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CAUSATIVE FACTORS ANALYSIS OF PASSENGER VESSEL ACCIDENTS IN INLAND WATERWAYS OF BANGLADESH

Causative Factors Analysis of Passenger Vessel Accidents in Inland Waterways of Bangladesh

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Recommendation of the Board of Examiners

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Dedication

I like to dedicate this thesis to my parents, my wife, and my teachers.

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Abstract

Bangladesh is a South Asian country that relies heavily on inland waterways as one of its primary modes of transportation. Locally available passenger-carrying vessels, such as launches, ferries, trawlers, speedboats, and country boats, are commonly used to cross rivers and travel between regions connected by waterways. While this mode of transportation is the most economical and environmentally friendly, it is often regarded as unsafe due to the severe accidents that pose significant risks to passengers' lives. To mitigate the dangers associated with inland waterway passenger vessel accidents, it is essential to identify the underlying factors contributing to the causes and severity of these incidents.

This study investigates the key factors related to inland waterway accidents, focusing on three core aspects: injury severity, the final condition of the vessel, and the causes of accidents. A dataset comprising 337 inland passenger vessel accidents between 1983 and 2017 was analyzed. Injury severity was categorized into three levels: no injury, injury, and fatal injury; vessel condition was classified as either sunk or afloat; and accident causes were divided into collision, overloading, storm, and other miscellaneous reasons. Three separate analyses were conducted, using the ordered probit model for injury severity, the binary logit model for the final condition of the vessel, and the multinomial logit model for the causes of accidents. Mixed-coefficients models were also employed in each study to identify the presence of heterogeneity across observations. Additionally, marginal effect analyses were performed to quantify the effect of a change in an independent variable on the dependent variables injury severity, final condition of vessel, and accident causes.

The timing, route and cause of the accident; vessel dimensions and condition after the accident; master's qualifications; and collision type were all significantly associated with injury severity. Furthermore, higher age of vessels, high number of passengers and lack of navigational tools contributed to vessel sinking. Factors related to collision-prone accidents were closely associated with the presence of navigation equipment, the number of vessels and an operator's recognition regarding responsibilities, while factors for storm-related accidents were based on seasonal patterns and lack of experienced operators. Such findings can provide a comprehensive outlook for the dynamics of inland waterway accidents in Bangladesh and policy recommendations. One of the preconditions for safer and secure Inland Waterway Transportation in countries like Bangladesh is that all existing vessels should be regulated to ensure compliance with strictly enforced safety standard, design accessibility requirements as well as regulation (including age regulations). The enhancement of crew skills, strict application of the capacity limitation for vessels and reinforcement of emergency response can greatly reduce the damage caused by accidents. Furthermore, specific enforced measures on high-risk sections such as during the monsoon season could be aimed to reduce fatal casualties and improve overall accident situation.

CHAPTER 1: INTRODUCTION

1.1 Background

Roadways, railways, and waterways are the three main components of a country's transportation network that contribute heavily to the economic development and regional integration between various regions. Roads are very convenient and easy to reach, advantageous for short-distance travel and goods exchange within cities. Railways are effective for carrying heavy cargo and many passengers over long distances. Inland waterways, such as rivers and canals, offer a cost-effective and environmentally friendly way to transport goods and people, especially where road and rail networks are limited (World Bank, 2007). In Bangladesh, the situation is quite similar, with roadways, railways, and inland waterways serving as the core pillars of the national transportation system. Between 2008 and 2014, a total of 18,771 transportation-related accidents were recorded, of which roadways accounted for 87%, railways for 12%, and inland waterways for just 1%. During the same period, roadways were responsible for 93% of casualties, while railways and waterways accounted for only 3% and 4%, respectively. At first glance, these figures suggest that inland waterways are the safest mode of transport. However, the reality is more complex. When measured by comparative fatality index and fatalities per accident, inland waterways recorded the highest figures (Prova & Hoque, 2018), indicating that although accidents are less frequent, they tend to be the most severe when they do occur. When accidents occur at sea or on inland waters, they often cause many deaths, such as the MV Dona Paz ferry disaster in the Philippines, which resulted in over 4,000 fatalities (Safety4Sea, 2022). Rescue efforts on water are also more difficult and take longer, increasing the chance of many lives being lost. Therefore, while inland waterways may seem safer, accidents on them can be extremely serious, making them an important issue globally.

This global concern becomes even more evident when comparing accident statistics and casualty patterns across different regions. In 2020, the number of maritime accidents reported by the European Union (EU) member states were 2,837 where 38 fatalities and 675 injuries have occurred (EMSA, 2021). Though for European maritime accidents, the number of fatalities is less compared to injuries but for Bangladesh inland waterway, the situation is different. Here fatalities cover the highest portion of the overall casualty (Uddin & Awal, 2017; Uddin & Awal, 2018; Mia et al., 2021). Compared to ocean vessels, those utilised in inland waterways are smaller in size and possess lower ability to handle emergencies. This leads to the probability of higher injury severity of an accident faced by a vessel operating in inland waterway (Wang & Yang, 2018). From the year 1994 to 2014, approximately 5,500 people died and 1,500 went missing in 658 waterway accidents in Bangladesh which reflects the heavy toll of human lives faced by this important medium of transportation (Rashid & Islam, 2017). Focusing on more recent data, in 2015, the inland waterway fatality index in Bangladesh was approximately 0.49 deaths per 100,000 passengers, based on 244.7 million passengers and 120 reported fatalities (ARI, BUET, 2019; BIWTA, 2022). In contrast, Canada recorded a significantly lower fatality index of 0.09 deaths per 100,000 passengers, with 6 fatalities among 64.7 million ferry passengers (Transportation Safety Board of Canada, 2016). This comparison, normalized by exposure, highlights that the risk of passenger fatalities in Bangladesh's inland waterways is more than five times higher than in Canada, emphasizing the urgent need for improved safety measures and regulatory enforcement.

After an inland waterway accident, a vessel can experience several final conditions, including remaining afloat but heavily damaged, capsizing, grounding, or sinking. Among these, sinking is considered the most dangerous because it poses immediate risks to human life, environmental harm, and economic loss (Jin, 2014). Sinking often leads to rapid immersion of the vessel, limiting time for evacuation and increasing the likelihood of casualties due to drowning or hypothermia (Weng & Yang, 2015). This amplifies the tragic outcomes of such accidents, making sinking a focal concern in inland waterway safety.

Inland waterway accidents in Bangladesh are mainly due to collision, overloading, capsize and sheer, nor'westers and cyclones, and occasional fires or explosion (Awal et al., 2006; Rahman, 2017). Collisions, such as with cargo or passenger ships, are one of the common causes for accidents and they result in severe injuries. Similarly, overcrowding especially in passenger ferries is often a cause of capsizing and mass fatalities. The second key factor is natural disasters, especially cyclones, which frequently result in vessel capsizes and high loss of life due to inaccurate weather forecasting and inadequacy of vessel design. Structural failures and unsafe vessel designs further contribute to severe injuries and sinking risks.

There are various types of vessels operate on the inland waterways of Bangladesh, including passenger vessels, ferries, country boats, trawlers, speedboats, sand carriers, and cargo carriers (Mia et al., 2021). Previously passenger vessels and cargo carriers were involved in most of the waterway accidents in Bangladesh (Uddin & Awal, 2017; Uddin et al., 2017a; Uddin et al., 2017b; Uddin & Awal, 2018) but in recent years the accident involvement of the passenger vessels are the highest among others (Mia et al., 2020).

Some studies in abroad tried to find out the different causal factors of waterway accidents but those findings are not appropriate for Bangladesh's passenger vessels' perspective. Because here the passenger vessels are different from developed countries and also there are diversifications in terms of vessel size, speed, and manoeuvrability. These may create challenges for the safe movement of the vessels as all of them are using the common routes. Additionally, smaller vessels may lack proper communication and navigational aids, while varying skill levels of the vessel masters can increase the risk level. Thus an in-depth statistical investigation is needed to be carried out in order to understand the causation of inland waterway accidents and related severity in Bangladesh. This research aims to address these issues by analyzing the influence of various factors on passenger vessel injury severity, final condition of the vessel, and the causes of accidents.

1.2 Objective of the Study

The main objectives of this study are,

- To investigate the effect of different factors on injury severity (no injury, injury, and fatal injury).
- To find the effect of different factors on final condition of vessel (sink or float).
- To explore the causal factors of different types of waterway accidents (collision, capsizing, hull damage, grounding, fire and explosion).
- To find the most sensitive factors leading to the occurrence of a waterway accident, final condition of vessel, and related severity.

1.3 Scope of Research

This study investigates the factors contributing to inland waterway accidents in Bangladesh, focusing on injury severity, final vessel conditions, and causal factors of accidents. Unlike previous research, which primarily summarized accident data, this study applies rigorous statistical models to identify key determinants, including vessel type, size, age, and engine capacity, as well as environmental and operational factors like weather conditions, time of day, and location.

The study examines inland waterway accidents involving various types of passenger vessels, including passenger launches, ferries, passenger trawlers, and speed boat, each with unique operational characteristics and accident risks. The analysis uses historical accident data and incorporates a comprehensive range of variables to understand their impact on three specific aspects: injury severity (no injury, injury, and fatal injury), final vessel condition (sink or float), and accident cause (collision, capsizing, hull damage, grounding, fire, and explosion).

The research also identifies the most sensitive factors leading to accidents, vessel conditions, and injury severity, providing insights into the complex interplay of operational, environmental, and design factors.

1.4 Significance of the Research

This study contributes significantly to the understanding of inland waterway accidents in Bangladesh and offers practical implications for improving safety. The key contributions of this research include:

1. The study systematically identifies key determinants, such as vessel type, size, and operational factors, influencing injury severity, vessel conditions, and accident cause.

2. By applying statistical models, the research overcomes the limitations of previous studies that lacked rigorous analysis and failed to account for critical factors like vessel features, availability of safety equipment, operator experience, and environmental conditions.

3. Unlike international studies that may not apply to Bangladesh due to differences in vessel characteristics, operational practices, and environmental conditions, this study provides context-specific insights relevant to Bangladesh's inland waterway system.

4. The findings will guide policymakers and regulatory bodies in implementing effective safety measures, improving vessel design standards, and optimizing operational practices to minimize accident risks.

5. The study will contribute to developing a more robust inland waterway safety framework by identifying sensitive factors and providing data-driven recommendations for accident prevention and mitigation.

6. By analyzing passenger vessel accidents, the research highlights specific risks and strategies to enhance safety for millions of passengers relying on inland waterways annually.

7. The findings align with broader objectives of promoting safe, efficient, and sustainable transportation systems, reducing fatalities, and improving public confidence in inland water transport.

This research not only enhances the understanding of inland waterway safety but also contributes to achieving sustainable development goals by addressing critical safety factors related to Bangladesh's transportation sector.

1.5 Outline of Thesis

The thesis is structured into seven chapters. Following the introductory chapter, the subsequent six chapters address the following topics:

Chapter 2-Literature Review

This chapter reviews factors associated with the injury severity of passengers, the final condition of vessels post-accident, and the causal factors of waterway accidents as explored in previous studies. Key information and findings from these studies are systematically documented.

Chapter 3-Data and Methodology

Chapter three details the sources of the database and the types of data collected from these sources. It further discusses the classification of injury severity, the final condition of vessels, and the causes of accidents. Additionally, the chapter provides an explanation of the statistical models employed for analysis, including ordered probit regression, binary logistic regression, and multinomial logistic regression.

Chapter 4, 5, and 6-Injury severity, final condition of vessels, and causes of accident model

Chapters Four through Six systematically present three analytical models: the Injury Severity Model, the Final Condition of Vessel Model, and the Causes of Accident Model. Each chapter offers a comprehensive discussion of the model development methodology, the criteria employed for evaluation, the validation approaches adopted, and an interpretation of the significant variables associated with each model.

Chapter 7-Conclusions and Recommendations

Finally, in chapter seven, a general discussion and overall analysis of the three model results are given. This is followed by recommendations and conclusions.

CHAPTER 2: LITERATURE REVIEW

In this thesis, the literature review is systematically presented to focus on inland waterway accident issues. The study opens with an account of the history and current state of inland waterways in Bangladesh, including the classification of waterways and types of vessels that use them. Next, this review discusses the evidence on other aspects of waterway accidents and injuries including severity of injury, post-accident status of the vehicles/vessels involved and causes. Lastly, the review highlights the key methodologies employed in analyzing waterway accidents. In conclusion, this literature review provides a comprehensive understanding of the factors influencing inland waterway accidents and the analytical approaches used to address them.

2.1 History and Present Scenario of IWT (Inland Water Transport) in Bangladesh

The history of IWT has begun in India 185 years ago with the introduction of first mechanized vessel. The name of the first inland steamer vessel that propelled in the river Ganges in 1834 was "Lord William Bentinck". The India General Navigation and Railway Company Ltd. (I.G.N.R.) was the first inland steamer company in India which was started in 1844. During the time period of 1880 to 1899 as many as 898 vessels used to ply on the route from Calcutta to Khulna through the Sundarban every year. At Pakistan period, in order to enhance the role of water transport in the economic sector of the country, five major inland ports were established with modern facilities in Dhaka, Narayanganj, Chandpur, Barisal and Khulna (Rahman, 2017). With the increase of commerce and industry in the post-independence period, six more inland ports were constructed followed by up-gradation and modernization. These ports are Patuakhali, Nagarbari, Aricha, Dauladia, Baghabari and Narshingdi. Apart from providing ports in the major cities and the commercial centers, landing facilities were provided to the people of the remote areas. Wayside terminals (ghats) were provided since 1971 and at present there are 1325 launch terminals for meeting the demand of the people in remote areas where water transport is the only mode of transportation. Out of these, only 136 launch terminals are managed and maintained by the government agency of BIWTA (Bangladesh Inland Water Transport Authority) (Huq & Dewan, 2003). There are about 70,00,000 river vessels are operating in the country and every year around 87.80 million passengers use inland waterways (BIWTA, 2009). Since independence in 1971 movements of goods and passengers from the district of the southern region of Bangladesh have increased and water transport is the only mode of transport to the capital city, Dhaka. Especially people from coastal districts and islands including Bhola, Barisal, Patuakhali, Barguna, Jhalokathi and Pirozpur have their day to day communication with Dhaka and other major cities through IWT (Islam et al., 2015). The inland water transport network of Bangladesh is shown in Figure 2.1. The combined length of rivers, streams, and canals of Bangladesh are 24,000 km among which only 3,865 km is navigable during the dry period. In the monsoon period the length of navigable route increases to 5,968 km. The summary of inland waterways of Bangladesh is shown in Table 2.1.

Table 2.1: Summary of inland waterways of Bangladesh (BIWTA, 2009)

Total length of inland waterways	24,000 km	
Length of navigable waterways	Dry Season	Monsoon
	3865 km	5968 km
Least available depth range	3.90 m to 1.50 m	
Annual water discharge (Source: BWDB)	1400 billion cubic meter	
Annual quantum of silt (Source: BWDB)	2.5 billion tons	
No. of passenger carried (In year)	87.80 million	
Quantum of cargo carried (In year)	0.58 million ton	

2.2 Classification of Inland Waterways

Inland waterways are specifically called "routes", which serve to interconnect or link various inland ports or "nodes". On the basis of scale of operation and the least available depth (LAD) the IWT routes are grouped into four classes (Azad, 2009):

- Class-I routes include the main arteries of traffic flow connecting the five principal river ports, viz. Dhaka, Narayanganj, Chandpur, Barisal and Khulna as well as connecting them with the sea ports of Chittagong and Mongla. The most important routes in this category are (i) Narayanganj-Chittagong via Chandpur (ii) Narayanganj-Mongla via Chandpur, Barisal and the Sundarban channels and (iii) Mongla-Khulna

- Class-II routes are secondary routes which provide links between the principal river ports and the secondary river front centers. On these routes, dredging operations are often required in order to maintain navigability. Some of the notable routes in this category are (i) Chandpur-Goalundo (ii) Chandpur-Barisal and (iii) Narayanganj/Dhaka-Chhatak (in Sylhet) via Bhairab Bazar.

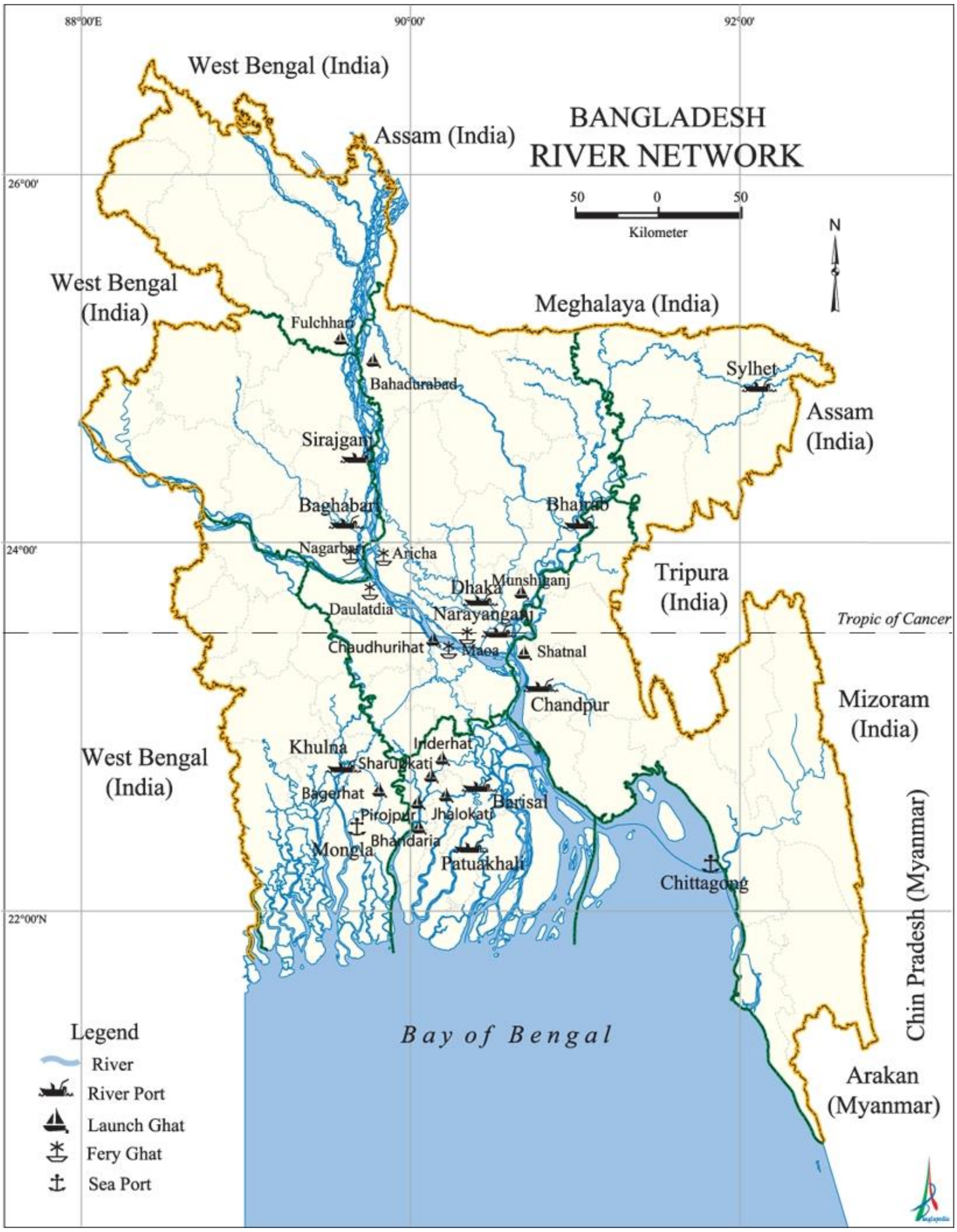

Figure 2.1: IWT network of Bangladesh (Islam et al., 2015)

- Class-III routes are IWT links of regional importance connecting smaller commercial centers like Patuakhali, Bagerhat, Kushtia, Jhalakati, Chilmari, Chandraghona etc.

- Class-IV routes are also often recognized for such routes which are entirely seasonal and serve as feeder routes to the other three classes of routes.

Table 2.2: Status of inland navigable routes (BIWTA, 2009)

Name of Route	Minimum Depth	Length of Route and Percentage	Minimum Vertical Clearance	Minimum Horizontal Clearance
Class-I	3.66 m	683 km (11.39 %)	18.30 m	76.22 m
Class-II	2.13 m	1027 km (17.13 %)	12.20 m	76.22 m
Class-III	1.52 m	1885 km (31.44 %)	7.62 m	30.48 m
Class-IV	Less than 1.52 m	2400 km (40.04 %)	5.00 m	20.00 m

2.3 Different types of Inland Waterway Vessels

There are two authorities responsible for the monitoring of Inland Water Transport (IWT) in Bangladesh. They are Department of Shipping (DOS) and Bangladesh Inland Water Transport Authority (BIWTA).

2.3.1 Launch

According to DOS the number of registered passenger launches in Bangladesh at the end of year 2018 is 832. They are generally made of steel hull with no designated cargo holds. Instead of conspicuous cargo compartments, passenger launch contains smaller private cabins to provide some luxury and privacy to the wealthy passengers.

Nevertheless, in most of the passenger launches there remain large open spaces on the decks where the economy class passengers can travel. Passenger launches are designed with mechanical or hydraulic steering and mostly being used for medium to long distance traveling in Bangladesh (Azad, 2009). There is single decker, double-decker and triple-decker passenger launches that ply on different routes daily. Launches traveling to near destinations around the capital city are smaller in size and make more than one return trip throughout the day. Large motor launches going to distant locations have specific time schedules (Islam et al., 2015).

Figure 2.2: Passenger Lunch (PL) (Samee, 2016)

2.3.2 Cargo

Cargo vessels, play a crucial role in Bangladesh's freight transportation system. These vessels, primarily made with robust steel hulls, are designed to safely handle bulk and containerized cargo, including industrial products, raw materials, and agricultural goods. To accommodate varying distances and routes, cargo vessels operate in singledecked or multi-decked configurations and are equipped with either mechanical or hydraulic steering systems for smooth navigation. Their spacious cargo holds are specifically tailored to optimize the transportation of diverse goods efficiently.

Figure 2.3: Cargo (C)

2.3.3 Oil tanker

Oil tankers, integral to the transportation of petroleum and its derivatives, feature specialized compartments to ensure the safe containment of flammable liquids. The vessels are designed with technological innovations for safety, such as double-hull configuration and the fire protection gear according to international standards. Oil tankers run on a regular schedule between the major ports and refineries, most of them serving no other purpose than transportation of oil.

Figure 2.4: Oil Tanker (OT)

2.3.4 Ferry

Ferries, another important type of vessel in Bangladesh, serve as a vital means of transportation between parts cut off by the many rivers. Vessel types also range in size to accommodate light ferries, medium-capacity ships on short line hauls, and passenger and vehicle transportation with several hundred passengers. Ferries are mainly developed for short to medium range services, and are often on high frequency service so that daily commuters and regional trade can be catered by them (Azad, 2009).

