

Development of Disaster Demand Matrix for Bangladesh

A Thesis Submitted in Fulfillment of the Requirements for the Degree of
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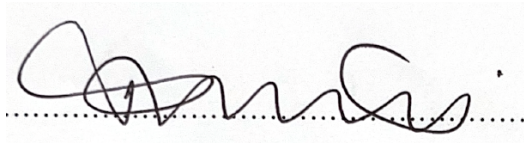
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Certification

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Abstract

Bangladesh, as one of the world's most hazard-vulnerable nations, experiences recurrent cyclone disasters that devastate coastal populations, livelihoods, and critical infrastructure, particularly in its densely populated littoral regions. While conventional disaster response mechanisms have achieved notable successes in casualty mitigation over recent decades, multifaceted gaps persist across the disaster management continuum, encompassing mitigation, preparedness, response, and recovery phases. These operational deficiencies reflect misalignment between national disaster management capacities and internationally established best practices, creating systematic barriers to comprehensive risk reduction and resilience augmentation. This doctoral research addresses this fundamental challenge through development of an evidence-based Disaster Demand Matrix (DDM) framework, systematically identifying and quantifying critical unmet demands across Bangladesh's cyclone disaster management architecture.

The study employs an integrative methodological approach combining multiple investigative dimensions. First, empirical analysis of four decades of cyclone data (1982–2024) establishes contemporary cyclone activity patterns and intensity trends affecting Bangladesh's coastal zone. Second, systematic comparative analysis of Bangladesh's existing disaster management practices against globally established best practices across thirteen cyclone-prone nations identifies substantive implementation gaps, institutional coordination deficiencies, and policy-practice divergences. Third, the research develops a comprehensive Disaster Demand Matrix encompassing nine major disaster management domains, comprising mitigation, preparedness, early warning, evacuation, emergency response, damage assessment, healthcare provision, recovery operations, and long-term reconstruction that systematically quantifies performance gaps between optimal operational standards and prevailing local realities.

To establish strategic prioritization among ninety multifaceted disaster management sub-activities, the research applies the Fuzzy Analytical Network Process (FANP) methodology, a sophisticated multi-criteria decision-making technique accommodating criterion interdependencies, decision-maker uncertainty, and complex priority interactions. This rigorous prioritization exercise synthesizes expert professional judgment from academicians, government functionaries, and

emergency management practitioners, yielding analytically derived hierarchical rankings of critical interventions requiring prioritized resource allocation and institutional development.

The prioritization results reveal that information dissemination and community risk communication systems constitute the paramount intervention priority, followed sequentially by spatially resolved evacuation coordination mechanisms, continuous meteorological monitoring with predictive analytics capabilities, and comprehensive community-level hazard awareness programming. These priority activities, representing foundational demand-driven interventions, collectively address systemic preparedness deficiencies, reduce information asymmetries, and enhance population protective action capacity, thereby generating multiplicative risk reduction benefits across all subsequent disaster management phases.

Beyond these principal findings, the research identifies priority institutional capacity-building requirements, governance-level coordination mechanisms, and policy-implementation frameworks necessary for effective DDM operationalization. The framework explicitly acknowledges methodological limitations, including constraints regarding empirical field-level validation, expert-judgment subjectivity, geographic specificity to coastal cyclone contexts, technical accessibility barriers for frontline practitioners, and data integration limitations, while simultaneously delineating prospective research trajectories for methodological extension and practical framework advancement.

Ultimately, this research contributes a novel, systematically derived decision-support instrument enabling Bangladesh's disaster management community to allocate resources strategically, prioritize institutional development investments, and align policy interventions toward addressing the most consequential unmet demands within the disaster management system. By facilitating demand-driven, evidence-based disaster management planning, the Disaster Demand Matrix framework supports sustainable resilience enhancement, accelerated emergency response effectiveness, and expedited recovery processes benefiting Bangladesh's climate-vulnerable coastal populations and contributing toward attainment of global Sendai Framework disaster risk reduction objectives.

Keywords: Disaster Demand Matrix, Cyclone Disaster Management, Bangladesh, Disaster Risk Reduction, Fuzzy Analytical Network Process, Coastal Resilience

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Chapter 1: Introduction

Chapter 1: Introduction

1.1 General

Bangladesh is widely recognized as one of the most disaster-prone countries in the world, owing to its unique geographical location, low-lying topography, and high population density. Among the various natural hazards it faces, cyclones pose a particularly severe and recurring threat, especially in the coastal regions, where millions of people live in vulnerable conditions. Over the past few decades, these extreme events have caused significant environmental degradation, loss of livelihood, and disruption of socioeconomic systems.

However, Bangladesh has also demonstrated notable progress in disaster risk reduction. Investments in early warning systems, improved cyclone forecasting, expanded shelter infrastructure, and well-coordinated evacuation procedures have collectively contributed to a substantial decline in disaster-related mortality. Community-based initiatives, supported by government and non-governmental organizations, have further strengthened local resilience by promoting awareness, preparedness, and rapid-response mechanisms. Despite these advancements, the increasing frequency and intensity of climate-related hazards continue to test the limits of the existing disaster management strategies.

However, critical challenges persist in achieving a fully integrated, efficient, and demand-driven disaster management framework. Current approaches often remain fragmented, with gaps in coordination, resource allocation, and alignment between community needs and institutional responses. Moreover, while significant attention has been given to response and recovery, comparatively less emphasis has been placed on systematically identifying unmet demands and prioritizing interventions based on local vulnerabilities and capacities.

In this context, there is a growing need for analytical tools that can bridge the gap between policies, practices, and community expectations. To address this need, this study aims to develop a Disaster Demand Matrix (DDM) for Bangladesh, using cyclone hazards as an example. This matrix will help systematically evaluate current disaster management actions, identify key gaps, and compare them with the actual needs of the affected communities.

Through this approach, the study aims to support a more coordinated, inclusive, and evidence-based disaster management system, ultimately strengthening resilience and promoting sustainable development in Bangladesh's high-risk coastal areas. Tropical cyclones, also known as hurricanes or typhoons, are defined as organized storm systems that form in the warm waters around the equator ([National Oceanic and Atmospheric Administration, 2024](#)). Tropical cyclones are among the world's deadliest disasters. On average, about 85 tropical storms form each year globally, roughly half of which reach category 4-5 strength cyclones ([WMO, 2024](#)). These storms affect millions of people and cause vast damage. Recent analyses estimate that each year, cyclones directly impact approximately 20 million people and inflict approximately \$51.5 billion in damage worldwide ([Huang et al., 2025](#)). Despite improvements in warning systems, the human toll remains severe, with thousands of fatalities occurring each year.

It is acknowledged that anthropogenic effects and climate change will have a significant impact on tropical cyclones in the future ([Bakkensen & Mendelsohn, 2019](#)). As the atmosphere and oceans warm, cyclones have been observed to grow stronger and last longer, with increased rainfall ([IPCC AR6, 2021](#)). Numerical models project even higher extremes; global tropical cyclone rain rates are expected to increase, and mean storm wind speeds are expected to rise. High-confidence projections indicate that a larger fraction of storms will reach major intensity (Category 4–5), with the median proportion of Category 4–5 cyclones rising by ~10% or more under continued warming ([Knutson, 2024](#)).

Scientists have raised concerns that human-driven climate change may play a major role in increasing the number of people affected and the economic losses observed from tropical cyclones in recent decades ([Islam, 2025](#)). Climate change may lead to a rise in the occurrence of high-intensity tropical cyclones and their compound impact with the rising mean sea level ([Camargo et al., 2023](#); [Knutson et al., 2020](#)). However, societal factors such as assets, infrastructure, and population growth also play pivotal roles in exacerbating TC-related impacts ([Weinkle et al., 2012](#)). As a result, many coastal residents, properties, and habitats would be severely impacted. This is particularly relevant to Bangladesh, a nation with a long-standing socio-economic connection to the sea ([Islam, 2025](#)).

Owing to its geographical location, Bangladesh is ranked as the fifth most disaster-prone country in terms of natural calamities ([Ahmed et al., 2016](#)). The coastal regions of Bangladesh are

particularly susceptible to tropical cyclones of varying intensities, which occur almost annually (Mallick et al., 2017). Moreover, the country's physiography plays a significant role in amplifying the intensity of cyclone landfall and the resulting impacts (Paul et al., 2010).

Historical data spanning a century reveal that out of the 508 cyclones formed in the Bay of Bengal, 17% have made landfall in the coastal areas of Bangladesh (Hoque et al., 2019). Although Bangladesh experiences only 1% of all cyclones worldwide, it accounts for 53% of the global cyclone-related deaths (Hoque et al., 2019). A brief overview of cyclone-related fatalities highlights this vulnerability: in 1970 there were 300,000 deaths, followed by 5,704 in 1988, 138,866 in 1991, 4,234 in 2007, and 190 in 2009 (Sonet et al., 2024).

A major factor contributing to these high casualty rates has been the lack of adequate warning systems and emergency infrastructure before two decades ago, which has historically resulted in significant loss of life and property (Quader et al., 2017). Looking ahead, Bangladesh is expected to face intensified climate change impacts (Abedin et al., 2019; Karim & Mimura, 2008). Rising sea levels and increasing temperatures are likely to intensify tropical cyclones in coastal districts, adversely affecting local economies and ecosystems (Sarwar & Woodroffe, 2013).

To mitigate losses caused by tropical cyclones, it is crucial to implement management approaches that focus on prevention and risk reduction (Ahmed et al., 2016; Joyce et al., 2009). It has been suggested that disaster risk reduction (DRR) can only be achieved by understanding and addressing the processes of disaster risk creation (DRC) (Alexander, 2016). Although Bangladesh is considered a highly tropical cyclone-prone country, studies related to tropical cyclone vulnerability assessments are very limited. The integration of functional disaster management and mitigation methods offers the potential to significantly mitigate the harmful effects of tropical cyclones (Bloemendaal et al., 2020; Matthews et al., 2019). A thorough risk assessment is crucial for developing effective mitigation measures (Das et al., 2024; Gopinath 2010; Jaman et al., 2021). The vulnerability of a community depends on factors such as exposure, hazard, existing mitigation, and preparedness capacities (Pattnaik, 2019).

Furthermore, siloed development and DRR policymaking, along with divided institutional responsibilities, can lead to government and private sector activities that fail to account for the risks generated (Lizarralde et al., 2020; Poudel et al., 2023; Raikes et al., 2022). Prioritization and effective allocation of resources based on the assessment of the importance of the parameters helps

in decision-making and resource allocation (Brennan & Flint, 2007; Das et al., 2024; Ruangpan et al., 2020). Assessing the importance of these parameters provides insights into potential risks and uncertainties and helps decision-makers make informed decisions (Das et al., 2024; Sakizadeh et al., 2019).

Therefore, developing sustainable DRR strategies requires detailed information on exposure, vulnerability, hazards, mitigation capacity, and the resulting risks associated with cyclone impacts (Khan, 2008). To support this, remote sensing, along with spatial and non-spatial data, is widely used to map the multiple criteria influencing tropical cyclone risk. Multi-criteria evaluation of each risk component is necessary to generate detailed spatial risk information. The Analytical Hierarchy Process (AHP) is considered an effective method for incorporating multi-criteria evaluation and integrating these components into a structured decision-making framework for cyclone risk mapping (Hoque et al., 2019). AHP applies a hierarchical structure to assign weights and rankings to different criteria, supported by expert judgment and user input (Roy & Blaschke, 2015), and has been successfully applied in several tropical cyclone risk studies (Mansour, 2019; Yin et al., 2013).

However, AHP assumes that decision criteria and their sub-criteria are functionally independent (Yüksel & Dağdeviren, 2010), whereas real-world decision-making often involves complex interactions among variables at different levels (Saaty & Vargas, 2006; Saaty, 1996). To address this limitation, Saaty (1996) proposed the Analytical Network Process (ANP), which extends the AHP by incorporating interdependencies and feedback relationships among criteria (Yüksel & Dağdeviren, 2010). ANP enables a more comprehensive evaluation by considering interactions and dependencies within the decision-making process (Zaim et al., 2014).

1.2 Problem Statement and Significance of the Study

Effective disaster management is integral to sustainable development, especially in countries prone to natural disasters, such as Bangladesh (Sabur, 2012). Despite progress, disaster management in Bangladesh remains a challenge, with poor integration of various disaster management activities for an effective and coordinated response (Khan 2008). Although Bangladesh has recently made substantial progress in reducing casualties from tropical cyclones through improved early warning systems and evacuation procedures, the overall impact on coastal areas remains severe (Hoque et al., 2021). Coastal communities continue to face significant economic and structural damage following these natural disasters, with the destruction of homes, infrastructure, and agricultural

land. The lingering effects of cyclones also pose long-term threats to livelihoods and sustainable development in vulnerable regions.

Under these circumstances, there is a pressing need to develop an effective and practical comprehensive disaster management action matrix for Bangladesh. Such a framework is essential to systematically address the diverse range of natural hazards affecting the country, including cyclones, floods, storm surges, and riverbank erosion. Despite ongoing efforts, existing disaster management practices often lack integration, coordination, and alignment with local needs, limiting their overall effectiveness. A well-structured action matrix provides a strategic platform for identifying vulnerabilities, prioritizing interventions, and allocating resources more efficiently across different sectors and regions.

Moreover, a comprehensive disaster management action matrix facilitates a more demand-driven approach by linking community-level needs with institutional responses. This would enable policymakers, planners, and stakeholders to better understand existing gaps in preparedness, response, recovery, and mitigation measures. By incorporating both technical assessments and local knowledge, such a matrix can enhance decision-making processes and promote more resilient and adaptive systems in the future. Ultimately, the development and implementation of this framework would contribute to reducing disaster risks, minimizing losses, and strengthening Bangladesh's overall capacity to manage and respond to multiple hazards sustainably.

1.3 Research Objectives

The main objective of this study is to design a Disaster Demand Matrix (DDM) for Bangladesh, with particular emphasis on coastal cyclones as a case. Once the DDM is developed for cyclone-related hazards, it can be adapted and applied to other types of disasters in Bangladesh as well as in different geographic contexts beyond the country. This approach aims to identify critical needs, assess existing gaps, and improve disaster management strategies in vulnerable coastal regions. The specific objectives to accomplish the main objective are as follows:

The specific objectives to accomplish the main objective are as follows:

1. To critically review existing studies on tropical cyclone disaster management in the Bay of Bengal region;

2. To empirically assess observed trends of tropical cyclone intensity along the Bangladesh coast;
3. To assess the globally ongoing best practices of disaster management activities for tropical cyclone;
4. To develop cyclone disaster demand matrix;
5. To prioritize the disaster management activities according to the demand matrix of Bangladesh.

This thesis critically evaluates tropical cyclone disaster management in Bangladesh by integrating empirical trend analysis with a novel, systematic gap-assessment framework. It first establishes the research problem and reviews existing literature on the Bay of Bengal cyclones. The study then analyzes four decades of cyclone data (1982–2024) to empirically test widely held assumptions about climate-driven increases in cyclone intensity. Following this trend analysis, current national practices are examined against global best practices to identify critical shortcomings for effective tropical cyclone disaster management. The core contribution of this research is the development of a DDM for cyclone as a case, a systematic benchmarking tool, that quantifies gaps between standard situation of disaster management and existing local realities across nine major disaster management activities.

To ensure precision and strategic prioritization, the thesis further ranks 42 sub-activities within these major categories using the Fuzzy Analytical Network Process (FANP) method. Ultimately, this study offers a robust, evidence-based strategic framework for strengthening Bangladesh's cyclone resilience by directing resources and policy attention to the most critical unmet demands.

1.4 Structure of the Thesis

In Chapter 1, the introduction provides context by emphasizing Bangladesh's susceptibility to tropical cyclones and other natural hazards. It underlines the significance of better disaster management in the country, as natural disasters, notably cyclones, continue to destroy coastal towns. The chapter describes the research objectives, which include creating a DDM to improve disaster resilience by identifying gaps in current management practices and the need for a demand-driven, systematic approach to disaster response and recovery in Bangladesh's coastal areas.

Chapter 2 reviews the literature on disaster management and risk reduction (DRR), focusing on Bangladesh. It explores the evolution of global and national disaster management systems, highlighting how past cyclones have driven reforms. The chapter also discusses key advancements, such as the Cyclone Preparedness Programme (CPP) and improvements in evacuation and forecasting. However, it identifies ongoing challenges, including governance gaps, insufficient preparedness, and resilience-building issues in coastal communities, alongside institutional and policy weaknesses.

Chapter 3 examines cyclone patterns along the Bangladesh coast using contemporary satellite data from 1982 to 2024. It looks at trends in cyclone frequency, severity, intensity, and length throughout time. Using a geographically layered framework, the study offers light on how cyclone patterns have changed, particularly the growing frequency and intensity of storms. These findings emphasize coastal populations' increasing vulnerability and the need for greater disaster management methods to meet the changing features of tropical storms.

Chapter 4 analyzes Bangladesh's present disaster management strategies and compares them to worldwide best practices for mitigation, readiness, response, and recovery. It assesses the country's legislative and policy frameworks, identifying deficiencies and inefficiencies that impede efficient disaster response. The study also identifies gaps between Bangladesh's disaster management policies and international norms, notably in terms of institutional coordination, resource allocation, and the ability to respond quickly and effectively to cyclone events.

In chapter 5, the thesis describes the development of the Disaster Demand Matrix (DDM), a framework for assessing and improving disaster management in Bangladesh. The chapter describes the data gathering procedures, which include expert surveys and validation processes. It then discusses how the matrix was created by comparing existing disaster management practices to an ideal situation. The DDM is a technique for identifying gaps in the disaster response system, which helps to prioritize critical changes in cyclone catastrophe management.

Chapter 6 focuses on using the Fuzzy Analytical Network Process (ANP) to prioritize disaster management operations. By examining the interrelationships across several disaster management domains, the study uses ANP to rank critical activities and indicate those that should be prioritized for improvement. The findings offer a roadmap for Bangladesh's disaster management initiatives,

ensuring that funds and resources are allocated to the most important and effective measures for reducing cyclone risks and building resilience in affected communities.

Chapter 7 highlights the research findings and proposes strategic recommendations for enhancing cyclone disaster management in Bangladesh. It suggests initiatives to improve early warning systems, preparedness planning, evacuation processes, and non-structural mitigation actions. The chapter also underlines the importance of enhanced governance, coordination, and financial structures to promote disaster resilience and long-term recovery. The recommendations seek to provide a more effective and comprehensive disaster management strategy, with an emphasis on strengthening local capacities and maintaining sustainability during recurring cyclone events.

