more preparation time (1.935 hours). Although occupation is related to household income, it revealed a significant correlation with evacuation preparation time. Low- and middle-income households needed more time to prepare before the start of an evacuation, varying from 1.900 to 1.925 hours. Households

whose monthly income exceeded 7,000 BDT required an average preparation time of 1.905 hours (**Figure 5.2 (6 income)**).

Households with around four or five family members needed more time for evacuation preparation, while households with seven or more members needed less time for preparation (**Figure 5.2 (7 household member)**). It seems that the higher number of household members means that they can help each other with different activities before starting their evacuation, thus requiring less time. Shelter distance from home is another important factor in household evacuation preparation time. However, the preparation time difference is very small among homes that are a short or long distance from shelters (**Figure 5.2 (8 shelter_distance)**). Next, evacuation companions are also a significant factor. Vulnerable household members such as children, older people, and people with disabilities can create difficulties; thus, households with such members need more time to manage things before starting their evacuation. According to the results, households with children, older people, and people with disabilities needed more time before starting an evacuation (**Figure 5.2 (9 evacuation_companion)**). However, it is interesting that households are concerned with all the vulnerable members together (children, older people, people with disabilities, and relatives) in the house rather than with specific vulnerable members.

7.4 Relationship Between Household Decision of Shelter Choice and Types of Evacuation Shelter

This research tried to investigate and analyze the efficacy of household evacuation behavior, focusing on evacuation shelter choice and types of shelter households evacuated during a cyclone. Results show that most households from Ward 3 (Jeliakhali and Lebubunia) follow responsible authority's advice. In contrast, Ward 2 (Gabura and Gabura Dakshin Para) and Ward 4 (Laksmikhali and kholisabunia) show the opposite view deciding their evacuation shelter. On the other hand, from Ward 3 and Ward 2 almost and, the majority of the household evacuated in the designated shelter. In contrast, from Ward 4, less than 30 percent of households evacuated at the designated shelter. According to risk profiling, Ward 2 is higher risk compared to Ward 3 and 4 concerning hazard and different socio-economic vulnerability [19]. However, concerning the location, Ward 3 is just beside the river and, far from the Union local government facilities and are exposed as most vulnerable to disaster concerning accessing of shelter.

Even though there is a designated shelter in Ward 3 but difficult to access during a disaster because of bad weather and road condition. So, households from Ward 3 mainly depend on local level authority's information and instruction, deciding evacuation shelter during a disaster. Furthermore, during the evacuation, households' evacuation shelter choice decision plays a significant role in understanding evacuation decision-making. The results revealed that most households (around 68 percent) followed responsible authority's advice choosing their evacuation shelter. This supports the findings from Nagarajan and Shaw (2021), officials' pre-information advice concerning sheltering and helping evacuees for sheltering is positively influenced while choosing an evacuation shelter or place [20]. In Bangladesh's perspective, previous research introduced some initiatives regarding shelter choice, and maps were presented, but still evacuation shelter choice in coastal communities remains a challenge to evacuees as shelter detail information and hazard maps are not available at community level use. So, people can't decide how to choose a shelter in coastal areas and go to shelter. Therefore, they rely on national and local level responsible authority and volunteers (especially CPP volunteers') information and instruction while choosing their evacuation shelter instead of following the maps. Informal interviews with local level government officials and CPP unit team leader also mentioned that together they disseminated the information, and CPP volunteers assisted evacuees as well for evacuation to a shelter or safer place. In addition, it shows the tendency that households who followed responsible authority's advice to determine the shelter, evacuate earlier seems they are aware and know the difficulties of evacuation at a later stage. But those households took more time for evacuation travel time means they have enough time to start evacuation earlier. Following the similar trend of Sadri et al. (2013), this research found that households who evacuated at the public shelter evacuated at an earlier stage and took less time for evacuation travel time [21]. Parady 2016 found no significant correlation of household socio-economic condition while choosing their evacuation destination during a Tsunami event [22]. This research does not support this finding, revealed some socio-economic factors are significantly related to the choice of shelter that household evacuated during cyclone Bulbul. Following this, gender and evacuation shelter choice positively correlate with each other, meaning males decided the evacuation shelter following the responsible authority's advice. Instead, they choose by themselves, discuss with relatives, or consider shelter near or consider road conditions. The data shows the tendency that low-income households tend to choose their evacuation shelter either by themselves, discuss with relatives, or consider the nearest shelter or consider road conditions. It seems that

low-income households are usually worried about protecting their house and belongings before starting the evacuation. Therefore, they typically evacuate later and suddenly decide where to go, reflecting their preference for choosing their evacuation shelter.