2.3.5 Passenger Trawler

Passenger trawlers, commonly used for local and short-distance riverine transportation, are smaller in size compared to launches and ferries. These vessels are constructed with both steel and wooden hulls and often lack advanced navigational systems, relying instead on manual steering. Passenger trawlers cater to individuals traveling within rural areas, providing an affordable and accessible mode of transportation across rivers and narrow waterways (Islam et al., 2015).

Figure 2.5: Ferry (F) (Dhaka Tribune, 2022)

Figure 2.6: Passenger Trawler (PT) (Rahman, 2008)

2.3.6 Sand Carrier

Sand carriers, essential to the construction industry, are designed to transport dredged sand from riverbeds to urban and industrial sites. These vessels typically feature open-deck designs with reinforced hulls to handle heavy loads. Sand carriers operate on specific river routes and are often managed by private operators, playing a vital role in supporting the infrastructure development of Bangladesh (UN.ESCAP, 2021)

Figure 2.7: Sand Carriers (SC)

2.4 Different aspects of waterway accidents

Inland waterway accidents in Bangladesh present significant challenges to both the safety of passengers and the operational integrity of vessels. These accidents can be analyzed through three critical aspects: injury severity, the final condition of the vessel, and the causes behind the accidents. Injury severity helps determine the human cost of accidents, highlighting the importance of safety measures and emergency preparedness. The final condition of the vessel reveals the extent of damage and the economic impact on the industry, while understanding the causes of these accidents, whether human error, mechanical failure, or environmental factors, is essential for preventing future occurrences.

2.4.1 Inland waterway accidents of Bangladesh

Many studies have been conducted considering the inland waterway accidents of Bangladesh. At first, researchers tried to identify the primary causes of waterway accidents and collisions, overloading, cyclones, grounding, fire, and explosions have been identified as the major reasons (Awal et al., 2006; Rahman, 2017). Accidents due to overloading and cyclones occur mainly during the monsoon season (Awal, 2006; Awal et al., 2010). Whereas majority of collision-type accidents occur during the winter season due to the scarcity of daylight and foggy weather (Uddin et al., 2017a; Mia et al., 2020). In contrast to this finding Uddin and Awal (2018) said that operational issues and human factors are the main reasons behind the collision-related accidents as they are also occurring in calm weather and good visibility conditions.

Regarding the occurrence time of waterway accidents, Awal et al. (2006) have not found any particular pattern but Awal (2006) said that accidents due to collisions and cyclones have occurred mostly in the evening and before midnight. In a later study, Awal et al. (2010) also mentioned the slightly higher tendency of waterway accidents during peak hours and midnight.

Though there are contradictions between the findings of different researchers but all of them agreed that collision is the main reason behind almost 60% of the waterway accidents in Bangladesh (Uddin et al., 2017a; Uddin et al., 2017b; Uddin & Awal, 2017; Uddin & Awal, 2018; Uddin et al., 2020). Also, southern zone routes have been identified as the most vulnerable (Mia et al., 2020). In almost half of the cases after a waterway accident, the vessel gets sunk which increases the probability of injury severity (Uddin et al. 2017; Uddin & Awal, 2018). Despite having some agreement and disagreement, none of these findings are statistically proven and factors affecting the injury severity, final condition of the vessel and accident causes were not the primary concern in any of the studies already mentioned.

2.4.2 Studies related to injury severity

Though there is a visible gap in the local context of injury severity analysis of waterway accidents, many foreign literatures exist where the researchers tried to identify the significant factors affecting the injury severity of sea-going vessels. As the tide, wind effect, and water depth are much more severe in the ocean compared to a river, so waterway accidents occur in seawater and their relative severity has always been a concern for the investigators.

For example, Talley et al. (2006) found that for larger vessels if capsizing occurs in an ocean, the number of missing persons becomes higher. According to their study, for passenger vessels, the number of fatalities is higher during rainy weather when poor visibility condition exists and a collision-type accident occurs. They have also found that vessels which carry both passengers and freight leading by an accident due to human error, tend to result in more severe injuries. In another study, Talley et al. (2008) revealed that accidents on ocean cruises are more likely to produce severe injuries compared to those on inland waterways and harbor cruises. Increased likelihood of both non-fatal and fatal injuries due to accidents caused by human error is another finding.

According to Jin (2014), the stability loss followed by the sinking of a fishing vessel in seawater increases the marginal probability of fatal injuries. Weng and Yang (2015) determined that the likelihood of fatal accidents and deaths at sea is significantly elevated for collision, fire/explosion, contact, and grounding incidents. Particularly, sinking incidents are identified as the most significant element in elevating the probability of deadly accidents and associated fatality rates. Also, fatalities are more common in accidents that occur at considerable distances from the port. Furthermore, cruise ships are associated with higher mortality rates compared to non-cruise ships.

In another study, Wang et al. (2021) found a positive link between the intensity of marine accidents with sinking incidents, distances from the port, heavy wind, and strong currents. Also, fishing boats and similar types of small vessels are most frequently involved in high-severity accidents. Additionally, seafarers with inappropriate theoretical knowledge and less experience, ships with faulty certification, insufficient crew members, and ships over 30 years old cause accidents of high severity. As per Li et al.s’ (2021) study, presence of heavy wind and waves increases the possibility of casualty at seawater. They have also found that collision-type accidents and fishing vessels are more likely to increase the severity of casualties compared to others. Wang et al. (2022) discovered that collision and vessel age significantly influence fatality and injury outcomes in incidents occurring in the English Channel and North Sea.

In a recent study, Cao et al. (2023) found that sinking, hull damage, and collision are the three accident types that can cause very serious casualties. Their another finding is the relation between vessel size and relative severity. According to them, small vessels like fishing vessels, passenger vessels, and chemical ships are often produce casualties of higher severity. They have also mentioned about the higher possibility of very serious casualties in coastal water compared to inland waterways and ports due to the reduced speed of the ship.

Existing research primarily emphasizes the severity of injuries resulting from accidents involving ocean-going vessels, highlighting factors such as vessel size, weather conditions, and operational characteristics. However, these studies offer limited applicability to inland waterways, particularly in countries like Bangladesh where medium and small passenger vessels dominate. The vulnerability of these vessels, combined with different operational environments and comparatively lower standards in training and enforcement, suggests the need for context-specific research. A critical gap remains in understanding the injury severity determinants within Bangladesh's inland waterways, where the dynamics of accidents differ substantially from marine contexts.

2.4.3 Analysis on final condition of vessel

Research examining the final condition of vessels after waterway accidents has explored diverse factors that lead to outcomes such as sinking, total loss, or severe structural damage.

Talley (1996) studied the factors influencing the severity of damage in containership accidents. The analysis revealed that collisions and groundings, classified as "shipmotion" accidents, were primary causes of extensive hull damage. Fires and explosions, categorized as "ship-integrity" accidents, were also significant contributors to vessel integrity compromise. Vessel size and material were noted as influential variables, with larger ships generally showing greater resilience, though this varied depending on the specific circumstances of the accident.

Chen et al. (2019) analyzed worldwide marine accidents that took place from 1998 to 2018, and foundering, stranding and fire/explosion were the primary causes of total-loss marine casualties across the globe. Their findings highlighted regional variations, and smaller ships like fishing boats and cargo vessels were particularly vulnerable. Their findings also pointed out that environmental and operational factors had to be taken into account in the risk management against total-loss accidents.

Jin (2014) investigated fishing vessel accidents in the U.S. and indicated that older vessels experienced more serious losses, particularly when plying in bad weather conditions. Smaller vessels had more severe damage that was a result of decreased stability. Environmental variables such as high wind and distance from shore were positively related to capsize and sink. These results highlighted the significance of vessel maintenance and structural integrity in mitigating accident severity.

Waskito et al. (2024) analyze ship sinking incidents in Indonesian waters. The results identified human error and inadequate maintenance as dominant risk factors. Older vessels with structural weaknesses were particularly prone to sinking. The authors emphasized that eliminating unsafe practices and improving crew training could reduce the probability of sinking by 17.2%.

Most of the studies mentioned here have analysed post-accident outcome of vessels. such as sinking or structural failure, concentrated on deep-sea or international maritime operations. These findings often overlook the operational realities of smaller, older, and less-regulated vessels prevalent in Bangladesh’s river systems. As a result, the impact of local maintenance practices, vessel age, and construction standards on accident outcomes remains underexplored. There is a clear lack of empirical investigation into how such factors influence the final condition of vessels in the context of Bangladesh’s inland waterways.

2.4.4 Summarization of waterway accidents

Accidents in waterways are typically caused by a combination of factors. However, there are several primary causes that recur consistently across different studies: collision, grounding, excessive current, storm conditions, and overloading. Each of these causes has been widely researched, and understanding them can help in designing better safety measures to prevent accidents.

Collisions are among the most frequent and serious types of waterway accidents. A collision is a type of accident in which one or more ships strike each other, or a ship runs aground. Such collisions can cause serious vessel damage, personal injury and even death. The fact that collisions are the result of bad navigation, inadequate communication and local situation, is stressed in several studies. Talley et al. (2008) also pointed out that collision-type occurrences are particularly frequent in waters with a lot of vessel traffic, such as crowded sea passages and ports. Collisions commonly happen when ships do not follow navigation regulations or crew members underestimate the distance between the two vessels. Talley (1996) concluded that collisions and groundings were especially abundant in narrow, confined waterways where vessels have a tendency to drift off course or misjudge turns. Wang et al. (2022) reported that vessel size and speed of navigation are also factors in the potential risk of collision. Larger boats are also less maneuverable and are capable of possessing more damaging force if an accident occurs. Furthermore, travel at high speed also tends to induce the danger of collision especially in areas of limited visibility or when navigating crowded waters.

Grounding is an unintended collision of a vessel with the sea bottom (generally referred to as "the bottom") and can cause severe damage to the hull. Grounding is especially hazardous in superficial, or uncharted waters. The main causes for grounding may be a lack of local knowledge and navigation; poor understanding of the water depths; not allowing for tides, currents and weather conditions. Weng and Yang (2015) shown that the accidents caused by grounding happen more frequently in shallow water or if a ship navigates beyond her planned route. Grounding also occurs in small channels, where freedom of movement is restricted. Jin (2014) pointed out that grounding incidents often occur to smaller ships, especially those navigating in coastal seas and under the unfavorable weather. Poor visibility as well as winds may cause the crew to lose their exact position. Waskito et al. (2024) confirmed this, finding that vessels in dense visibility areas or high traffic regions are at higher risk of grounding. Miscommunication or inexperience of the surrounding area frequently cause ships to run aground.

Strong currents such as tidal, river and sea currents can also have profound impact on vessels safety. Powerful currents can cause ships to veer off course, resulting in accidents like collisions or groundings. Such currents are extremely hazardous when a vessel is restricted in its ability to maneuver. Li et al. (2021) states that strong currents is one of the main causes reported in collision and grounding accidents, especially where rapid current changes are experienced in tidally influenced waters or rivers. In that kind of weather, there are more chances for boats at sea to hit rocks, shorelines and other ships. Wang et al. (2021) emphasized the importance of strong current in hydrodynamics, e.g., some areas such as the English Channel, where ships navigate a narrow and fast moving water body, may have trouble containing their speeds or directions. Strong currents can cause vessels to be forced off course or out of control. According to Jin (2014), small fishing boats are vulnerable to excessive currents due to poor power and little space for the vessel against which the water current can act, making it overturned or drifted direction wise towards the potential dangers.

Storms and inclement conditions of weather (including high wind, heavy rain and thunderstorms) represent one of the most critical sources of accidents on waterways. Such environmental conditions can impair visibility, reduce stability of the vessel and increase risk of rolling over or sinking in collisions. Weng and Yang (2015) also observed that marine casualties become more serious during stormy weather. Heavy winds and seas make it difficult for the crews to get their ships under control, particularly small ones. Besides, torrential rain and fog lead to a short visual range and thus prompt more probabilities of collision or grounding. Talley et al. (2006) and Li et al. (2021) show that the stormy condition ends up by an explosion of mortality in maritime accidents. In a heavy sea and adverse weather conditions the typical vessel shall be driven under, wash or capsized (if it were not equipped with modern navigation instruments or if there is no crew members wanting to manage bad weather). Wang et al. (2021) pointed out that when ships are operating in coastal or offshore areas they become extremely susceptible, as high waves and fluctuating wind velocities can cause incidents to happen quickly. In addition, ships that are in distant locations (not close to their home port), or in areas where rescue capability is not well-established, would be more vulnerable to a catastrophic event.

Another major factor in maritime accidents is overloading. When the weight of a ship grows beyond its designed capability to support it, that vessel can become unstable and prone to capsize, run aground or develop hull complications. Overloading is the consequence of inappropriate loading, inadequate regulation enforcement and human negligence causes caused by it. The overloading is also an important risk factor for small fishing vessels, as the load or fish catch tends to be too heavy with reference to the safety of vessel. This decreases the craft's buoyancy, making it more likely to be capsized in rough seas. Wang et al. (2021) found that larger commercial vessels can be unstable with overload condition and are more likely to capsize or sink, particularly in stormy weather or high waves. Overloading was identified as an additional factor that could increase the risk of physical damage, in particular to the collision bulkhead (Talley, 1996). The extra weight can put so much undue stress on the vessel that cracks, leaks and other kinds of damage will occur which are harmful to the integrity of the vessel.

Research into the causes of maritime accidents has identified recurring factors such as collisions, groundings, and severe weather. Yet, these investigations are largely situated in highly regulated maritime regions, where navigational systems, crew training, and vessel standards are comparatively robust. In contrast, Bangladesh's riverine transport sector faces challenges including overcrowded channels, outdated vessels, poor enforcement of safety regulations, and limited navigation aids. Despite these differences, little research has been conducted to examine how these local risk factors contribute to accidents. This gap highlights the urgent need for focused studies on accident causation within the inland waterway systems of Bangladesh.

2.5 Research methodologies in maritime accident analysis

Over the years, various research methodologies have been developed and employed to understand the causes, impacts, and preventative measures of maritime accidents. The most widely used research methodologies in maritime accident analysis, including the type of risk factors considered, are summarized in Table 2.3.

In light of the reviewed literature and the main objectives of this study, which are to identify the key factors influencing injury severity, vessel conditions after accidents, and the causes of inland waterway accidents in Bangladesh, it is both appropriate and necessary to use a combination of statistical methods as analytical tools. Models such as ordered probit, binary logit, and multinomial logit are useful for accurately measuring the relationships between explanatory variables and different accident outcomes. However, to further improve the depth of analysis and capture complex probabilistic relationships, marginal effect analysis can also be conducted. Marginal effects represent causal relationships within a probabilistic framework, allowing for a more complete understanding of how different factors individually influence accident scenarios. Therefore, analysis of statistical models incorporated with marginal effect is suitable for achieving the goals of this study.

Table 2.3: Methodologies and risk factors considered in maritime accident analysis

Category	Methodology	Risk factors considered	Sources
Human Factor Models	HFACS- Human factors analysis and classification system, TRACEr- Technique for the retrospective analysis of cognitive errors, CREAM- Cognitive reliability and error analysis method, AcciMap- frameworks for analyzing human and organizational errors	Human factors, operational errors, organizational influences	Chen et al. (2013), Akyuz (2015), Sotiralis et al. (2016), Yang et al. (2013), Wu et al. (2017)
Risk Modeling	FSA- formal safety assessment integrating ship, human, organizational, and technical aspects	Ship condition, crew performance, organizational control	Antao and Soares (2006), Zhang et al. (2013)
Causal Analysis	FTA- fault tree analysis to map accident causality	Basic events, technical failures, human operations	Ronza et al. (2003), Kum and Sahin (2015)
Probabilistic Modeling	Bayesian Networks- statistical inference of accident likelihoods	Weather, ship type, location, human error	Sotiralis et al. (2016), Zhang et al. (2013)
Fuzzy Logic	Fuzzy based risk assessment handles uncertainty in evaluation	Ship speed, ship condition, environmental uncertainty	Balmat et al. (2011)
Statistical Modeling	Ordered Probit- estimates severity levels, Binary Logit- binary outcomes, Multinomial Logit- multiple discrete outcomes	Accident severity, accident occurrence, type of accident	Wang et al. (2022), Gao et al. (2023), Debnath et al. (2011), Chen et al. (2015)

CHAPTER 3: DATA AND METHODOLOGY

This chapter describes the methods used to collect data and develop the database, as well as how injury severity, final condition of the vessel, and cause of accidents were analyzed. Multiple regression models and marginal effect analysis are implemented to explore the determinants of these outcomes. The purpose of these models is to gain insight into how they can be used to meet the study's ultimate goal: analyzing variability in severity of injury, post-accident state of vessels and various determinants for accident on inland waterways. The types of data collected and used within the study are also presented in the chapter before the mathematical formulation of the models and estimation procedures are explained.

3.1 Main Steps in Methodology

To achieve the objectives of this study, it is essential to select appropriate statistical models. These models will be developed using data related to inland waterway accidents, vessel characteristics, available safety equipment, and information about vessel masters/operators. Model calibration will be performed to identify the optimal model from a set of competing alternatives. The results of the finalized models will then be analyzed to determine the significant factors influencing injury severity, the vessel's final condition, and accident cause. Based on the significant factors identified through these models, marginal effect analysis will be conducted to identify the most critical determinants impacting injury severity, the vessel's final condition, and the causes of accident.

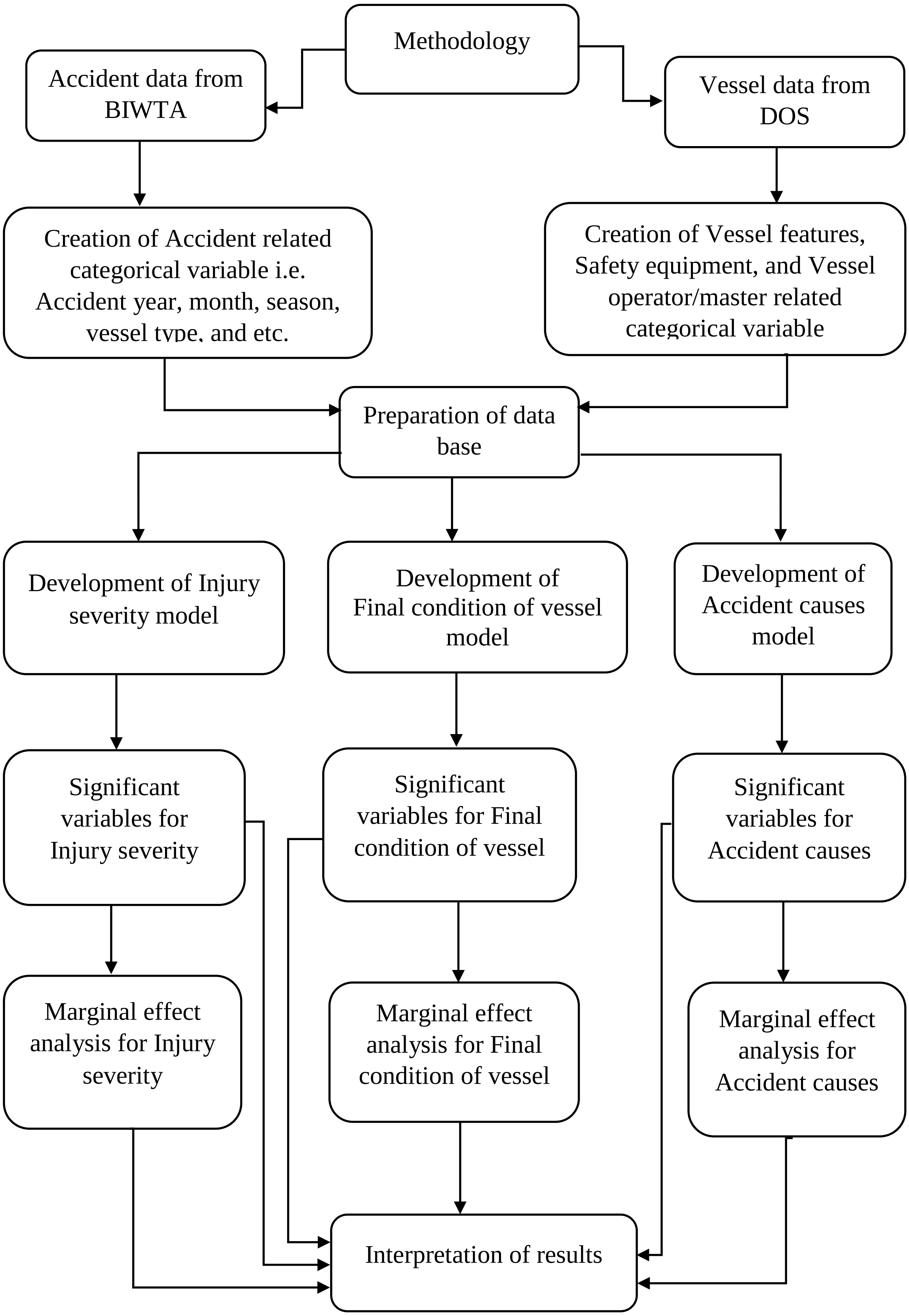

Figure 3.1: Methodology flow chart

The methodology can be divided into four main steps:

(a) Collection of inland waterway accident data and preparation of data for the formation of different variables and model development.

(b) Application of ordered probit model to find the significant factors affecting the injury severity of waterway accidents.

(c) Establishment of Logistic regression models to analyze the effects of different factors on final condition of the vessel, and different causes of accident.

(d) Analysis of marginal effect for injury severity, final condition of the vessel, and different accident causes to identify the most critical factors affecting them.

3.2 Description of Data

The waterway accident data used in this study were collected from two primary entities namely Bangladesh Inland Water Transport Authority (BIWTA) and Department of Shipping (DOS). The accident data was collected from the official record book of BIWTA (1983–2017). Incomplete or unreasonable observations were filtered out in order to guarantee the reliability of dataset. As the regulatory authority for issuance of permits to vessels operating in inland waterways within the nation, the DOS has a rather large data base of some 13,000 registered vessels. In addition to these BIWTA data, vessel specific information such as records of safety equipment and operator/master particulars were obtained from the DOS database using a link table that was created by combining vessel names with registration numbers. The final dataset On combining the datasets of BIWTA and DOS, a total of 337 inland waterway accidents were collected for final analysis. Because of this high-dimensional nature, we concentrate in this thesis on summary statistics only of those variables that are significant in the subsequent model estimations.