The conclusion in chapter 8 summarizes the results of the study, emphasizing the effectiveness of the Disaster Demand Matrix (DDM) in addressing deficiencies in Bangladesh's disaster management system. It demonstrates the need for a more comprehensive, evidence-based approach to disaster resilience that considers both physical and socioeconomic vulnerabilities. The chapter concludes by recommending more research and practical methods to execute the strategic suggestions, with an emphasis on strengthening disaster planning, response, and recovery systems, which will strengthen Bangladesh's disaster resilience.

Chapter 2: Literature Review

Chapter 2: Literature Review

2.1 Conceptual Framework of Disaster Management and Disaster Risk Reduction

Disaster management is widely recognized as a systematic and cyclical process essential for reducing the impacts of natural hazards on infrastructure, livelihoods, and communities. At the global level, the United Nations Office for Disaster Risk Reduction framework, particularly the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNDRR, 2015) provides a comprehensive policy structure that integrates preparedness, response, recovery, and mitigation to minimize disaster losses in hazard-prone regions. Expanding on this, Tay et al. (2022) analyze the Disaster Management Cycle (DMC) and identify key risk variables distributed across its four phases, emphasizing that weaknesses in any single phase can undermine the effectiveness of the entire system.

From a community-based perspective, Kafle (2010) demonstrates through the Integrated Community-Based Risk Reduction (ICBRR) model that resilience is best achieved when all phases of the DMC are cohesively integrated into local-level actions involving multiple stakeholders. This view is reinforced by Bali (2024), who conceptualizes disaster management as a continuous and self-reinforcing process rather than a set of discrete interventions. Furthermore, Joakim & Wismer (2015) highlight that insufficient monitoring of livelihood recovery programs can significantly weaken long-term resilience, while Oloruntoba et al. (2018) show that effective pre-disaster preparedness contributes directly to faster and more efficient recovery outcomes.

2.2 Evolution of Disaster Management in Bangladesh

In hazard-prone contexts of Bangladesh, these principles are particularly evident. Haque and Uddin (2013) document the country's transition from a reactive, relief-oriented approach to a more proactive system emphasizing preparedness and mitigation through institutional collaboration. Similarly, Azad et al. (2019) illustrate how large-scale partnerships have strengthened community-based initiatives, promoting more localized and adaptive risk reduction strategies. Vermiglio et al. (2022) argue that integrated governance frameworks spanning all phases of the DMC are crucial for effective disaster management at the organizational level. Collectively, these studies

demonstrate that effective disaster management requires a holistic and integrated approach, where mitigation reduces baseline risks, preparedness enhances capacity, response limits immediate impacts, and recovery supports the restoration of livelihoods and long-term resilience.

2.3 Historical Cyclone Disasters as Catalysts for Reform

The history of disaster management in Bangladesh has been profoundly shaped by the catastrophic impacts of tropical cyclones, particularly the Bhola Cyclone and Cyclone Gorky, which served as pivotal turning points in the nation's approach to disaster preparedness and response. The 1970 Bhola Cyclone, which claimed approximately 300,000 lives, exposed severe governance failures, including deficiencies in early warning systems, inadequate cyclone shelter infrastructure, and weak institutional coordination under the then Pakistani administration (Biswas & Daly, 2020; Hossain, 2018). The unprecedented loss of life revealed a significant governance gap, 'put disaster management on the nationalist agenda', and established 'a social contract to protect the population against disasters' following independence (Hossain, 2018). These events prompted initial institutional responses, most notably the establishment of the Cyclone Preparedness Programme (CPP) in 1973 (Haque et al., 2022; Khan, 2008), which aimed to enhance early warning dissemination and community awareness through volunteer-based mechanisms (Singh, 2010).

Despite these efforts, the 1991 Cyclone Gorky, which caused over 138,000 fatalities and extensive damage to infrastructure, agriculture, and the economy demonstrated that early measures were insufficient (Alam et al., 2024; Bern et al., 1993). It revealed persistent weaknesses in evacuation systems, coastal protection, and public trust in warning mechanisms, as well as fragmented coordination among government agencies and non-governmental organizations, highlighting the limitations of a reactive, relief-oriented approach (Haque, 1995; Haque & Blair, 1992). The scale of devastation underscored the urgent need for a more structured and systematic disaster management system (Bern et al., 1993; Sabur, 2012).

2.4 Institutional Development and Policy Frameworks

The Bhola and Gorky cyclones revealed major weaknesses in Bangladesh's disaster management system and acted as a catalyst for reform. In response, the government incorporated international best practices in hazard identification, mitigation, and community preparedness. A formal legal

framework was established, culminating in the Standing Orders on Disaster (1997), which clarified responsibilities across government agencies. Institutional capacity was strengthened through the creation of the Disaster Management Bureau (DMB) in 1993 under the Ministry of Food and Disaster Management, serving as the central coordinating body. These initiatives together laid the foundation for a more structured and coordinated disaster management system in Bangladesh (Sabur, 2012; Shaw et al., 2013).

2.5 Transition to Disaster Risk Reduction and Preparedness Paradigm

For decades, post-event aid and rehabilitation constituted the main priorities of Bangladesh's reactive disaster management. However, since the 1990s, the Sendai Framework for Disaster Risk Reduction (2015–2030) and the Hyogo Framework for Action (2005–2015) have served as the essential components of disaster management for all member states in an effort to shift the core principles of global disaster management from disaster prevention to disaster risk reduction (Sony et al., 2023; Kelman & Glantz, 2015). Over time, the trend in cyclone impact in the coastal regions of Bangladesh has showed noticeable improvements in disaster preparedness, disaster risk reduction, and community resilience, suggesting a potential paradigm shift (Azad & Khan, 2015; Panda et al., 2011). Aila in 2009, which struck both India and Bangladesh with limited fatalities of 200 in Bangladesh, further illustrated this change (Haque & Uddin, 2013).

2.6 Advancements in Disaster Management

In Bangladesh, the key development in disaster governance is the transition from a top-down, relief-centric model to a proactive, community-focused approach. Current national policies prioritize local, people-centered risk reduction and encourage partnerships across different scales to enhance community resilience, supported by various measures aimed at decentralizing disaster management (Azad et al., 2019). This institutional evolution has led to significant investments in technology and infrastructure, particularly in multi-hazard early warning systems (EWS), interactive voice response (IVR), and the Cyclone Preparedness Program (CPP), which provide timely information to households, saving lives and livelihoods (Syed et al., 2021). Thus, the latest approach unites preparedness, EWS, risk reduction, mitigation, and long-term recovery planning into a multi-hazard management framework.

2.6.1 Cyclone Preparedness Programme (CPP)

Bangladesh is known for its strong disaster risk management, especially in dealing with tropical cyclones. A key factor in this success is the Cyclone Preparedness Programme (CPP), a long-standing partnership between the government and the Bangladesh Red Crescent Society, focused on community-based preparedness and spreading early warnings ([Habib et al., 2012](#); [Haque et al., 2022](#); [UNDRR, 2025](#)). The CPP trains and organizes over 76,000 local volunteers, including a large number of women, to communicate official warnings, support evacuations, and provide basic emergency assistance to vulnerable populations before and during cyclone events ([Kazi et al., 2022](#); [MoDMR, 2021](#); [UNDRR, 2025](#)).

Volunteers play a key role in connecting national warnings to communities, ensuring timely evacuations. During Cyclone Bulbul in 2019, CPP volunteers helped evacuate around 2.1 million people, highlighting the importance of community involvement in disaster preparedness ([Islam et al., 2022](#); [UNDP, 2019](#)).

2.6.2 Effectiveness of Evacuation and Forecast-Based Action

Recent research shows that while early warning and evacuation systems have improved, social norms and governance barriers still affect evacuation decisions, especially for women and vulnerable groups ([Hossain, 2026](#); [Masud-All-Kamal et al., 2025](#)). Improving community communication and support is key to better preparedness and reducing losses. Bangladesh has also implemented Forecast-based Action (FbA), which uses weather forecasts to trigger early actions like preparing shelters and mobilizing resources ([Mahmud et al., 2026](#); [Tanner et al., 2019](#)). While this proactive approach has strengthened community resilience, challenges like shelter access and uneven evacuation capacity persist ([Daiyan et al., 2025](#); [Zakaria et al., 2025](#); [Zaman et al., 2025](#)).

2.7 Persistent Challenges in Disaster Management in Bangladesh

Despite Bangladesh's internationally acknowledged progress in disaster risk reduction, the available literature identifies persistent structural and systemic challenges that hinder the long-term efficacy of its disaster management framework, especially in light of the developing requirements of climate change ([Hasan et al., 2013](#); [Rocha & Falduto, 2019](#)). Institutional capacity constraints, particularly at sub-national levels, constitute a basic restriction. Research shows that while national policies are generally strong, local institutions often lack operational autonomy,

skilled staff, and technical know-how, which causes gaps between policy design and execution ([Zaman et al., 2022](#)). Effective last-mile execution of services is further hindered by an absence of vertical compatibility between national and local governing systems.

The disarray of coordinating and governance structures is a further major issue. Several ministries and agencies are involved in disaster management in Bangladesh, while these entities usually function in institutional silos, which leads to poor interdisciplinary coordination and ineffective management of cross-cutting hazards like climate change ([Barua, 2021](#); [Haque et al., 2024](#); [Zaman et al., 2022](#)). According to [Uddin \(2022\)](#), this dispersion impedes exchange of information and integrated planning in parallel with creating repetition of efforts. Scientific study also identifies irregular coordination procedures and bureaucratic rigidity as obstacles to successful implementation. Additionally, there are still a lot of financial and strategic planning limitations. Bangladesh has created ambitious plans for disaster and climate resilience, but the amount of funding needed is significantly more than what is available internally ([Hasan et al., 2013](#)). According to recent evaluations, putting climate-resilient development routes into action would need significant long-term funding, most of which is now reliant on donations from outside sources ([Arfanuzzaman, 2024](#)). Concerns about national ownership of disaster management programs, sustainability, and continuity are raised by this dependency.

Moreover, issues related to sustainability and execution difficulties persist at the project level. Project-driven, short-term oriented approaches are often used to conduct disaster risk reduction (DRR) initiatives which can result in sectoral silos across livelihood, climate adaptation, and disaster management programs, limiting their long-term efficacy and integration ([Haque et al., 2024](#); [Hasan et al., 2013](#); [Hoque et al., 2019](#)). Ultimately, more equitable and tailored approaches are absolutely essential in the effectiveness of emergency preparation measures like evacuation is still limited by psychosocial and governmental barriers, including gender inequality, societal stratification, and low community engagement ([Masud-All-Kamal et al., 2025](#)). According to the Paris Agreement, vulnerability is increased when marginalized groups continue to be excluded during decision-making processes ([Falkner, 2016](#)). Strengthening institutional capacity across scales, guaranteeing consistent and varied funding, improving interagency coordination, and encouraging inclusive, community-driven approaches are all necessary to address these interrelated issues and create resilient and adaptable disaster management systems in Bangladesh.

Chapter 3: Tropical Cyclones Trend Along Bangladesh Coast (1982–2024)

Chapter 3: Tropical Cyclones Trend Along the Bangladesh Coast (1982–2024)

3.1 General

Intense Tropical Cyclones (TCs), fueled by warm tropical seas and the jet stream, have been a major cause of fatalities and economic losses. Climate change projections for the twenty-first century indicate that tropical cyclones will likely be impacted by increased wind speeds and heavier rainfall, in addition to the effects of rising Sea Surface Temperatures (SST) on storm formation and behavior ([Hibbert et al., 2023](#); [Seneviratne et al., 2021](#)). Furthermore, global models indicate that in the upcoming decades, global warming will cause some locations to experience an increase in rapid intensification, poleward migration, or a slowdown of TCs, although it is difficult to attribute these changes to anthropogenic forcing ([Knutson et al., 2021](#); [Kossin, 2018](#); [Kossin et al., 2014](#)).

Despite global projections linking anthropogenic warming to increased TCs intensity, observational evidence presents a more nuanced picture ([Hibbert et al., 2023](#); [Wang et al., 2025](#)). This regional complexity is part of a broader global picture where the fingerprint of climate change on TCs is strongly mediated by the pattern of sea surface warming, with localized changes consequently linked to key environmental variables. A comprehensive review by [Wang et al. \(2025\)](#) highlights that over 80% of CMIP6 climate models project an El Niño-like warming pattern in the tropical Pacific, whereas observations since 1950 consistently have shown a relative cooling in the eastern equatorial Pacific, a La Niña-like pattern. These contradictions, arising from model biases in cloud feedbacks and ocean dynamics, lead to large uncertainties in projecting future TC activity ([Wang et al., 2025](#)). These future projection uncertainties are especially important in basins like the North Indian Ocean, where it is difficult to identify and attribute long-term trends due to the observational record itself.

In the North Indian Ocean, reported changes in cyclone intensity and frequency are highly sensitive to the choice of time frame and the reliability of detection systems, complicating attribution to anthropogenic forcing. For example, [Balaguru et al., \(2014\)](#) identified increased post-monsoon Bay of Bengal TC intensity during 1981–2010, linking it to rising SST, ocean heat content, and

moist static energy in the eastern basin, and suggesting increasingly favorable large-scale conditions (Balaguru et al., 2014). However, this 30-year window may reflect decadal variability rather than a robust long-term secular trend. While some studies report a rising incidence of severe TCs under favorable thermodynamic and dynamical conditions, including reduced vertical wind shear and enhanced low-level vorticity (Mohapatra et al., 2015), century-scale records from multiple basins indicate either declining or weakly varying TC frequencies, although there is only low confidence in distinguishing anthropogenic signals from natural variability and observational biases (Knutson et al., 2019; Kossin et al., 2020). Moreover, recent basin-focused analyses, based on a homogenized best-track dataset, further complicate this narrative by showing largely stationary trends in TC frequency and intensified severity probability during 1965–2020. These trends imply a divergence: the likelihood that any given cyclone becomes severe may be rising, yet the overall frequency of cyclonic disturbances and their subsequent intensification has decreased (Mohapatra et al., 2021).

Inconsistencies between studies can be partly linked to uncertainties in pre-satellite cyclone records and increasing detection capabilities, emphasizing the need for cautious interpretation of long-term TC trends and strengthening gaps in reconciling global forecasts with regional data. Prior to the modern satellite era, consistent detection of weaker systems, particularly depressions and deep depressions, was highly sensitive to observational capabilities (Landsea et al., 2010). The cyclone archive maintained by the India Meteorological Department (IMD) is considered climatologically reliable from 1961 onward, reflecting improved observational practices. Nevertheless, detection consistency for weaker disturbances remained variable through the pre-satellite and early satellite periods. Substantial improvements in detection fidelity and intensity estimation occurred with the deployment of India's Indian National Satellite System (INSAT) series in 1982, which enabled continuous, basin-focused satellite monitoring over the North Indian Ocean and markedly reduced uncertainties in cyclone identification and classification (Mohanty et al., 2014).

There is ongoing discussion over the evolution of tropical cyclone activity over Bangladesh, which has a long record of suffering damage from severe TCs because of its geographic location. The Bay of Bengal, the principal sub-basin of the North Indian Ocean, represents a persistent center of tropical cyclone activity, accounting for an average of 3.96 annual landfalls out of approximately

4.36 total tropical disturbance landfalls recorded across the region (Mohapatra et al., 2021). Situated at the northern vertex of the Bay of Bengal, Bangladesh forms the terminal point of a vast ocean-atmosphere system that generates some of the world's most destructive tropical cyclones (Fig. 3.1). On top of that, the distinctive geomorphology of the Bangladesh coastline, characterized by a shallow, funnel-shaped continental shelf that amplifies storm surges, combined with high coastal population density, transforms basin-scale meteorological phenomena into large-scale national disasters. Consequently, trends observed at the basin scale do not necessarily translate linearly into coastal risk; a cyclone forming in the central Bay of Bengal must navigate a complex propagation pathway before potentially threatening the Bangladesh coast. This spatial heterogeneity underscores the need for domain-specific analyses that distinguish between basin-wide genesis zones, near-coastal regions, and direct landfall areas.

While foundational studies have depicted long-term frequency trends over the North Indian Ocean (Mohapatra et al., 2015; Mohapatra et al., 2021), they predominantly operate at basin scale and span periods with heterogeneous observational capabilities, leaving unresolved the question of how projected increases in severe storm proportions manifest along Bangladesh's vulnerable shoreline. Moreover, previous studies of cyclones on the Bay of Bengal have mostly concentrated on long-term cyclone activity, frequency, climatology, isolated intensity measures, and predicting wind speed return duration without making any connections to temporal nonlinear shifting or proportionate severity shifts (Bhardwaj & Singh, 2020; Mohanty et al., 2014; Wahiduzzaman & Yeasmin, 2024). These approaches carry the risk of minimizing two important aspects of the evolution of storms: (1) spatially heterogeneous trends between coastal impact regions and open-ocean genesis zones; and (2) non-stationary temporal patterns that could involve regime shifts, acceleration, or thresholds instead of monotonic linear change. Addressing this gap requires a spatially nested, data-aware framework that isolates the modern satellite era's most reliable observations to determine whether the trend projected basin-wise is propagating towards Bangladesh's coast.

The present study addresses these issues by restricting analysis to the modern satellite era (1982–2024), a 43-year period where geostationary satellite coverage, Dvorak intensity estimation, and cyclone detection radar networks were sufficiently mature to ensure consistent detection across the full disturbance spectrum. This temporal restriction, while reducing sample size, prioritizes

data reliability over record length, a necessary precondition for distinguishing genuine climate signals from detection artefacts. Furthermore, to define the change in tropical storm intensification, the present study introduces a geographically nested, hierarchical framework, progressing from linear regression to nonlinear models (quadratic and Generalized Additive Model (GAM)), and logistic regression for event-level severity odds. This multi-model approach explicitly evaluates sensitivity to intensity thresholds and weak-system detection, while capturing spatially heterogeneous and non-stationary dynamics across landfall, near-coastal, and basin-wide domains. Such a framework provides a more practical foundation for coastal adaptation by isolating the evolution of hazards prevalent along the Bangladesh coast while formally testing for the nonlinear responses anticipated from interacting climate causes, including threshold-dependent intensification and El Niño–Southern Oscillation (ENSO) non-stationarity.