Findings reveal that about 84 percent of the household took shelter at designated cyclone shelters, and only 11 percent took shelter at other types of govt. buildings during Cyclone Bulbul. The rest of the household evacuees took shelter at rich people's houses, relatives' houses, and Mosques (religious places). But this finding didn't follow the previous research concerning the same study area, which mentioned the majority of the evacuee's 69 percent, took shelter on embankments or high roads. In comparison, only about 10 percent took shelter at the shelter [9]. According to the choice of shelter type, households' preliminary plan to stay at the shelter was a long time if they choose the shelter as other govt. buildings, rich people's houses, relatives' houses, or Mosques (religious place), indicates that they need to find these facilities and check the availability to stay. Findings are also consistent with previous research of Hasan et al. (2014), household income can be affected evacuees' decisions while deciding their evacuation shelter for evacuation [23]. On the other hand, if households decided to evacuate at the govt, building, or designated shelter for evacuation took more time for evacuation travel time. It seems that sometimes those shelters are far from the house, which generally takes a longer travel time for evacuation, or maybe the nearest shelter reached its capacity. Following this, the tendency to stay longer at the designated shelter after evacuation indicates better facilities and availability.

Similarly, low-income households' tendency also revealed that always choose shelter which is not designated shelter means as they usually evacuate at a later stage. Thus, they didn't have enough time to check shelter conditions or facilities instead, they chose a possible shelter near their home. These results are also the opposite of previous research's findings on shelter choice in similar cases. For instance, low-income households decide to go designated evacuation shelters while high-income households tend to go to other places that are not designated shelters [24].

7.5 References

1. C. Bern, J. Sniezek, G.M. Mathbor, M.S. Siddiqi, C. Ronsmans, A.M. Chowdhury, A.E. Choudhury, K. Islam, M. Bennish, and E. Noji, "Risk factors for mortality in the

- Bangladesh cyclone of 1991," *Bulletin of the World Health Organization*, 71(1): 73–78, 1993.
2. U. Haque, M. Hashizume, K. N. Kolivras, H. J. Overgaard, B. Das, and T. Yamamoto, "Reduced death rates from cyclones in Bangladesh: What more needs to be done?," *Bull. World Health Organ.*, 2012.
 3. A. Paul and M. Rahman, "Cyclone mitigation perspectives in the Islands of Bangladesh: A case of Sandwip and Hatia islands," *Coast. Manag.*, 2006.
 4. C. Roy, S. K. Sarkar, J. Åberg, and R. Kovordanyi, "The current cyclone early warning system in Bangladesh: Providers' and receivers' views," *Int. J. Disaster Risk Reduct.*, vol. 12, no. 12, pp. 285–299, 2015.
 5. N. Y. Yun and M. Hamada, "A Study on Evacuation Behaviors in the 2011 Great Japan Earthquake," *15th World Conf. Earthq. Eng.*, 2012.
 6. N. Y. Yun and M. Hamada, "Evacuation behavior and fatality rate during the 2011 Tohoku-oki earthquake and tsunami," *Earthquake Spectra*. 2015.
 7. M. Shoji and A. Murata, "Social Capital Encourages Disaster Evacuation: Evidence from a Cyclone in Bangladesh," *J. Dev. Stud.*, no. 178, 2020.
 8. R. R. Thompson, D. R. Garfin, and R. C. Silver, "Evacuation from Natural Disasters: A Systematic Review of the Literature," *Risk Anal.*, 2017.
 9. G. A. Parvin, M. Sakamoto, R. Shaw, H. Nakagawa, and M. S. Sadik, "Evacuation scenarios of cyclone Aila in Bangladesh: Investigating the factors influencing evacuation decision and destination," *Prog. Disaster Sci.*, vol. 2, p. 100032, 2019.
 10. M. K. Lindell and R. W. Perry, "Household adjustment to earthquake hazard: A review of research," *Environment and Behavior*. 2000.
 11. K. Ikeda, "Gender Differences in Human Loss and Vulnerability in Natural Disasters: A Case Study from Bangladesh," *Indian J. Gend. Stud.*, vol. 2, no. 2, pp. 171–193, 1995.
 12. A. Ghosh and P. Dey, "Flood Severity assessment of the coastal tract situated between Muriganga and Saptamukhi estuaries of Sundarban delta of India using Frequency Ratio (FR), Fuzzy Logic (FL), Logistic Regression (LR) and Random Forest (RF) models," *Reg. Stud. Mar. Sci.*, vol. 42, p. 101624, 2021.
 13. C. Li, C. Liao, X. Meng, H. Chen, W. Chen, B. Wei, and P. Zhu., "Effective analysis of inpatient satisfaction: The random forest algorithm," *Patient Prefer. Adherence*, vol. 15, pp. 691–703, 2021.
 14. Z. Wang, C. Lai, X. Chen, B. Yang, S. Zhao, and X. Bai, "Flood hazard risk assessment model based on random forest," *J. Hydrol.*, vol. 527, pp. 1130–1141, 2015.