3.2.1 Accident-Related Data

The accident-related data collected from BIWTA includes a wide range of variables that describe the characteristics of accidents occurring within the inland waterway transport system. These variables are: Accident year, Month, and Season, which provide temporal and seasonal information about when the accident took place; Time, which indicates the specific time of the incident; Accident cause, which details the reason behind the accident; Collision type; Number of injured, dead, and missing persons, which quantifies the human toll of each accident; Location of accident, which specifies whether the accident occurred in a near or far location; Waterway Route, which identifies the specific waterway route where the incident took place; and Final condition of vessel after accident, which describes the post-accident state of the vessel. These variables collectively provide a detailed record of the circumstances and a comprehensive overview of the conditions surrounding each accident. For example, the year-wise trend in injury severity indicates that fatal accidents occurred more frequently than those resulting in injuries only or no injuries, with the highest number of fatalities reported in 2005 (Figure 3.2). Similarly, the final condition of the vessels, whether they remained afloat or sunk, varied significantly across the years, with constant presence of sinking-type incidents from 2005 to 2017 (Figure 3.3). An analysis of accident causes reveals that collisions are the dominant cause throughout the study period, peaking in 2005 with 23 incidents, while other causes such as overloading and storm-related events appear less frequently (Figure 3.4). In terms of location, Figure 3.5 compares accidents occurring in near vs. far locations. The data show that accidents in far locations are more likely to result in fatal injuries, whereas for near locations the chances of fatal injury and no injury type incidents are almost similar. This suggests that remoteness may impact rescue response times or severity of conditions, thereby increasing the likelihood of fatalities in far-off incidents. The month and season-wise trend in accident frequency (Figure 3.6) reveals distinct seasonal patterns. The highest number of collisions occurred during the winter season, which can likely be attributed to fog, as reduced visibility obstructs the vessel master's line of sight. In contrast, no specific monthly or seasonal pattern was observed for overloading-related accidents. This is because such accidents in Bangladesh primarily occur during festival periods, particularly during the two major festivals, Eid-ul-Fitr and Eid-ul-Adha, which do not fall in fixed months or seasons, as they are determined by the lunar calendar rather than the Gregorian calendar. For storm-related accidents, the highest frequency was recorded in March, April, and May, most likely due to the occurrence of Kalboishakhi (Nor'wester) storms during this period. Finally, for bottom-rupture accidents, a slight increase was observed in winter and summer, probably due to reduced water depth in rivers and channels during these seasons, which increases the likelihood of vessel bottoms colliding with the riverbed. It should be noted that these correlations, derived from the observed data, are hypothetical and require verification through appropriate statistical analyses.

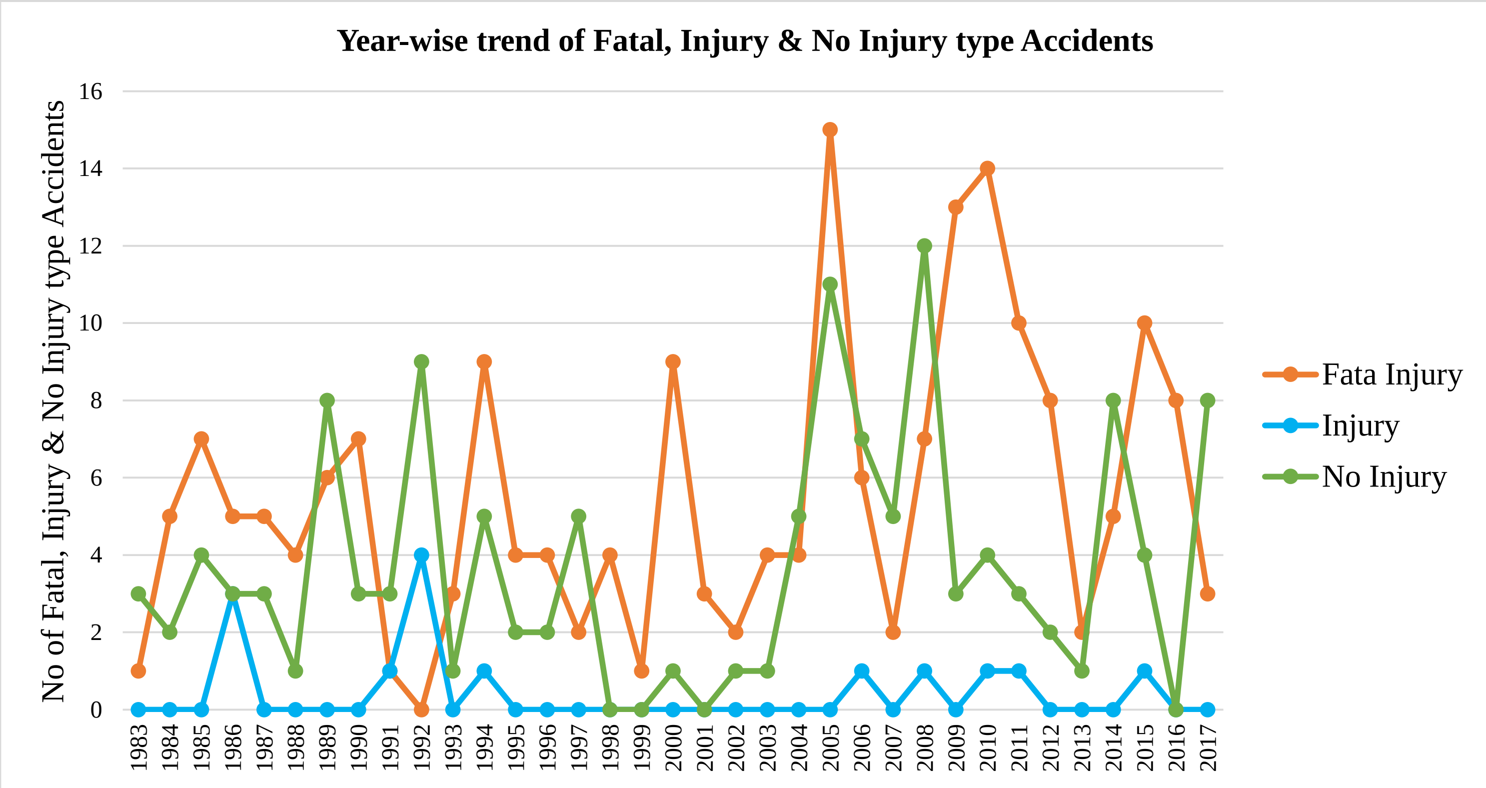

Figure 3.2: Year-wise injury severity trend

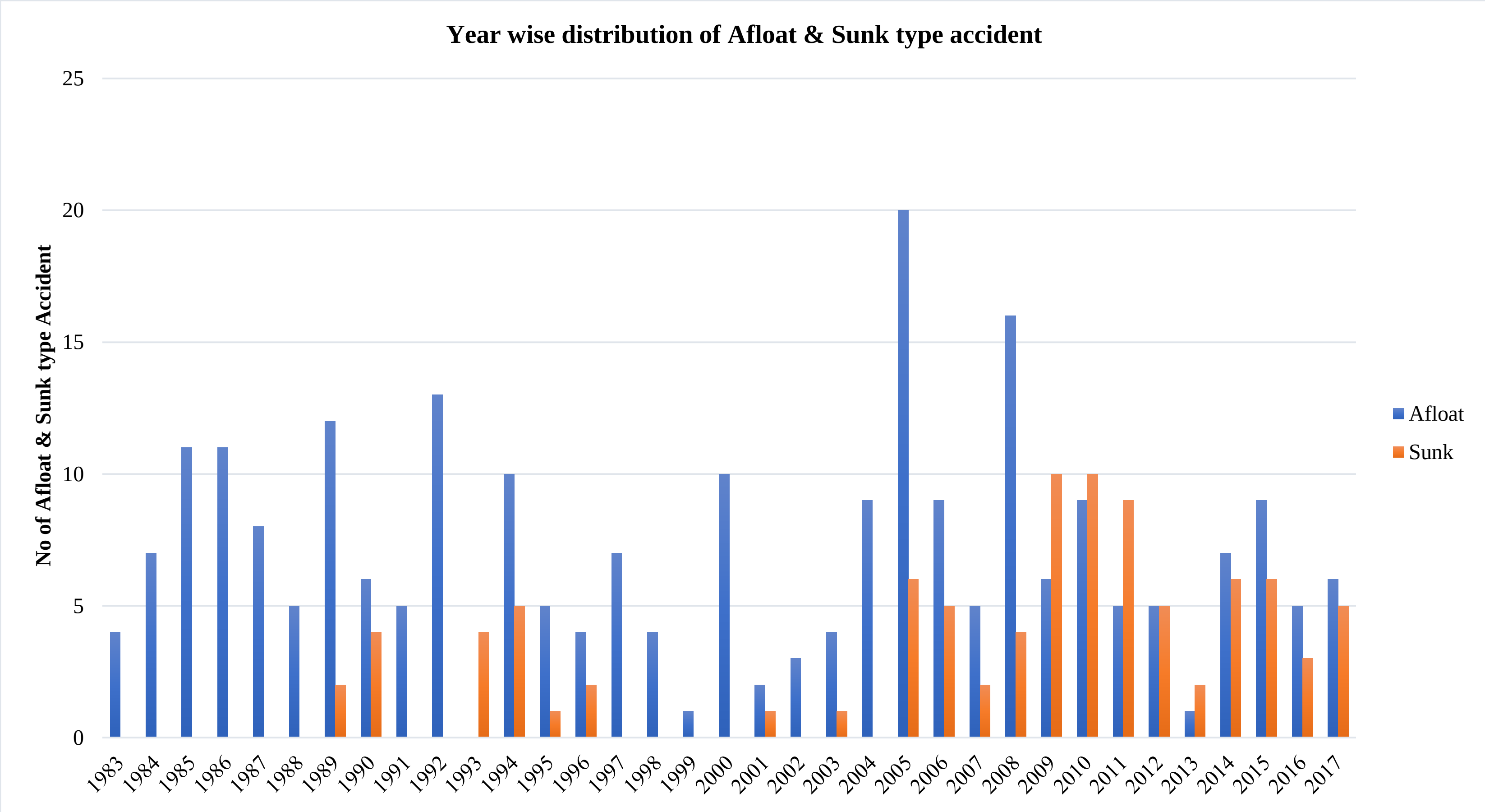

Figure 3.3: Year-wise final condition of vessel

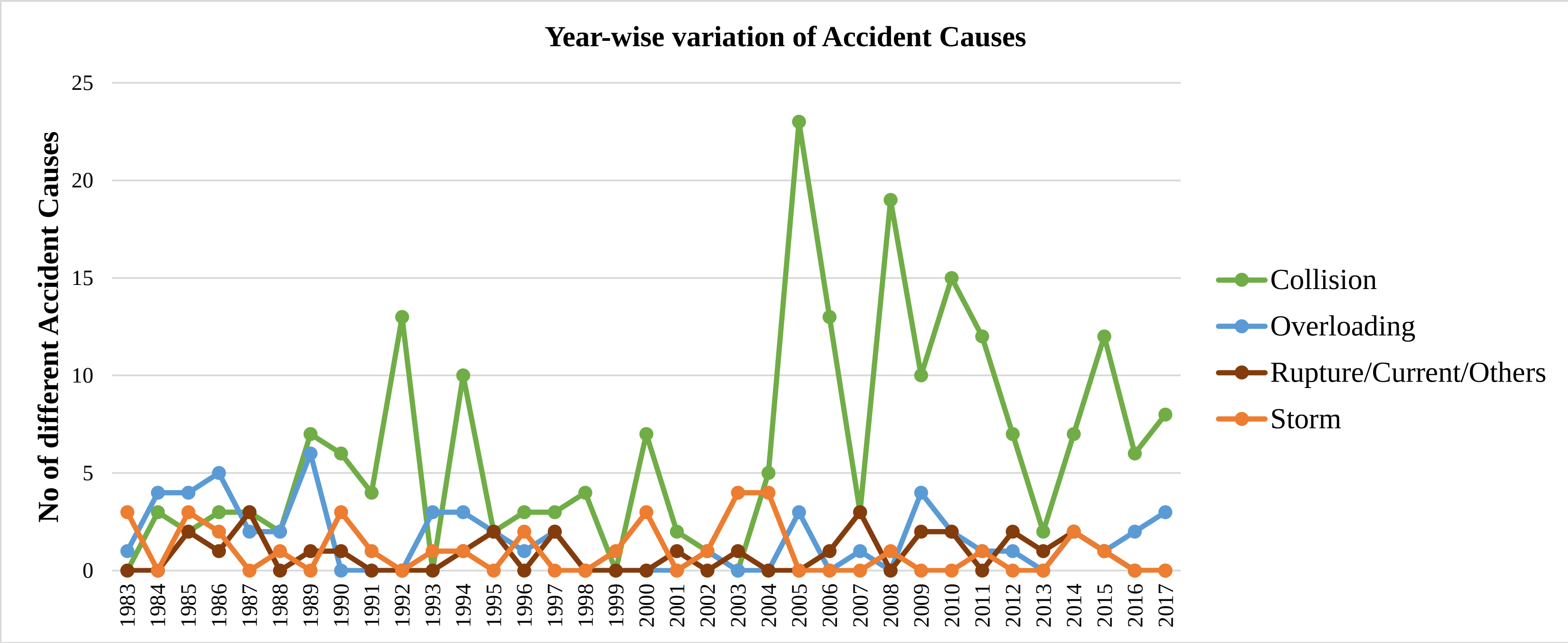

Figure 3.4: Year-wise variation of accident causes

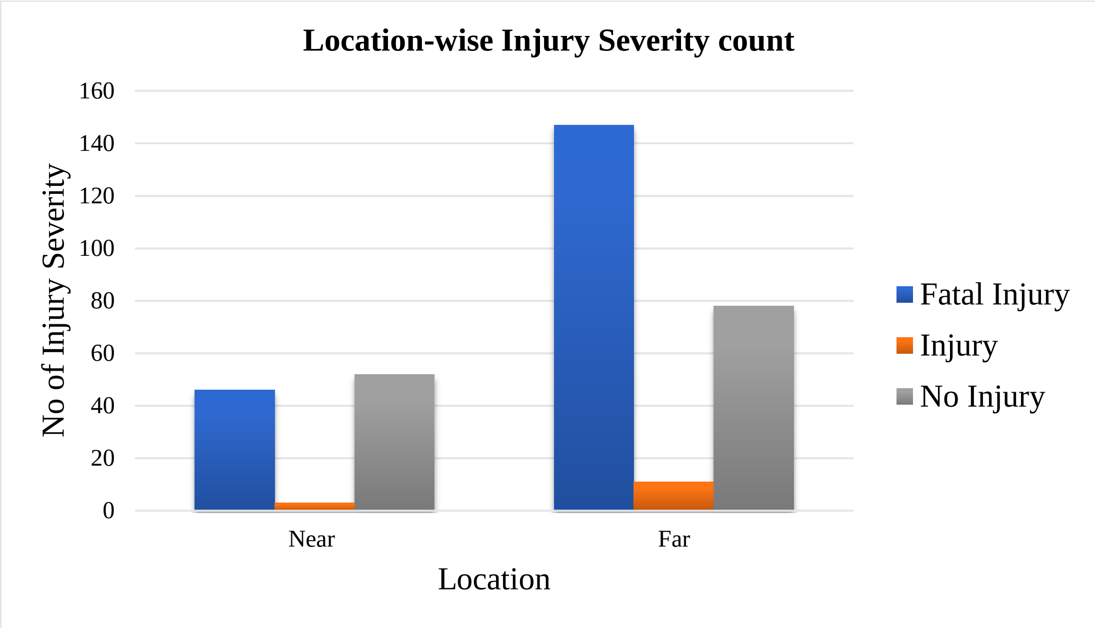

Figure 3.5: Injury severity based on location

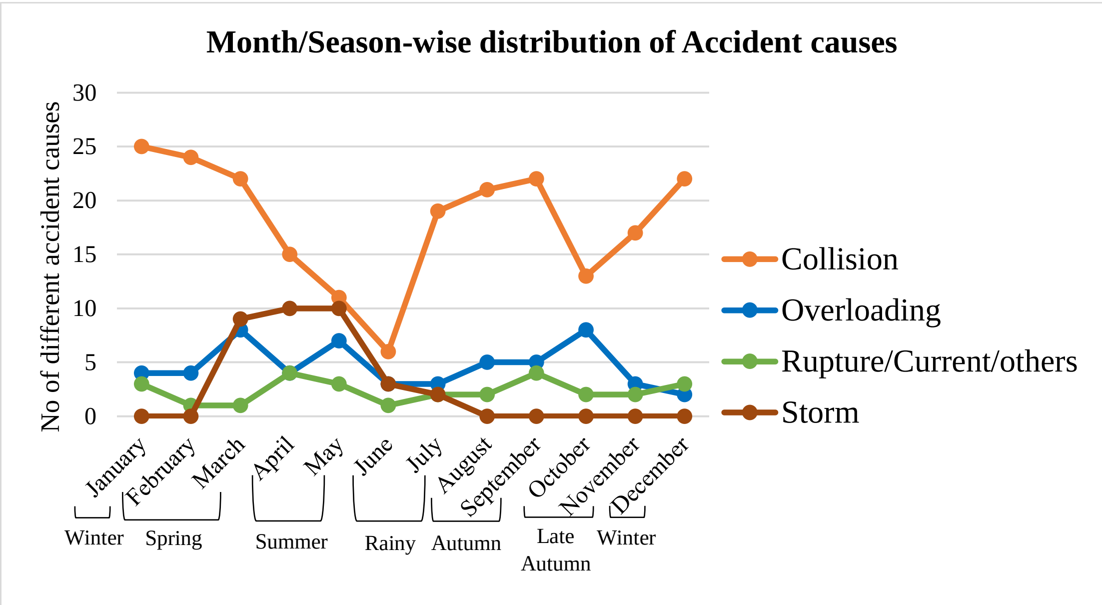

Figure 3.6: Month/Season-wise distribution of accident causes

3.2.2 Vessel Features Related Data

The vessel features related data collected from DOS includes various types of variables. These include continuous numerical data such as the length, width, and depth of the vessel, as well as BHP (Braking horsepower) and GRT (Gross Registered Tonnage), which represent the vessel's power and internal volume. Discrete numerical data includes the number of engines, age of vessel at the time of the accident, passenger capacity, and the passenger capacity of the first, second, and third decks, as well as the number of cabins on the second and third decks. Additionally, categorical data is used to represent the type of passenger vessel and whether any modification history exists for the vessel. These variables provide a comprehensive set of technical specifications for the vessels involved in accidents. Figure 3.7 illustrates the relationship between vessel age and accident involvement, showing that newer vessels (0-5 years) have the highest percentage of accidents among both passenger launches and trawlers, followed by vessels over 10 years of age. Moreover, the impact of vessel modifications on accident involvement is highlighted in Figure 3.8, where vessels that had not undergone any modification exhibit significantly higher accident percentages compared to those that were modified or rebuilt.

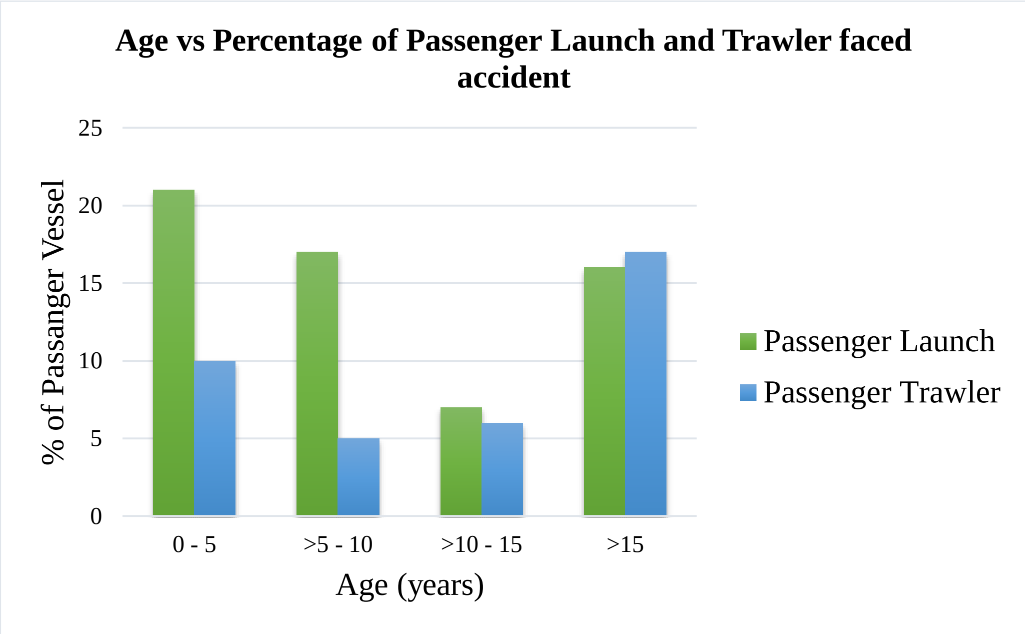

Figure 3.7: Passenger vessel age vs accident involvement

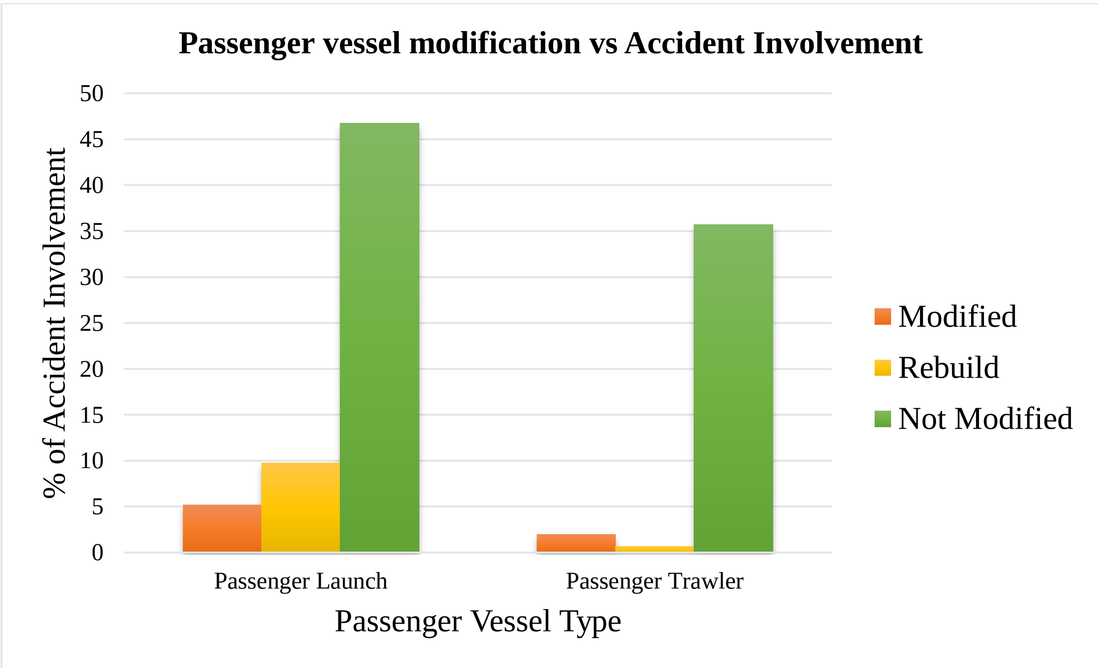

Figure 3.8: Passenger vessel modification vs accident involvement

3.2.3 Safety Equipment-Related Data

The safety equipment-related data obtained from DOS includes various variables that describe the safety provisions available on vessels. These variables are: Number of fire buckets, First aid boxes, Life buoys, Pump, Life jackets, Life rafts, Sand boxes, Fire-fighting instruments, and the Presence of safety lamp/torch, Radio, and Compass. These variables indicate the presence and quantity of essential safety equipment, providing a measure of the preparedness of vessels in the event of emergencies. As illustrated in Figure 3.9, equipment such as sand-boxes, radios, and safety lamps/torches were found on most vessels, indicating a reasonable level of basic safety provisioning. However, the extremely low number of life rafts highlights a significant shortfall in critical life-saving equipment, raising concerns about the overall emergency preparedness of the vessels involved. The comparatively lower presence of compasses also suggests that navigational safety may have been compromised in a substantial portion of the operating passenger vessels.