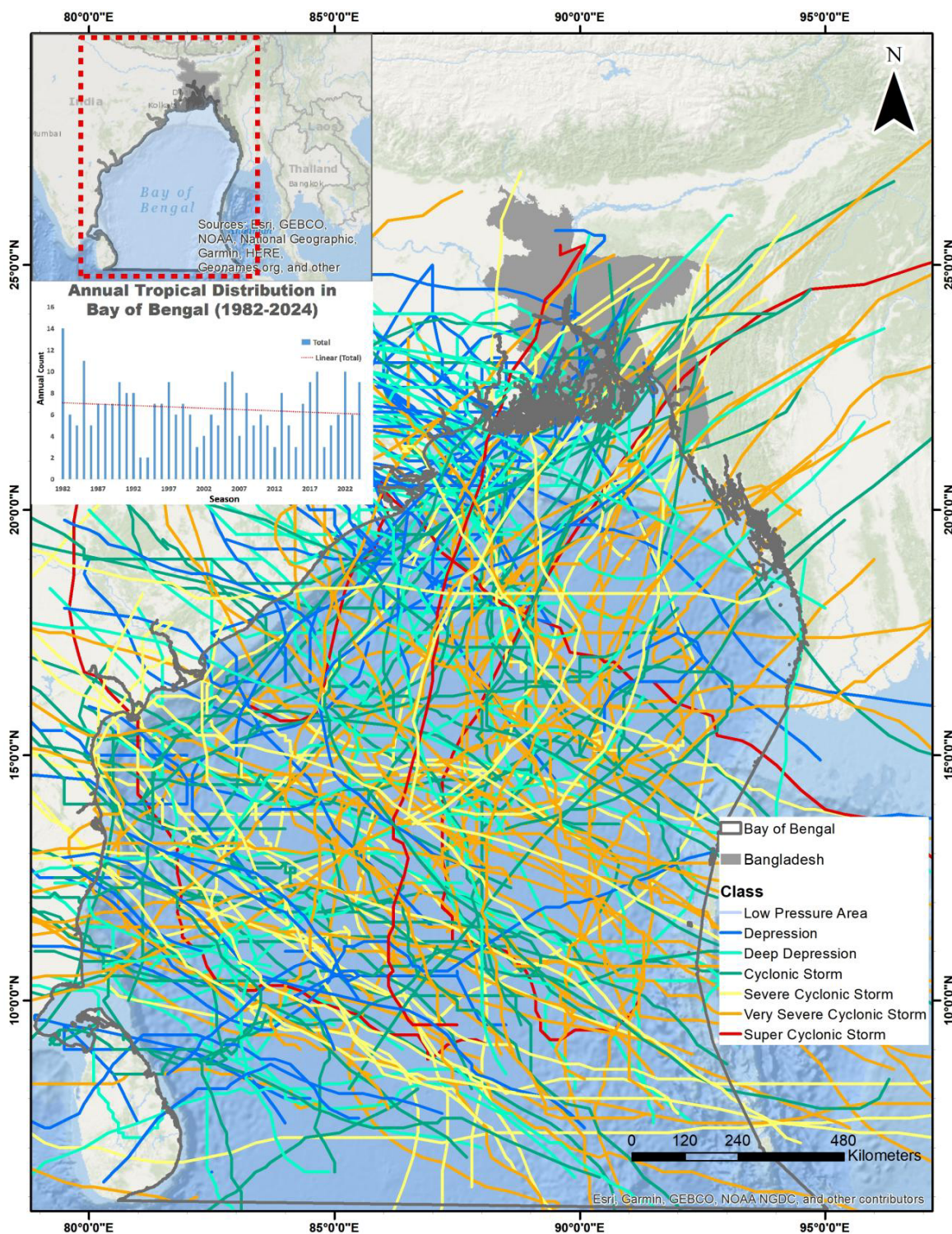


Fig. 3.1 The spatial distribution of cyclonic disturbances in the northern Bay of Bengal along Bangladesh coast from 1982 to 2024 is classified by intensity according to the New Delhi grading system of the WMO RSMC, based on maximum sustained wind speed (knots) [Source: [National Oceanic and Atmospheric Administration, 2024](#)]. The inset graph of tropical disturbance frequency during that corresponding era shows a slight decline in the annual total of events in recent years.

3.2 Materials and Methods

3.2.1 Study Area and Data Selection

The current analysis provides a deeper examination of storm dynamics for the last 43 years (1982–2024) to understand the changing nature of cyclone severity in Bangladesh by stratifying tropical events into genesis, coastal-threat, and landfall domains. The IMD best-track archive and the National Oceanic and Atmospheric Administration (NOAA) International Best Track Archive for Climate Stewardship (IBTrACS) dataset were used to collect and filter the atmospheric parameters for tropical disturbances from 1982 to 2024 to optimize precision for tropical storms that affected Bangladesh.

Three nested domains were defined: the basin-wide genesis zone, a 400 km near-coastal buffer, and a 50 km direct coastal buffer. All low-pressure systems located within 400 km of the shoreline were taken into consideration to provide a thorough assessment of the tropical cyclones that affect the region. This distance was selected because, although direct cyclone impacts tend to decrease beyond this range, indirect impacts, such as increased monsoon rainfall, storm surges, and ocean swells, can still significantly affect the area. This criterion ensures that relevant incidents are recorded without overstretching the domain by matching predicted cyclone influence zones and observed R34 wind radii (~100–400 km) (Busireddy et al., 2022). On the other hand, the 50 km buffer is supported by Feng et al. (2023), who documented that even the smallest tropical cyclone in their study (Meranti) exhibited an inner-core radius of 30–50 km, ensuring this threshold uniformly captures core dynamics across all storm sizes for trend analysis (Feng et al., 2023).

The cases were classified according to the India Meteorological Department (IMD) (New Delhi), which is widely adopted across South Asia. The classes are: Low Pressure Area ($W < 17$ knots), Depression ($17 \leq W < 28$ knots), Deep Depression ($28 \leq W < 34$ knots), Cyclonic Storm ($34 \leq W < 48$ knots), Severe Cyclonic Storm ($48 \leq W < 64$ knots), Very Severe Cyclonic Storm ($64 \leq W < 120$ knots), and Super Cyclonic Storm ($W \geq 120$ knots). The latter three of the seven types, beginning with Severe Cyclonic Storm, are categorized as intense or catastrophic cyclones because they are considered stronger phenomena. The dataset includes 282 records between 1982 and 2024, of which 80 were classified as severe. All statistical analyses were conducted via R coding.

3.2.2 Trend Analysis

3.2.2.1 Frequency and Proportionality Trends

To analyze trends in the annual frequency of cyclone events, an Ordinary Least Squares (OLS) linear regression was applied first to the annual count time series for both non-severe and severe categories across all three domains. The model estimated the slope (representing the average annual change in cyclone count), its 95% confidence interval, and the coefficient of determination (R^2). To determine if trends were more complex than a simple linear change, the linear model was compared against two non-linear alternatives, the Quadratic Model and the GAM. Model selection was guided by the Akaike Information Criterion to avoid overfitting and ensure statistically meaningful results.

Trends in the composition of cyclone severity were assessed using two complementary methods. First, an OLS regression was performed on the annual severe share (the proportion of severe events relative to the total annual count for each domain) for each domain. Second, to analyze severity at the event level while accounting for annual variability, a binary logistic regression was employed. In this model, the binary outcome (severe vs. non-severe) for each individual cyclone event was modeled as a function of the year, with the domains analyzed separately. The resulting odds ratio for the 'year' term indicates the annual multiplicative change in the probability of an event being severe.

Ordinary Least Squares (OLS): OLS establishes whether monotonic change exists in the simplest, most interpretable way. Linear trends provide direct effect sizes (slope, CI) and a baseline AIC for subsequent comparisons. Annual proportion (severe/total events) was modeled using OLS.

$$Y_t = \beta_0 + \beta_1 \text{year}_t + \varepsilon_t \quad (3.1)$$

Quadratic: Tests parsimonious curvature (single turning point) to capture multi-decadal shifts without overfitting. Serves as a nested parametric extension to OLS.

$$y_t = \beta_0 + \beta_1 \text{year}_t + \beta_2 \text{year}_t^2 + \varepsilon_t \quad (3.2)$$

GAM: Allows flexible, data-driven nonlinearity using penalized splines; controls complexity via effective degrees of freedom (edf) and smoothing penalties, avoiding spurious wiggle.

$$y_t = \beta_0 + s(\text{year}_t) + \varepsilon_t \quad (3.3)$$

Logistic regression (event-level severity odds): Shifts from aggregates to event-level severity probability over time, checking whether composition shifts are intrinsic to events rather than aggregation artifacts.

$$\log \frac{p_t}{1 - p_t} = \alpha + \gamma \text{ year}_t \quad (3.4)$$

3.2.2.2 Intensity and Persistence Trends

For the cyclone-specific variables of maximum wind speed and duration, OLS regression at the event level was applied. The slope estimates the average annual change in a cyclone's peak intensity (knots/year) or its lifespan (hours/year). Given the hierarchical structure of the data (events nested within years and domains), this approach provides a direct measure of how the characteristics of individual cyclones, rather than just the annual counts, have evolved over the study period. All statistical analyses were performed to detect significant trends at a 95% confidence level ($p < 0.05$).

3.3 Results

3.3.1 Trends in Cyclone Frequency

3.3.1.1 Linear Trend

The analysis of annual cyclone frequency from 1982 to 2024 revealed predominantly neutral trends across all domains and severity classes (Fig. 3.2, Table 3.1). The OLS regression slopes for both non-severe and severe events were negative but statistically non-significant in all cases ($p > 0.05$). For instance, in the Bay of Bengal Basin Genesis domain, non-severe events showed a slight, non-significant decline (slope = -0.018 events/year, $p = 0.54$), as did severe events (slope = -0.007 events/year, $p = 0.61$). The Near-Coastal Impact Zone (400 km) for Bangladesh exhibited a similarly non-significant negative slope for both categories. The Direct Coastal Impact Zone (50 km) showed the flattest trends, with a near-zero slope for severe events.

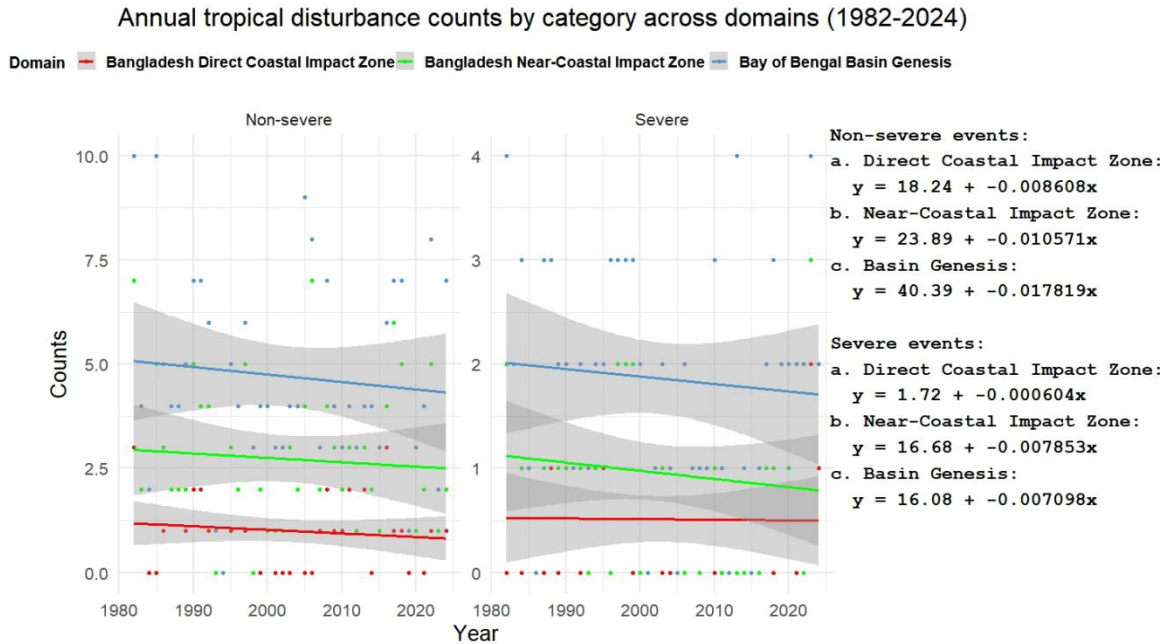


Fig. 3.2 Annual tropical disturbance counts by intensity category across spatial domains (1982–2024). Panels show non-severe (left) and severe (right) events for the Bangladesh direct coastal impact zone, Bangladesh near-coastal impact zone, and the Bay of Bengal basin genesis region. Points represent observed annual counts, and solid lines indicate fitted linear trends with shaded 95% confidence intervals.

Table 3.1 Summary of linear trends in annual tropical cyclone frequency (1982–2024). A negative slope indicates a decreasing trend over time. All p-values are >0.05 , indicating no statistically significant linear trend.

Domain	Category	Mean Annual Count (n)	Slope (events/year)	P-value	R ²
BD Direct Coastal Impact Zone	Non-severe	1	-0.0086	0.429	0.0153
BD Direct Coastal Impact Zone	Severe	0.512	-0.0006	0.9459	0.0001
BD Near-Coastal Impact Zone	Non-severe	2.721	-0.0106	0.637	0.0055
BD Near-Coastal Impact Zone	Severe	0.953	-0.0079	0.47	0.0128
Bay of Bengal Basin Genesis	Non-severe	4.697	-0.0178	0.539	0.0093
Bay of Bengal Basin Genesis	Severe	1.861	-0.0071	0.607	0.0065

3.3.1.2 Non-linear Trend

The comparison of linear, quadratic, and GAM models using AIC further supported the lack of a strong temporal trend (Fig. 3.3, Table 3.2). In five out of six domain-category combinations, the linear model had the lowest (or near-lowest) AIC, suggesting it was the most frugal description of the data and that adding complexity did not improve model fit. The sole exception was for severe events in the Bangladesh Near-Coastal Zone (400 km), where the GAM provided a superior fit ($AIC_{GAM} = 107.15$ vs. $AIC_{linear} = 114.64$) and showed a significant non-linear trend ($p = 0.024$ for the smooth term). This indicates multi-decadal fluctuation in severe cyclone frequency within 400 km of the coast. The estimated degrees of freedom (edf) for this GAM (edf ≈ 3.27) confirms a moderately complex, non-linear pattern. Notably, this signal is absent in the 50 km direct coastal zone, a discrepancy that may arise from either the reduced sample size in the inner domain (mean annual severe count = 0.51) acting as a statistical filter, or from genuine physical processes that dampen these fluctuations within the final 50 km of the coastline.

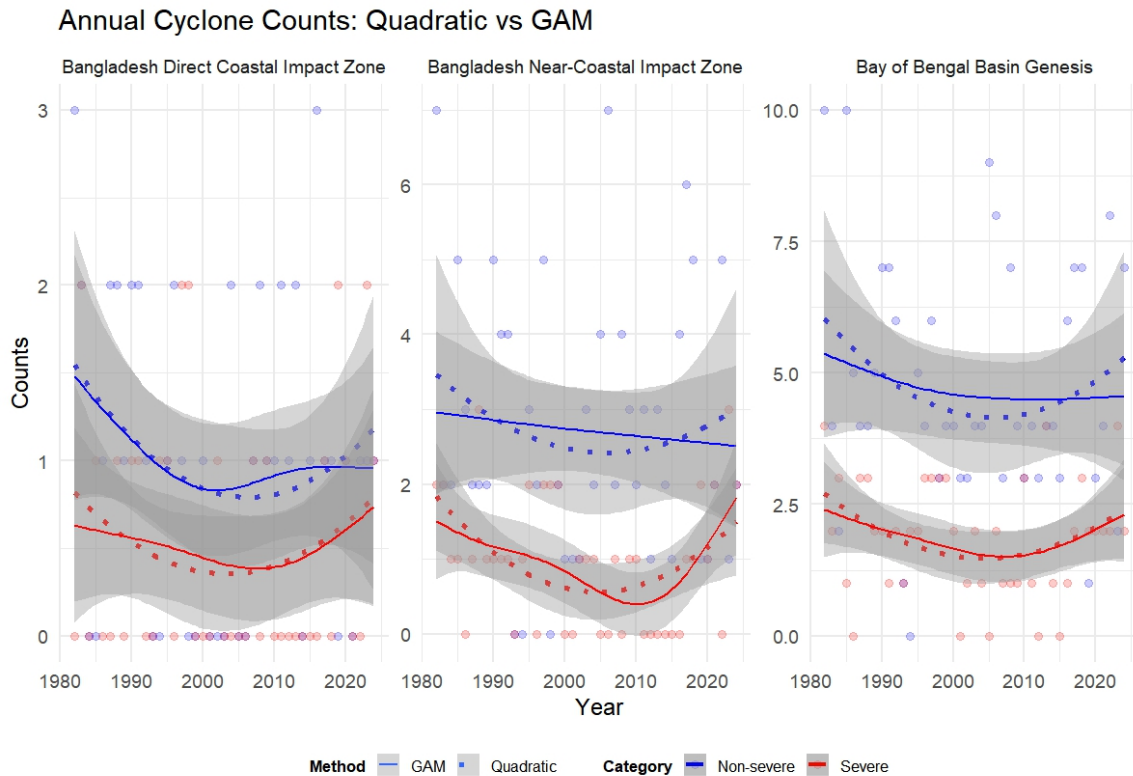


Fig. 3.3 Quadratic and GAM-based representations of annual tropical cyclone count for the Bangladesh direct coastal impact zone, Bangladesh near-coastal impact zone, and the Bay of Bengal genesis region (1982–2024). Blue and red denote non-severe and severe events, respectively. Solid lines show GAM smooths, dashed lines quadratic fits, and shaded areas indicate

95% confidence intervals. Observations are shown as points, illustrating generally weak and non-robust nonlinear trends across domains.

Table 3.2 Model selection for annual cyclone frequency. AIC values are shown for linear, quadratic, and GAMs. Lower AIC values indicate a better fit. The GAM smooth term's p-value (pval_s_gam) is also provided.

Domain	Category	AIC _{Linear}	AIC _{Quadratic}	AIC _{GAM}	edf _{gam}	GAM P-value
BD Direct Coastal Impact Zone	Non-severe	114.66	114.86	114.51	2.005	0.44
BD Direct Coastal Impact Zone	Severe	96.68	96.88	96.73	1.929	0.636
BD Near-Coastal Impact Zone	Non-severe	176.88	177.99	176.94	1.036	0.676
BD Near-Coastal Impact Zone	Severe	114.64	109.1	107.15	3.273	0.024
Bay of Bengal Basin Genesis	Non-severe	199.18	199.37	199.57	1.384	0.65
Bay of Bengal Basin Genesis	Severe	135.22	132.84	133.7	2.2244	0.276

3.3.2 Trends in Cyclone Severity Composition

The proportion of cyclones reaching severe status also showed no significant linear trend over the study period (Fig. 3.4, Table 3.3). For all three domains, the OLS regression on the annual severe share yielded negative but statistically non-significant slopes ($p > 0.05$). The mean share of severe events was remarkably consistent across domains, ranging from 27.3% in the Bangladesh Near-Coastal Zone to 31.9% in the Direct Coastal Zone, with the basin-wide mean at 30.2%.