15. M. A. Rahman, A. HOKUGO, N. OHTSU, and S. Chakma, "Evacuation Preparation Scenarios of Households during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh," *IDRiM J.*, 2021.
16. S. K. Huang, M. K. Lindell, and C. S. Prater, "Who Leaves and Who Stays? A Review and Statistical Meta-Analysis of Hurricane Evacuation Studies," *Environ. Behav.*, vol. 48, no. 8, pp. 991–1029, 2016.
17. M. K. Lindell, J. H. Sorensen, E. J. Baker, and W. P. Lehman, "Community response to hurricane threat: Estimates of household evacuation preparation time distributions," *Transp. Res. Part D Transp. Environ.*, vol. 85, no. July, p. 102457, 2020.
18. M. K. Lindell and C. S. Prater, "Estimating Evacuation Time Components: Lessons from Nuclear Power Plants, Hurricanes, and the First World Trade Center Bombing," no. February 2014, p. 5, 2004.
19. R. Hassan and S. M. Haque, "Developing Local Level Disaster Risk Reduction Strategies Considering the Spatial Variation of Storm Surge Risk: a Case Study on Gabura Union, Syamnagar Upazila," pp. 530–534, 2019.
20. M. Nagarajan and D. Shaw, "A behavioural simulation study of allocating evacuees to public emergency shelters," *Int. J. Disaster Risk Reduct.*, vol. 55, no. July 2020, p. 102083, 2021.
21. A. M. Sadri, S. V. Ukkusuri, and P. Murray-Tuite, "A random parameter ordered probit model to understand the mobilization time during hurricane evacuation," *Transp. Res. Part C Emerg. Technol.*, vol. 32, pp. 21–30, 2013.
22. G. Troncoso Parady and E. Hato, "Accounting for spatial correlation in tsunami evacuation destination choice: a case study of the Great East Japan Earthquake," *Nat. Hazards*, vol. 84, no. 2, pp. 797–807, 2016.
23. S. Hasan, R. Mesa-Arango, and S. Ukkusuri, "A random-parameter hazard-based model to understand household evacuation timing behavior," *Transportation research part C: emerging technologies*, 27, 108-116, 2013.
24. M. B. B. Lim, H. R. Lim, and J. M. L. Anabo, "Evacuation destination choice behavior of households in Eastern Samar, Philippines during the 2013 Typhoon Haiyan," *Int. J. Disaster Risk Reduct.*, vol. 56, no. February, p. 102137, 2021.
25. M. A. Rahman, A. Hokugo, N. Ohtsu, and S. Chakma, "Evacuation Preparation Scenarios of Households during Early and Emergency Evacuation: A Case Study of Cyclone Bulbul in Southwestern Coastal Bangladesh," *IDRiM J.*, 2021.