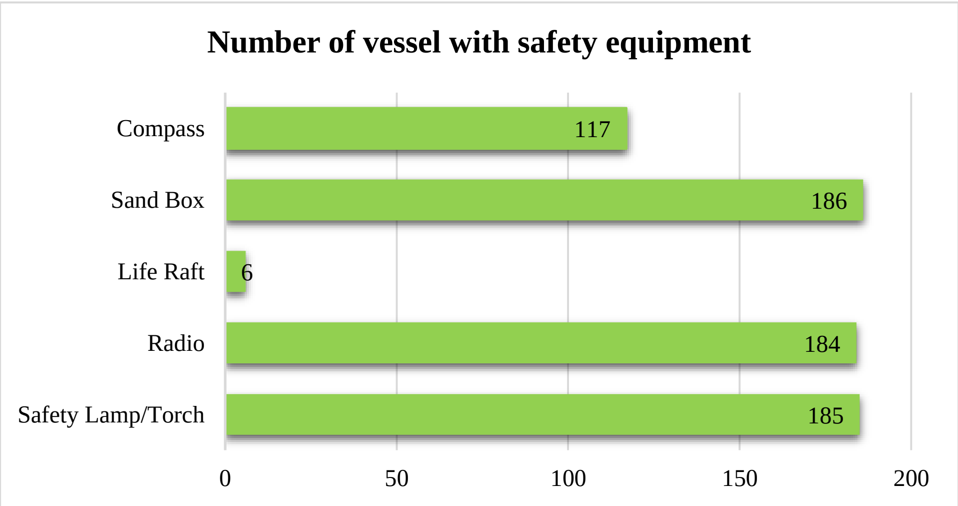

Figure 3.9: Number of vessels with different safety equipment

3.2.4 Vessel Operator/Master Related Data

The vessel operator/master related data includes variables that provide details about the personnel operating the vessel. These variables are: Number of engineer/driver, which indicates the total number of engineers or drivers aboard; Engineer/Driver class, which classifies the engineers or drivers based on their qualifications; Number of master, representing the total number of masters on board; Master class, which categorizes the masters according to their certification or rank; and Number of crew, which represents the total number of crew members aboard the vessel. These variables provide important information about the human resources involved in vessel operations. As shown in Figure 3.10, accident involvement is noticeably higher among masters with no certification, whereas certified masters exhibit lower rates of accident involvement, highlighting the significance of formal qualifications in promoting safer vessel operations. Similarly, Figure 3.11 illustrates that vessels with a moderate number of crew (6–12) are more frequently involved in accidents, whereas vessels with larger crew sizes tend to have lower accident involvement, suggesting a potential link between crew adequacy and operational safety.

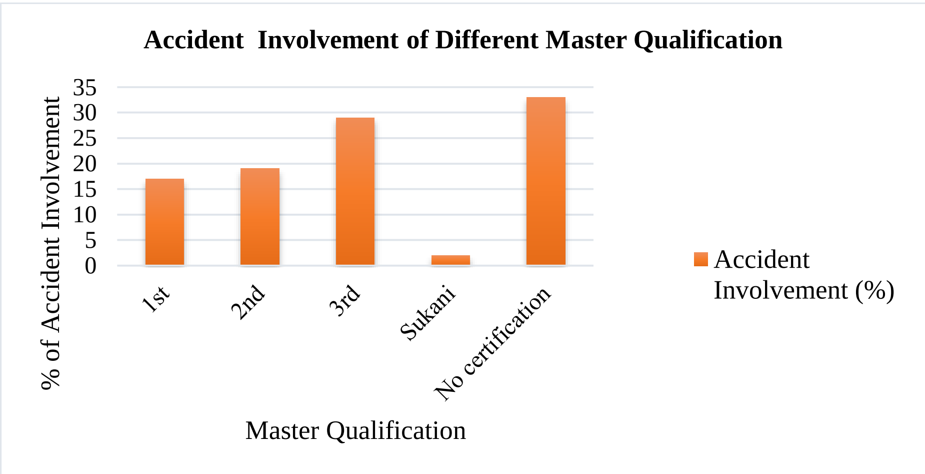

Figure 3.10: Accident involvement of different qualification of masters’

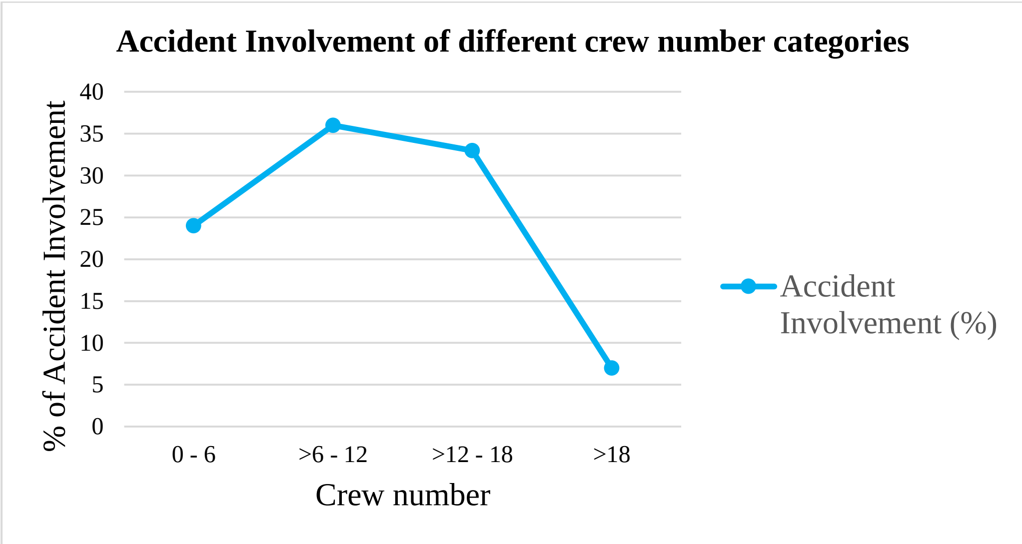

Figure 3.11: Accident involvement of different crew number categories

3.3 Classification of Accident Severity, Final Condition of Vessel, and Accident Type

3.3.1 Severity of Accident Classification

Severity of accident can be considered as an ordinal variable that allows for the assignment of a ranking to the outcomes. When evaluating severity of waterway accidents, the classification approach can differ among various authorities. In China, marine accident severity is categorized into five levels: minor, general, major, critical, and catastrophic (MOT China, 2014). In contrast, the International Maritime Organization (IMO) classifies waterway accident severity into four levels: "marine incidents," "less serious casualties," "serious casualties," and "very serious casualties" (IMO, 2008). In Bangladesh, the Bangladesh Inland Water Transport Authority (BIWTA) maintains a record book of accident data, documenting the number of missing, deceased, and injured individuals following waterway incidents. For the purpose of simplifying analysis, in our study, we have categorized injuries into three groups: fatal injury, injury, and no injury. The definitions of these categories are as follows:

(1) Injury severity has been classified as "fatal injury" if the record book includes information about deceased or missing individuals. Given that missing persons are logically considered deceased, consolidating both deceased and missing cases under a single severity category termed as "fatal injury" proved more convenient.

(2) The severity category has been considered as "injury" when the record indicates the presence of injured individuals but no evidence of deceased or missing persons.

(3) The "no injury" category has been assigned if there was no evidence of injured, deceased, or missing individual followed by a waterway incident.

3.3.2 Final Condition of Vessel Classification

The final condition of a vessel following an inland waterway accident serves as a critical indicator for assessing the severity of the incident. Minor or general accidents typically result in superficial damage, such as scratches or dents, which do not compromise the vessel's functionality or safety. In contrast, major accidents may cause structural damage, partial flooding, or temporary loss of propulsion, necessitating repairs but not rendering the vessel irreparable. Critical accidents often involve extensive damage, such as hull breaches or severe mechanical failures, which may lead to abandonment or towing of the vessel. Catastrophic or very serious casualties are characterized by total loss scenarios, including sinking or capsizing, with significant implications for human life, environmental protection, and navigation safety (IMO, 2008; MOT China, 2014). Notably, the BIWTA record book documents the final condition of a vessel only in cases of capsizing and sinking; for other accident scenarios, no details regarding the vessel's final condition are provided. Based on the BIWTA record book, we have classified the final condition of the vessel after an accident into two categories: sunk and afloat. The definitions of these categories are given below:

(1) The final condition of a vessel is classified as “sunk” when it becomes fully or partially submerged below the waterline following an accident. In the BIWTA record book, a vessel recorded as “capsized” is also treated as a sinking incident in our analysis. This classification is based on the assumption that a capsized vessel is likely to lose its buoyancy over time, leading to its eventual sinking. Thus, both capsizing and sinking are considered under a single category “sunk”.

(2) The condition of the vessel is considered as “afloat” if there is no indication of sinking or capsizing in the accident record book as the subsequent state of the vessel.

3.3.3 Classification of Accident Causes

In Bangladesh, the primary causes of inland waterway accidents are collision, overloading, cyclone, grounding, fire, and explosion (Awal et al., 2006, Rahman, 2017). From the obtained data of the BIWTA record book, we have classified the causes of inland waterway accidents into four major gropus: collision, overloading, storm, and bottom rupture/excessive current/others. The definitions of these categories are as follows:

(1) The accident is categorized as “collision” if a vessel comes into unavoidable contact with another vessel or any stationary object, such as bridges, dredging pipes, or submerged obstacles like underwater trees.

(2) Accidents are classified as “overloading” when they result from stability failure due to the vessel carrying more passengers than its designed capacity.

(3) The “storm” category encompasses accidents caused by adverse environmental conditions, such as cyclones, nor'westers, or other severe weather phenomena.

(4) The accidents are classified as “bottom rupture/excessive current/others” if it is caused due to damage to the vessel’s hull, excessive river currents, or any other reasons not covered by the aforementioned categories.

3.4 Selection of Suitable Models for Analysis

In order to successfully explore the diverse consequences of accidents in inland waterways, i.e., injuries’ severity, vessel condition and causes of accidents, we have utilized a combination of appropriate statistical models in this study. Models were selected based on the nature of dependent variables (ordinal, binary and nominal) and requirement to cover both fixed and random effects over observations. Based on the existing literatures and previous empirical work, models related to orders, such as ordered probit model, binary logit model, multinomial logit mod, mixed coefficient model, and marginal effect analysis were selected. Each of them provides some advantages to analyze special sections of the accident data that produce robust and interpretable results suited to the problem structure.

3.4.1 Ordered Probit Model

In the injury severity model, severity of the casualties caused by waterway accidents have been considered as the dependent variable. Ordered probit and ordered logit models have been adopted in many studies to examine the severity of injury because these methods provide consistent and efficient estimates (Quddus et al., 2002, Rifaat and Chin, 2007, Pai and Saleh, 2007, Yang et al., 2011, Rifaat et al., 2012). Since the waterway injury severity outcome is ordinal, thus an ordered probit model has considered to determine the factors which significantly influence injury severity of waterway accident.

The standard ordered probit model assumes that the observed ordinal variable Y_i is determined by an unobserved latent variable Y_i^* through a threshold mechanism. Mathematically, the model can be defined as:

$$Y_i = x_i\beta + \epsilon_i \tag{1}$$

where x_i = vector of explanatory variables; β = vector of coefficients to be estimated; and ϵ_i = normally distributed error term.

The observed ordinal outcome Y_i is related to Y_i^* through a set of threshold parameters τ:

$$Y_i = \begin{cases} 1 & \text{if} \quad Y_i^* \leq \tau_1 \text{ (no injury)} \\ 2 & \text{if} \quad \tau_1 < Y_i^* \leq \tau_2 \text{ (injury)} \\ 3 & \text{if} \quad Y_i^* \geq \tau_{j-1} \text{ (fatal injury)} \end{cases} \tag{2}$$

3.4.2 Binary Logit Model

In analyzing the final condition of a vessel after an accident, the dependent variable is binary, indicating whether the vessel was classified as either “sunk” or “afloat”. To model this binary outcome, the binary logistic regression model is commonly employed due to its ability to efficiently estimate the relationship between a set of explanatory variables and a binary dependent variable (Hosmer & Lemeshow, 2000, Menard, 2002). The binary logistic model is ideal in this context, as it predicts the probability of the vessel being in one of the two possible final conditions.

The binary logistic model assumes that the log-odds of the dependent variable are a linear function of the explanatory variables. Mathematically, the model can be expressed as:

$$\text{logit}\left(P(Y_i = 1)\right) = \ln\left(\frac{P(Y_i=1)}{1 - P(Y_i=1)}\right) = x_i\beta \quad (3)$$

Where, P(Yi =1) = the probability that the vessel is classified as "sunk", x_i = the vector of explanatory variables (such as vessel characteristics, environmental factors, and accident details), and β = the vector of coefficients to be estimated.

The predicted probability of the vessel being "sunk" (i.e., Yi=1) is given by:

$$P(Y_i = 1) = \frac{1}{1+\exp(-x_i\beta)} \quad (4)$$

This equation guarantees that the estimated probability will fall between 0 and 1, which is appropriate when modeling a binary event. The straightforward picture of the effect of each explanatory variable on a vessel's odds to be sunk is provided by the logistic regression framework. Positive coefficients make it more likely to sink; negative coefficients less so.

3.4.3 Multinomial Logit Model

When considering the factors that cause accidents in inland waterway, the dependent variable is categorical with several alternative values representing different causes of accident (e.g., collision, overloading, storm etc.). As the outcome is nominal, not ordered, a multinomial logistic model may be used to describe the relationship between the set of explanatory variables and the various classes of accident causes (McFadden 1974; Greene 2003). The multiple, exclusive and unordered categories of accident causes can be analyzed according to this model, revealing the critical factors relative to these types of accidents.

The multinomial logistic model assumes that the probability of observing any particular accident cause is a function of a set of explanatory variables. It can be mathematically expressed as follows:

$$\left(\mathrm{P}(\mathrm{Y_i} = \mathrm{j})\right) = \frac{\exp(\mathrm{x_i}\beta_\mathrm{j})}{1 + \sum_{k=1}^{j} \exp(\mathrm{x_i}\beta_\mathrm{k})} \quad (5)$$

Where, $\mathrm{P}(\mathrm{Y_i} = \mathrm{j})$ = the probability that the i^{th} observation (accident) is assigned to the j^{th} accident cause category, $\mathrm{x_i}$ = the vector of explanatory variables (such as vessel characteristics, crew experience, weather conditions, and environmental factors), β_j = the vector of coefficients to be estimated for the j^{th} category, and j = the total number of possible accident causes.

The denominator ensures that the probabilities across all categories sum to 1, as the outcome must be one of the predefined accident causes. The multinomial logistic model is a generalization of the binary logit model, where instead of just two possible outcomes, multiple categories are modeled simultaneously.

The interpretation of the coefficients is relative to a base category, often referred to as the “reference category”. The coefficients for the other categories represent the effect of each explanatory variable on the odds of choosing that category relative to the reference category. Positive coefficients increase the odds of an accident being attributed to a specific cause, while negative coefficients decrease those odds.

3.4.4 Mixed Co-efficient Model

A standard ordered probit or logit model (binary or multinomial) assumes that the relationship between the dependent and independent variables does not change across observations. To address this issue, some researchers in recent years used mixed coefficient model in which coefficients of the variables are treated as random across observations to capture individual-level heterogeneity (Cunto and Ferreira, 2016; Chang et al., 2016; Xin et al., 2017; Lin and Fan, 2019; Khales et al., 2020; Saric et al., 2021; Xiao et al., 2022). This randomness is obtained by allowing the co-efficient β_i to vary across individuals:

$$\beta_i = \beta + \eta_i \tag{6}$$

where β = population mean co-efficient; and η_i = individual-specific deviation (random effect) with a mean of zero and variance σ_k^2. For a particular variable, the random co-efficient β_i has been assigned if the standard deviation σ_k is significantly greater than zero. Otherwise, the co-efficient of that variable was considered as fixed across the observations (Chang et al., 2016, Lin and Fan, 2019). For η_i, different distributions, including normal, uniform, lognormal, and triangular, have been employed; nevertheless, the normal distribution has demonstrated superior statistical fit (Cunto and Ferreira, 2016, Xin et al., 2017, Lin and Fan, 2019, Khales et al., 2020). Estimation of maximum likelihood utilising Halton draws is typically employed for mixed coefficient models (Train, 2009).

3.4.5 Marginal effect Analysis

Marginal effect analysis was conducted for the ordered probit, binary logit, and multinomial logit models to provide a more interpretable understanding of the relationships between the explanatory variables and the dependent variable. While the coefficients of these nonlinear models indicate the direction and relative strength of the relationships, they do not directly measure the change in the probability of the outcome associated with a unit change in the predictors. Marginal effects address this limitation by quantifying the expected change in the probability of each outcome category for a given change in the explanatory variables (Zhang et al., 2013, Jiang et al., 2013, Tay, 2016). This approach allows for a more meaningful interpretation of the results and facilitates comparison of the influence of different predictors across models and outcome categories. The use of marginal effect analysis enhances the practical and policy relevance of the findings by translating the model estimates into probabilities that are easier to interpret and understand.

CHAPTER 4: INJURY SEVERITY MODEL

This chapter focuses on the development process of statistical models to analyze and predict injury severity in inland waterway accidents in Bangladesh. The primary aim of this chapter is to identify the key factors that influence the severity of accidents and to develop a robust model to quantify these factors. To achieve this, two ordered probit models, fixed and mixed coefficient models were utilized and evaluated using various statistical metrics to determine the best-fitting model. The most suitable model was then selected based on the evaluation results. Subsequently, Marginal effect analysis was constructed to further examine the relationships between significant variables and injury severity.

4.1 Development of Injury Severity Models

To develop the injury severity models, this study uses waterway accident data collected between 1983 to 2017. Over this 34-year period, a total of 337 waterway accidents were recorded. Among these cases, 57% were classified as fatal, 39% involved injuries, and 4% resulted in no injuries (Figure 4.1).

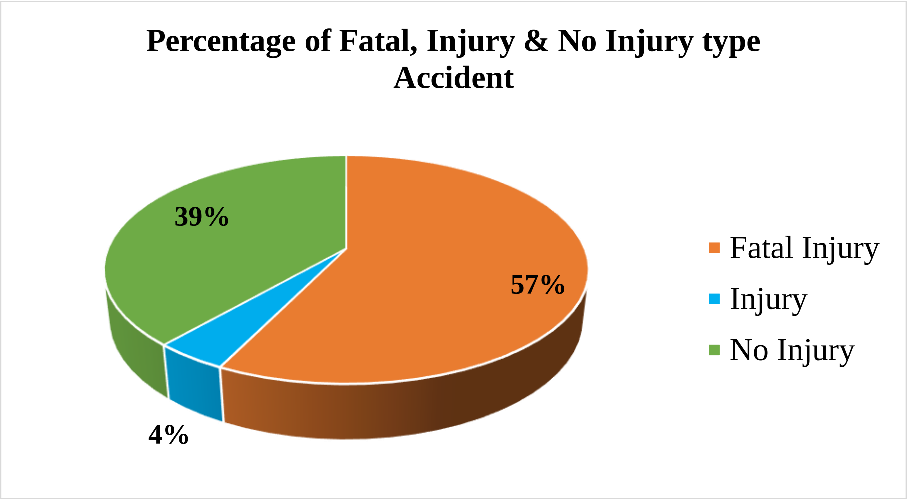

Figure 4.1: Percentage of different injury types

4.1.1 Ordered Probit models

In the developed ordered probit models, the dependent variable is injury severity, which can take one of three values according to the recorded degree of injury: fatal injury, injury, or no injury. Each accident is classified based on the most severe condition sustained by any of the casualties.

The fixed coefficient ordered probit model was developed using the statistical software "STATA-15", while the mixed coefficient ordered probit model was estimated using the "R" programming language. For the mixed model, the "Rchoice" package was utilized to handle random parameter estimation and analyze the injury severity data. 102 variables from 15 factors are retained in the final models and these are shown in Table 4.1 together with their definition, mean, and standard deviation. Significant variables have been identified using both the fixed and mixed coefficient ordered probit model. These models were compared using several evaluation metrics, including pseudo-R-square, log-likelihood, and the Akaike Information Criterion (AIC) (Anastasopoulos and Mannering, 2009, Rifaat et al., 2012).

The results of the developed models are presented in Table 4.2, where the independent variables are categorized into five groups (I to V), comprising 15 factors in total: (I) general characteristics, (II) accident characteristics, (III) vessel characteristics, (IV) safety equipment characteristics, and (V) master/driver/crew characteristics. The model with the best statistical fit was selected to identify the significant variables. From this best-fitting model, 12 significant factors were determined. To avoid multicollinearity, correlations among these variables were examined (Daoud, 2017).

The analysis confirmed that none of the significant factors were correlated, ensuring the model's robustness and interpretability.