Annual Proportionality (Severe/Total) Across The Domains (1982–2024)

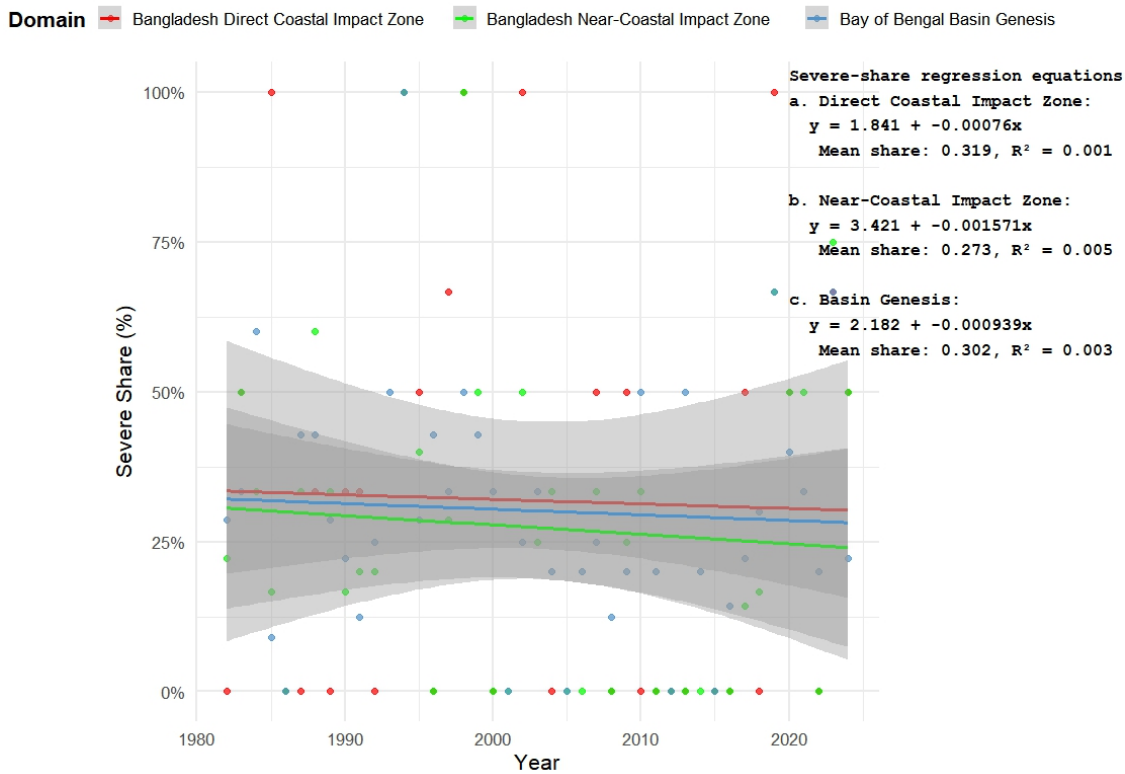


Fig. 3.4 Annual proportion of severe tropical cyclones relative to the total count for each domain (1982–2024). The dashed line represents the linear trend. The flat trajectories across all panels confirm the lack of a systematic change in the composition of cyclone severity over time.

Table 3.3 Linear trends in the annual proportion (share) of severe cyclones (1982–2024). All slopes are statistically non-significant ($p > 0.05$).

Domain	Mean Severe Share	Slope (fraction/year)	p_value	R ²
BD Direct Coastal Impact Zone	0.319	-0.00076	0.88	0.00073
BD Near-Coastal Impact Zone	0.273	-0.00157	0.645	0.00536
Bay of Bengal Basin Genesis	0.302	-0.00094	0.713	0.00332

However, the event-level logistic regression, which models the probability of an individual cyclone being severe as a function of time, revealed distinct domain-specific patterns that were masked in the aggregated annual proportion analysis (Table 3.4).

In the Bangladesh Direct Coastal Impact Zone (50 km), the odds ratio for year was effectively 1.00 (OR = 0.99998, 95% CI: 0.98–1.02, $p = 0.998$), indicating stability in the probability of a landfalling cyclone being severe over the 43-year period. However, the confidence intervals, spanning from a 2% annual decrease to a 2% annual increase in odds, again reminds that no statistically significant trend was detectable given the available data. The extremely wide confidence intervals for the intercept reflect the sparse event count in this near-shore zone, where severe cyclones are rare (mean = 0.51 per year).

For the Bangladesh Near-Coastal Impact Zone (400 km), the odds ratio suggested a slight, non-significant decline in the odds of severity over time (OR = 0.996, 95% CI: 0.97–1.02, $p = 0.781$). This negative tendency, while not statistically significant, aligns with the non-linear pattern detected by the GAM for severe frequency in this same domain (Table 3.2), where a significant smooth term ($p = 0.024$) indicated multi-decadal fluctuations. The Bay of Bengal Basin Genesis domain exhibited a weak, non-significant positive trend (OR = 1.006, 95% CI: 0.97–1.05, $p = 0.746$). This suggests that at the broad, basin-wide scale, the thermodynamic odds of cyclone intensification to severe status have remained more-or-less constant since 1982. However, it is important to note that the confidence intervals for all three domains are wide and overlapping (Table 3.4), indicating substantial uncertainty in the precise magnitude of any trend. For example, the basin-wide estimate (OR = 1.006) has a 95% confidence interval spanning 0.97–1.05, consistent with anything from a 3% annual decrease to a 5% annual increase in severe odds.

Table 3.4 Event-level logistic regression results for severe cyclone probability (1982–2024). An odds ratio (estimate for year) >1 indicates increasing odds of severity over time, while <1 indicates decreasing odds.

Domain	Term	Estimate (Odds Ratio)	95% Conf. Interval		P-value
			Low	High	
BD Direct Coastal Impact Zone	year	0.99998	0.98028	1.0200	0.99845
BD Near-Coastal Impact Zone	year	0.99619	0.96954	1.02334	0.78065
Bay of Bengal Basin Genesis	year	1.00631	0.96845	1.04594	0.74630

3.3.3 Trends in Cyclone Intensity and Duration

In contrast to the stable frequency and composition, a different picture emerges when analyzing event-level characteristics (Fig. 3.5, Fig. 3.6, and Table 3.5) Scatter plot of individual cyclone events showing maximum wind speed over time (1982–2024) for each domain. The solid blue line represents the linear trend. The slight downward slope is visually consistent across domains, but the scatter is high. The maximum wind speed achieved by cyclones showed a consistent, albeit statistically non-significant, negative trend across all domains. The largest decline was observed for basin-wide cyclones (slope = -0.23 knots/year, $p = 0.22$), followed by the Near-Coastal Zone (slope = -0.20 knots/year, $p = 0.46$). The point estimates suggest that the average peak intensity of cyclones may have weakened by approximately 2.3 knots per decade basin-wide, but this trend is not strong enough to be distinguished from random variability.

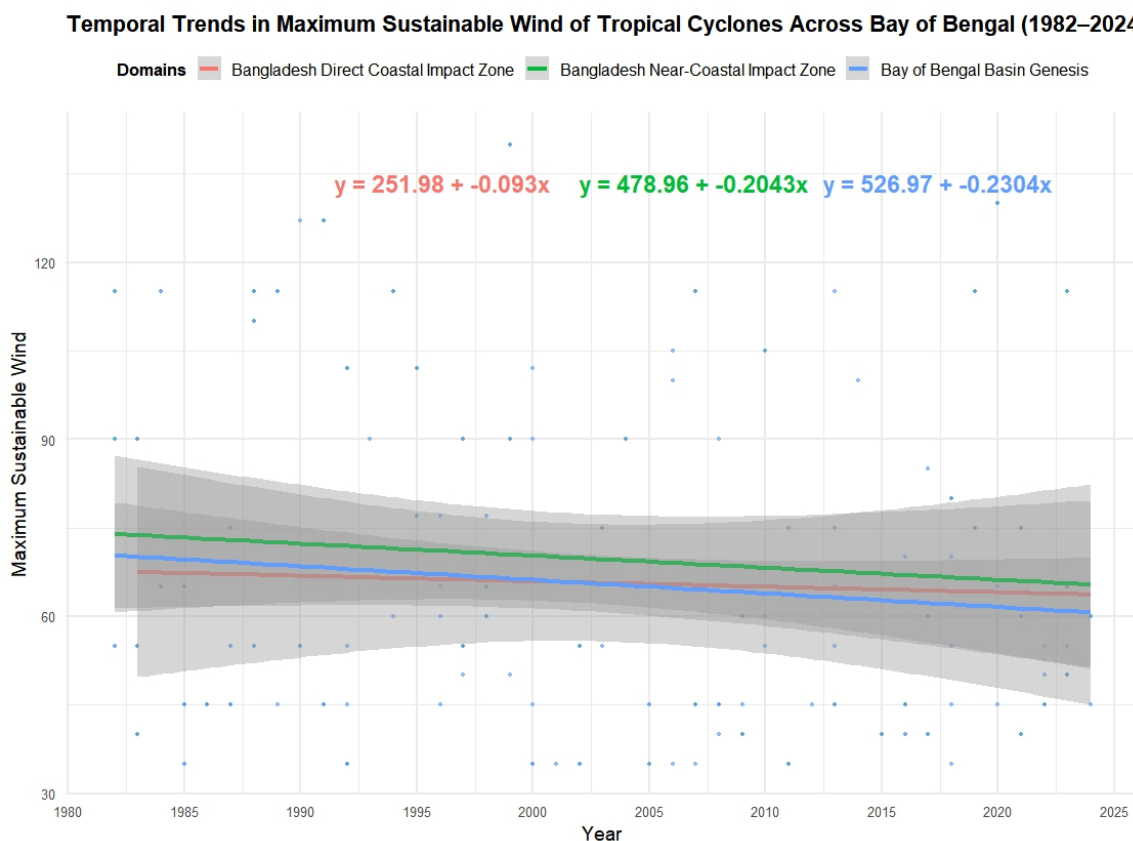


Fig. 3.5 Scatter plot of individual cyclone events showing maximum wind speed over time (1982–2024) for each domain. The solid blue line represents the linear trend. The slight downward slope is visually consistent across domains, but the scatter is high.

Trends in cyclone duration were more ambiguous and domain dependent. Cyclones impacting the immediate Bangladesh coast (50 km) exhibited a weak tendency to shorten over time (slope = -0.25 hours/year, $p = 0.75$). Conversely, cyclones in the broader basin (Basin Genesis and the Near-Coastal 400 km zone) showed a non-significant tendency towards longer durations, with basin-wide storms lasting about 1.8 hours longer per decade (slope = +0.18 hours/year, $p = 0.72$). However, given the high p -values, this duration trends are not statistically robust.

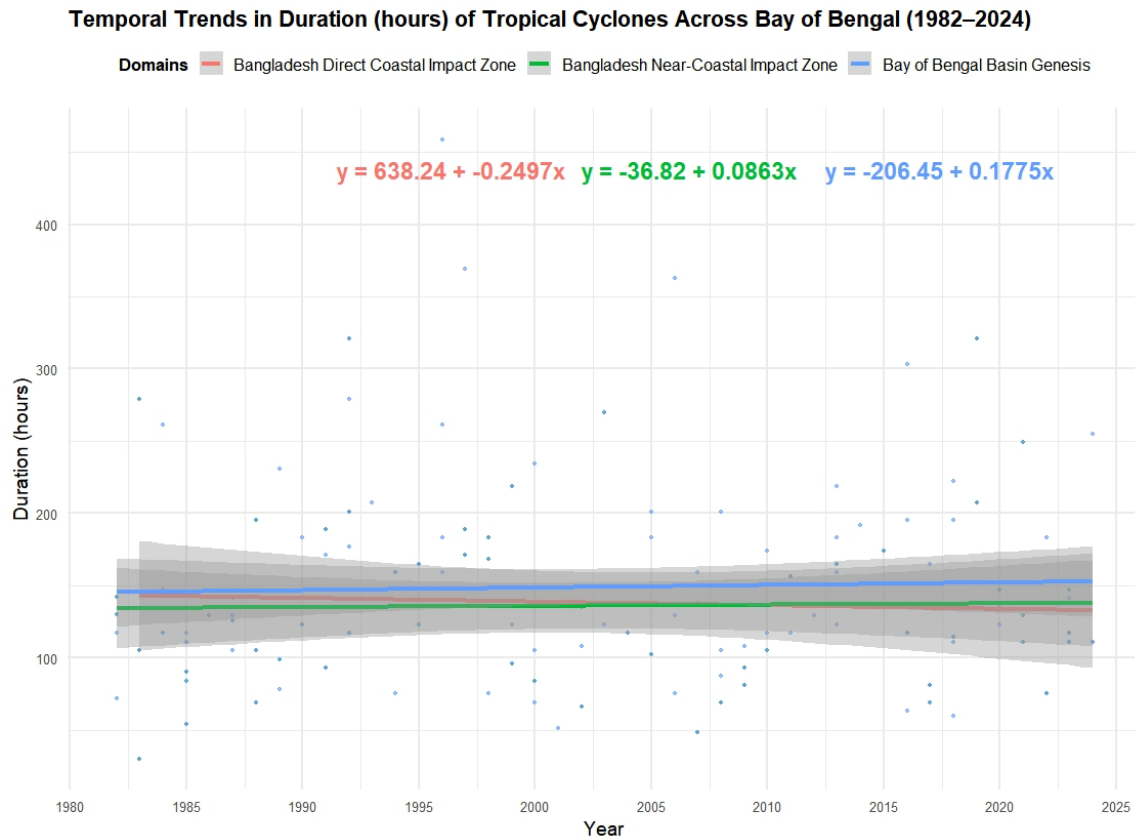


Fig. 3.6 Scatter plot of individual cyclone events showing total duration over time (1982–2024) for each domain. The linear trend lines show domain-dependent directions (slightly negative for the 50 km zone, slightly positive for the basin), but all are statistically non-significant.

Table 3.5 Linear trends in cyclone intensity (maximum wind) and duration (1982–2024). Slopes represent the average annual change in knots or hours per cyclone event.

Variable	Domain	Slope (per year)	P-value	R ²
Max Wind (knots)	BD Direct Coastal Impact Zone	-0.0930	0.802	0.0019
	BD Near-Coastal Impact Zone	-0.2043	0.459	0.0092
	Bay of Bengal Basin Genesis	-0.2303	0.220	0.012
Duration (hours)	BD Direct Coastal Impact Zone	-0.2497	0.750	0.0030
	BD Near-Coastal Impact Zone	0.0863	0.881	0.0004
	Bay of Bengal Basin Genesis	0.1775	0.719	0.001

3.4 Discussion

The present study adopts a spatially nested, data-aware analytical framework to investigate multi-decadal (1982–2024) trends in tropical cyclone characteristics relevant to Bangladesh, highlighting a pronounced divergence between basin-scale expectations and coastal-scale behavior. The findings based on the modern observational era indicate that widely cited global signals of cyclone intensification, largely inferred from pre-geostationary satellite records, do not translate in a linear or uniform manner to the Bangladesh coastline.

The significant non-linear fluctuations detected in the near-coastal zone (400 km) underscore the value of flexible analytical approaches for capturing multi-decadal variability. However, the disappearance of this signal in the direct coastal zone (50 km) presents an important interpretive challenge. Two non-mutually exclusive explanations can be considered: (1) statistical attenuation due to a smaller sample size in the inner domain, reducing power to detect complex patterns; or (2) genuine physical filtering whereby nearshore processes, such as bathymetric steering, enhanced friction, or boundary layer interactions, dampen the expression of basin-scale multi-decadal oscillations. This study cannot definitively discriminate between these mechanisms, highlighting a critical direction for future research employing higher-resolution modeling and longer observational records. Apart from this non-linear signal, the broader analysis reveals only slight, statistically non-significant declines in cyclone counts and peak wind speeds at the basin-wide

scale, consistent with century-scale records showing weak or declining frequencies over extended observational windows ([Knutson et al., 2019](#); [Kossin et al., 2020](#)).

The hierarchical analytical framework employed here reveals that cyclone behavior in the immediate coastal zone (50 km buffer) is decoupled from dynamics operating in the open basin. While the Bay of Bengal Basin Genesis domain exhibited a non-significant negative trend in maximum wind speed (slope = -0.23 knots/year, $p = 0.22$), the Direct Coastal Impact Zone showed a markedly attenuated decline (slope = -0.09 knots/year, $p = 0.80$). This spatial pattern, whereby the negative tendency in intensity is numerically smaller as cyclones approach the Bangladesh coastline, raises the possibility that nearshore processes may modulate basin-scale thermodynamic forcing.

However, given the wide confidence intervals and overlapping uncertainty ranges (Table 3.5), this apparent gradient should be interpreted cautiously. Formal statistical testing reveals no significant difference between the coastal and basin slopes, indicating that the observed pattern, while suggestive, does not constitute robust evidence of differential trends. This spatial pattern is more appropriately interpreted through the lens of coastal ocean dynamics rather than terrestrial feedback. The shallow, funnel-shaped continental shelf characterizing the Bangladesh coast generates unique air-sea interaction processes that may influence cyclone intensity as storms transit the shelf waters. Specifically, reduced ocean heat content in shallow, well-mixed shelf waters can limit enthalpy fluxes available for intensification, while simultaneously, the concave bathymetry may enhance wave setup and storm surge without necessarily increasing wind speeds ([Busireddy et al., 2022](#); [Needham et al., 2015](#)).

The persistence of severe cyclone probability in the direct coastal zone (mean ≈ 0.5 events annually) underscores a hidden dimension of risk: even in the absence of increasing frequency, the destructive potential of landfalling cyclones remains undiminished. This finding underscores the importance of downscaling global projections to regional coastlines. While global models project future increases in intense cyclone proportions ([Emanuel, 2005](#); [Knutson et al., 2021](#)), the observational record for Bangladesh shows no detectable trend in severe landfall probability over the past 43 years.