26. B. K. Paul, "Factors Affecting Evacuation Behavior: The Case of 2007 Cyclone Sidr, Bangladesh," *Prof. Geogr.*, 2012.
27. B. K. Paul, H. Rashid, M. S. Islam, and L. M. Hunt, "Cyclone evacuation in bangladesh: Tropical cyclones gorky (1991) vs. sidr (2007)," *Environ. Hazards*, 2010.
28. M. N. Ahsan, K. Takeuchi, K. Vink, and M. Ohara, "A systematic review of the factors affecting the cyclone evacuation decision process in Bangladesh," *J. Disaster Res.*, vol. 11, no. 4, pp. 742–753, 2016.
29. S. K. Paul, "Determinants of Evacuation Response To Cyclone Warning in Coastal Areas of Bangladesh : a Comparative Study," *Orient. Geogr.*, vol. 55, no. 01, pp. 57–83, 2011.
30. S. K. Paul and J. K. Routray, "An Analysis of the Causes of Non-Responses to Cyclone Warnings and the Use of Indigenous Knowledge for Cyclone Forecasting in Bangladesh," in *Climate Change Management*, 2013.
31. B. K. Paul and S. Dutt, "Hazard warnings and responses to evacuation orders: The case of Bangladesh's cyclone Sidr," *Geogr. Rev.*, 2010.
32. K. Ikeda, "Gender Differences in Human Loss and Vulnerability in Natural Disasters: A Case Study from Bangladesh," *Indian J. Gen. Stud.*, vol. 2, no. 2, pp. 171–193, 1995.
33. C. E. Haque and D. Blair, "Vulnerability to Tropical Cyclones: Evidence from the April 1991 Cyclone in Coastal Bangladesh," *Disasters*, vol. 16, no. 3, pp. 217–229, 1992.
34. C. Roy, S. K. Sarkar, J. Åberg, and R. Kovordanyi, "The current cyclone early warning system in Bangladesh: Providers' and receivers' views," *Int. J. Disaster Risk Reduct.*, vol. 12, no. 12, pp. 285–299, 2015.
35. A. M. R. Chowdhury, A. U. Bhuyia, A. Y. Choudhury, and R. Sen, "The Bangladesh Cyclone of 1991: Why So Many People Died," *Disasters*, vol. 17, no. 4, pp. 291–304, 1993.
36. M. Esteban, V. P. Valenzuela, N. Y. Yun, T. Mikami, T. Shibayama, R. Matsumaru, H. Takagi, N. D. Thao, M. D. Leon, T. Oyama, and R. Nakamura, "Typhoon Haiyan 2013 Evacuation Preparation and Awareness", *J-SustaiN*, vol. 3, no. 1, pp. 37-45, 2015.
37. C. Walch, "Evacuation ahead of natural disasters: Evidence from cyclone Phailin in India and typhoon Haiyan in the Philippines", *Geo: Geography and Environment*. 5. 10.1002/geo2.51, 2018.
38. J. K. Lazo, A. Bostrom, R. E. Morss, J. L. Demuth, and H. Lazrus, "Factors Affecting Hurricane Evacuation Intentions", *Risk Anal.* 35(10):1837-1857, 2015.