Table 4.1: Summary statistics of key variables for injury severity

Variable	Measurement	Mean	Std. Dev.
Dependent variable			
Injury severity	1 if severity was no injury (39%)	2.187	0.961
	2 if severity was injury (4%)		
	3 if severity was fatal injury (57%)		
Explanatory variable			
I. GENERAL			
1. Accident year			
1983	1 if 1983, else 0	0.012	0.108
1984	1 if 1984, else 0	0.021	0.143
1985	1 if 1985, else 0	0.033	0.178
1986	1 if 1986, else 0	0.033	0.178
1987	1 if 1987, else 0	0.024	0.152
1988	1 if 1988, else 0	0.015	0.121
1989	1 if 1989, else 0	0.041	0.199
1990	1 if 1990, else 0	0.029	0.169
1991	1 if 1991, else 0	0.015	0.121
1992	1 if 1992, else 0	0.038	0.192
1993	1 if 1993, else 0	0.012	0.108

1994	1 if 1994, else 0	0.044	0.206
1995	1 if 1995, else 0	0.018	0.132
1996	1 if 1996, else 0	0.018	0.132
1997	1 if 1997, else 0	0.021	0.143
1998	1 if 1998, else 0	0.012	0.108
1999	1 if 1999, else 0	0.003	0.054
2000	1 if 2000, else 0	0.029	0.169
2001	1 if 2001, else 0	0.009	0.094
2002	1 if 2002, else 0	0.009	0.094
2003	1 if 2003, else 0	0.015	0.121
2004	1 if 2004, else 0	0.027	0.161
2005	1 if 2005, else 0	0.077	0.267
2006	1 if 2006, else 0	0.041	0.199
2007	1 if 2007, else 0	0.021	0.143
2008	1 if 2008, else 0	0.059	0.236
2009	1 if 2009, else 0	0.047	0.213
2010	1 if 2010, else 0	0.056	0.231
2011	1 if 2011, else 0	0.041	0.199
2012	1 if 2012, else 0	0.029	0.169
2013	1 if 2013, else 0	0.009	0.094
2014	1 if 2014, else 0	0.038	0.192
2015	1 if 2015, else 0	0.044	0.206
2016	1 if 2016, else 0	0.024	0.152

2017	1 if 2017, else 0	0.033	0.178
2. Month			
January	1 if the accident happened in january, else 0	0.095	0.293
February	1 if the accident happened in february, else 0	0.086	0.280
March	1 if the accident happened in march, else 0	0.119	0.323
April	1 if the accident happened in april, else 0	0.098	0.297
May	1 if the accident happened in may, else 0	0.092	0.289
June	1 if the accident happened in june, else 0	0.038	0.192
July	1 if the accident happened in july, else 0	0.077	0.267
August	1 if the accident happened in august, else 0	0.083	0.276
September	1 if the accident happened in september, else 0	0.092	0.289
October	1 if the accident happened in october, else 0	0.068	0.252
November	1 if the accident happened in november, else 0	0.065	0.247
December	1 if the accident happened in december, else 0	0.080	0.271
3. Season			
Winter	1 if the accident happened in winter season, else 0	0.175	0.380
Spring	1 if the accident happened in spring season, else 0	0.205	0.403
Summer	1 if the accident happened in summer season, else 0	0.189	0.392
Rainy	1 if the accident happened in rainy season, else 0	0.116	0.312
Autumn	1 if the accident happened in autumn season, else 0	0.175	0.380
Late Autumn	1 if the accident happened in late autumn season, else 0	0.133	0.340

4. Time			
Morning	1 if morning, else 0	0.202	0.401
Afternoon	1 if afternoon, else 0	0.116	0.319
Evening	1 if evening, else 0	0.116	0.319
Night	1 if night, else 0	0.214	0.409
5. Route			
Dhaka-Barishal	1 if the accident happened in dhaka-barishal route, else 0	0.041	0.199
Dhaka-Patuakhali	1 if the the accident happened in dhaka-patuakhali route, else 0	0.021	0.143
Chandpur-Faridpur	1 if the accident happened in chandpur-faridpur route, else 0	0.009	0.094
Others	1 if the accident happened in others route, else 0	0.929	0.257
6. Location			
Near	1 if the accident happened near from the port, else 0	0.261	0.439
Far	1 if the accident happened far from the port, else 0	0.700	0.458
II. ACCIDENT CHARACTERISTICS			
7. Accident cause			
Collision	1 if collision, else 0	0.644	0.479
Overloading	1 if overloading, else 0	0.139	0.346
Storm	1 if storm, else 0	0.104	0.305
Stability failure	1 if stability failure, else 0	0.027	0.161
Bottom rupture	1 if bottom rupture, else 0	0.015	0.121
Excessive current	1 if excessive current, else 0	0.015	0.121
Others	1 if other causes, else 0	0.056	0.231
8. Involve vessel			

1	1 if 1 vessel was involved, else 0	0.392	0.488
2	1 if 2 vessel was involved, else 0	0.564	0.496
3	1 if 3 vessel was involved, else 0	0.044	0.206
9. Collision type			
No collision	1 if no collision, else 0	0.356	0.479
PL vs C/OT	1 if PL vs C/OT, else 0	0.047	0.213
PL vs PL/F	1 if PL vs PL/F, else 0	0.166	0.372
PL vs PT/SC	1 if PL vs PT/SC, else 0	0.127	0.334
PT vs C/OT	1 if PT vs C/OT, else 0	0.041	0.199
PT vs PT/SC	1 if PT vs PT/SC, else 0	0.104	0.305
PL vs C/SC vs C/SC	1 if PL vs C/SC vs C/SC, else 0	0.012	0.108
PL vs PL vs PL/C	1 if PL vs PL vs PL/C, else 0	0.021	0.143
Others	1 if other type of collision, else 0	0.033	0.178
10. Final Condition			
Afloat	1 if vessel was afloat after accident, else 0	0.264	0.441
Sunk	1 if vessel was sunk after accident, else 0	0.279	0.448
III. VESSEL CHARACTERISTICS			
11. Width of vessel			
0 to 4 meters	1 if 0 to 4 meters, else 0	0.107	0.309
>4 to 8 meters	1 if >4 to 8 meters, else 0	0.472	0.499
>8 to 12 meters	1 if >8 to 12 meters, else 0	0.379	0.485
>12 meters	1 if >12 meters, else 0	0.041	0.199
12. Passenger capacity			

0 to 150	1 if 0 to 150, else 0	0.211	0.408
>150 to 300	1 if >150 to 300, else 0	0.095	0.293
>300 to 450	1 if >300 to 450, else 0	0.077	0.267
>450	1 if >450, else 0	0.166	0.372
13. Vessel age			
0 to 5 years	1 if 0 to 5 years, else 0	0.136	0.343
>5 to 10 years	1 if >5 to 10 years, else 0	0.098	0.297
>10 to 15 years	1 if >10 to 15 years, else 0	0.059	0.236
>15 years	1 if >15 years, else 0	0.148	0.355
IV. SAFETY EQUIPMENT CHARACTERISTICS			
14. Compass			
Yes	1 if compass was available in vessel, else 0	0.347	0.476
No	1 if compass was not available in vessel, else 0	0.430	0.495
V. MASTER/DRIVER/CREW CHARACTERISTICS			
15. Master class			
1st	1 if the vessel master was 1st class, else 0	0.127	0.334
2nd	1 if the vessel master was 2nd class, else 0	0.145	0.352
3rd	1 if the vessel master was 3rd class, else 0	0.222	0.416
Sukani	1 if the vessel master was Sukani, else 0	0.018	0.132
No certification	1 if the vessel master did not have any formal certification, else 0	0.249	0.432

Table 4.2: Model estimation results for fixed and mixed-coefficient ordered probit models

Variable	**Ordered probit parameter estimates**			
	Fixed- coefficient model		**Mixed- coefficient model**	
	Co-efficient (β)	**z-value (p-value)**	**Co-efficient (β)**	**z-value (p-value)**
I. GENERAL				
1. Accident year (2017)	-1.380**	-2.430 (0.015)	-2.168*	-1.816 (0.069)
2. Month (September)	-0.718***	-2.600 (0.009)	-1.249***	-2.808 (0.005)
3. Season (Summer)	0.449**	2.133 (0.033)		
4. Time (Afternoon)	0.430*	1.651 (0.099)	0.968**	2.063 (0.039)
5. Route (Chandpur-Faridpur)	-1.428*	-1.757 (0.079)	-1.634*	-1.650 (0.099)
6. Location (Far)	0.492***	2.900 (0.004)	0.625***	2.689 (0.007)

Standard deviation of parameter distribution			*0.066*	*0.138 (0.890)*
II. ACCIDENT CHARACTERISTICS				
7. Accident cause (Overloading)	1.059***	3.791 (0.000)	1.965**	2.202 (0.028)
8. Involve vessel (1)	-0.572***	-2.829 (0.005)	-0.481	-1.151 (0.250)
Standard deviation of parameter distribution			*2.346***	*2.535 (0.011)*
9. Collision type (PL vs PL/F)	0.599**	2.519 (0.012)	0.808***	2.889 (0.004)
10. Final condition (Sunk)	0.777***	3.809 (0.000)	1.179***	2.962 (0.003)
III. VESSEL CHARACTERISTICS				
11. Width of vessel (>4 to 8 meters)	0.738***	4.302 (0.000)	0.775***	2.938 (0.003)
Standard deviation of parameter distribution			*0.618*	*1.073 (0.283)*
12. Passenger capacity (>150 to 300)	-0.479*	-1.722 (0.085)		
13. Vessel age (10 to 15 years)	0.652*	1.873 (0.061)		
IV. SAFETY EQUIPMENT CHARACTERISTICS				
14. Compass (Yes)	-0.690***	-3.455 (0.000)	-0.973***	-3.565 (0.000)

Standard deviation of parameter distribution			*0.006*	*0.005 (0.996)*
V. MASTER/DRIVER/CREW CHARACTERISTICS				
15. Master class (Second)	-0.586**	-2.347 (0.019)	-0.541*	-1.802 (0.072)
Cut 1	0.237	1.194 (0.234)	0.203***	3.431 (0.001)
Cut 2	0.379*	1.904 (0.058)	1.029***	4.910 (0.000)
Pseudo R-square		0.203		0.284
Log-likelihood		-219.9		-219.6
AIC		473.839		475.273

*Statistically significant at α = 0.10, **Statistically significant at α = 0.05, ***Statistically significant at α = 0.01

Table 4.3: Marginal effect analysis for variables affecting injury severity

Variable	No Injury	Injury	Fatal Injury
Accident year (2017)	0.398	-0.085	-0.313
Month (September)	0.259	-0.038	-0.221
Time (Afternoon)	-0.180	-0.0226	0.202
Route (Chandpur-Faridpur)	0.321	-0.059	-0.262
Location (Far)	-0.131	0.008	0.123
Accident cause (Overloading)	-0.299	-0.080	0.379
Involve vessel (1)	0.122	-0.076	-0.046
Collision type (PL vs PL/F)	-0.149	-0.007	0.157
Final condition (Sunk)	-0.222	-0.037	0.259
Width of vessel (>4 to 8 meters)	-0.145	-0.016	0.161
Compass (yes)	0.209	-0.005	-0.204
Master class (2nd)	0.115	-0.008	-0.107

4.2 Goodness-of-fit of ordered probit models

Table 4.2 reports estimated results for the fixed and mixed coefficient ordered probit models. Both models had a good correspondence to the data, as indicated by strong fit indices. As per the modelling, there was little variation in estimated coefficients between Fixed and Mixed coefficient ordered probit with only a difference of significance (number of variables that are statistically significant). The values for Log-likelihood and AIC were similar between models whereas the mixed coefficient ordered probit model was slightly superior to the fixed coefficient in terms of Pseudo

R-square. Moreover, for the mixed coefficient model both cut point 1 and cut point 2 were statistically significant, in fixed coefficient model only cut point 2 is significant, while cut point 1 become insignificant. Cut points are particularly critical in an ordered probit model since they divide the categories of an ordinal outcome variable. The importance of these cut points indicates that the model is successfully identifying categories (İşçi Güneri et al., 2022). Hence, the existence of two significant cut points in the mixed coefficient model also indicates its superiority in this study. The fixed coefficient ordered probit model reveals that among the 15 variables identified to be significant, the passenger capacity, season, and vessel age are screened out of these factors because they are not statistically significant in the mixed coefficient model. In the last step, 12 significant factors from the mixed coefficient model were chosen for subsequent reasoning.

4.3 Interpretation of the significant variables

This section explains the meaning of the critical explanatory variables of the ordered probit models and the marginal effects, i.e. how general factors, accident characteristics, vessel conditions, safety measures, and master/crew qualifications influence injury severity in inland waterway accidents.

General Characteristics

In the present study, accidents in 2017 generated less severe injury in comparison with former years. This is shown by the negative coefficient (-2.618, $p<0.10$) in Table 4.2. Reduction in the severity of injury sustained during 2017 could possibly be due to a joint initiative between government of Bangladesh and World Bank emphasizing on the enhanced safety of vessel and strict enforcement of safety regulations (World

Bank, 2016). Additionally, the marginal effects in the analysis (Table 4.3) give further support for this result, pointing out that tragedies during 2017 was associated with a 31.3 percentage points lower probability of fatal injuries relative to other years.

Upon considering the month variable, it was found that accidents occurring on the inland waterways of Bangladesh in September were associated with a reduction in accident severity when compared to other months. This is evidenced by the negative coefficient (-1.249, $p<0.01$) for September, as shown in Table 4.2, which suggests a reducing effect on accident severity during this particular month. According to the marginal effect results, the likelihood of fatal injuries decreased by 22.1 percentage points for accidents occurring in September compared to other months. While prior studies have highlighted that the monsoon season (June to September) typically exacerbates waterway accidents due to heavy rainfall and Nor'westers (Awal et al., 2006; Awal, 2006), September marks the transition between the peak monsoon and the post-monsoon period. Monsoonal activity finishes, resulting in a decrease of rainfall and river flows as well as the intensity of the environment overall, indicating more comfortable weather. The decrease of adverse weather influences may be responsible, in part, for the lower level of injury severity observed during September and is an important contributor to the understanding of seasonal variation in terms of injury severity.

A review of times at which accidents occurred demonstrated that afternoon accidents ($p = 0.039$) were much more frequent in causing severe injuries than those during the morning, evening or night. 'The higher risk may be related to the busyness of large cabin carriers (launches that can carry passengers with inside seating) during the afternoon peak. These bigger ships, in turn, can create wave that topples smaller vessels nearest them and makes them more prone to capsizing. This indicates that the afternoon is an important factor for injuring severity, probably because bigger vessels have an influence over water condition.

In comparing the different waterway routes examined, we observed that the Chandpur-Faridpur (p = 0.099) route is associated with significantly less severe injuries when compared to the southern zone inland waterways of Bangladesh (Dhaka-Barishal and Dhaka-Patuakhali). The marginal effects analysis also reveal the same trend where accidents on Chandpur–Faridpur route reduce the likelihood of fatal injury by 26.2 percentage points relative to other IW routes. This result is also in agreement with the reports of Uddin et al. (2020). Less injury severity on the Chandpur-Faridpur route can be explained by less distance between these two stations compared with Dhaka-Barishal and Dhaka-Patuakhali; According to general evidences, exposure of an individual for shorter trips is less towards hazardous and operation complexity factors which ultimately results in mild injuries during the accident.

It has been observed that waterway accidents occurring far from the port or the shore are correlated with an increased likelihood of severe injuries compared to those occurring in close proximity. The marginal effects analysis further supports this result, showing that the probability of a fatal injury increases by 12.3 percentage points at ‘Far’ compared to accidents occurring near the port or shore (Table 4.3). These findings align with existing literature (Weng and Yang, 2015, Wang et al., 2021). In this study, the location (far) variable was treated as a normally distributed random parameter, with a mean of 0.625 and a standard deviation of 0.066 (Table 4.2). The insignificant standard deviation (p = 0.890) suggests that the effect of distance on injury severity was consistently positive across nearly all observations and there was not enough variation. This homogeneity is likely due to factors such as delayed emergency response times and reduced accessibility in more remote locations.

Accident Characteristics

While considering the accident characteristics for injury severity, overloading ($\beta = 1.965$, $p < 0.05$) was identified as a significant factor in increasing the probability of severe accidents compared to collision, storm, bottom rupture, excessive current, and other causes. The marginal effects analysis (Table 4.3) further confirms this finding, indicating that the probability of fatal injuries increases by 37.9 percentage points in overloaded vessels compared to accidents caused by other factors. Overloading compromises a vessel's stability by reducing buoyancy and raising its centre of gravity, making it more susceptible to capsizing. In such cases, passengers may come into direct contact with the water, facing the risk of drowning or becoming trapped inside the vessel. This increased instability due to overloading leads to more severe accidents, which is also supported by Talley et al. (2006) and Jin (2014).

In terms of the number of vessels involved in an accident, it has been indicated by the findings that accidents involving only one vessel result in lower injury severity compared to those involving two or three vessels. In this analysis, "Involve vessel (1)" has been treated as a normally distributed random variable, with a mean of -0.481 and a standard deviation of 2.346 (Table 4.2). The significant standard deviation ($p = 0.011$) suggests the presence of heterogeneity across the observations. Based on these estimates, in 41.7% of cases where only one vessel was involved, the severity of injuries decreased, whereas in 58.3% of cases, the involvement of a single vessel led to an increase in injury severity. Typically, multiple-vessel involvement is most common in collision-type accidents. However, as demonstrated earlier in this study, overloading tends to increase injury severity compared to collisions, and overloading incidents often involve a single vessel. Therefore, the variability observed in the impact of one-vessel involvement on injury severity is consistent with the nature of these accidents and supports the justification of the findings.

While analysing the relationship of collision between different types of vessels with injury severity, we observed that collisions involving "Passenger Launch vs. Passenger Launch or Ferry (PL vs. PL/F)" ($\beta = 0.808$, $p < 0.01$) significantly increase the likelihood of severe injuries compared to other collision types, such as "PL vs. Cargo," "PL vs. Small Trawlers," "Cargo vs. Small Trawlers," and collisions between two small trawlers. The high risk of severe injuries in PL vs. PL/F collisions may be attributed to the large number of passengers on board in both vessels, which increases the likelihood of significant injuries during an accident. Additionally, crashes involving larger vessels generate greater impact forces, leading to a higher probability of severe injuries. These factors likely account for the elevated injury severity observed in this type of collision.

In this study, the final condition of a vessel following an accident has also been examined. As anticipated, the findings revealed that when a vessel sinks ($\beta = 0.179$, $p < 0.01$) after an accident, the likelihood of serious injuries significantly increases compared to when it remains afloat. The marginal effects analysis supports this finding, indicating that the probability of fatal injuries increases by 25.9 percentage points when a vessel sinks after an accident compared to when it remains afloat (Table 4.3). This conclusion aligns with the findings of Jin (2014), Weng and Yang (2015), Uddin et al. (2017), Uddin and Awal (2018), Wang et al. (2021), and Cao et al. (2023), who also noted that sinking accidents are associated with a higher probability of fatal injuries. This is primarily due to the immediate risk of drowning faced by passengers when a vessel submerges.

Vessel Characteristics

In this study, various characteristics of vessels, including length, width, and depth, were examined. The findings revealed that passenger vessels with widths between >4 to 8 meters ($p = 0.003$) significantly increase the probability of more severe accidents compared to vessels with widths of >8 to 12 meters and over 12 meters. The variable for vessel width (>4 to 8 meters) was treated as random, following a normal distribution with a mean of 0.775 and a standard deviation of 0.618 (Table 4.2). Based on these estimates, 89.4% of vessels involved in accidents with widths of >4 to 8 meters had a positive coefficient, while 10.6% had a negative coefficient. It is likely that vessels with smaller widths are also smaller in overall size compared to those with larger widths. As noted in previous studies, smaller vessels tend to be more vulnerable to severe injuries in accidents (Wang et al., 2021, Cao et al., 2023) due to their limited capacity to manage emergency situations (Wang and Yang, 2018). This may explain why nearly 90% of cases involving passenger vessels with smaller widths are associated with a higher incidence of injury-related accidents.

Safety Equipment Characteristics

In Bangladesh's inland waterways, all passenger-carrying launches are required to have a compass on board. However, malfunctions or absences of this essential tool sometimes may occur due to vessel operators' negligence or careless behaviour. While examining the availability of navigational aids and safety equipment, this study identified a significant association between the presence of a compass ($\beta = -0.973$, $p < 0.01$) in passenger vessels and a reduction in injury severity, compared to vessels without this navigational tool. In this analysis, the variable "Compass (yes)" was modelled as a normally distributed random variable with a mean of -0.973 and a standard deviation of 0.006 (Table 4.2). The insignificant standard deviation ($p = 0.996$) suggests that the presence of a compass consistently had a negative impact on injury severity in the majority of cases. This outcome is logically sound, as the availability of a compass serves as a crucial navigational aid, enabling vessel operators to avoid navigational errors and thus mitigate the severity of injuries during incidents by avoiding unwanted mistakes.

Master/Driver/Crew Characteristics

This study also examined the role of vessel masters' qualifications, including 1st class, 2nd class, 3rd class, sukani, and masters without formal certification. The results indicate that masters holding at least a 2nd class qualification ($\beta = –0.541$, $p < 0.10$) were associated with a significantly lower likelihood of severe injuries. This effect is likely attributable to the greater experience and training of more qualified masters, which enhance their ability to minimize the impact of collisions and respond effectively to emergency situations.

4.4 Summary

This chapter examines the determinants of severity of injury associated with inland waterway accidents in Bangladesh using ordered probit models. The study reveals several factors (general, accident, vessel, safety equipment and master/crew characteristics) influencing injured severity in these accidents.

The importance of general variables such as year, month, and time of accident is emphasized in this study. In 2017, fewer serious injuries were caused by accidents, which can be attributed to the increase in vessel safety measures brought about by the government and World Bank. Also, September accidents also had fewer injuries than expected because of improving weather following the monsoon. Proportion of accidents resulting in major injuries was higher among afternoon accidents, which might be explained by water turbulences because of large vessel movements during rush hours.

In consideration of accident attributes, overloading has been recognized as a significant factor in intensifying injury. Overloading caused a reduction in vessel stability resulting in increased likelihood of capsizing and consequently, greater severity of injury. Single-vessel accidents were also less severe in the case of this study. Passenger ship collisions, especially "PL vs. PL or Ferry (PL/F)", were classified as an evident risk for severe injury, because of the high number and size of passengers involved and increasing forces developed in collision.

Under Vessel characteristics, it was found that smaller vessels with width of 4–8 m were more prone to sustain serious injuries than those boats of bigger sizes. This is due to the fact that smaller ships are less able to manage emergencies and thus have a higher exposure risk in accidents. The authors of the study also discovered that vessels which sank in accidents were more likely to lead to fatal injuries, thus emphasizing the highly dangerous nature of sinking accidents.

Ultimately, the type of safety equipment and master/crew traits also highly influenced injury severity. Having a compass on board resulted in decreased injury severity, given the reduction of navigational mistakes. In addition, the rank of vessel master had a crucial influence, with higher-ranking masters having lower probability to sustain severe injuries; probably this was related to his/her better capability in dealing with emergencies.

CHAPTER 5: FINAL CONDITION OF VESSEL MODEL

This chapter studies the ultimate state of vessels involved in inland waterway accidents of Bangladesh and its aim is to comprehend the status of a vessel just after an accident. It is aimed to, firstly, identify the influential factors leading to the final state of a vessel after an accident and then develop a systematic evaluation model for these effects. For this, a fixed coefficient and mixed coefficient model was used to measure the impact of specific determinants on the eventual state of the vessel. Models were validated and compared with a range of performance metrics to confirm the best fit. The analysis of marginal effects was also performed to obtain the change in probability of the last condition of the boat given a variation in each independent variable. The findings intend to contribute to a better insight into the most essential factors in vessel outcomes and may help improve safety procedures and preventive measures.

5.1 Development of Final Condition of Vessel Models

The final condition of vessel models have been developed using 337 waterway accident data occurred between 1983 to 2017. Among these incidents, 72% of the vessels remained afloat after the accident, whereas 28% were classified as sunk, representing their ultimate condition following the accident (Figure 5.1).