Projections are for future climate states under continued warming, while observations reflect historical variability. This apparent divergence emphasizes that global-scale signals may be modulated or delayed at local scales by processes not fully represented in models. Such as, ENSO-related variability complicates the TC scenario, as multi-decadal oscillations strongly modulate Bay of Bengal cyclone activity (Chu & Murakami, 2022), producing domain-specific outcomes that cannot be captured by basin-scale analyses alone. Taken together, these results emphasize that adaptation planning must prioritize coastal-specific hazard assessments. Stable severe cyclone probabilities at landfall translate into persistent national risk, demanding continued investment in early warning systems, cyclone shelters, and embankment protection. Future work should extend beyond wind intensity to incorporate cyclone size, forward speed, and tidal timing, enabling multivariate assessments of coastal destructiveness.

3.5 Summary

Using a spatially nested analytical framework over the period from 1982 to 2024, this study examines tropical cyclones affecting Bangladesh and finds no statistically significant long-term trends in frequency, severity composition, intensity, or duration across various spatial domains. While there are numerical differences in trend magnitudes, formal statistical testing reveals these are not significant, highlighting the limitations imposed by sample size and natural variability.

Notably, the study identifies statistically significant non-linear variability in severe cyclone frequency within the near-coastal zone (400 km), unlike the direct impact area (50 km). This observation suggests that multi-decadal variability might be less pronounced as cyclones near the coast, although it cannot definitively separate physical nearshore effects from statistical power limitations.

Event-level analysis confirms that the likelihood of a cyclone achieving severe intensity at landfall has no statistically detectable change over the last four decades. This corresponds to an observed mean severe landfall rate of approximately 0.5 events per year. The absence of a detectable trend does not imply reduced hazard; rather, it reflects the persistence of exposure to high-impact cyclones despite the lack of evidence for systematic intensification.

The findings indicate that, during the modern satellite era, expectations of intensification observed globally and across basins do not translate into measurable changes in coastal cyclone characteristics for Bangladesh. The coastal risk persists mainly due to inherent variability rather than systemic increases, underscoring the importance of further research. Subsequent studies should encompass cyclone size, translation speed, rainfall impacts, and interactions with storm surge and tides, while also considering climate-mode variability such as ENSO and Indian Ocean Dipole (IOD). This comprehensive approach is vital for disentangling natural variability from anthropogenic influences and enhancing the understanding of coastal cyclone hazards amid climate change.

Chapter 4: Current Practices and Policy Gaps

Chapter 4: Current Practices and Policy Gaps

4.1 General

Tropical cyclones (TCs) are the most destructive weather events in coastal regions, causing significant loss of life, property damage, agricultural losses, and communication disruptions (Chauhan & Liou, 2022; Shamsuzoha et al., 2024; Sobel et al., 2016). Coastal regions around the world are regularly threatened and affected by these cyclones. In contrast, an increasing number of countries across the globe have experienced severe flooding due to cyclones, typhoons, or hurricanes in recent years (van Genuchten, 2024). Climate variability, rapid urbanization, and land-use changes are increasing the frequency and severity of TC-induced disasters in many coastal countries (Islam et al., 2021).

Strong winds, heavy precipitation, and storm surges are notable destructive characteristics of tropical cyclones (Chen & Liu, 2016; Hoque et al., 2021; Sahoo & Bhaskaran, 2018). These natural events often cause significant casualties, widespread damage to agriculture and properties, and disruptions to communication networks (Hoque et al., 2021; Mazumdar & Paul, 2018). On average, 90 tropical cyclones originate each year across several cyclone basins worldwide (Bakkensen & Mendelsohn, 2019; Mansour, 2019). When vulnerable populations do not receive early warning information in a timely and effective manner, the destructive power of cyclones is further increased (Parvin et al., 2019).

According to the World Meteorological Organization (WMO), TC caused about 1,965 billion US dollars' worth of global damage between 1970 and 2019 (WMO, 2020). Other findings from the WMO Tropical Cyclone Program suggested that about 85 tropical storms form annually over the warm tropical oceans worldwide. Among these, a little more than half (45) become tropical cyclone/hurricane/typhoon. Out of the 85 tropical storms, 72% form in the northern hemisphere and 28% in the southern hemisphere (WMO, 2024).

Bangladesh is bounded on the south by the Bay of Bengal, where TCs form frequently during early summer (April to June) and the late rainy season (September to November) (Paul, 2009; Uddin et al., 2019). The southern and southeastern peripheral regions of Bangladesh are particularly vulnerable to TCs due to their low elevation, gentle slopes, proximity to the sea, numerous historical cyclone tracks, susceptible land cover (including settlements and cropland), and

inadequate socioeconomic structures (Hoque et al., 2021; Haque et al., 2024). Most of these tropical cyclones hit the coastal areas of Bangladesh (Hoque et al., 2019). Coastal populations are more vulnerable to disasters due to underdeveloped infrastructure and socioeconomic marginalization (Islam & Islam, 2026).

Evacuation decisions during cyclones in Bangladesh vary across four distinct behavioral groups, shaped by differences in risk perception, warning communication, timing, and access to safe shelters, emphasizing the need for group-specific evacuation strategies. Evacuation decisions are frequently influenced by communication breakdowns, power outages, and mistrust of official communications (Parvin et al., 2019). The existing mitigation and resilience measures, such as the construction of cyclone shelters, coastal barriers, road networks for evacuation, effective early warning systems, and administrative capacity in these risk-prone areas, are significantly inadequate for effective disaster risk reduction in Bangladesh (Hoque et al., 2021). Recent disaster research has highlighted similar issues of low community preparedness and low risk literacy (Ahsan et al., 2026). The destructive impact of tropical cyclones can be reduced through appropriate management measures. An effective cyclone disaster management plan is designed into four phases: response, recovery, mitigation, and preparedness (Joyce et al., 2009; Khan, 2008).

Mitigation (prevention/reduction) and preparedness are considered in the pre-disaster phase, while the post-disaster phase is covered by response and recovery. The mitigation (prevention/reduction) and preparedness phases comprise appropriate measures and proper planning execution that reduce the likelihood and impact of tropical cyclone disasters (Islam & Chik, 2011; Westen et al., 2013). Cyclone risk management is necessary to generate the information required for pre-disaster phases in the context of cyclone vulnerability, hazard, and capacity assessment and modelling (Fang et al., 2016; Li & Sheng, 2013; Taubenböck et al., 2008). It is increasingly recognized that enhancing long-term adaptive capacity through inclusive, well-coordinated planning is essential (Islam et al., 2025).

This study aims to develop a global standard for ongoing disaster management for tropical cyclones, enabling comparison with current practices in Bangladesh. Although developing a universal standard is challenging due to variations in socioeconomic and geographic contexts, this research addresses this gap by systematically reviewing disaster management policies and practices across 12 cyclone-prone countries recognized for their advanced resilience strategies.

The review encompasses the full disaster management cycle and incorporates Bangladesh's disaster management acts, policies, and long-term plans targeting climate-resilient development.

Despite extensive research on cyclone hazards, there remains a notable lack of comparative analyses that synthesize global best practices and critically evaluate Bangladesh's governance structures. Existing studies are fragmented and often limited by accessibility, language constraints, and incomplete documentation of management initiatives. According to recent research, to ensure locally relevant, egalitarian, and science-driven disaster management, transformative governance reform is crucial ([Islam & Islam, 2026](#); [Islam et al., 2021](#)).

This study contributes the first comprehensive, systematic comparison of tropical cyclone disaster management approaches between global leaders and Bangladesh. It establishes a standardized evaluation framework, identifies key governance and implementation gaps, particularly in institutional coordination, local empowerment, early warning integration, and evidence-based planning, and provides actionable recommendations to strengthen national resilience in the face of future climate change impacts.

4.2 Methodology and Materials

This study employed a systematic review of relevant literature to identify best global practices and gaps in Bangladesh's regulatory framework. The study used the methods outlined in [Pickering & Byrne \(2014\)](#), following the systematic flow developed by [Moher et al. \(2009\)](#). The materials and systematic processing flow used in this study are explained in the following sections and presented in Fig. 4.1.

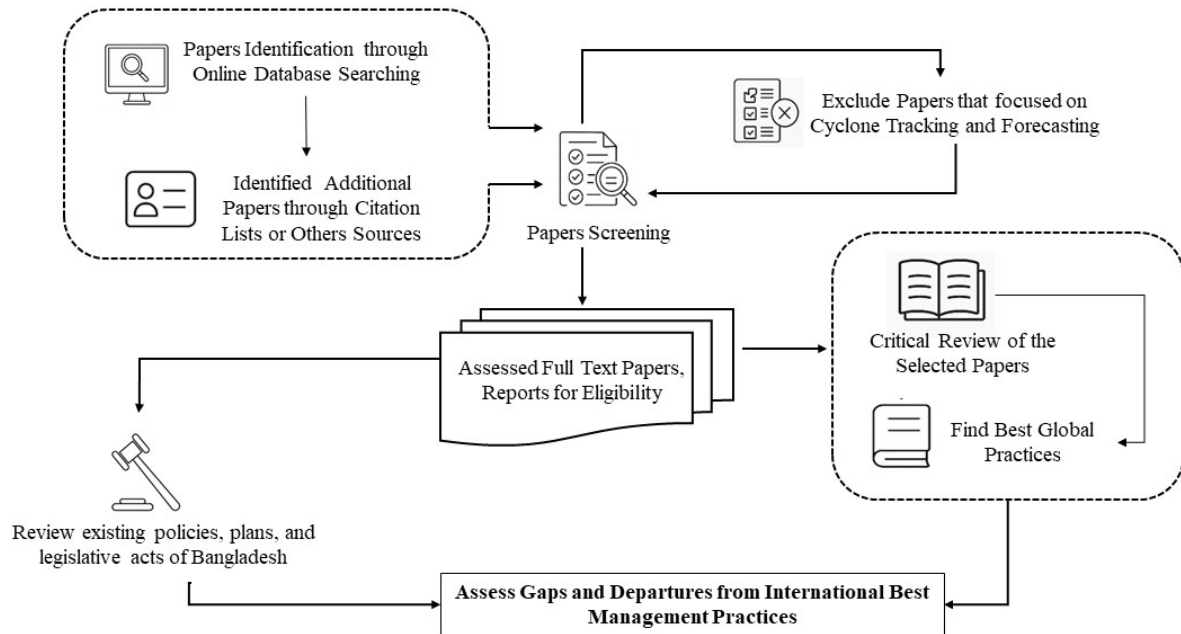


Fig. 4.1 Methodological Framework for reviewing global cyclone disaster management practices and identifying gaps.

4.2.1 Document Identification

We searched for documents on cyclone disaster management in different cyclone-prone countries from online sources, including Google Scholar, ScienceDirect, Web of Science, and Google, between January 2021 and August 2021. A total of 107 articles were downloaded using the keywords 'tropical cyclone,' 'typhoon,' 'hurricane,' 'disaster management' and combination of the following terms, 'mitigation', 'preparedness', 'response', 'recovery', 'damage and loss assessment', 'risk assessment', 'remote sensing', 'geographic information system (GIS)', 'storm surge', 'impact assessment'.

An additional 17 articles were identified from citation lists and other sources. Of the total 124 articles, we selected 61 for this study, following the selection criteria explained in section 4.2.2.

4.2.2 Document Screening

We initially considered peer-reviewed papers on tropical cyclone disaster management, book chapters, international and national guidelines, organizational reports, and event-based documentation. To ensure diversity of practices, we selected 13 countries (Australia, China, Hong Kong, India, Japan, Malaysia, South Korea, the Philippines, Taiwan, Thailand, the USA, and Vietnam), including Bangladesh.

4.2.3 Document Categorization and Review

The selected documents were first categorized by country of focus and by the phases of the cyclone disaster management cycle (mitigation, preparedness, response, or recovery). However, these phases are closely interconnected and often addressed simultaneously within the literature. Studies were reviewed with attention to acknowledging overlaps across multiple disaster management stages.

4.3 Global Disaster Management Practices

Effective disaster management requires learning from diverse global experiences, particularly in regions regularly impacted by tropical cyclones, hurricanes, or typhoons. This study reviewed existing global practices to highlight best management strategies to reduce disaster risk, protect lives and livelihoods, and support faster recovery, while socioeconomic conditions, institutional capacities, and geographic settings differ, many nations have adopted innovative approaches that demonstrate how coordinated policies, resilient infrastructure, community engagement, and technological advancement can significantly strengthen preparedness and response. Examining these established practices provides essential insights into how cyclone-prone countries can enhance resilience and adapt to increasing climate-related hazards.

4.3.1 Mitigation Approaches

Mitigation is commonly defined as any sustained effort to reduce a hazard's risk or the adverse effects of a hazard by reducing the likelihood and/or the consequences of that hazard's risk ([UNISDR, 2009](#); [Coppola, 2011](#)). Mitigation measures encompass engineering techniques and hazard-resistant construction as well as improved environmental policies and public awareness ([UNISDR, 2009](#)). The mitigation measures are grouped into two primary categories: structural and nonstructural.

4.3.1.1 Structural and Nonstructural Measures

Structural mitigation reduces cyclone risk through engineered modifications to the physical environment, while non-structural mitigation addresses risk by changing human behavior and natural processes without relying on engineered structures ([Coppola, 2011](#)). Table 4.1 summarizes key disaster risk reduction strategies adopted in cyclone-prone countries, grouping them into structural measures, non-structural measures, and preparedness planning tools. Structural

strategies focus on reducing direct hazard exposure through resilient infrastructure, whereas non-structural approaches target vulnerability reduction through policy, awareness, and institutional mechanisms. Preparedness measures complement both by strengthening planning and logistics for effective emergency response.

Table 4.1 Structural and Non-Structural Mitigation and Preparedness Measures for Cyclone Risk Reduction.

Category	Measure	Description	References
Structural	Cyclone-resilient shelters	Multipurpose cyclone shelters (schools/community halls) ensure regular use, maintenance, and community benefits; practiced in Andhra Pradesh	NDMA (2017)
	Coastal afforestation	Coastal shelterbelts and forest regeneration under National Afforestation Plans to reduce storm-surge impacts	MoEFCC (2019)
	Coastal embankments and barriers	Levees, dunes, floodwalls, and elevation standards widely used in the USA; saline embankments in India remain vulnerable to intense cyclones	FEMA (2010); Srivastava & Kanji, 2020
	Infrastructure reinforcement	Strengthening load paths, roofs, and connections; sloped roofs reduce wind pressure and improve load transfer	FEMA (2010)
	Drainage improvement systems	Coastal canal systems prioritized over roads in deltaic regions where bridge and road construction is difficult	NDMA (2009)
	Strengthening critical facilities	Improved monitoring and warning systems under national disaster-mitigation programs	Lixin et al., (2012)
	Communication & transmission tower protection	Towers designed for wind speeds $1.3 \times$ code values; deeper foundations and galvanized steel to resist corrosion	NDMA (2017)
	Flood-proofing and retention systems	Wet/dry floodproofing, structure elevation or relocation, and flood barriers to address cyclone-induced flooding	FEMA (2010); Ayanian (2020)
Non-structural	Risk and damage assessment systems	Integrated situational awareness, predictive risk analysis, and information dissemination	Department of Home Affairs (2018)
	Public awareness and education	Disaster education, early warning systems, public reporting, camps, and awareness programs	Yi et al. (2009)

Risk analysis	Multi-hazard engineering approaches for flood mapping, dam safety, and hurricane programs	Yi et al. (2009)
Risk transfer, sharing, and spreading	Dyke maintenance, live-with-flood strategies, and seasonal crop adjustments	CEDMHA (2018)
Community-based disaster risk mitigation	Integration of disaster mitigation with socioeconomic development and participatory planning	CEDMHA (2020) ; Yi et al. (2009)
Hazard Mitigation Grant Program	Grants for long-term hazard mitigation and resilient rebuilding by governments	FEMA (2021)

4.3.1.2 Regulatory Measures

China has positioned disaster mitigation as a core pillar of national sustainable development, formalized through the promulgation of the PRC Disaster Mitigation Plan (1998–2010), which set strategic guidelines and emphasized integrating disaster risk reduction into economic development planning ([Gao et al., 2009](#)). Consistent with international guidance, regulatory frameworks should incorporate safeguards for development sites and downstream areas to reduce development-induced disaster risks ([UNISDR, 2008](#)). In Korea, the Disaster Impact Assessment (DIA) system provides a comprehensive regulatory tool that addresses hazards such as cyclones and storm surges by assessing vulnerabilities of people, assets, and geographic settings, while also accounting for adaptive capacity, including socioeconomic and governmental dimensions, thereby aligning disaster risk reduction with sustainable development objectives ([Kang et al., 2018](#)). Legal foundations are critical for effective disaster governance; accordingly, China has prioritized a robust disaster-management legal framework, including dedicated legislation on meteorological disasters and marine disasters to strengthen typhoon risk management ([Wang et al., 2007](#)).

4.3.2 Preparedness

UNISDR defines preparedness as the knowledge and capacities developed by governments, professional response and recovery organizations, communities, and individuals to anticipate, respond to, and recover effectively from the impacts of likely, imminent, or current hazard events or conditions ([UNISDR, 2009](#)). The range of activities that constitute the preparedness component of the comprehensive emergency management cycle is expansive, and these actions are often the primary factors in determining whether response actions are successful. The Table 4.2 sections

present an overview of disaster preparedness. This Table presents a structured synthesis of preparedness measures adopted across cyclone-prone countries, highlighting planning, training, coordination, technology use, early-warning development, and statutory mechanisms.

Table 4.2 Preparedness Components and Key Institutional Practices for Effective Cyclone Disaster Management.