39. M. K. Lindell, J. C. Lu, and C. S. Prater, "Household decision making and evacuation in response to Hurricane Lili", *Nat Hazards Rev*, 6 (4), pp. 171-179, 2005.
40. S. K. Huang, M. K. Lindell, and C. S. Prater, "Household evacuation decision-making in response to Hurricane Ike", *Nat Hazards Rev*, 6 (4), 13:283-296, 2012.
41. M. A. Meyer, B. Mitchell, J. C. Purdum, K. Breen, and R. L. Iles, "Previous Hurricane Evacuation Decisions and Future Evacuation Intentions Among Residents of South Louisiana", *Int J Disaster Risk Reduct* 31:1231–1244, 2018.
42. B. K. Paul, "Hazard Warnings and Compliance with Evacuation Orders: The Case of Bangladesh's Cyclone Sidr. The Natural Hazards Center", University of Colorado at Boulder, Quick Response Report, 2008.
43. I. Matsuda, "Loss of Human Lives Induced by the Cyclone of 29-30 April, 1991 in Bangladesh", *Geo Journal*, V. 31, no 4, pp. 319-325, 1993.
44. N. Leelawat, C. M. R. Mateo, S. M. Gaspay, A. Suppasri, and F. Imamura, "Filipinos' views on the disaster information for the 2013 Super Typhoon Haiyan in the Philippines", *Int. J. Sustain. Future Hum. Sec. J. Sustain.* 2 (2), 16–28, 2014.
45. A. M. F. Lagmay, R. P. Agaton, M. A. C. Bahala, J. B. L. T. Briones, K. M. C. Cabacaba, C. V. C. Caro, L. L. Dasallas, L. A. L. Gonzalo, C. N. Ladiero, J. P. Lapidez, M. T. F. Mungcal, J. V. R. Puno, M. M. A. C. Ramos, J. Santiago, J. K. Suarez, and J. Tablazon, "Devastating storm surges of Typhoon Haiyan", *Int. J. Disaster Risk Reduct*, 11, 1–12, 2015.
46. Y. Jibiki, S. Kure, M. Kuri, and Y. Ono, "Analysis of early warning systems: The case of super-typhoon Haiyan," *International Journal of Disaster Risk Reduction*, 15, 24–28, 2016.
47. H. Takagi, S. Li, M. E. Mario de Leon, T. Mikami, R. Matsumaru, T. Shibayama, and R. Nakamura "Storm Surge and Evacuation in Urban Areas during the Peak of a Storm," *Coast Eng* 108:1–9, 2016.
48. N. Dash, and H. Gladwin, "Evacuation decision making and behavioral responses: Individual and household," *Natural Hazards Review*, 8(3):69–77, 2007.
49. F. Zhang, R. E. Morss, J. A. Sippel, T. K. Beckman, N. C. Clements, N. L. Hampshire, J. N. Harvey, J. M. Hernandez, Z. C. Morgan, R. M. Mosier, S. Wang, and S. D. Winkley SD, "An in-person survey investigating public perceptions of and responses to Hurricane Rita forecasts along the Texas coast. *Weather and Forecasting*", 22:1177–1190, 2007.

50. R. E. Morss, J. L. Demuth, J. K. Lazo, K. Dickinson, H. Lazrus, and B. H. Morrow, "Understanding public hurricane evacuation decisions and responses to forecast and warning messages," *Weather Forecast* 31(2):395–417, 2016.
51. R. E. Morss, and M. H. Hayden, "Storm surge and "certain death": interviews with Texas coastal residents following Hurricane Ike," *Weather, Climate, and Society* 2(3):174–189, 2010.
52. H. C. Wu, M. K. Lindell, and C. Prater C, "Logistics of Hurricane evacuation in Hurricanes Katrina and Rita," *Transportation Research Part F*, 15(4), 445-461, 2012.

Chapter 8 Conclusion

8.1 Conclusion

This research is tried to investigate the overall performance of evacuation and associated factors that affect the evacuation-decision-making process. The findings from the previous studies revealed similarities with evacuation tendencies from Bangladesh, the Philippines, and the USA concerning cyclones, typhoons, and hurricanes, respectively. This can be considerable because of geographic situation, condition, and types of disaster. The comparison analysis concerning warning, weather, shelter, and people's perception regarding the time of impact, nature of risk, and associated factors can address issues and challenges from different perspectives. This will help to consider better planning and preparedness regardless of specific disasters but similar type of disasters.

Furthermore, this research sought to determine the factors influencing early evacuation decisions, early evacuation, and emergency evacuation based on the evacuation situation during Cyclone Bulbul. Cyclone Bulbul was identified as a very severe cyclonic storm, and 0.73 million people in 29 Upazilas in Bangladesh's coastal area were directly affected. Compared to past cyclone disasters in Bangladesh, the evacuation rate increased during Cyclone Bulbul because of improved disaster preparedness plans, better early warning systems, increased number of designated cyclone shelters, and increased awareness among people about evacuation. Additionally, the CPP plays an essential role in issuing and disseminating early warnings and providing evacuation guidance to the community during the evacuation, even when essential services such as electricity are not functional. This enables the safe evacuation of evacuees to shelters or other safer places [1]. Sometimes, it is difficult for local authorities to reach the community, especially when the weather condition worsens. However, informal interviews with respondents and CPP unit team leaders also mentioned that CPP volunteers assist people evacuating, but sometimes it is also difficult for them to reach the individual household as weather conditions worsen. Accordingly, it is recommended that CPP volunteers participate in the evacuation process with local authorities to make the evacuation more effective and complete it in a safer location. According to Haque and Blair (1992), people in coastal areas in Bangladesh consider evacuation at the very last moment—usually a barrier to complete and safe