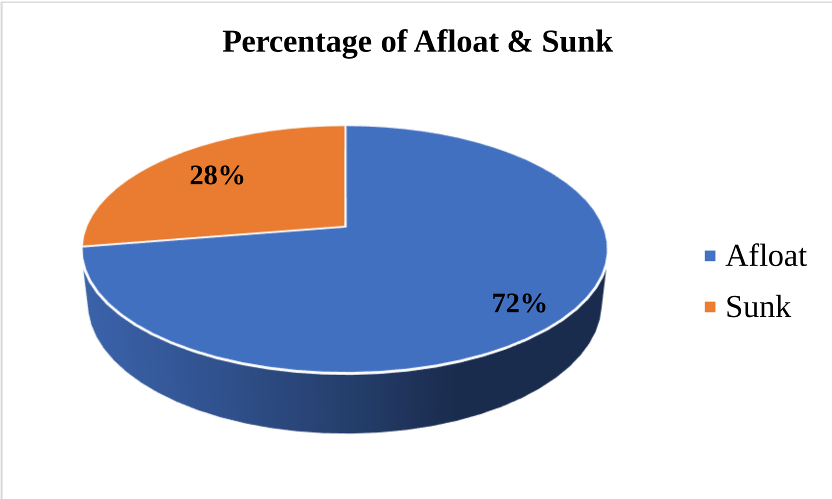

Figure 5.1: Percentage of different final condition of vessel

5.1.1 Binary Logit models

In the developed binary logit models, the dependent variable is final condition of vessel, which is a dummy variable and can take only two values (i.e., either sunk or afloat).

The development of the fixed coefficient binary logit model, as similar to Chapter 4, was carried out using STATA-15, while the mixed coefficient binary logit model was implemented using the "R" programming language. Consistent with the mixed coefficient model of previous chapter, the "Rchoice" package was used to handle the random parameters. 99 variables from 14 factors are retained in the final models and these are shown in Table 5.1 together with their definition, mean, and standard deviation. Key factors were identified in both the fixed and mixed coefficient models, and a comparative analysis was conducted using matrices similar to those employed in Chapter 4.

The results of the developed models are presented in Table 5.2, where the independent variables are categorized into four groups (I to IV), comprising 14 factors in total: (I) general characteristics, (II) accident characteristics, (III) vessel characteristics, and (IV) safety equipment characteristics. The model with the best statistical fit was selected to identify the significant variables. The best-fitting model revealed 14 significant factors, while ensuring the avoidance of multicollinearity.

Table 5.1: Summary statistics of key variables for final condition of vessel

Variable	Measurement	Mean	Std. Dev.
Dependent Variable			
Final Condition of vessel	0 if Afloat (72%)	0.279	0.448
	1 if Sunk (28%)		
Explanatory variable			
I. GENERAL			
1. Accident year			
1983	1 if 1983, else 0	0.012	0.108
1984	1 if 1984, else 0	0.021	0.143
1985	1 if 1985, else 0	0.033	0.178
1986	1 if 1986, else 0	0.033	0.178
1987	1 if 1987, else 0	0.024	0.152
1988	1 if 1988, else 0	0.015	0.121
1989	1 if 1989, else 0	0.041	0.199
1990	1 if 1990, else 0	0.029	0.169

1991	1 if 1991, else 0	0.015	0.121
1992	1 if 1992, else 0	0.038	0.192
1993	1 if 1993, else 0	0.012	0.108
1994	1 if 1994, else 0	0.044	0.206
1995	1 if 1995, else 0	0.018	0.132
1996	1 if 1996, else 0	0.018	0.132
1997	1 if 1997, else 0	0.021	0.143
1998	1 if 1998, else 0	0.012	0.108
1999	1 if 1999, else 0	0.003	0.054
2000	1 if 2000, else 0	0.029	0.169
2001	1 if 2001, else 0	0.009	0.094
2002	1 if 2002, else 0	0.009	0.094
2003	1 if 2003, else 0	0.015	0.121
2004	1 if 2004, else 0	0.027	0.161
2005	1 if 2005, else 0	0.077	0.267
2006	1 if 2006, else 0	0.041	0.199
2007	1 if 2007, else 0	0.021	0.143
2008	1 if 2008, else 0	0.059	0.236
2009	1 if 2009, else 0	0.047	0.213
2010	1 if 2010, else 0	0.056	0.231
2011	1 if 2011, else 0	0.041	0.199
2012	1 if 2012, else 0	0.029	0.169
2013	1 if 2013, else 0	0.009	0.094

2014	1 if 2014, else 0	0.038	0.192
2015	1 if 2015, else 0	0.044	0.206
2016	1 if 2016, else 0	0.024	0.152
2017	1 if 2017, else 0	0.033	0.178
2. Month			
January	1 if the accident happened in january, else 0	0.095	0.293
February	1 if the accident happened in february, else 0	0.086	0.280
March	1 if the accident happened in march, else 0	0.119	0.323
April	1 if the accident happened in april, else 0	0.098	0.297
May	1 if the accident happened in may, else 0	0.092	0.289
June	1 if the accident happened in june, else 0	0.038	0.192
July	1 if the accident happened in july, else 0	0.077	0.267
August	1 if the accident happened in august, else 0	0.083	0.276
September	1 if the accident happened in september, else 0	0.092	0.289
October	1 if the accident happened in october, else 0	0.068	0.252
November	1 if the accident happened in november, else 0	0.065	0.247
December	1 if the accident happened in december, else 0	0.080	0.271
II. ACCIDENT CHARACTERISTICS			
3. Accident cause			
Collision	1 if collision, else 0	0.644	0.479
Overloading	1 if overloading, else 0	0.139	0.346
Storm	1 if storm, else 0	0.104	0.305

Stability failure	1 if stability failure, else 0	0.027	0.161
Bottom rupture	1 if bottom rupture, else 0	0.015	0.121
Excessive current	1 if excessive current, else 0	0.015	0.121
Others	1 if other causes, else 0	0.056	0.231
4. Involve vessel			
1	1 if 1 vessel was involved, else 0	0.392	0.488
2	1 if 2 vessel was involved, else 0	0.564	0.496
3	1 if 3 vessel was involved, else 0	0.044	0.206
5. Collision type			
No collision	1 if no collision, else 0	0.356	0.479
PL vs C/OT	1 if PL vs C/OT, else 0	0.047	0.213
PL vs PL/F	1 if PL vs PL/F, else 0	0.166	0.372
PL vs PT/SC	1 if PL vs PT/SC, else 0	0.127	0.334
PT vs C/OT	1 if PT vs C/OT, else 0	0.041	0.199
PT vs PT/SC	1 if PT vs PT/SC, else 0	0.104	0.305
PL vs C/SC vs C/SC	1 if PL vs C/SC vs C/SC, else 0	0.012	0.108
PL vs PL vs PL/C	1 if PL vs PL vs PL/C, else 0	0.021	0.143
Others	1 if other type of collision, else 0	0.033	0.178
III. VESSEL CHARACTERISTICS			
6. Length of vessel			
0 to 30 meters	1 if 0 to 30 meters, else 0	0.445	0.497
>30 to 50 meters	1 if >30 to 50 meters, else 0	0.166	0.372
>50 to 70 meters	1 if >50 to 70 meters, else 0	0.317	0.465

>70 meters	1 if >70 meters, else 0	0.071	0.26
7. Passenger capacity			
0 to 150	1 if 0 to 150, else 0	0.211	0.408
>150 to 300	1 if >150 to 300, else 0	0.095	0.293
>300 to 450	1 if >300 to 450, else 0	0.077	0.267
>450	1 if >450, else 0	0.166	0.372
8. 1st deck passenger capacity			
0 to 65	1 if 0 to 65, else 0	0.163	0.369
>65 to 130	1 if >65 to 130, else 0	0.113	0.316
>130 to 200	1 if >130 to 200, else 0	0.092	0.289
>200	1 if >200, else 0	0.184	0.387
9. Breaking horse-power			
0 to 125	1 if 0 to 125, else 0	0.154	0.361
>125 to 250	1 if >125 to 250, else 0	0.130	0.337
>250 to 375	1 if >250 to 375, else 0	0.012	0.108
>375	1 if >375, else 0	0.258	0.438
10. Vessel age			
0 to 5 years	1 if 0 to 5 years, else 0	0.136	0.343
>5 to 10 years	1 if >5 to 10 years, else 0	0.098	0.297
>10 to 15 years	1 if >10 to 15 years, else 0	0.059	0.236
>15 years	1 if >15 years, else 0	0.148	0.355
11. Modification of vessel			
No	1 if No, else 0	0.380	0.490

Yes	1 if Yes, else 0	0.030	0.180
Rebuild	1 if Rebuild, else 0	0.050	0.210
IV. SAFETY EQUIPMENT CHARACTERISTICS			
12. Life jacket nos.			
0 to 20	1 if 0 to 20, else 0	0.635	0.481
>20 to 40	1 if >20 to 40, else 0	0.119	0.323
>40 to 60	1 if >40 to 60, else 0	0.009	0.094
>60	1 if >60, else 0	0.015	0.121
13. Pump nos.			
0	1 if 0, else 0	0.237	0.425
1	1 if 1, else 0	0.519	0.499
>1	1 if >1, else 0	0.021	0.143
14. Fire-fighting instrument nos.			
0 to 2	1 if 0 to 2, else 0	0.379	0.485
3 to 4	1 if 3 to 4, else 0	0.127	0.334
5 to 6	1 if 5 to 6, else 0	0.145	0.352
>6	1 if >6, else 0	0.125	0.330

Table 5.2: Model estimation results for fixed and mixed-coefficient binary logit models

Variable	Binary logit parameter estimates					
	Fixed- coefficient model			Mixed- coefficient model		
	Co-efficient (β)	Odd ratio	Z-value (P-value)	Co-efficient (β)	Odd ratio	Z-value (P-value)
I. GENERAL						
1. Accident year (2011)	1.904***	6.713	2.610 (0.009)	1.143***	3.136	2.685 (0.007)
2. Month (February)	0.935*	2.547	1.830 (0.067)	0.594*	1.811	1.959 (0.050)
II. ACCIDENT CHARACTERISTICS						
3. Accident cause (Stability failure)	2.447**	11.554	2.140 (0.032)	1.264**	3.540	2.223 (0.026)
4. Involve vessel (2)	-1.456***	0.233	-3.980 (0.000)	-0.909***	0.403	-4.308 (0.000)
Standard deviation of parameter distribution	-	-	-	*0.011*	*1.011*	*0.025 (0.980)*
5. Collision type (PL vs PT/SC)	0.940*	2.560	1.870 (0.061)	0.579**	1.784	2.001 (0.045)

III. VESSEL CHARACTERISTICS						
6. Length of vessel (>50 to 70 meters)	-1.855***	0.156	-4.73 (0.000)	-1.145***	0.318	-4.947 (0.000)
Standard deviation of parameter distribution	-	-	-	*0.110*	*1.116*	*0.192 (0.848)*
7. Passenger capacity (0 to 150)	-0.899**	0.407	-2.380 (0.017)	-0.539**	0.583	-2.410 (0.016)
8. Passenger capacity (>300 to 450)	2.926*	18.653	1.930 (0.054)	1.400*	4.055	1.769 (0.077)
9. 1st deck passenger capacity (>65 to 130)	-1.149**	0.317	-2.110 (0.035)	-0.673**	0.510	-2.127 (0.033)
10. Breaking horse-power (>375)	-2.886***	0.056	-2.990 (0.003)	-1.179***	0.308	-3.139 (0.002)
11. Vessel age (>5 to 10 years)	1.974***	7.199	2.770 (0.006)	1.099***	3.001	2.746 (0.006)
12. Modification of vessel (Yes)	2.191**	8.944	2.060 (0.039)	1.087**	2.965	2.028 (0.043)
IV. SAFETY EQUIPMENT CHARACTERISTICS						
13. Life jacket nos. (>20 to 40)	-2.767**	0.063	-2.210 (0.027)	-1.574**	0.207	-2.331 (0.020)
14. Pump nos. (>1)	2.162*	8.688	1.650 (0.099)	-	-	-
15. Fire-fighting instrument nos. (5 to 6)	-1.549*	0.212	-1.790 (0.073)	-1.138**	0.320	-2.377 (0.017)
Pseudo R-square			0.290			0.290

Log-likelihood			-141.6			-142
AIC			315.2			318

*Statistically significant at α = 0.10, **Statistically significant at α = 0.05, ***Statistically significant at α = 0.01.

Table 5.3: Marginal effect analysis for variables affecting final condition of vessel

Variable	**Sunk**
Accident year (2011)	0.223
Month (February)	0.113
Accident cause (Stability failure)	0.247
Involve vessel (2)	-0.168
Collision type (PL vs PT/SC)	0.108
Length of vessel (>50 to 70 meters)	-0.197
Passenger capacity (0 to 150)	-0.093
Passenger capacity (>300 to 450)	0.2662
1st deck passenger capacity (>65 to 130)	-0.113
Breaking horse-power (>375)	-0.196
Vessel age (>5 to 10 years)	0.208
Modification of vessel (Yes)	0.209
Life jacket nos. (>20 to 40)	-0.228
Fire-fighting instrument nos. (5 to 6)	-0.181

5.2 Goodness-of-fit of binary logit models

The estimated results for the fixed and mixed coefficient binary logit models pertaining to the final condition of the vessel are presented in Table 5.2. Both models exhibited a satisfactory fit to the data, as indicated by strong goodness-of-fit measures. The results from the fixed and mixed coefficient models were nearly identical, with only a minor discrepancy in the number of significant variables. Despite performing similarly in terms of log-likelihood, AIC values, and Pseudo R-squared, the mixed coefficient binary logit model was chosen for further analysis due to its ability to capture unobserved heterogeneity. While the fixed coefficient model identified 15 significant variables, the variable "Pump nos". was excluded from the mixed coefficient model because it did not show significance. Consequently, 14 significant variables from the mixed coefficient model were selected for subsequent analysis.

5.3 Interpretation of the significant variables

The interpretation of the major variables investigated here is discussed below, considering the important contributors to vessel sinking in inland waterway accidents of Bangladesh. The study examines multiple attributes such as overall accident patterns, type of accident causes, vessel features, and safety devices to see the effect on the risk of sinking. The understanding provided by this interpretation process in the vessel accidents provides invaluable input to better safety measures for inland waterway transport.

General Characteristics

It was found in this study that the inland waterway accidents occurring in 2011 had a significantly increased chance of vessel sinking compared to other years as can be seen, it is supported by the positive coefficient (1.143, $p < 0.01$) presented at Table 5.2. This result is robust as the marginal effect analysis (Table 5.3) also reveals that the probability of sinking rose by 22.3 percentage points for accidents in 2011 compared to other years. This increased risk could be explained by the lifting of a temporary ban on unsafe vessels in 2010. Based on Prothom Alo (2011), the ban was lifted because of the increasing pressure from ship owners in 2011, leading to that structurally weakened or not up-to-date vessels were permitted to go back into operations and that cause more serious accidents.

A consideration of the monthly patterns reveals that, inland waterway accidents in Bangladesh, taking place in February are much more likely to end by a vessel sinking than accidents in other months. This is confirmed by the Odd ratio (OR) > 1 for February in Table 5.2, which denotes a high risk of sinking at this month. February is the end of winter and a part of the dry season in Bangladesh, when water levels in rivers and canals are usually low. Accordingly, vessel operators in such conditions are known to attempt to recover lower trip frequencies by overcrowding passengers. In this respect, overloading in shallow water exacerbates stability because ships are assuming having less buoyancy and even less depth under the hulls, which means they can more quickly roll over with little aggravation. Such higher susceptibility may have contributed to the higher rate of vessel sinking in February (Vantorre et al., 2017; Terziev et al., 2018).

Accident Characteristics

Among the different factors inducing waterway accidents considered in this study, Stability Failure ($\beta = 1.264$, $p < .05$) appears to have a stronger impact on occurrence of vessel sinking compared with collision, overloading, storm, bottom rupture, and excessive current. Marginal effect analysis also shows that when an accident is attributed to "Stability Failure", the probability of sinking is higher (by 24.7 percentage points) than other causes. Stability loss compromises the equilibrium of a ship and frequently results in sudden capsizing. Other causes for an accident, however (e.g., a collision, or overloading) may enable some response time and containment. A complete loss of stability, accompanied by inability to recover, makes a substantial contribution to the increased risk of sinking. This finding also correlates with the findings of Vassalos (2014) who suggested stability failure as being a key factor in ship accidents.

In the present study, waterway accidents in which two vessels are involved (OR < 1) result in a decreased probability of sinking than those with only one vessel. These results are in line with previous studies (Aziz et al., 2019; Zhang et al., 2020). In the present study, the parameter "Involve Vessel (2)" was formulated as a normally distributed random one with the mean (-0.909) and standard deviation (0.011) in table 5.2. The small value of the standard deviation ($p = 0.980$) shows that the impact of having two vessels involved in an accident was consistently negative with regard to the likelihood for a sinking, for all observations. In the case of a collision between two ships, localized damage occurs and there is time for emergency responses. This might be a reason why in two-vessel accidents the vessel is less susceptible to sinking as opposed to single-vessel cases like failure due to overloading or stability where there are high risk of capsizing immediately.

An analysis of the collision type and sinking reveals that collisions in "PL vs PT/SC" show higher probabilities of a vessel becoming sunk in comparison to other categories of collision as implied by the positive parameter (0.579, $p < 0.05$). Such increased vulnerability could be due to the structural weaknesses of smaller vessels like passenger trawlers and sand carriers. If these small vessels struck a larger passenger launch, the probability of critical damage to them would be higher due to their lesser strength and integrity (Murthy et al., 2012).

Vessel Characteristics

The estimates suggest that vessels faces accident of size between 50 to 70 meters (OR<1) are substantially less likely to be sunk than smaller ones measuring from 0 to 50 meters. These results are consistent with a previous study by Rahman (2017) who found vessel length was an important factor associated with casualty outcome. "In the current analysis the parameter "Length > 50 to 70" was modelled as a normally distributed random parameter with mean -1.145 and standard deviation 0.110 (Table 5.2). Since the value of standard deviation is small compared with the mean, it means that vessel length effect range was dominated by consistent negative response across most records, thus confirming the robustness of the result. Furthermore, vessels longer than 50 meters are required to be fitted with advanced navigation aids, which includes the use of radar, compass and communications systems to enhance situational awareness rendering them less likely to sink compared to those smaller vessels that carries fewer instruments.

The present study suggests that vessels having a carrying capacity of more than 300 to 450 passengers (OR>1) have a higher likelihood of sinking as compared to those with lower ones. On the other hand, among accidents in which 0 to 150 passenger carrying vessels (OR<1) are involved, they are less likely to sink. This conclusion is further substantiated by an examination of the marginal effect: vessels with 300-450 passengers appear to have a 26.6 percent higher chance in sinking if they are involved in any accidents. On the other hand, vessels with a capacity between 0 and 150 have a 9.3 percentage points decrease in probability of sinking under similar conditions. Larger vessels, especially those having capacities of 300 or more passengers, are more vulnerable to overloading particularly during peak seasons such as the Eid festival celebrations in Bangladesh. Excess load could seriously affect the stability of vessel and is one of the main causes for ship capsizing, which can rationally explain this phenomenon. This is also supported by the study of Murthy et al. (2012)

This research concludes that vessels with passenger capacity between 65 to 130 on the first deck are less likely ($\beta = -0.673$, $p < 0.05$) to sink in accidents than are those with a capacity of more than 130 persons. Ships in this size range are referred to as medium-sized or mid-range, and such vessels can usually be evacuated more easily in an emergency due to their simple structure. On the other hand, passengers may have greater difficulty in evacuating from larger vessels with first deck capacities of over 130. Better management of mid-size vessels at emergency can also decrease the panic induced instability which leads to sink or capsize (Zytoon & Basahel, 2017; Davis et al., 2019).

With respect to brake horsepower (BHP), this study suggests that passenger vessels equipped with engines exceeding 375 BHP are less likely to sink following an accident which is reflected by its negative coefficient (-1.179, $p < 0.01$). Previous studies by Wang et al. (2018) also corroborate this conclusion, emphasizing that high-powered engines specifically those exceeding 300 BHP enhance a vessel's maneuverability. Improved maneuverability enables more effective responses to emergency situations, including strong currents, collisions, and unexpected obstacles, thereby reducing the likelihood of capsizing or sinking.

When considering the age of vessels, it was observed that those older than five to ten years ($OR>1$) are more susceptible to sinking following an accident compared to relatively newer vessels. Marginal effect analysis further indicates that when a vessel aged 5 to 10 years experiences an accident, the probability of sinking increases by 20.8 percentage points compared to vessels in other age groups. This heightened risk may be attributed to inadequate maintenance by vessel owners, as well as the accumulation of excessive silt in the rivers of Bangladesh, which can lead to hull corrosion (Rahman, 2017; Wang et al., 2018).

In this study, it has been found that passenger vessels which have undergone modifications ($p = 0.043$) are significantly more likely to sink following an accident compared to those that have not been altered or rebuilt. This observation is further supported by marginal effect analysis, which shows that when a vessel that has undergone modifications experiences an accident, the probability of sinking increases by 20.9 percentage points compared to vessels that have not been modified or rebuilt. Structural modifications, particularly those that are informal or unregulated, can compromise the vessel's original design integrity. Common alterations such as the addition of upper decks or cabins to increase passenger capacity, hull lengthening, or changes to the vessel's shape can adversely affect balance and structural strength. These changes may weaken hull integrity or create structural imbalances, thereby increasing the likelihood of rapid capsizing or sinking during hazardous events (Uddin & Awal, 2017; Rahman, 2017).

Safety Equipment Characteristics

In this study, the relationship between the number of life jackets on board and the probability of vessel sinking has also been analyzed. The analysis revealed that vessels equipped with 21 to 40 life jackets ($\beta = -1.574$, $p < 0.05$) exhibit a lower likelihood of sinking compared to both larger vessels (with more than 40 life jackets) and smaller vessels (with fewer than 20 life jackets). Notably, marginal effect analysis indicated that when a vessel having number of life jackets in between 20 to 40 faces an accident, the probability of sinking reduced by 22.8 percentage points. This range likely corresponds to medium-sized vessels, such as mid-sized passenger launches, which may benefit from an optimal balance between capacity, design, and operational control. In contrast, vessels carrying more than 40 life jackets are typically larger and may be prone to overloading, while those with fewer than 20 life jackets are often smaller, less structurally robust trawlers with inadequate safety features. These findings are consistent with those of Jin et al. (2001) and Zytoon and Basahel (2017), who reported that mid-sized passenger vessels tend to be the safest in inland waterway operations.

At last, while analyzing the final condition of vessels following accidents, our findings indicate that passenger vessels equipped with five to six firefighting instruments are less likely to sink compared to those with fewer safety devices, which is reflected by the Odd ratio (OR) < 1 . This conclusion is supported by marginal effect analysis, which shows that when a vessel equipped with five to six fire-fighting instruments experiences an accident, the probability of sinking decreases by 18.1 percentage points. Similar conclusions have been drawn by Jacobs and Hawley (2011), who emphasize that vessels with multiple fire extinguishers are more likely to adhere to safety protocols and employ trained personnel. The presence of such equipment reflects a broader commitment to operational discipline and emergency preparedness. A strong safety culture and heightened awareness of emergency procedures contribute to greater survivability during critical incidents, thereby reducing the likelihood of sinking.

5.4 Summary

This chapter studied the eventual situation of vessels in inland waterway accidents in Bangladesh with an aim to understanding key reasons for which how a vessel becomes sunk. To do this, binary logit fixed-effect and mixed-coefficient models were finally estimated with marginal effects. Finally the mixed coefficient model was chosen, as it allowed for unobserved heterogeneity. 14 significant variables were selected and further analyzed.