Domain	Measure	Description	References
Planning	Contingency planning	Institutional contingency frameworks and whole-of-government crisis coordination systems support national decision-making during disasters	ESU (2019); AGDoHA (2017)
	Preparedness guidelines	National preparedness guidelines synchronize and organize disaster readiness across agencies	Yi et al. (2009)
	Emergency response planning	Emphasis on household safety, continuity of communication, and preparedness for multiple emergency scenarios	CDC (2020, 2018)
	Logistics planning	Pre-disaster storage of long-shelf-life food and water for people and pets	CDC (2019)
	Protection in humanitarian action	National humanitarian protection frameworks guide disaster management policies through multi-stakeholder coordination	AusAID (2013)
	Volunteer management	Trained volunteer networks play a central role in cyclone preparedness and response; flagship models replicated globally	BDRCS (2020); McLennan & Birch (2005); NDMA (2017)
	Record keeping and reporting	Operational Terrain Mapping and centralized data systems support contingency planning across agencies	Yi et al. (2009)
	Financial management and reimbursement	Disaster relief and recovery arrangements reduce subnational financial burdens and enable rapid assistance	AGDoHA (2017)
	Legal liabilities and protections	Humanitarian action policies provide strategic legal guidance for effective disaster response	AusAID (2011)
	Inter-organizational coordination	Humanitarian partnership agreements strengthen coordination and funding mechanisms among government and NGOs	Department of Foreign Affairs and Trade (DFAT, 2019)

Exercise	Disaster drills and exercises	Regular national disaster reduction drills institutionalize preparedness practices	Disaster Management Authority (DMA, 2011)
	Evacuation mapping	Digital evacuation maps with ingress/egress routes improve evacuation efficiency and responder access	Peters & McEntire (2010)
	Advanced tabletop preparedness	DEM, remote sensing, and spatial data support storm surge modeling; most models remain regional, with limited local-scale applications	Fang et al. (2016); Frazier et al. (2010); Jakobsen et al. (2006); Lewis et al. (2013, 2014); Ozcelik et al. (2012); Puotinen (2007); Ward et al. (2011)
Early warning	Cyclone tracking and forecasting	Integrated meteorological monitoring, online coordination platforms, and satellite backups enable early warnings	Aung & Clerk (2013);
	Information management	Reliable communication systems (VHF, integrated radio networks) are critical for effective early warning dissemination	NDMA (2017); WMO (2005)
	Investment in warning systems	National emergency warning systems enhance public alerts and post-disaster survivor identification	
	Public education	Public guidance on warnings, preparedness actions, and emergency behavior reduces cyclone impacts	CDC (2020)
Statutory authority	Institutional mandates	National strategies emphasize leadership, logistics, and coordination; meteorological and emergency agencies lead preparedness and response	CEDMHA (2017, 2018, 2020); Lixin et al. (2012)

4.3.3 Response

Response is the provision of emergency services and public assistance during or immediately after a disaster to save lives, reduce health impacts, ensure public safety, and meet the basic needs of affected people. Disaster response is primarily focused on immediate, short-term needs and is sometimes called ‘disaster relief’. Generally, it is one of the primary responsibilities of the affected state ([UNISDR, 2009](#)). During the response, unnecessary delay directly translates to tragedy and destruction ([Coppola, 2011](#)). Table 4.3 provides a structured overview of global response practices

applied before and after cyclone landfall, illustrating how different countries operationalize early warning dissemination, evacuation management, resource prepositioning, and the rapid mobilization of emergency services.

Table 4.3 Pre-Disaster and Post-Disaster Response Measures Implemented Across Cyclone-Prone Countries.

Phase	Response Component	Description	References
Pre-disaster	Warning and evacuation	Timely and reliable warning dissemination and evacuation reduce casualties and asset loss; effectiveness depends on authority responsiveness, community cooperation, and credibility of warnings	Yi et al. (2009)
	Web-based evacuation decision support	Web-based platforms provide real-time evacuation guidance and hazard information for emergency managers	
	Pre-positioning of resources and supplies	Early warnings enable advance transport of relief supplies, reducing delays and risks; portable disaster kits support rapid deployment	Commonwealth of Australia and Republic of Indonesia (2015)
Post-disaster	Search and rescue	Search and rescue operations involve locating, extracting, and providing immediate medical assistance to victims	CEDMHA (2017); Coppola (2006);
	First-aid and emergency medical treatment	On-site medical stabilization and deployment of mobile medical teams when hospital capacity is exceeded	ESU (2019)
	Provision of water, food, and shelter	Delivery of essential supplies and temporary shelter when normal supply chains are disrupted	Department of Home Affairs (2018)
	Rapid disaster damage and needs assessment	Rapid assessments inform decision-makers on impacts and needs to ensure timely and appropriate support	Department of Home Affairs (2018)

Rapid needs assessment tools	Standardized rapid assessment tools (e.g., CASPER) identify community health and relief needs within 72 hours	Bayleyegn et al. (2015)
Logistics and supply chain management	Establishment of emergency supply chains for essential services, materials, and utilities	Department of Home Affairs (2018)
Volunteer management	Mobilization and coordination of trained and spontaneous volunteers during response operations	Chan (2012)
Incident command and coordination	Centralized incident command systems define leadership, division of responsibilities, and operational coordination	Peters & McEntire (2010)
Government inter-agency coordination	Rapid coordination among government and private actors supports recovery financing and long-term disaster risk management	Chan (2012)
National disaster management operations	Unified leadership with graded response systems balance central oversight and local implementation	Lixin et al. (2012)

4.3.4 Recovery

Even with the best mitigation and preparedness initiatives, there will almost always be some level of property damage, disruption of social and economic systems, and casualties. Thus, a recovery stage is inevitable. UNISDR defines recovery as the restoration and improvement of facilities and living conditions of disaster-affected communities, including efforts to reduce disaster risk factors. The recovery task of rehabilitation and reconstruction begins soon after the emergency phase has ended. Recovery programs offer a valuable opportunity to develop and implement disaster risk reduction measures and to apply the ‘build back better’ principle ([UNISDR, 2009](#)).

Recovery can be divided into two distinct phases, each with very different activities: short-term and long-term. Table 4.4 demonstrates short term and long-term recovery global practices. The short-term recovery phase immediately follows the hazard event, beginning while emergency response operations are ongoing. Long-term recovery does not begin in earnest until after the emergency phase of the disaster has ended.

Table 4.4 Short-term and long-term recovery global practices.

Recovery Phase	Recovery Component	Concise Description	References
Short-term	Temporary relief and early rehabilitation	Provision of food, blankets, and essential items through designated emergency relief teams	ESU (2019)
	Restoration of critical infrastructure	Rapid restoration of utilities, transport, and services to support response and recovery; integration of cost-effective resilience measures and continuity strategies	Department of Home Affairs (2018) ; NDMA (2017) ; World Bank (2014)
	Early debris clearance	Priority-based clearance of road blockages to enable traffic flow and emergency access	ESU (2019)
Long-term	Joint damage and needs assessment	Initial and joint preliminary damage assessments quantify impacts and unmet needs to guide recovery planning	FEMA (2021)
	Strategic recovery planning	National and local recovery funds support property reconstruction, implemented directly or via subsidized local authorities	Yi et al. (2009)
	Restoration of basic services	Undergrounding or relocation of utility lines to reduce future typhoon damage and enhance service reliability	World Bank (2014)
	Infrastructure reconstruction and development	Repair and reconstruction of housing, utilities, and services to stabilize affected and non-affected areas and restore business-as-usual activities	Department of Home Affairs (2018)
	Post-disaster reconstruction and resettlement (case: Taiwan)	Legal frameworks and NGO partnerships accelerated permanent housing; resettlement raised challenges of community integration and cultural preservation	Wang et al. (2015)
	Economic recovery and development	Policy incentives, livelihood support, and land access to restore economic activity and sustainability	Department of Home Affairs (2018) ; Xuan (2005) ; Chan (2012)
	Business continuity and supply chains	Contingency planning and alternative sourcing strengthen supply-chain resilience during recovery	Chan (2012) ; Yi et al. (2009)

Flood insurance policy	Insurance-based recovery incentives linked to compliance with updated building codes and land-use regulations	FEMA (2010)
Strengthening institutional capacity	Coordinated planning, local leadership empowerment, and capacity-building investments enhance recovery governance	Australian Emergency Management Committee (2011); Department of Home Affairs (2018)
Building back better	Recovery and reconstruction integrate improved protective measures through government-supported, household-led rebuilding	Xuan (2005)

4.3.4.1 Cross-cutting Issues of Recovery

Recovery involves more than rebuilding physical structures; it also encompasses the social, institutional, and equity considerations that shape communities' long-term ability to recover and adapt. Addressing these cross-cutting concerns is essential to ensure that recovery efforts are inclusive, sustainable, and responsive to local priorities. Such issues highlight the need to strengthen community participation, safeguard vulnerable populations, and establish governance mechanisms that guarantee fair access to recovery support.

Empowering individuals and communities: A central, cross-cutting priority in post-disaster recovery is empowering affected populations. The Community-Based Disaster Risk Management (CBDRM) approach is to reduce vulnerabilities and strengthen people's capacity to cope with disaster risk. CBDRM has been applied in disaster-prone areas. Thailand, through the Department of Disaster Prevention and Mitigation (DDPM), has cooperated with local agencies to raise awareness among the public about the advantages of the CBDRM approach.

Protection of vulnerable people: The Australian Home Affairs department aims to provide assistance that helps people achieve adequate functioning after an emergency event ([Department of Home Affairs, 2018](#)).

4.4 Governance Framework: Acts, Policies, and Plans for Disaster Management in Bangladesh

Effective disaster governance is crucial to resilience, particularly in Bangladesh, which faces frequent hazards, such as tropical cyclones. A robust governance framework, including legislation, policies, and coordination mechanisms, is vital for reducing risk and enhancing preparedness. Bangladesh has made progress in disaster management, shifting towards proactive risk reduction, yet significant gaps remain in the execution and coordination of disaster risk reduction (DRR) within national development. After assessing the legislative and institutional landscape, its effectiveness relative to international standards, the ongoing governance challenges are highlighted that hinder disaster management progress.

4.4.1 Present Legislative and Policy Instruments

The Government of Bangladesh has established an extensive Disaster Risk Management (DRM) architecture comprising policies, plans, and legal instruments, including the National Adaptation Programme of Action (NAPA, 2005), Standing Orders on Disaster (SOD, 2010; revised 2019), the Disaster Management Act (2012), the National Disaster Management Policy (NDMP, 2015), and the National Plan for Disaster Management (NPDM) 2021–2025 (Chisty et al., 2022; Shaw et al., 2013). In 2024, the National Early Action Protocol (N-EAP) for monsoon floods and cyclones was adopted (GoB, 2024; Zevenbergen et al., 2018). The Bangladesh Delta Plan (BDP) 2100, which offers a long-term development strategy and divides the nation into six hydrological ‘hotspots’ to direct risk-informed planning in areas vulnerable to disasters, is in line with these tools (Arfanuzzaman, 2024). However, global evidence suggests that such long-term strategic frameworks often outpace local operational capacity, a persistent challenge in Bangladesh and other hazard-prone countries (Fernandez & Ahmed, 2019).

Historically, Bangladesh's disaster management policy evolved through a predominantly reactive phase, emphasizing relief, response, and structural mitigation during the colonial, Pakistan, and early post-independence periods (Barua et al., 2024; Haque et al., 2024). Policy shifts in the 1970s and 1980s were driven by large-scale infrastructure projects and repeated extreme events, including floods, famines, and cyclones (Younus, 2014). This gradual transition from relief-oriented approaches toward risk reduction mirrors trajectories observed in other developing countries such as Vietnam, China, and the Philippines (Mannan et al., 2021).

Despite a robust policy framework, implementation remains uneven. Empirical studies attribute weak enforcement to infrequent committee meetings, bureaucratic inertia, corruption, limited data availability, and resource constraints (Barua, 2022). Although the Disaster Management Act (2012) introduced progressive provisions, gaps persist in financial accountability, grievance mechanisms, and urban disaster management guidelines (Haque et al., 2017). Similarly, while the SOD clearly defines institutional roles across government agencies, NGOs, and communities, it insufficiently addresses stakeholder accountability (Nasreen, 2017). Weak monitoring and coordination, exemplified by irregular meetings of the National Coordination Committee, further undermine oversight and effectiveness (Uddin et al., 2022), a pattern common in cyclone-prone developing countries, specifically the cyclone shelters (Akon & Mia, 2024).

Effective disaster management in Bangladesh is further constrained by fragmented coordination among national, district, and local actors, communication gaps, limited preparedness planning, and inadequate institutional autonomy and capacity (Islam & Islam, 2026; Ogra et al., 2021). These challenges are consistent with global findings that centralized governance structures often struggle with multilevel coordination (Fernandez & Ahmed, 2019).

Institutionally, Bangladesh maintains a two-tier disaster management structure at national and local levels. Under the NPDM 2021–2025, Ward-level Disaster Management Committees (WDMCs) have been introduced to strengthen community-based disaster risk reduction (NPDM, 2020). While this represents progress toward localization, studies report persistent shortcomings in cyclone shelter management, local committee functionality, and evacuation coordination due to poor maintenance, uneven staffing, and weak inter-agency collaboration (Akon & Mia, 2024).

Finally, scholars highlight that Bangladeshi disaster governance often prioritizes national networks over local connectedness, limiting community ownership and effectiveness (Islam & Walkerden, 2017). Implementation is further hampered by public misconceptions, weak leadership, financial mismanagement, skills shortages, and rapid urbanization pressures (Ahmed et al., 2015; Rahman et al., 2021; UNDRR, 2020). Together, these factors indicate that while Bangladesh has developed a comprehensive legislative and policy framework, strengthening institutional accountability, coordination, and local capacity remains critical for translating policy intent into effective disaster risk reduction outcomes.

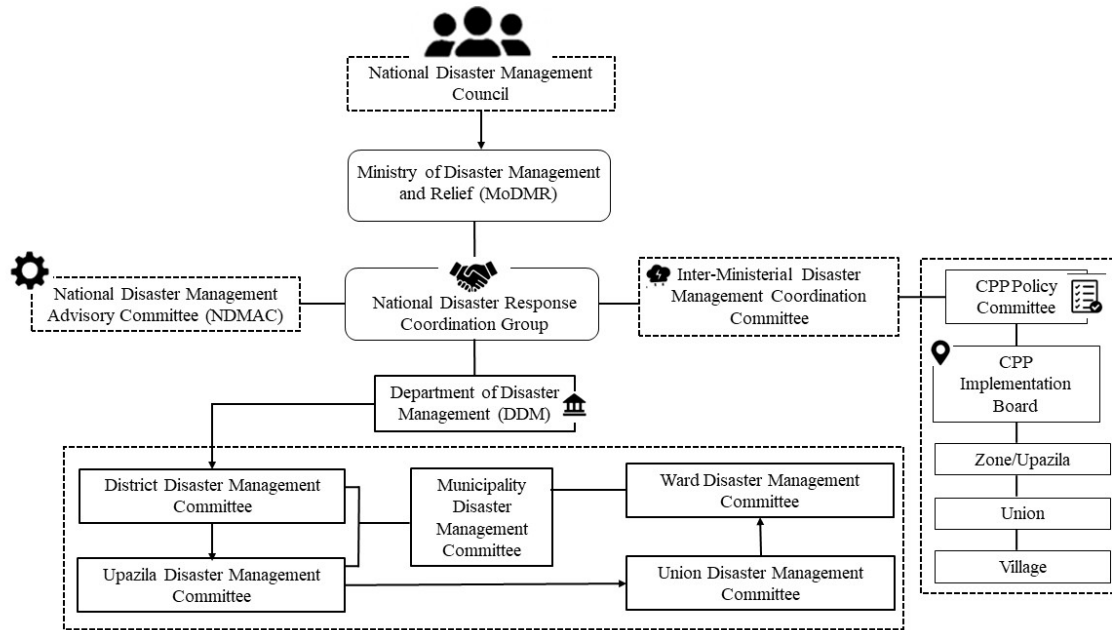


Fig. 4.2 Institutional Framework for Disaster Management in Bangladesh; Adopted from [Uddin et al. \(2022\)](#) and [UNDRR \(2020\)](#).

4.4.2 Gaps and Divergences from International Best Practices

Despite considerable progress in building Disaster Management (DM) policies, institutions, and frameworks, several gaps persist when Bangladesh's current practices are assessed against established international standards. These shortcomings appear across early warning, preparation, community participation, governance, coordination, policy execution, and recovery planning. The following subsections outline these divergences in a structured manner, highlighting where Bangladesh's system departs from global best practice.

4.4.2.1 Inadequate Policy Execution and Institutional Accountability

Bangladesh has established a comprehensive policy foundation, including the Disaster Management Act (2012), Standing Orders on Disaster (SOD 2010a, 2019b), and the NPDM 2021–2025, yet implementation remains inconsistent. Disaster management committees frequently meet irregularly, suffer from bureaucratic delays, and lack effective accountability mechanisms ([Haque et al., 2017](#); [Uddin et al., 2022](#)). This implementation deficit creates a systemic bottleneck that also limits progress in other domains of disaster governance. For instance, weak accountability structures reduce the effectiveness of local-level engagement, contributing to the issues discussed in the next subsection.

4.4.2.2 Local-Level Empowerment Gaps

Internationally, strong community participation and decentralized governance are recognized as essential to effective DM, as demonstrated in Vietnam and Thailand (Yi et al., 2009). In Bangladesh, however, local institutions, such as UDMCs and WDMCs often lack autonomy, financial capacity, and trained personnel (Abdeen et al., 2021; Rahman et al., 2021). This limited empowerment not only hampers local decision-making but also exacerbates coordination and communication barriers, issues further explored in the subsequent subsection.

4.4.2.3 Limited Institutional Coordination and Communication Gaps

Effective disaster governance requires clear role distribution and seamless information flow. While best-practice countries maintain integrated systems, such as China's unified command structure (Lixin et al., 2012) and Australia's EMA chain of command, Bangladesh faces overlapping mandates, fragmented responsibilities, and weak inter-agency communication (Islam et al., 2020; Ogra et al., 2021).

These coordination gaps undermine not only operational responses but also the quality of preparedness and early warning dissemination. As it will be discussed next, limitations in early warning integration further weaken timely and effective disaster response.

4.4.2.4 Lack in Preparedness Planning and Early Warning Integration

Countries, such as Japan, Australia, and Hong Kong employ sophisticated early warning systems that include digital evacuation mapping, standardized training, and multi-channel communication (AGDoHA, 2017; ESU, 2019; Peters & McEntire, 2010). In Bangladesh, however, challenges persist in disseminating warnings to remote areas, integrating multi-hazard information, and translating technical messages into formats that are locally comprehensible (Nasreen, 2017). These preparedness shortcomings are closely linked with broader systemic issues in data availability and risk analytics, which form the basis of the following subsection.

4.4.2.5 Challenges in Disaster Data Collection, Monitoring, and Evidence-Led Planning

Global best practices show that robust data ecosystems, supported by geospatial analysis, predictive modelling, and multi-hazard mapping, are essential for informed decision-making, as

exemplified by the U.S. HURREVAC system and Australia's national hazard-mapping tools (Department of Home Affairs, 2018). In Bangladesh, persistent data gaps, limited accessibility, and weak analytical capacity (Barua, 2022; Haque et al., 2024) hinder proactive planning. These limitations also weaken long-term recovery efforts, an area where Bangladesh diverges substantially from international norms, as discussed below.