evacuation [2]. This research found that, even though the evacuation rate increased, many people still did not evacuate because of the poor road network, distance to cyclone shelters, delayed dissemination of evacuation orders, concern for protecting household goods and livestock, and the presence of vulnerable members in the house. However, it is essential to focus on safe evacuation to reduce physical damage, particularly casualties and injuries during a cyclone. Follow-up surveys should further explore safe evacuation as many have died over the past years because of natural disasters, and people in Bangladesh's coastal areas are expected to face similar disasters in the future. Because people in Bangladesh's coastal areas lack ample knowledge about the severity of cyclones, they are worried about their timely and safe evacuation. The results revealed that household respondents are also concerned about their houses and other belongings needed for their daily lives, and they have to protect them. Therefore, it is also necessary for the government to take initiatives to help coastal people build their houses in low-risk zones and therefore provide possible support for this, considering the long-term disaster preparedness plan.

Parvin et al. (2019) revealed the gender-based evacuation preparation time before starting evacuation during Cyclone Aila in 2009, which could be an excellent issue for evacuation at the right time [3]. However, evacuating with household members, especially with vulnerable members, is also a great concern, particularly regarding early evacuation concerning evacuation preparation time. This research investigated household evacuation preparation time rather than individual time because the coastal community usually evacuates with household members, not individually. The results showed that if there are vulnerable members in the house, those households need longer preparation times and longer evacuation travel times. Similarly, this research found that women face difficulties while evacuating with sick members during a disaster. Therefore, it will be better to identify and recognize such types of households and help them safely evacuate future disasters. The data also showed that the early evacuation rate was relatively lower among households with vulnerable members. People want to evacuate early when they have vulnerable members in the house to ensure safe and successful evacuation because they are aware of the difficulties of evacuating with such members, especially when they must evacuate by walking. Therefore, responsible authorities should focus on effective preparedness for early evacuation and plan for safe and complete evacuation during a disaster. Although this research investigated specific vulnerable members in the house in detail, it is also necessary to include the pregnant member, therefore analyzing the possible consequences of safe

evacuation as well. Steps such as the early issue of evacuation orders should be taken to increase the possibility of early and safe evacuation in the future, especially when there are vulnerable members in a house.

Furthermore, disaster management should focus on the preparation time, as the amount of time available for organizing things before evacuation decides whether it would be an early evacuation or emergency evacuation. Identifying the right time for evacuation is essential for safe and successful evacuation because various associated factors affect evacuation time, which can delay the evacuation time. Therefore, early evacuation could be an advantage for effective and safe evacuation. However, the early evacuation time is different for different disasters [4]. The most significant contribution of this research is that it provides a better understanding of people's perceptions about early evacuation decisions and sheds light on the factors influencing early evacuation based on an analysis of the evacuation-related difficulties they faced during Cyclone Bulbul. This research revealed that almost half of the household respondents took early evacuation decisions, but in actual cases, they did not. This research recommends the issue of proper and timely evacuation orders and proper guidelines, which would help increase the early evacuation rate among coastal residents, especially when they have vulnerable members in their households. By ensuring that vulnerable members have enough time to complete the evacuation safely and successfully before the weather condition changes from bad to worse during a disaster. This research recommends the issue of proper and timely evacuation orders, which would help increase the early evacuation rate among coastal residents, especially when they have vulnerable members in their households. Ensuring that they have enough time to complete the evacuation safely and successfully before the weather condition changes from bad to worse during a disaster. Responsible authorities should review existing policy actions and modify their approach where necessary to improve the possibility of early evacuation during future disasters. This may help reduce the risk of injuries and casualties during cyclones in the Bangladesh coastal regions.