With respect to general features, the accidents in 2011 were a significant predictor for the likelihood of vessels sinking. This rise in risk was found to be due to removal of a temporary ban on unfit vessels, so that those which were structurally challenged could return to service. Also in February, accidents demonstrated higher susceptibility to sinking that was related to low water levels and overloading in the dry season.

As for accident features, stability loss was identified as the most significant factor contributing to ferry sinking because it has a direct impact on ship balance and stability. Single-vessel accidents were more likely to result in capsizing and sinking than two vessel accidents, as they appeared to have had an inherent risk of immediate rolling during stability failure or over-exceeding. Moreover, accidents with a smaller vessel, such as "Passenger Launch vs. Passenger Trawler or Sand Carrier," were also observed to have higher probability of sinking because of the structural weakness in nature for those types of involved smaller vessels.

The characteristics of vessels was also an important factor, where those more than 50 meters in length were less likely to sink, probably as a result of better provision and

increased stability. Conversely the larger passenger capacity (300 to 450 passengers or more) ships were prone to sinking with overloading as a significant issue. Mid-size (50-70 meters) vessels had decreased odds of capsizing compared to small vessels, which implied that larger, well-equipped vessels became less likely to capsize.

Regarding safety equipment composition, the study proved that boats equipped with an intermediate number of life jackets (between 21 and 40) have lower chances of sinking, which reveals a balance among vessel size, design and safety characteristics. Vessels with over 40 life jackets or less than 20 were more likely to sink presumably because of either overloading or insufficient structural strength. Moreover, vessels with the 5-6 fire-fighting equipment even had a relatively low probability of sinking because these safety measures could indicate better preparation for disaster and safer behavior.

In general, this research sheds new light on the various driving and restraining factors of vessel sinking in inland waterway environments. The results highlight the effectiveness of strict safety requirements, regular vessel maintenance and expertise in design for improvement of vessel survival probabilities and prevention against catastrophic events in waterway transportation.

CHAPTER 6: CAUSES OF ACCIDENT MODEL

This chapter aims to explore the root causes of inland waterway accidents in Bangladesh, and to identify the major variables that cause these accidents. Following the methodological procedures in previous chapters of ordered probit model and binary logistic regression model, fixed coefficient model and mixed coefficient model are used to analyze the effects of different determinants on causes associated with inland waterway accidents. The comparison criteria for those models were the same as used in the previous chapters. Subsequently, marginal effect analyses were conducted to quantify the effect of different variables on accident causes. The findings are intended to enhance the understanding of the most influential factors contributing to inland waterway accidents in Bangladesh and to inform the development of more effective safety strategies and preventive measures.

6.1 Development of Causes of Accident Models

Consistent with the methodologies employed in Chapters 4 and 5, the models addressing the causes of accidents have been developed using data from 337 waterway accidents that occurred between 1983 to 2017. Among these accidents, 64% were due to collision, 17% to overloading, and 10% to storm-related events, while the remaining 9% resulted from bottom rupture/excessive current/other factors (Figure 6.1).

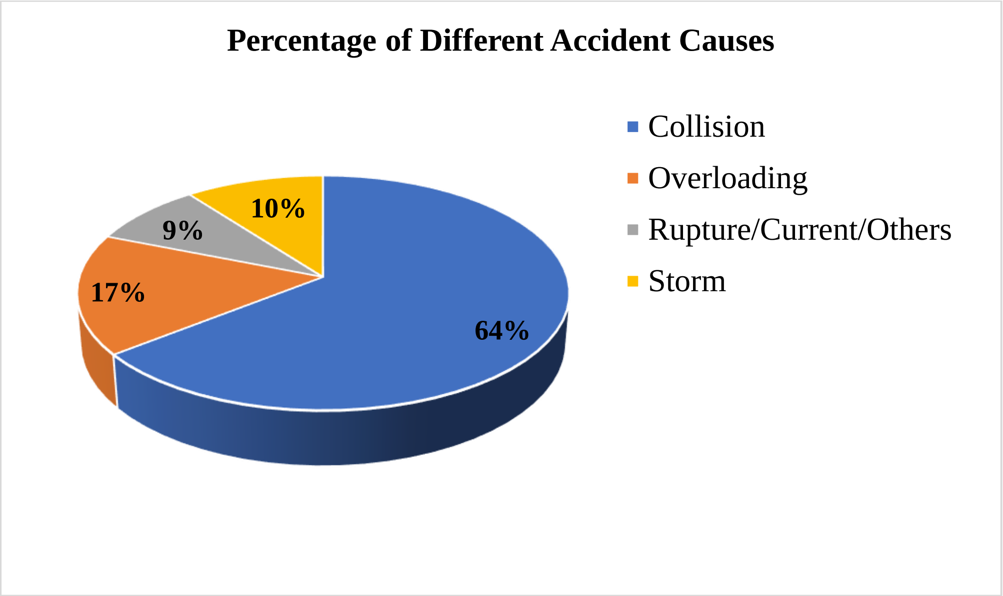

Figure 6.1: Percentage of different accident causes

6.1.1 Multinomial Logit models

In the developed multinomial logit models, the dependent variable represents the cause of the accident, which may assume one of four categories: collision, overloading, storm, and bottom rupture/excessive current/other causes. Using “overloading” as the base or reference category, key explanatory variables were identified for the remaining three categories: collision, storm, and bottom rupture/excessive current/others.

The fixed coefficient multinomial logit model, consistent with the methodological framework adopted in Chapters 4 and 5, was implemented using STATA-15. In addition, the mixed coefficient multinomial logit model was developed within the R programming environment, employing the “mlogit” package to incorporate random parameters. A total of 99 variables, derived from 16 factors, were retained in the final models; these variables, along with their definitions, means, and standard deviations, are presented in Table 6.1. Key factors were identified for both the fixed and mixed coefficient models, and a comparative analysis was undertaken using matrices similar to those utilized in Chapters 4 and 5.

The outcomes of the developed models are summarized in Table 6.2, where the independent variables are organized into four categories: (I) general characteristics, (II) vessel characteristics, (III) safety equipment characteristics, and (IV) master/driver/crew characteristics, comprising a total of 16 factors. The model demonstrating the strongest statistical fit was selected to determine the significant variables. Within this model, 15 variables were identified as significant for collisions, 10 for storm-related incidents, and 3 for bottom rupture/excessive current/other causes, while maintaining the robustness of the analysis by avoiding multicollinearity.

Table 6.1: Summary statistics of key variables for accident causes of vessel

Variable	**Measurement**	**Mean**	**Std. Dev.**
Dependent Variable			
Accident Causes	1 if Collision (64%)	1.632	0.978
	2 if Overloading (17%)		
	3 if Storm (10%)		
	4 if Bottom rupture/Excessive current/others (9%)		
Explanatory variable			
I. GENERAL			
1. Accident year			
1983	1 if 1983, else 0	0.012	0.108

1984	1 if 1984, else 0	0.021	0.143
1985	1 if 1985, else 0	0.033	0.178
1986	1 if 1986, else 0	0.033	0.178
1987	1 if 1987, else 0	0.024	0.152
1988	1 if 1988, else 0	0.015	0.121
1989	1 if 1989, else 0	0.041	0.199
1990	1 if 1990, else 0	0.029	0.169
1991	1 if 1991, else 0	0.015	0.121
1992	1 if 1992, else 0	0.038	0.192
1993	1 if 1993, else 0	0.012	0.108
1994	1 if 1994, else 0	0.044	0.206
1995	1 if 1995, else 0	0.018	0.132
1996	1 if 1996, else 0	0.018	0.132
1997	1 if 1997, else 0	0.021	0.143
1998	1 if 1998, else 0	0.012	0.108
1999	1 if 1999, else 0	0.003	0.054
2000	1 if 2000, else 0	0.029	0.169
2001	1 if 2001, else 0	0.009	0.094
2002	1 if 2002, else 0	0.009	0.094
2003	1 if 2003, else 0	0.015	0.121
2004	1 if 2004, else 0	0.027	0.161
2005	1 if 2005, else 0	0.077	0.267
2006	1 if 2006, else 0	0.041	0.199

2007	1 if 2007, else 0	0.021	0.143
2008	1 if 2008, else 0	0.059	0.236
2009	1 if 2009, else 0	0.047	0.213
2010	1 if 2010, else 0	0.056	0.231
2011	1 if 2011, else 0	0.041	0.199
2012	1 if 2012, else 0	0.029	0.169
2013	1 if 2013, else 0	0.009	0.094
2014	1 if 2014, else 0	0.038	0.192
2015	1 if 2015, else 0	0.044	0.206
2016	1 if 2016, else 0	0.024	0.152
2017	1 if 2017, else 0	0.033	0.178
2. Month			
January	1 if the accident happened in january, else 0	0.095	0.293
February	1 if the accident happened in february, else 0	0.086	0.280
March	1 if the accident happened in march, else 0	0.119	0.323
April	1 if the accident happened in april, else 0	0.098	0.297
May	1 if the accident happened in may, else 0	0.092	0.289
June	1 if the accident happened in june, else 0	0.038	0.192
July	1 if the accident happened in july, else 0	0.077	0.267

August	1 if the accident happened in august, else 0	0.083	0.276
September	1 if the accident happened in september, else 0	0.092	0.289
October	1 if the accident happened in october, else 0	0.068	0.252
November	1 if the accident happened in november, else 0	0.065	0.247
December	1 if the accident happened in december, else 0	0.080	0.271
3. Season			
Winter	1 if the accident happened in winter, else 0	0.175	0.380
Spring	1 if the accident happened in spring, else 0	0.205	0.404
Summer	1 if the accident happened in summer, else 0	0.189	0.392
Rainy	1 if the accident happened in rainy season, else 0	0.116	0.319
Autumn	1 if the accident happened in autumn, else 0	0.175	0.380
Late autumn	1 if the accident happened in late autumn, else 0	0.134	0.340
4. Time			
Morning	1 if morning, else 0	0.202	0.401
Afternoon	1 if afternoon, else 0	0.116	0.319
Evening	1 if evening, else 0	0.116	0.319
Night	1 if night, else 0	0.214	0.409

II. VESSEL CHARACTERISTICS			
5. Length of vessel			
0 to 30 meters	1 if 0 to 30 meters, else 0	0.445	0.497
>30 to 50 meters	1 if >30 to 50 meters, else 0	0.166	0.372
>50 to 70 meters	1 if >50 to 70 meters, else 0	0.317	0.465
>70 meters	1 if >70 meters, else 0	0.071	0.260
6. 1st deck passenger capacity			
0 to 65	1 if 0 to 65, else 0	0.163	0.369
>65 to 130	1 if >65 to 130, else 0	0.113	0.316
>130 to 200	1 if >130 to 200, else 0	0.092	0.289
>200	1 if >200, else 0	0.184	0.387
7. Cabin nos. (2nd deck)			
0 to 6	1 if nos. of cabin at 2nd deck was 0 to 6, else 0	0.534	0.499
>6 to 12	1 if nos. of cabin at 2nd deck was >6 to 12, else 0	0.083	0.276
>12 to 18	1 if nos. of cabin at 2nd deck was >12 to 18, else 0	0.045	0.206
>18	1 if nos. of cabin at 2nd deck was >18, else 0	0.098	0.297
8. Breaking horse-power			
0 to 125	1 if 0 to 125, else 0	0.154	0.361
>125 to 250	1 if >125 to 250, else 0	0.130	0.337
>250 to 375	1 if >250 to 375, else 0	0.012	0.108
>375	1 if >375, else 0	0.258	0.438

9. Gross registered tonnage			
0 to 175	1 if 0 to 175, else 0	0.240	0.427
>175 to 350	1 if >175 to 350, else 0	0.036	0.185
>350 to 525	1 if >350 to 525, else 0	0.039	0.193
>525	1 if >525, else 0	0.240	0.427
10. Vessel age			
0 to 5 years	1 if 0 to 5 years, else 0	0.136	0.343
>5 to 10 years	1 if >5 to 10 years, else 0	0.098	0.297
>10 to 15 years	1 if >10 to 15 years, else 0	0.059	0.236
>15 years	1 if >15 years, else 0	0.148	0.355
III. SAFETY EQUIPMENT CHARACTERISTICS			
11. Compass			
Yes	1 if compass was available in vessel, else 0	0.347	0.476
No	1 if compass was not available in vessel, else 0	0.430	0.495
12. Fire-fighting instrument nos.			
0 to 2	1 if 0 to 2, else 0	0.379	0.485
3 to 4	1 if 3 to 4, else 0	0.127	0.334
5 to 6	1 if 5 to 6, else 0	0.145	0.352
>6	1 if >6, else 0	0.125	0.330
IV. MASTER/DRIVER/CREW CHARACTERISTICS			
13. 1st Engineer-Driver			
Yes	1 if 1st Engineer-Driver was available, else 0	0.504	0.499

No	1 if 1st Engineer-Driver was not available, else 0	0.258	0.438
14. 2nd Engineer-Driver			
Yes	1 if 2nd Engineer-Driver was available, else 0	0.261	0.439
No	1 if 2nd Engineer-Driver was not available, else 0	0.504	0.499
15. 2nd Engineer-Driver class			
1st	1 if 2nd engineer-driver was 1st class, else 0	0.045	0.206
2nd	1 if 2nd engineer-driver was 2nd class, else 0	0.059	0.236
3rd	1 if 2nd engineer-driver was 3rd class, else 0	0.154	0.361
Gridger	1 if 2nd engineer-driver was gridger, else 0	0.003	0.054
No certification	1 if 2nd engineer-driver did not have any formal certification, else 0	0.504	0.499
16. Nos. of crew			
0 to 6	1 if 0 to 6 nos. of crew were supposed to be onboard, else 0	0.136	0.343
>6 to 12	1 if >6 to 12 nos. of crew were supposed to be onboard, else 0	0.205	0.404
>12 to 18	1 if >12 to 18 nos. of crew were supposed to be onboard, else 0	0.184	0.387
>18	1 if >18 nos. of crew were supposed to be onboard, else 0	0.039	0.193

Table 6.2: Model estimation results for fixed and mixed-coefficient multinomial logit models

Variable	Multinomial logit parameter estimates					
	Fixed- coefficient model			Mixed- coefficient model		
	Co-efficient (β)	Relative risk ratio	Z-value (P-value)	Co-efficient (β)	Relative risk ratio	Z-value (P-value)
Collision						
I. GENERAL						
1. Accident Year (1985)	-2.135**	0.118	-2.500 (0.012)	-2.461**	0.085	-2.204 (0.027)
2. Accident Year (1986)	-1.606**	0.201	-2.140 (0.032)	-2.752***	0.064	-2.833 (0.005)
3. Month (May)	-1.555***	0.211	-2.650 (0.008)	-2.005**	0.135	-2.343 (0.019)
4. Month (June)	-1.732**	0.177	-2.270 (0.023)	-1.370*	0.254	-1.663 (0.096)
5. Time (Afternoon)	-1.732***	0.177	-4.000 (0.000)	-2.148***	0.117	-3.494 (0.000)
II. VESSEL CHARACTERISTICS						
6. Length of vessel (0 to 30 meters)	-4.278***	0.014	-4.100 (0.000)	-3.559***	0.028	-3.012 (0.003)

7. Length of vessel (>50 to 70 meters)	-1.411*	0.244	-1.770 (0.077)	-0.339	0.712	-0.283 (0.777)
Standard deviation of parameter distribution	-	-	-	*2.617***	*13.695*	*2.356 (0.018)*
8. 1st deck passenger capacity (0 to 65)	-1.430**	0.239	-2.530 (0.011)	-	-	-
9. 1st deck passenger capacity (>130 to 200)	-1.324**	0.266	-2.090 (0.037)	-	-	-
10. Cabine nos. (2nd deck) (>6 to 12)	-2.129**	0.119	-2.390 (0.017)	-2.665**	0.070	-2.255 (0.024)
11. Breaking horse-power (>375)	1.908**	6.74	2.420 (0.015)	2.442**	11.496	2.204 (0.027)
12. Gross registered tonnage (0 to 175)	1.053*	2.866	1.900 (0.057)	-	-	-
III. SAFETY EQUIPMENT CHARACTERISTICS						
13. Compass (Yes)	1.146**	3.146	2.260 (0.024)	1.094*	2.986	1.886 (0.059)
IV. MASTER/DRIVER/CREW CHARACTERISTICS						
14. 2nd Engineer-Driver class (No certification)	2.788***	16.248	2.930 (0.003)	2.949**	19.087	2.419 (0.016)
Standard deviation of parameter distribution	-	-	-	-0.159	0.853	-0.139 (0.889)
15. Nos. of crew (>18)	-2.279**	0.102	-1.970 (0.049)	-	-	-

Storm						
I. GENERAL						
1. Accident Year (1996)	3.372**	29.137	2.180 (0.029)	5.237**	188.10	1.969 (0.049)
2. Month (April)	6.397***	600.04	4.240 (0.000)	6.708**	818.93	2.335 (0.019)
3. Month (May)	5.820***	336.97	3.790 (0.000)	6.147**	467.31	2.133 (0.033)
4. Season (Spring)	4.982***	145.76	3.370 (0.000)	5.547*	256.46	1.923 (0.054)
5. Season (Rainy)	4.303***	73.921	2.950 (0.003)	4.752*	115.81	1.649 (0.099)
6. Accident Time (Morning)	-2.063***	0.127	-2.960 (0.003)	-1.989**	0.137	-2.550 (0.011)
7. Accident Time (Afternoon)	-1.991***	0.137	-2.730 (0.006)	-1.724**	0.178	-2.069 (0.038)
II. VESSEL CHARACTERISTICS						
8. Vessel age (>15 years)	-2.043**	0.130	-2.150 (0.032)	-	-	-
IV. MASTER/DRIVER/CREW CHARACTERISTICS						
9. 1st Engineer-Driver (Yes)	2.969***	19.472	4.220 (0.000)	2.028***	7.599	3.109 (0.002)
10. 2nd Engineer-Driver (Yes)	-2.899***	0.055	-2.680 (0.007)	-2.392*	0.091	-1.846 (0.065)

Bottom rupture/Excessive current/others						
I. GENERAL						
1. Season (Spring)	-1.568*	0.208	-1.900 (0.057)	-	-	-
II. VESSEL CHARACTERISTICS						
2. Breaking horse-power (>125 to 250)	1.925***	6.855	3.190 (0.001)	1.428**	4.170	2.352 (0.019)
III. SAFETY EQUIPMENT CHARACTERISTICS						
3. Fire-fighting instrument nos. (5 to 6)	1.837***	6.278	2.750 (0.006)	1.957***	7.078	2.841 (0.004)
Pseudo R-square			0.297			0.268
Log-likelihood			-243.67			-253.73
AIC			549.34			557.46

*Statistically significant at α = 0.10, **Statistically significant at α = 0.05, ***Statistically significant at α = 0.01.

Table 6.3: Marginal effect analysis for Collision

Variable	**Collision**
Accident year (1985)	-0.336
Accident year (1986)	-0.259
Month (May)	-0.470
Month (June)	-0.275
Time (Afternoon)	-0.243
Length of vessel (0 to 30 meters)	-0.473
Length of vessel (>50 to 70 meters)	-0.216
1st deck passenger capacity (0 to 65)	-0.223
1st deck passenger capacity (>130 to 200)	-0.209
Cabin nos. (2nd deck) (>6 to 12)	-0.317
Breaking horse-power (>375)	0.261
Gross registered tonnage (0 to 175)	0.149
Compass (Yes)	0.169
2nd Engineer-Driver class (No certification)	0.339
Nos. of crew (>18)	-0.339

Table 6.4: Marginal effect analysis for Storm

Variable	Storm
Accident Year (1996)	0.281
Month (April)	0.514
Month (May)	0.545
Season (Spring)	0.317
Season (Rainy)	0.309
Accident Time (Morning)	-0.098
Accident Time (Afternoon)	-0.061
Vessel age (>15 years)	-0.088
1st Engineer-Driver (Yes)	0.187
2nd Engineer-Driver (Yes)	-0.119

Table 6.5: Marginal effect analysis for Bottom rupture/Excessive current/others

Variable	Bottom rupture/Excessive current/others
Season (Spring)	-0.087
Breaking horse-power (>125 to 250)	0.207
Fire-fighting instrument nos. (5 to 6)	0.196

6.2 Goodness-of-fit of multinomial logit models

The estimation results for both the fixed and mixed coefficient multinomial logit models related to accident causes are presented in Table 6.2. Both models demonstrated an acceptable fit to the data, as evidenced by favorable goodness-of-fit indicators. However, based on a comparative evaluation using the number of significant variables, log-likelihood values, Akaike Information Criterion (AIC), and Pseudo R-squared statistics, the fixed coefficient multinomial logit model consistently outperformed the mixed coefficient model across all evaluation categories. Consequently, the fixed coefficient model was selected for subsequent analyses and the estimation of marginal effect.

6.3 Interpretation of the significant variables

Given that the significant variables identified through the multinomial logistic regression models are specific to individual accident cause categories, the relevant variables for each outcome will be discussed in separate sections to facilitate clearer interpretation and understanding of the results.

6.3.1 Significant variables related to collision

General Characteristics

In the analysis of inland waterway accident causes of Bangladesh, it was observed that the probability of collisions as a cause of accidents decreased in the years 1985 ($p = 0.012$) and 1986 ($p = 0.032$) compared to overloading incidents. Specifically, the relative risk ratio (RRR) for collisions was 0.118 in 1985 and 0.201 in 1986 (Table 6.2), indicating a lower likelihood of collision-related incidents relative to the baseline category. The marginal effect analysis further showed that accidents occurring in 1985 or 1986 were associated with a 33.6 and 25.9 percentage point reduction, respectively, in the probability of collisions compared to overloading (Table 6.3). During the mid-1980s, the regulatory framework governing Bangladesh's inland waterways was insufficiently robust to prevent overloading. The lack of comprehensive legislation and enforcement mechanisms allowed unsafe practices to continue, contributing to the prominence of overloading as a cause of accidents during that period (World Bank, 2007; Mia et al., 2021).

When examining the month variable in relation to collision as a cause of accident, it was observed that incidents occurring in May ($\beta = -1.555$, $p < 0.01$) and June ($\beta = -1.732$, $p < 0.05$) were more frequently associated with overloading rather than collisions. The RRRs for collision were 0.211 in May and 0.177 in June, which means a lower probability of incidents involving a collision during these months compared to the reference category. Supporting the trend, the marginal effect analysis showed that accidents in May and June significantly lowered the probability of collision compared to overloading by 47.0% and 27.5%, respectively. It appears from these findings that the dominant cause of accidents changes over time and there is an increasing proportion due to overloading in the early monsoon period. One possible reason for this pattern is that vessel operators intentionally overload the vessels more in May and June to capture higher revenues, knowing that passenger numbers may drop once heavy monsoon rain arrives. Because capacity control has been rarely enforced, this results in an increase in the number of waterway overloading-related accidents, and it is the main factor for those accidents during this time span.

It was realized in this study that afternoon incidents ($p = 0.000$) have more overloading problems associated to them rather than collisions. This can be attributed to vessel scheduling practices; most long-distance and inter-district trips are scheduled in early morning or late afternoon, resulting in elevated passenger levels during those hours.