4.4.2.6 Long-Term Recovery Challenges and Poor Alignment with 'Build Back Better' Principles

Best-practice countries institutionalize recovery frameworks through dedicated legislation and reconstruction funds, as in Japan and Taiwan (Yi et al., 2009). Bangladesh's recovery processes, however, are constrained by limited financial resources, poor inter-ministerial coordination, reconstruction delays, and the absence of systematic evaluation mechanisms (Ahmed et al., 2015; Ahmed et al., 2016; UNDRR, 2020). These deficiencies also contribute to inadequate integration of disaster risk reduction (DRR) principles into broader national development processes, which is addressed in the final subsection.

4.4.2.7 Insufficient Institutionalization of DRR in Bangladesh's Development Planning

Countries like Vietnam and China embed DRR considerations into socioeconomic development, land-use planning, and infrastructure design (CEDMHA, 2018; Xuan, 2005). Although Bangladesh's Delta Plan 2100 and NPDM aim to promote such integration, implementation remains inconsistent due to limited technical capacity and challenges with inter-agency coordination (General Economics Division, 2018; UNDRR, 2020). This underscores the overarching need for a whole-of-government approach to risk governance, aligning national development strategies more closely with global DRR standards.

4.5 Summary

This study identifies effective tropical cyclone Disaster Risk Reduction (DRR) initiatives by synthesizing international best practices and critically reviewing Bangladesh's existing legal, policy, and institutional frameworks. The disaster management cycle is structured into four phases, mitigation, preparedness, response, and recovery, to assess how structural and non-structural measures, planning, coordination, and emergency actions are implemented across developed and

developing country contexts. Comparative analysis and selected case studies are used to illustrate planning processes, operational implementation, and post-event feedback.

While Bangladesh has achieved notable progress, particularly in reducing cyclone-related fatalities and strengthening evacuation systems, it has yet to attain model status in comprehensive disaster management. The analysis reviews key national instruments and practices, including the Standing Orders on Disaster (SOD), the National Plan for Disaster Management, the Bangladesh Delta Plan 2100, the mainstreaming of DRR and the SDGs into Five-Year and Annual Development Plans, and cyclone shelter construction, maintenance, and management policies. Owing to gaps in the peer-reviewed literature, the study also draws on government and organizational reports as needed. Overall, the study proposes a standardized, phase-wise framework for evaluating national disaster management capacity, grounded in outputs and contextual relevance for tropical cyclones. This framework is adaptable to other hazards by disaggregating activities across the core phases of disaster management.

Chapter 5: Developing Disaster Demand Matrix (DDM)

Chapter 5: Developing Disaster Demand Matrix (DDM)

5.1 General

Coastal regions around the world are regularly threatened and affected by Tropical Cyclones (TCs) or Hurricanes whereas more and more countries across the globe have experienced severe flooding due to the phenomena in recent years ([van Genuchten, 2024](#)). Strong winds, heavy precipitations, and storm surges are notable destructive characteristics of tropical cyclones ([Chen & Liu, 2016](#); [Hoque et al., 2021](#); [Sahoo & Bhaskaran, 2018](#)). According to the report of the World Meteorological Organization (WMO), TC caused about 1,965 billion US dollars' worth of global damages between 1970 and 2019 ([WMO, 2020](#)). A recent study by [Garner et al. \(2024\)](#) suggested that tropical cyclones are significantly changing the trajectories in recent decades, with more intense and longer-lasting cyclones in the Bay of Bengal, leading to increased hazard impacts for the coastal communities ([Garner et al., 2024](#)).

The southern and southeastern peripheral regions of Bangladesh are particularly vulnerable to TCs due to their low elevation, gentle slopes, proximity to the sea, numerous historical cyclone tracks, susceptible land cover (including settlements and cropland), and inadequate socio-economic structures ([Hoque et al., 2021](#); [Haque et al., 2024](#)). The existing mitigation and resilient measures, such as construction of cyclone shelters, coastal barriers, road networks for evacuation, effective early warning systems, and administrative capacity in these risk-prone areas are significantly inadequate for effective Disaster Risk Reduction (DRR) for Bangladesh ([Hoque et al., 2021](#)).

It has been suggested that DRR may only truly be achieved by understanding and addressing processes of Disaster Risk Creation (DRC) ([Alexander, 2016](#)). Although Bangladesh is considered a highly tropical cyclone-prone country, the studies related to tropical cyclone vulnerability assessment are very limited. The integration of functional disaster management and mitigation methods offers the potential to significantly mitigate the harmful effects of TCs ([Bloemendaal et al., 2020](#); [Matthews et al., 2019](#)). A thorough risk assessment is crucial for developing effective mitigation measures ([Das et al., 2024](#); [Gopinath, 2010](#); [Jaman et al., 2021](#)). The vulnerability of a community depends on factors such as exposure, hazard, and existing mitigation and preparedness capacities ([Pattnaik, 2019](#)).

Siloed development and DRR policy-making and departmental responsibilities can result in government and private sector development activities that are insensitive to the risks they produce (Lizarralde et al., 2020; Poudel et al., 2023; Raikes et al., 2022). Prioritization and effective allocation of resources based on the assessment of the importance of the parameters helps in decision-making and allocation of resources (Brennan & Flint, 2007; Das et al., 2024; Ruangpan et al., 2020). Assessing the importance of these parameters provides insights into potential risks and uncertainties and helps decision-makers make sound decisions (Das et al., 2024; Sakizadeh et al., 2019).

Ensuring sustainable development, disaster management approaches should be effective for any disaster-prone country like Bangladesh (Sabur, 2012). Though Bangladesh could minimize the casualties in few phenomena, there remain significant challenges to implement disaster management activities in a coordinated and accurate way (Khan, 2008). For example, in case of tropical cyclone, lack of impact-based early warning system and shortcomings in evacuation and shelter management remain fragile in Bangladesh (Hoque et al., 2021). As a result, coastal communities still lose their assets and the long-term effects of cyclones also threat on livelihood of the exposed region. In these circumstances, there is a pressing need of an effective and feasible action matrix for comprehensively managing the catastrophic impacts of cyclones.

5.2 Methods

This study is divided into two segments. The first one is developing Disaster Demand Matrix (DDM) with Likert Scale for nine major disaster management activities, considering their 43 sub-activities. These nine major activities and associated activities are identified through a systematic literature review. Then next chapter illustrates the prioritization process of the disaster management sub-activities by applying the Fuzzy ANP method.

5.3 Data Collection and Validation

The acquired data was collected into two phases. A total of 60 respondents, practitioners and academician expert in tropical cyclone disaster management or relevant fields, have responded in this study while we contacted 200 practitioners. Firstly, nine major activities and 43 sub-activities of disaster management were identified through extensive literature review and discussion with disaster management specialists from academic, government and non-government organizations

in the context of Bangladesh. The 43 identified sub-activities were validated using a questionnaire survey, in which respondents' responses were measured on a five-point Likert scale: (1 = strongly disagree, 2 = disagree, 3 = partially agree, 4 = agree, and 5 = strongly agree). There were 23 respondents from different fields, including academic, disaster management practitioners in the government and non-government sectors. In this study, numerous disaster management specialists were assigned to develop relative relevancy matrices for all potential sub-activity combinations. Many people expressed disinterest because they found the procedure difficult and time-consuming. There were ten respondents who evaluated the detailed pairwise comparison of the disaster management activities. In the second phase, the nine major components have been represented in three different matrices: the first matrix represents the ideal situation, the second matrix represents the current situation, and the last matrix represents the action required items. Another Likert scale (1: very poor, 2: poor, 3: average, 4: satisfactory, and 5: very satisfactory) has been used here to measure the respondents' assessments. In this section, we received responses from 37 experts out of the 73 we contacted. The remaining experts were unable to participate due to their busy schedules. In this survey, 13 coastal districts' government disaster management focal, disaster management department representatives, experienced academicians, and disaster management practitioners of non-government organizations participated in these surveys.

The sub-activities were finalized based on the importance in emergency management according to descriptive statistics of mean and relative scoring. The relative value of each sub-component was estimated by dividing the mean component by the scale's maximum score (=5). Factors having a relative value of 0.90 (90%) or above were considered highly significant. Furthermore, the sub-activities have been investigated employing the coefficient of variation, which is the proportion of standard deviation to mean. A smaller coefficient of variation implies a lower level of variability, whereas a greater value implies higher variance. According to Yadav and Brave, while the coefficient variance value is 0.25 or less than 0.25 for a variable, the variable has been considered as an important factor after discussion with experts (Yadav & Barve, 2019). According to this scale, a variable with a threshold value of below 0.25 is regarded as a significant factor.

Table 5.1 Descriptive statistics of disaster management activities.

Major Components	Name of Sub-components	Relative Values	Mean	SD	Coefficient of Variance
Structural Mitigation Measures (SM) (C1)	Established Environmentally Sustainable Smart Cyclone Shelter (SM1)	90.43	4.52	0.51	0.113
	Coastal Afforestation (SM2)	93.04	4.65	0.57	0.123
	Construction of Coastal Embankment (SM3)	91.43	4.57	0.60	0.131
	Reconstruction/Reinforcing Critical Infrastructure (SM4)	88.70	4.43	0.73	0.164
	Construction/Renovation of Canals and Embankments for Improved Drainage (SM5)	92.17	4.61	0.50	0.108
	Design and Maintenance Considerations of Communication and Transmission Line Towers (SM6)	86.96	4.35	0.65	0.149
Non-structural Mitigation Measures (NSM) (C2)	Building Public Awareness and Education Programs (NSM1)	95.65	4.78	0.52	0.108
	Regulatory Measures (NSM2)	89.57	4.48	0.51	0.114
	Risk Transfer, Sharing and Spreading (NSM3)	81.74	4.09	1.04	0.255
	Hazard Mitigation Grant Program (NSM4)	84.35	4.22	1.00	0.237
Planning for Preparedness (PP) (C3)	Contingency Plan (PP1)	96.52	4.83	0.49	0.102
	Preparedness Guidelines (PP2)	91.30	4.57	0.59	0.129
	Emergency Response Plan (PP3)	93.91	4.70	0.47	0.100
	Logistics Planning (PP4)	92.17	4.61	0.50	0.108
	Volunteer Management (PP5)	86.09	4.30	0.76	0.178
	Recordkeeping and Reporting (PP6)	80.00	4.00	0.52	0.131
	Financial Management and Plan of Reimbursement for Services and Resources (PP7)	92.17	4.61	0.50	0.108
	Establishing Coordination among different Organizations (PP8)	94.78	4.74	0.45	0.095
Exercise for Preparedness (EP) (C4)	Disaster Reduction Drills and Exercises (EP1)	91.30	4.57	0.66	0.145
	Evacuation Mapping (EP2)	92.17	4.61	0.66	0.142
Effective Early Warning System Development EEWSDP) (C5)	Cyclone Tracking and Forecasting (EEWSDP1)	95.65	4.78	0.52	0.108
	Proper Information Management (EEWSDP2)	93.04	4.65	0.49	0.105
	Investment in Developing Disaster Early Warning (EEWSDP3)	93.91	4.70	0.47	0.100
	Public Education on Early Warning (EEWSDP4)	87.83	4.39	0.72	0.164
Pre-disaster Response (Pre-R) (C6)	Warning and Evacuation (Pre-R1)	98.26	4.91	0.29	0.059
	Pre-position Resources and Supplies (Pre-R2)	89.57	4.48	0.59	0.132
Post-disaster Response (Post-R) (C7)	Search and Rescue (Post-R1)	93.04	4.65	0.65	0.139
	First Aid Medical Treatment (Post-R2)	86.96	4.35	0.49	0.112
	Volunteer Management for Rapid Response (Post-R3)	95.65	4.78	0.42	0.088
	Rapid Disaster Damage and Need Assessment (Post-R4)	90.43	4.52	0.59	0.131
	Provision of Water, Food and Temporary Shelter (Post-R5)	93.91	4.70	0.47	0.100
	Logistics and Supply Chain Management (Post-R6)	91.30	4.57	0.66	0.145

	Coordination (Incident Command System) (Post-R7)	96.52	4.83	0.49	0.102
Short-term Recovery (STR) (C8)	Provision of Temporary Early Rehabilitation (STR1)	86.96	4.35	0.78	0.178
	Restoration of Critical Infrastructure (STR2)	86.09	4.30	0.82	0.191
	Early Debris Clearance (but not removal or disposal) for Road Transport (STR3)	80.00	4.00	0.95	0.238
Long-term Recovery (LTR) (C9)	Joint Damage and Needs Assessment (LTR1)	84.35	4.22	0.67	0.159
	Strategic Planning for Recovery (LTR2)	87.83	4.39	0.58	0.133
	Restoration of Basic Services (LTR3)	93.04	4.65	0.49	0.105
	Infrastructure Reconstruction and Development (LTR4)	91.30	4.57	0.51	0.111
	Economic Recovery and Development (LTR5)	91.30	4.57	0.59	0.129
	Strengthening Institutional Capacities (LTR6)	89.57	4.48	0.59	0.132
	Empowering Individuals and Communities (LTR7)	91.30	4.57	0.66	0.145

5.4 Data Analysis

In this study, four phases, such as mitigation, preparedness, response and recovery, were considered in the disaster management cycle. These phases encompass nine major components, which were further disaggregated into 43 sub-components. These nine components were represented in three different matrices: i) ideal situation matrix, ii) current situation matrix, and action required matrix. Likert scale was used here to measure the respondents' assessments and literature review data about disaster management activities. To analyze the data, it is coded as follows.

Very Poor	Poor	Moderate	Satisfied	Extremely Satisfied
1	2	3	4	5

For the ideal situation, every component of the disaster management cycle was assigned the highest value of 5 on the Likert scale, indicating very satisfied. As the sub-components' values represented the value of their respective major component, the sub-components of the major activities were given the maximum value of 5 according to Likert scale. On the other hand, when considering the existing situation for tropical cyclone in Bangladesh, the values of each major components and sub-components were also scored from 1 to 5 in the same scale mentioned above.

The values of difference between ideal situation and existing situation represent the action required items matrix, which shows the lack of actions for better disaster management of specific major

components considering tropical cyclones in Bangladesh. If we consider the shorter form of major disaster management activities¹, we can find the DDM as follows:

$$\begin{array}{|c|} \hline \text{SM}=5 \\ \text{NSM}=5 \\ \text{PP}=5 \\ \text{PE}=5 \\ \text{EEWS}=5 \\ \text{Pre-R}=5 \\ \text{Post-R}=5 \\ \text{STR}=5 \\ \text{LTR}=5 \\ \hline \end{array} - \begin{array}{|c|} \hline \text{SM}=x \\ \text{NSM}=y \\ \text{PP}=z \\ \text{PE}=m \\ \text{EEWS}=n \\ \text{Pre-R}=p \\ \text{Post-R}=q \\ \text{STR}=r \\ \text{LTR}=s \\ \hline \end{array} = \begin{array}{|c|} \hline \text{SM}=5-x \\ \text{NSM}=5-y \\ \text{PP}=5-z \\ \text{PE}=5-m \\ \text{EEWS}=5-n \\ \text{Pre-R}=5-p \\ \text{Post-R}=5-q \\ \text{STR}=5-r \\ \text{LTR}=5-s \\ \hline \end{array} \quad (5.1)$$

Ideal Situation Existing Situation Action Required Matrix

Fig. 5.1 Conceptual form of the disaster demand matrix.

The results obtained from the required disaster management activities will be used in the final prioritization of disaster management sub-components, taking into account the context, overall comprehensiveness, and the characteristics of the cyclone affecting specific coastal areas of Bangladesh.

5.5 Results

Based on the description above, the nine major disaster management activities were assigned the highest value (5, or very satisfactory) in an ideal situation according to the Likert scale. In contrast, the same nine activities were evaluated in the current context by experts, including academics and professionals from both government and non-government sectors, considering the present circumstances in Bangladesh. Out of the 73 experts contacted, we received responses from 37, while the remaining experts were unable to participate due to their busy schedules. These nine major activities consist of a total of 42 sub-activities, with each sub-activity being weighted using the Likert scale. The values for each sub-activity were averaged and then normalized to the average values of the sub-components. Normalization means that values greater than 3.5 were considered as 4, while values less than or equal to 3.5 (≤ 3.5) were considered as 3. Afterward, we averaged the normalized values for the sub-components based on the major activities and then normalized

¹ Here nine major disaster management activities are represented into short format. Structural Measures = SM, Non-structural measures = NSM, Planning for Preparedness = PP, Exercise for preparedness = PE, Effective Early Warning System = EEWS, Pre-disaster Response = Pre-R, Post-disaster Response = Post-R, Short-term Recovery = STR, Long-term Recovery = LTR.

the values of the major activities again. The detailed values for the major components and sub-components are presented in Table 5.2 below.

Table 5.2 Present situation weighted values of major disaster management activities.

Major Disaster Management Activities	Sub-Activity Name	Sub-component Likert scale value	Relative sub-component value	Average sub-component values for Major Activities	Relative major component values
Structural Mitigation Measures	Established Environmentally Sustainable Smart Cyclone Shelter	3.4595	3	2.5	2
	Coastal Afforestation	2.8919	3		
	Construction of Coastal Embankment	2.3243	2		
	Reconstruction/Reinforcing Critical Infrastructure	2.6486	2		
	Construction/Renovation of Canals and Embankments for Improved Drainage	2.4595	2		
	Design and Maintenance Considerations of Communication and Transmission Line Towers	3.2973	3		
Non-Structural Mitigation Measures	Building Public Awareness and Education Programs	3.8108	4	3.33	3
	Regulatory Measures	3.3513	3		
	Hazard Mitigation Grant Program	2.7567	3		
Planning for Preparedness	Contingency Plan	3.4864	3	3.13	3
	Preparedness Guidelines	3.4864	3		
	Emergency Response Plan	3.8648	4		
	Logistics Planning	2.8378	3		
	Volunteer Management	4.4324	4		
	Recordkeeping and Reporting	2.4864	2		
	Financial Management and Plan of Reimbursement for Services and Resources	2.7567	3		
	Establishing Coordination among different Organizations	3.4864	3		
Drill and Exercises	Disaster Reduction Drills and Exercises	2.5675	3	2.5	2

	Evacuation Mapping	2.2432	2		
Early Warning System Development	Cyclone Tracking and Forecasting	3.6756	4	3.5	3
	Proper Information Management	3.2162	3		
	Investment in Developing Disaster Early Warning	3.0270	3		
	Public Education on Early Warning	3.7027	4		
Pre-Disaster Response	Warning and Evacuation	3.7838	4	3.5	3
	Pre-position Resources and Supplies	2.973	3		
Post- Disaster Response	Search and Rescue	3.6216	4	3.29	3
	First Aid Medical Treatment	3	3		
	Volunteer Management for Rapid Response	3.892	4		
	Rapid Disaster Damage and Need Assessment	3.3513	3		
	Provision of Water, Food, And Temporary Shelter	2.892	3		
	Logistics and Supply Chain Management	2.8378	3		
	Coordination (Incident Command System)	3.3243	3		
Short-term Recovery	Provision of Temporary Early Rehabilitation	2.92	3	3	3
	Restoration of Critical Infrastructure	3.108	3		
	Early Debris Clearance (but not removal or disposal) for Road Transport	2.73	3		
Long-term Recovery	Joint Damage and Needs Assessment	2.6756	2	2.43	2
	Strategic Planning for Recovery	2.4864	2		
	Restoration of Basic Services	2.9189	3		
	Infrastructure Reconstruction and Development	2.4864	2		
	Economic Recovery and Development	2.4864	2		
	Strengthening Institutional Capacities	2.648	3		
	Empowering Individuals and Communities	3.3513	3		

From Table 5.2, the study identifies the status of cyclone disaster management activities based on expert input. It shows that a large proportion of the major activities fall within the poor to average range when assessed against standard conditions. In contrast, a few sub-activities of tropical cyclone management have achieved satisfactory ratings, such as public awareness and education programs, volunteer management, emergency response planning, cyclone tracking, and forecasting. According to the assessment, these components perform relatively well during emergencies, although a considerable number of sub-activities perform poorly during extreme weather events in Bangladesh. As a result, significant shortcomings remain and need to be addressed to ensure effective disaster management in Bangladesh and strengthen its administrative capacity.