Due to climate change and global warming fluctuations, natural disasters often occur in the coastal areas of many regions and countries, especially in developing countries. Therefore, people living in these coastal areas are vulnerable to natural disasters, especially cyclones, typhoons, and hurricanes. Moreover, proper steps and plans should be taken to reduce the disaster risk for inhabitants of coastal areas. The overall prediction results are more accurate and realistic than the traditional method and can be used in other parts of

Bangladesh's coastal region, which experience similar natural disasters. In addition, this method can also be used in coastal areas of other countries, especially in developing countries, based on different conditions and characteristics of natural disasters. For example, the input variables used in this study can be altered based on the type of natural disaster and severity, depending on regional circumstances and related factors. The proposed method also investigated the influential factors through variable importance and PDP to present a detailed relationship between different demographic and behavioral factors and household evacuation preparation time. It is found that if children, disabled and older people in the house those houses need longer preparation time. So, it is recommended that responsible authorities identify and list those houses and take some initiatives to update the list all year round. Therefore, during disaster time, they help that household in the preparation phase with volunteers, especially with CPP volunteers, in priority to ensure their safe evacuation. In addition, results showed that young people are very active and need less time as evacuation preparation time. So, it is better to encourage younger people to help other households during preparation and evacuation. Following this, the local disaster management authority takes some initiatives to arrange workshops and provide basic training concerning evacuation preparedness. That will probably greatly influence the evacuation preparation phase, which leads to safe evacuation. Another important finding is that a designated shelter is not enough concerning distance but has better facilities that's why evacuees need fewer things to prepare and less preparation time. Some temporary shelter plans considering safe places like embankments or higher places with basic facilities could be effective shortly during an emergency. Poor people always want to save their belongings while taking longer preparation time have difficulties in making safe evacuation as evacuation at a later stage. So, it is better to identify risk and safe zone and allocate people to a safe area, providing them possible financial support to reduce the disaster risk.

Finally, the overall results revealed that some demographic and behavioral factors, such as evacuation companion, age, income, type of shelter, shelter distance, and age, have a significant correlation on household evacuation preparation time. But it may be different for other areas based on population, information access, geographic location, and related condition. So, we suggest using this type of prediction model to analyze the associated influential factors regarding similar types of disasters to reduce future disaster damage and casualties and ensure safe evacuations. Furthermore, this prediction model for evacuation preparation time, which is essential for effective evacuation decision-making processes, is

the initial approach based on a cyclone disaster. This will also help governments and individual concern groups understand the situation and condition of individual households and the types of difficulties and factors that affect their evacuation preparation time. Therefore, using this data will enable the creation of better evacuation plans for future cases of similar types of disasters, considering the issues that affect timely and safe evacuations.

8.2 References

1. M. Miyaji, K. Okazaki, and C. Ochiai, "A Study on the use of Cyclone Shelters in Bangladesh," *J. Archit. Plan. (Transactions AIJ)*, 2017.
2. C. E. Haque and D. Blair, "Vulnerability to Tropical Cyclones: Evidence from the April 1991 Cyclone in Coastal Bangladesh," *Disasters*, vol. 16, no. 3, pp. 217–229, 1992.
3. G. A. Parvin, M. Sakamoto, R. Shaw, H. Nakagawa, and M. S. Sadik, "Evacuation scenarios of cyclone Aila in Bangladesh: Investigating the factors influencing evacuation decision and destination," *Prog. Disaster Sci.*, vol. 2, p. 100032, 2019.
4. N. Y. Yun and M. Hamada, "Evacuation behavior and fatality rate during the 2011 Tohoku-oki earthquake and tsunami," *Earthquake Spectra*. 2015.

Doctoral Dissertation, Kobe University

“A Study on Prediction of Evacuation Preparation Time Based on Factors Affecting Households' Evacuation Decision in Response to Cyclone in Bangladesh (バングラデシュにおけるサイクロン災害時の世帯での避難意思決定要因に基づく避難準備時間の推定)”, Total 110 pages

Submitted on January, 20, 2022

The date of publication is printed in cover of repository version published in Kobe University Repository Kernel.

© MD ATIKUR RAHMAN
All Right Reserved, 2022