Moreover, afternoon time in Bangladesh is vulnerable to Nor'wester storms ("Kalboishakhi") that increases the risk for the overloaded vessels (Awal et al., 2006; Uddin et al., 2017a).

Vessel Characteristics

While considering the length of vessels associated with accident causes, it has been observed that vessels with lengths ranging from 0 to 30 meters ($\beta = -4.278$, $p < 0.01$) or >50 to 70 meters ($\beta = -1.411$, $p < 0.10$) were more likely to be associated with overloading than collisions. The relative risk ratio of collision was 0.014 for vessels between 0 to 30 meters and 0.244 for those between >50 to 70 meters, indicating a reduced likelihood of collision in smaller vessels and a slightly increased likelihood in larger vessels. Marginal effect analysis further revealed that passenger vessels with lengths between 0 to 30 meters or greater than 50 to 70 meters reduced the probability of collision, compared to overloading, by 47.3 and 21.6 percentage points, respectively. Smaller vessels tend to navigate congested routes and face higher risks of overloading due to capacity limitations, especially during peak periods, while larger vessels, although less prone to collisions, still experience overloading due to operational pressures during high passenger demand. These findings are supported by studies such as Uddin et al. (2017b), which noted the overloading tendencies of smaller vessels, and Mia et al. (2020), which highlighted that larger vessels also face significant overloading during periods of high traffic.

While considering the relationship between passenger capacity and the causes of accidents, it has been observed that vessels with 1st deck passenger capacities of 0 to 65 ($p = 0.011$) or >130 to 200 ($p = 0.037$) have a lower probability of collision compared to overloading incidents. The relative risk ratios (RRR) for these categories are 0.239 and 0.266, respectively. This trend may be attributed to better maneuverability in smaller vessels and stricter regulation or experienced operators in larger ones, both reducing collision risks. However, overloading remains a concern due to economic pressures and inconsistent enforcement. Similar patterns have been noted in prior studies (Uddin et al., 2017b; Rahman, 2017), which highlight the role of vessel size, regulatory oversight, and operational behavior in influencing accident types.

Focusing on the number of cabins in passenger vessels, it was found that vessels with >6 to 12 cabins on the second deck ($\beta = -2.129$, $p < 0.05$) had a decreased likelihood of collision-related accidents compared to overloading. Marginal effect analysis further indicated that, for vessels with more than 6 to 12 cabins on the second deck, the likelihood of collision decreased by 31.7 percentage points relative to overloading. This can be explained by the fact that vessels with more cabins carry more passengers on the upper deck, raising the center of gravity. When overloaded, this shift in the center of gravity makes the vessel more prone to stability failure, increasing the risk of capsizing, particularly in rough conditions. Despite their larger capacities, these vessels are more vulnerable to stability issues when overloaded, as the load distribution becomes uneven. Previous studies, such as Talley (1996) and Balmat et al. (2011), have shown that overloaded vessels with a high center of gravity are more likely to experience stability failures and capsizing, especially in turbulent conditions.

It has been observed that vessels with a brake horsepower (BHP) greater than 375 ($p = 0.015$) showed a significantly higher likelihood of collision-related incidents compared to overloading. Specifically, the relative risk ratio for collision in vessels with BHP > 375 was 6.74, meaning these vessels were 6.74 times more likely to experience a collision than overloading. This trend may be attributed to the operational characteristics of higher-powered vessels, which are typically faster and may lead to more aggressive maneuvering in congested or challenging waterways. Higher-powered vessels are better suited for carrying larger loads without overloading, thus reducing the likelihood of overloading-related accidents. This is consistent with findings by Awal et al. (2006), which noted that larger, more powerful vessels tend to have higher collision risks due to faster speeds and less careful operation.

It has been found that inland waterway vessels in Bangladesh with a gross registered tonnage (GRT) between 0 to 175 ($\beta = 1.053$, $p < 0.10$) are more likely to be involved in collisions than in overloading incidents. The relative risk ratio (RRR) for collision within this GRT range is 2.866, suggesting a significantly elevated risk. While smaller vessels generally have greater maneuverability, this advantage may be undermined by a lack of trained or licensed vessel masters, poor navigational judgment, and insufficient regulatory enforcement. These limitations can increase the likelihood of collision despite the vessel's physical agility.

Safety Equipment Characteristics

While considering the presence of compass in a vessel it has been observed that vessels equipped with a compass ($p = 0.024$) were more likely to be involved in collisions compared to overloading, with a relative risk ratio (RRR) of 3.146. This finding can be attributed to the fact that larger vessels, which are more likely to be equipped with a compass, are also more prone to collisions, similar to vessels with BHP > 375. These vessels often operate on longer, more complex routes, and while a compass aids navigation, it may encourage faster, riskier operation, particularly in congested areas. Additionally, larger vessels are less prone to overloading due to their greater capacity. This aligns with studies by Awal (2006) and Awal et al. (2006), which highlight that larger, faster vessels are more susceptible to collisions despite having better navigational tools.

Master/Driver/Crew Characteristics

In Bangladesh, passenger launches that operate 24 hours a day are required to have two engineer-drivers. The present study reveals that if the second engineer-driver lacks formal certification ($\beta = 2.788$, $p < 0.01$), the probability of a collision increases 16.25 times compared to the probability of overloading. Marginal effect analysis also demonstrates that, under such circumstances, the probability of collision increases by 33.9 percentage points relative to overloading. Larger passenger vessels, which typically operate around the clock, are generally required to have two engineer-drivers. From the previous studies we have already seen that these larger vessels are less prone to overloading due to their greater capacity. However, when a larger passenger vessel's second engineer-driver lacks formal training or certification, it is reasonable to infer that the vessel may be at a higher risk of collisions. This increased risk is likely due to the incompetence or lack of expertise of the second engineer-driver, particularly when assuming operational responsibilities while the primary vessel master rests. Such findings highlight the critical role of proper training and certification in reducing accident risks in the inland waterway transport sector.

Lastly, it has been found that, in the context of inland waterway accidents in Bangladesh, vessels with more than 18 crew members ($\beta = -2.279$, $p < 0.05$) exhibit a lower probability of collision compared to overloading incidents. The relative risk ratio (RRR) for collision in this category is 0.102, indicating a significantly reduced likelihood of such events. Marginal effect analysis also shows that, for vessels with more than 18 crew members on board, the probability of collision decreases by 33.9 percentage points relative to overloading. This trend can be logically explained by the fact that vessels with larger crews are typically larger in size and subject to more stringent regulatory oversight. They are also more likely to be operated by trained and experienced personnel, including certified engineers and vessel drivers. The presence of a skilled crew enhances operational safety, effective communication, and adherence to navigational protocols, thereby lowering the risk of collision. This finding is consistent with existing literature. According to Rashid and Islam (2017), well-staffed and properly managed vessels tend to have better safety records due to improved situational awareness and division of responsibilities. Similarly, Rahman (2017) noted that human resource capacity, particularly the training and competency of crew members, plays a critical role in reducing navigational accidents on inland waterways.

6.3.2 Significant variables related to storm

General Characteristics

While considering the year 1996 ($p = 0.029$), it has been observed that vessels involved in accidents during this year were more likely to face storm-related incidents compared to overloading, with a relative risk ratio (RRR) of 29.137 (Table 6.2). This finding suggests that unusual climatic conditions in 1996, particularly the occurrence of severe tropical storms and intense monsoons, contributed to a higher frequency of storm-related accidents. While there was no major cyclone that year, 1996 saw above-average rainfall and stronger-than-usual cyclonic activity in the Bay of Bengal, which led to smaller but significant storms that affected inland waterway safety. In cases of major cyclones, preventive measures like halting vessel movement can be implemented, but with smaller storms, such precautions are not always feasible, resulting in vessels operating under hazardous conditions. These conditions likely disrupted maritime operations and increased the likelihood of accidents due to weather. It indicates that, during this particular year, storms were a more significant factor than operational issues like overloading. This is supported by studies such as those Azad (2009) and Awal (2006), which emphasize the dominant role of extreme weather conditions in maritime accidents, particularly in regions like South Asia during monsoon seasons.

During the months of April ($\beta = 6.397$, $p < 0.01$) and May ($\beta = 5.820$, $p < 0.01$), it has been observed that passenger vessels involved in accidents were more likely to face storm-related incidents compared to overloading. Marginal effect analysis shows that, when an accident occurs in April or May, the probability of storm-related incidents increases by 51.4 and 54.5 percentage points, respectively, relative to overloading. This finding suggests that the pre-monsoon months of April and May are marked by the occurrence of Kalboishakhi or Nor'wester storms, which are common in Bangladesh. These storms are characterized by high winds, heavy rainfall, and sudden onset, creating dangerous conditions for vessels operating on inland waterways. While these storms may not always reach the intensity of full cyclones, their rapid development and severe weather impact can still cause significant disruptions. The lack of preventive measures, such as halting vessel movement, during such smaller storms increases the risk of accidents. The findings underscore the heightened vulnerability of vessels to storm-related incidents during these months, with Kalboishakhi storms playing a critical role in influencing the safety of inland waterway operations.

In this study, it has been found that passenger vessels involved in accidents during spring ($\beta = 4.982$, $p < 0.01$) or rainy ($\beta = 4.303$, $p < 0.01$) seasons were more likely to face storm-related incidents compared to overloading. The relative risk ratios (RRR) for the spring and rainy seasons were found to be 145.77 and 73.92, respectively, indicating a significantly higher likelihood of storm-related accidents during these periods. Marginal effect analysis also reveals that, if an accident occurs during the spring or rainy season, the likelihood of storm-related incidents increases by 31.7 and 30.9 percentage points, respectively, relative to overloading-related accidents. This suggests that the spring and rainy seasons are closely linked to increased storm activity, particularly Kalboishakhi or Nor'wester storms, which are common during these times. These storms, though not as severe as major cyclones, create hazardous conditions for vessels, and without preventive measures, vessels remain exposed to risks. The association between these seasons and storms is supported by the Bangladesh Meteorological Department (BMD, 2018), which notes that Kalboishakhi storms are frequent in the spring and rainy seasons, increasing the risk to maritime operations. Alam and Pomeroy (2008) also emphasize the heightened occurrence of Nor'wester storms in these months, contributing to disruptions in inland waterway safety. These findings underline the significant impact of storms during the spring and rainy seasons, overshadowing the risk of overloading.

Examining the time of day, it has been observed that passenger vessels involved in accidents during the morning ($p = 0.003$) or afternoon ($p = 0.006$) were less likely to experience storm-related incidents compared to overloading. The relative risk ratios (RRR) for morning and afternoon were 0.127 and 0.137, respectively, indicating a substantially lower risk of storm-related accidents during these periods. This suggests that operational factors such as overloading play a more prominent role in accidents during daylight hours, likely because weather conditions tend to be calmer and visibility becomes better, reducing storm-related risks. Moreover, vessels are often busier during these hours, increasing the chance of human errors or violations of loading regulations. Supporting this, Uddin and Awal (2017) highlight that overloading is a major cause of inland waterway accidents in Bangladesh, especially during peak operational hours when demand for transport is high. Similarly, Awal et al. (2010) emphasize that overloading is more prevalent during daytime operations due to commercial pressures, contributing significantly to accident risk. These findings underscore that while storms pose a serious threat, overloading remains the dominant factor influencing accidents during morning and afternoon periods.

Vessel Characteristics

When examining vessels older than 15 years ($\beta = -2.043$, $p < 0.05$) involved in inland waterway accidents, it has been found that the probability of storm-related accidents decreased compared to overloading, with a relative risk ratio (RRR) of 0.130. This low RRR indicates that for older vessels, overloading is a much more prominent cause of accidents than storms. Older vessels often have diminished structural integrity and stability due to wear and tear, making them more susceptible to accidents caused by excessive loading rather than environmental factors. Supporting this, Rahman (2017) highlights that aged vessels in Bangladesh's inland waterways are frequently overloaded, which significantly increases the likelihood of capsizing and mechanical failures. Similarly, Uddin and Awal (2018) note that vessel age correlates strongly with vulnerability to overloading-related accidents due to reduced maintenance and structural weaknesses. These findings emphasize that, for older vessels, overloading remains the dominant risk factor over storm-related incidents.

Master/Driver/Crew Characteristics

Analyzing the presence of engineer-drivers onboard, it has been found that passenger vessels with only a 1st (primary) engineer-driver ($p = 0.000$), typically smaller vessels operating 8 to 12 hours, have a significantly higher probability of storm-related accidents compared to overloading, with a relative risk ratio (RRR) of 19.472. In contrast, vessels with both 1st and 2nd (secondary) engineer-drivers ($p = 0.007$), usually larger vessels operating 24 hours, show a much lower probability of storm-related accidents relative to overloading, with an RRR of 0.055. This difference can be explained by vessel design and operational factors. Smaller vessels often have poorer stability and less robust structural design, making them more vulnerable to adverse weather conditions like storms. Larger vessels, by contrast, are better designed for stability and can withstand rougher conditions, but they face a higher risk of overloading, especially during festival seasons when passenger demand surges. The economic pressure to carry more passengers during these peak times increases the likelihood of overloading-related accidents despite better vessel stability. Supporting this, Uddin et al. (2017b) note that smaller inland vessels in Bangladesh generally have limited stability features, making them susceptible to capsizing during storms. Meanwhile, Uddin et al. (2017a) emphasize that larger vessels are frequently overloaded during festivals, which is a leading cause of accidents in these periods. These findings highlight how vessel size, design, and operational context collectively shape the risk profile of inland waterway accidents, with storms dominating risks for smaller vessels and overloading for larger ones.

6.3.3 Significant variables related to bottom rupture/excessive current/others

General Characteristics

In this study, while considering the seasonal effect on accident causes, it was found that during the spring season ($\beta = -1.568$, $p < 0.10$) (Table 6.2), the probability of accidents due to bottom rupture, excessive current, or other causes decreases, while overloading-related accidents increase. Spring in Bangladesh corresponds to the dry pre-monsoon period, when river currents are calmer and water levels are lower, reducing the likelihood of current-induced or bottom-related accidents. At the same time, spring features major cultural events like Pohela Boishakh, which significantly increase passenger traffic. In response, vessel operators often exceed capacity limits, leading to a higher incidence of overloading. These findings are supported by Mia et al. (2021), who highlight overloading as a key accident factor during high-demand periods, and Uddin and Awal (2017), who found that structural and hydrological accidents are more common during monsoon seasons than in spring.

Vessel Characteristics

While considering the association of vessel power with accident causes, it was found that vessels with brake horsepower (BHP) >125 to 250 ($\beta = 1.925$, $p < 0.01$) are more likely to face accidents due to bottom rupture/excessive current/other causes than overloading. The relative risk ratio for these causes in this BHP category is 6.855.

Marginal effect analysis shows that, if a vessel with BHP of 125 to 250 faces an accident, the likelihood of bottom rupture/excessive currents/other types of incidents increases by 20.7 percentage points relative to overloading. Higher-powered vessels often operate at greater speeds and in more demanding river conditions, increasing their exposure to hydrodynamic stress and structural risks. These vessels may also be less frequently overloaded due to better regulation or operational discipline. Similar patterns are reflected by Rashid and Islam (2017), who identified operational and environmental factors as key contributors to inland water accidents, and in Azad (2009), who noted that poor safety practices in challenging conditions often lead to structural failures.

Safety Equipment Characteristics

In this study, it has been found that vessels equipped with fire-fighting instruments between 5 to 6 ($p = 0.006$) are more likely to experience accidents due to bottom rupture/excessive current/other causes than overloading. The relative risk ratio for these causes in this category is 6.278. Marginal effect analysis further reveals that, if a vessel has 5 to 6 firefighting instruments on board, the probability of bottom rupture/excessive currents/other types of accidents increases by 19.6 percentage points relative to overloading. These vessels are typically larger and operate in more challenging river conditions, which expose them to hydrodynamic and structural hazards rather than overloading. At the same time, they may adhere more strictly to loading regulations, lowering the likelihood of overloading-related incidents. These findings are supported by Talley et al. (2008), who linked safety equipment levels with operational risk exposure, and Sotiralis et al. (2016), who emphasize the role of environmental and human factors in better-regulated vessels. Zytoon and Basahel

(2017) similarly highlight that vessel characteristics influence the dominant accident causes in inland waterways.

6.4 Summary

This chapter investigates the main determinants affecting causes of Inland Waterway accidents in Bangladesh employing multinomial logit model and marginal effect analysis. Cause of accidents was grouped as collision, overloading, storm, and bottom rupture or excess current or others and overloading served as the reference category. The data was best fit by a fixed coefficient multinomial logit model.

Major observations indicate that collisions are less severe than overloading, which is a paramount factor particularly during the festival season when passenger traffic peaks. Overloading accidents are more prone to smaller vessels that operate during the peak hours in the afternoon. The larger vessels have highly developed methods of navigation such as compasses and staffs and are manned by qualified crew but are more prone to collisions because of operational complexity and speed. Nevertheless, inadequate training of the second engineer-driver implies too much collision risk.

The incidents of storm-related accidents spiked particularly in 1996 and during the pre-monsoon months of April–May on account of violent meteorological events including Kalboishakhi storms. But the dangers of storms abate by day, when incidents such as overloading is more common amid calm waters and busier traffic. Vessel size and stability affect accident causes as well: while smaller, less stable vessels are more at risk because of storms, the larger ships are vulnerable to overloading, particularly when the travel demand is higher.

Furthermore, the older ships (>15 years) have less chance of vessel accidents caused by severe wind as compared with the newer vessels, but due to hull weakening by aging they are more inclined towards overloading type incidents. Bottom rupture and excessive current incidents occur more frequently with larger, higher-powered vessels working in the most arduous river conditions though they are supposed to adhere to strict rules and regulations.

The chapter highlights the intricate interaction of vessel's characteristics, environmental situations, operations and crew competences in shaping of accident causes. Such observations establish a basis for specific safety interventions and policy improvements aimed at reducing accidents on the inland waterways of Bangladesh.

CHAPTER 7: CONCLUSION AND RECOMMENDATIONS

This chapter presents the major findings of the study and recommendations of practical applications through analyzing passenger vessel accidents on inland waterways in Bangladesh. Using a range of sophisticated statistical and probabilistic modeling techniques, i.e., ordered probit, binary logit, multinomial logit, mixed coefficients models, and marginal effects analysis, the chapter summarizes those variables that are most important in influencing accident outcomes. It also converts these observations into practical recommendations for enhancing vessel safety, regulation regime as well as emergency response system. Reconciling empirical findings with policy implications, this section acts as a conduit from academic investigation to the practical world by providing pointers for advancing research, refining regulation and improving operational safety in Bangladesh's water-based transport on its inland waterways.

7.1 Conclusions and Policy Recommendations

In this study, 337 record of inland waterway passenger vessel accidents occurring in Bangladesh were analysed to investigate the following three perspectives: injury severity, vessel end-states and causes of accidents. Based on ordered probit and mixed coefficient models, we found twelve robust and statistically significant factors to be the major determining factors of injury severity. Marginal effect analysis provided more insights by determining factors associated most to injury severity. Seasonal trends were evident with September's accidents causing relatively less injury due to better weather, and remote incidents had increased proportion of injuries reflecting partial delaying of prompt reply, illustrating inadequate medical and rescue facilities in many of the less developed riverine areas. The Chandpur-Faridpur route emerged as comparatively safer among the southern routes, indicating that the navigability and supervision of safety vary between routes. The study also found that overloading, vessel age and narrow widths increased the risks of injury, and that older ships were more likely to capsize, a problem inextricably related to Bangladesh's dependence on aging fleets and its lax control over passenger numbers. Failure of stability, inadequate design and lack of maintenance were major responsibilities for these. Which combines with the challenges of under-scrutinized shipbuilding and minimal culture of maintenance in local dry-docks. Lastly, accident causation analysis identified collisions as the most common cause and closely associated vessel size, absence of navigational aids and poor crew training; and storm-related accidents subgroup were both less frequent but particularly serious due to lack of experience and inadequacy in communication infrastructure (which is exacerbated during months with high rains such as monsoon in Bangladesh's situation) and weak communication systems, which are particularly challenging under Bangladeshi monsoon season or cyclone-prone coastal zones.

To meet these challenges, a number of strategic interventions are proposed. Every passenger carrying vessel should compulsorily be equipped with vital navigational equipment such as compass and radio, which many small and medium vessels in Bangladesh do not possess today. The consequent implementation of a training-based protocol has historically been loose in the country's inland shipping space and certification criteria will need to be lifted and policed by means of period competency audits. The licensing regime must be reformed so as to include vessel age limits, mandatory structural surveys and design assessments since the current practice of 30-

year long service life extends well beyond what Bangladesh's humid climate and high usage of river vessels around-the-year can accommodate. The 30-year licensing life span, which is in practice at present, should be reconsidered for scrapping purpose as older (above 10 year) vessels have significantly high severity damage that is a matter of great concern especially to Bangladesh where old age vessels make up the majority fleet. Overloading needs to be curtailed by strictly enforcing the capacity, particularly for narrow and smaller crafts that are generally used on local routes responding to higher footfall including during peak seasons of travel like Eid holidays. The basic infrastructure of the Bangladesh Coast Guard’s emergency response has to be improved with increased capability to deploy swiftly also in isolated and inaccessible areas which are only accessible by shipping on rivers. Special focus on safety measures is also required for high-risk routes such as Dhaka-Barishal and Dhaka-Patuakhali in terms of pre-positioned rescue units and route-specific protocols; as these are the heavily utilized economic corridors critical to urban-rural connectivity. The three strategy statements seek to contribute to a more robust and safer system of inland waterways mobility in Bangladesh, underpinned by evidence good policy decisions considering the unique geographic, climate, and socio-economic realities prevalent.

7.2 Limitations and Future Scope of the Study

Although the present study provides important knowledge on predictors of inland waterway accidents of Bangladesh, it has its own limitations. First, the study relied on secondary data of accidents that might not be reliable because of their incompleteness and lack of quality control, or attributed to omission by information recording or input. This may have induced a bias, or reduced the granularity of some variables (e.g., minutes and specific number of fatalities in an event at risk period). Secondly, the models used are statistically sound for better focussing on variables that drive the changes in control circuits but lack an approach to account for complex interdependencies that can be handled using advanced statistical models such as Bayesian network model based methods. Third, this work did not consider dynamic and spatial information (e.g., traces of GPS or weather prediction), which could improve the precision of the time and location. Finally, human factors, if they were based on fatigue, stress decision making or non-compliance behaviour could not be measured from the dataset directly and hence only partially inferred.

In light of these results, several fruitful lines of investigation are suggested for future research. The implementation of real-time data acquisition systems (e.g., AIS, weather sensors, on board monitoring systems) could provide dynamic perspective on traffic risk influenced by changing environmental and operational conditions. Machine learning algorithms can also be used to improve predictive modeling, especially in the selection of high-risk vessels or routes. Furthermore, a spatial risk analysis with GIS method might be helpful for policy makers in developing geographically specific safety intervention. Additional research might investigate crew conduct, safety culture, and institutional sanctioning structures using qualitative approaches such as interviews or surveys. Lastly, a comparison with other countries from the South Asian region could be useful for benchmarking and knowledge transfer on Bangladesh's inland waterway safety practice.

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