The study finds that structural mitigation (SM), exercises or drills for preparedness (PE), and long-term recovery (LTR) have received a score of two (2) on the Likert scale, indicating poor conditions for these major disaster management activities. On the other hand, non-structural mitigation (NSM), planning for preparedness (PP), an effective early warning system (EEWS), pre-disaster response (Pre-R), post-disaster response (Post-R), and short-term recovery (STR) have received a score of three (3) on the Likert scale, indicating average conditions for these major activities in managing cyclone disasters in Bangladesh.

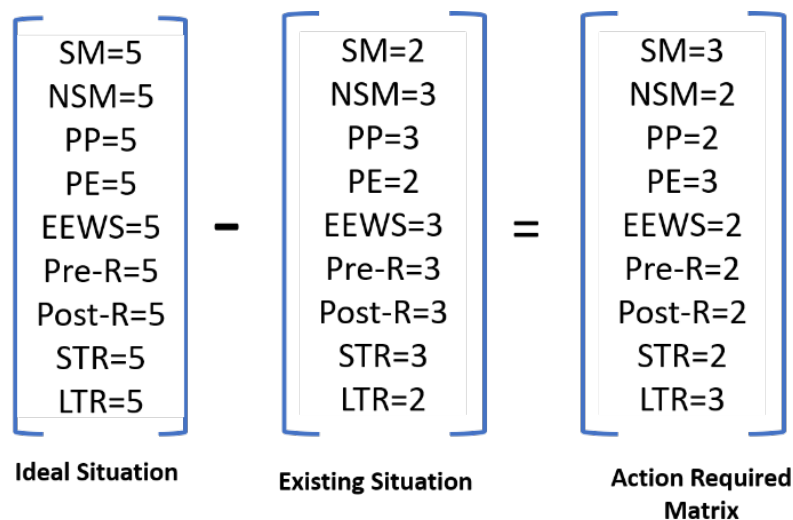


Fig. 5.2 Cyclone Disaster Demand Matrix (DDM) for Bangladesh.

5.6 Discussion

To address the increasing frequency and severity of tropical cyclones caused by climate change, a robust and comprehensive approach is essential to enhance community resilience. A novel aspect

of this study is the development of a matrix that identifies shortcomings of existing disaster management to reduce tropical cyclone risks among the nine major activities. This study has aggregated existing disaster management activities from 42 sub-activities in Table 5.1. Furthermore, Figure 5.3 uses a radar chart to illustrate the disaster demand matrix, where the green line represents the ideal scenario with optimal performance across all major and sub-activities. On the other hand, the red line depicts the current state of cyclone disaster management in Bangladesh. The gaps between the green and red lines highlight the areas demanding improvement to elevate overall disaster management effectiveness.

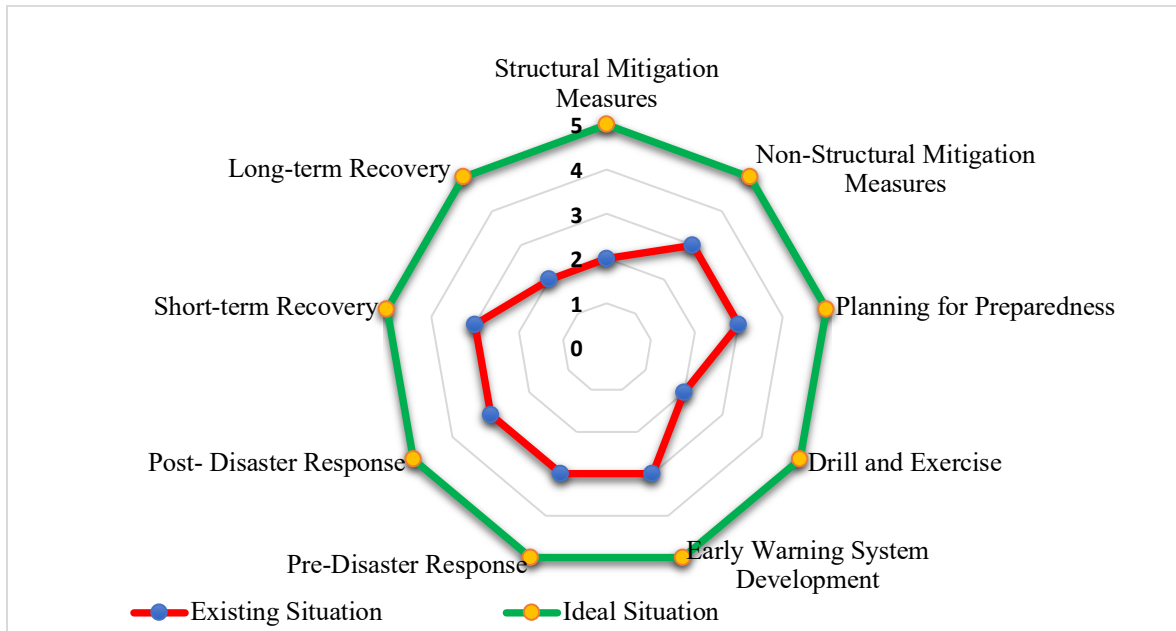


Fig. 5.3 The ideal situational matrix and existing situational matrix of Bangladesh, considering tropical cyclones.

The Fig. 5.3 shows that structural mitigation measures are far below the ideal level. Experts have rated coastal embankment construction, critical infrastructure reinforcement, and drainage improvement poorly, while cyclone shelters and coastal afforestation have been considered average. Overall, structural mitigation remains inadequate, underscoring the need to strengthen embankments, reconstruct or retrofit critical infrastructure, and enhance drainage in coastal areas. While disaster awareness initiatives in Bangladesh received satisfactory ratings among non-structural mitigation activities, regulatory measures, and hazard mitigation grants were rated average, resulting in an overall moderate performance for non-structural mitigation.

One of the most crucial components of disaster management is planning for preparedness, although this category has received an average score in this study. The sub-activity recordkeeping and reporting has been evaluated as the lowest among the activities due to poor documentation processes. However, significant progress has been noted in the emergency response plan and volunteer management, and the Cyclone Preparedness Program (CPP) is recognized as an indispensable organization for emergency management in Bangladesh.

Drill and evacuation mapping are key activities within the major criteria of drills and exercises, as an effective evacuation system can significantly reduce casualties during catastrophic events. However, Bangladesh remains in poor condition in this regard due to the lack of proper emergency drills for vulnerable populations and the absence of evacuation maps for specific coastal regions. For these reasons, the criteria of drill and exercise have been rated as poor in terms of standard cyclone disaster management.

An effective early warning system is vital for timely evacuation and preparedness. Bangladesh has recently improved in cyclone tracking, forecasting, and community awareness through school curricula. But there are resource limitations and lack of investment in using advanced technologies and effective early warning dissemination channel installation. Consequently, cyclone tracking, forecasting, and early warning education received satisfactory scores in the assessment, while the other components received average scores.

In the pre-disaster response category, the pre-positioning of resources and supplies in Bangladesh remains unsatisfactory. Similarly, during the post-disaster response period, first aid medical treatment facilities, rapid damage and loss assessment, and logistic supply chain management are insufficient compared to the demand during cyclone disaster situations. Consequently, for both pre-disaster and post-disaster response times, the disaster management situation in Bangladesh has received an average score.

The study further identifies that Bangladesh is performing poorly in long-term recovery, especially in areas such as joint detailed damage and needs assessment, strategic planning for recovery, infrastructure reconstruction and development, and sustainable economic recovery and development. Overall, these gaps underscore the urgent need to prioritize development to enhance the effectiveness of the disaster management framework.

Chapter 6: Prioritization of Disaster Management Activities

Chapter 6: Prioritization of Disaster Management Activities

6.1 General

Decision-making in real-life situations involves various criteria and can range from simple element selection to more complex issues. To address multi-criteria unstructured problems in economics, social sciences, and management, Thomas L. Saaty introduced a methodology in the 1970's known as the Analytical Hierarchy Process (AHP) (Cheng et al., 1999). This approach breaks down a complicated multiple criteria problem that includes both qualitative and quantitative data (Ruiz-Padillo et al., 2016) into its essential parts and arranges them in a hierarchical structure to represent a particular perspective (Calabrese et al., 2013). The core concept of AHP theory is the functional independence of choice criteria, their sub-criteria, and alternatives (Yüksel & Dağdeviren, 2010).

However, decision-making issues often involve interactions among variables at different levels (Saaty & Vargas, 2006; Saaty, 1996). Saaty (1996) recommended using the Analytical Network Process (ANP) for problems with dependent alternatives or criteria in lieu of AHP for problems with independent alternatives or criteria (Yüksel & Dağdeviren, 2010). ANP, developed by Thomas L. Saaty in 1996, incorporates feedback and interdependencies between decision parts to expand the Analytic Hierarchy Process (AHP). Unlike AHP, ANP enables the evaluation of complex relationships by explicitly modeling interactions, mutual influences, and feedback loops within the decision-making framework (Zaim et al., 2014).

The ANP methodology has been widely applied by many scholars in a variety of decision-making scenarios during the past thirty years, including studies pertaining to disasters. Wu et al. (2014) applied ANP evaluating factors for building a model to predict landslide disasters in Taiwan, Asadzadeh et al. (2015) created an array of parameters for earthquake resilience indicators using an ANP model, Sun et al. (2016) developed and assessed the dimensions of flood catastrophe resilience in China using ANP, whereas Sujatha and Sridhar (2017) employed a susceptibility map of debris flow in Tamil Nadu, and FathiZahraei et al. (2015) proposed an ANP model for risk reduction in a crisis scenario by adopting GIS (Asadzadeh et al., 2015; FathiZahraei et al., 2015; Sujatha & Sridhar, 2017; Sun et al., 2016; Wu et al., 2014).

Nevertheless, ANP is limited by its inability to model the inaccuracy of collective decision-making via pairwise comparisons (Hsu et al., 2012; Kiriş, 2013). Fuzzy set theory is combined with ANP

to resolve this ambiguity, offering a potent method for resolving a wide range of multi-criteria decision-making issues in engineering and business (Büyüközkan et al., 2004). Decision-makers like using language variables to convey their subjective assessments (Kiriş, 2013), which are then converted into triangular fuzzy numbers (TFN) for pairwise comparison. The combination of TFN with ANP is effective in various fields. Therefore, this study adopts the FANP to solve a multi-criteria decision-making problem for selecting comprehensive cyclone disaster management strategies. A range of methods has been developed to address the challenges associated with fuzzy pairwise comparison matrices (Buckley, 1985; Lee, 2010). The most often referenced approach is Chang's extent method (Chang, 1992, 1996), according to a study of the literature by Büyüközkan et al. (2004). This method is preferred due to its lower computational complexity compared to other available methods, making it widely accepted.

6.2 Data Analysis

This research applies Chang's extent analysis method to assess disaster management activities and subsequently proposes a prioritized ranking of mitigation, preparedness, response, and recovery components based on the evaluation results.

Table 6.1 Linguistic variables and their TFN conversation scale.

Linguistic scale	Likert Scale	Triangular Fuzzy Scale	Triangular Fuzzy reciprocal scale
Just equal	1	(1,1,1)	(1,1,1)
Moderate	2	(1, 1.5,2)	(0.5, 0.667, 1)
Strong	3	(1.5,2,2.5)	(0.4, 0.5, 0.667)
Very Strong	4	(2,2.5,3)	(0.33, 0.4, 0.5)
Extremely Strong	5	(2.5,3,3.5)	(0.286, 0.33, 0.4)

Source: (Calabrese et al., 2013; Lee, 2010)

Steps of Fuzzy ANP Approach

Step 1: Defining the Goal

This objective of this step is to formulate the pertinent objective, criteria, sub-criteria, and/or problem-related alternatives in a hierarchy model. These factors are found by critically analyzing the literature and consulting experts.

Step 2: Pairwise comparison matrix construction assuming no interdependencies

In order to record the relative significance matrices for every feasible combination using the scale specified in Table 6.1, K number of experts are consulted in the second phase. The paired assessments of language are transformed to triangular fuzzy integers and organized in fuzzy comparison matrices.

Step 3: Compute the consistency ratio of pair-comparison matrices

The definition of the consistency ratio in a pair-wise comparison matrix is ‘a ratio between the consistency index (CI) of a given evaluation matrix and random index (RI) of a random matrix’ (Saaty, 2008). For each comparison matrix, the consistency ratio is required to be below 0.10 to ensure acceptable consistency.

The RI values corresponding to different matrix sizes are provided below:

n	1	2	3	4	5	6	7	8	9	10
RI (Value)	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Nevertheless, in order to analyze the consistency exhibited by the fuzzy comparison matrices, they need to be transformed to crisp or precise values. The following sub-steps can be utilized to create crisp matrices that correspond to the recorded fuzzy matrices:

Step 3a: The mean fuzzy comparison matrix

The following equation may be used to derive the mean fuzzy number (l_{ij}, m_{ij}, r_{ij}) from all K matrices (Büyüközkan et al., 2004; Chen et al., 2015).

$$\begin{aligned}
 l_{ij} &= \min(l_{ijk}) & k = 1, 2, \dots, K \\
 m_{ij} &= \sqrt[k]{\prod_{k=1}^K m_{ijk}} & \dots\dots\dots (6.1) \\
 r_{ij} &= \max(r_{ijk}) & k = 1, 2, \dots, K
 \end{aligned}$$

Step 3b: Converting the average fuzzy comparison matrix to a crisp comparison matrix

The following method is used for de-fuzzifying fuzzy numbers into crisp numbers, which is presented below.

$$(a_{ij}^{\alpha}) = [\lambda \times l_{ij}^{\alpha} + (1 - \lambda) \times r_{ij}^{\alpha}] \dots\dots\dots (6.2)$$

Step 4: Calculate the local priority weights

Chang (1996) developed an extensive analytical technique for estimating a local precedence vector from a uniform triangular fuzzy comparison matrix, which is described below.

To calculate the relative row total for each row in the fuzzy comparison matrix A, proceed with the following steps:

$$RS = \sum_{j=1}^n \tilde{a} = (\sum_{j=1}^n l_{ij}, \sum_{j=1}^n m_{ij}, \sum_{j=1}^n r_{ij}) \quad i = 1, \dots, n \dots\dots\dots (6.3)$$

Secondly, normalize using the normalization formula. To address the limitations of the existing normalization method, [Wang & Elhag \(2006\)](#) suggest a modified Chang's normalization formula.

$$\begin{aligned} \tilde{S} &= \frac{RS_i}{\sum_{j=1}^n RS_i} = \left(\frac{\sum_{j=1}^n l_{ij}}{\sum_{j=1}^n l_{ij} + \sum_{k=1, k \neq i}^n \sum_{j=1}^n r_{kj}} + \frac{\sum_{j=1}^n m_{ij}}{\sum_{k=1, k \neq i}^n \sum_{j=1}^n m_{kj}} + \frac{\sum_{j=1}^n r_{ij}}{\sum_{j=1}^n r_{ij} + \sum_{k=1, k \neq i}^n \sum_{j=1}^n l_{kj}} \right) \\ &= (l_i, m_i, r_i) \quad i = 1, \dots, n \dots\dots\dots (6.4) \end{aligned}$$

Thirdly, compute the degree of possibility of $\tilde{S}_i \geq \tilde{S}_j$

The degree of possibility of $\tilde{S}_1 = (l_1, m_1, r_1) \geq \tilde{S}_2 = (l_2, m_2, r_2)$ is defined as:

$$V(\tilde{S}_2 \geq \tilde{S}_1) = hgt(\tilde{S}_2 \cap \tilde{S}_1) = [\mu N_1(x), \mu N_2(y)] \dots\dots\dots (6.5)$$

When $m_1 \geq m_2$

$$V(\tilde{S}_1 \geq \tilde{S}_2) = 1 \dots\dots\dots (6.6)$$

Otherwise, the ordinate of the highest intersection point is calculated as

$$V(\tilde{S}_2 \geq \tilde{S}_1) = hgt(\tilde{S}_2 \cap \tilde{S}_1) = \mu(d) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \dots\dots\dots (6.7)$$

Where d is the ordinate of the highest intersection point.

Fourthly, calculate the degree of possibility of $\tilde{S}_i$ over all the other (n-1) fuzzy numbers by

$$V(S \geq \tilde{S}_1, \tilde{S}_2, \dots, \tilde{S}_k) = \min V(S \geq \tilde{S}_i), \quad i = 1, 2, \dots, k \dots\dots\dots (6.8)$$

$$d(\tilde{S}_i) = \min V(\tilde{S}_i \geq \tilde{S}_k) = W'_i \quad k = 1, 2, \dots, n \text{ and } k \neq i$$

Based on the above procedure, the weights of the factors are

$$W' = (W'_1, W'_2, \dots, W'_k)^T \dots\dots\dots (6.9)$$

After normalization, the priority weights are as follows

$$W = (W_1, W_2, \dots, W_k)^T \dots\dots\dots (6.10)$$

Step 5: Establishing pair-comparison matrices (considering interrelationships)

Step 2: Establishment of pairwise comparative matrices (without taking interrelationships into account)

In this study, a number of disaster management specialists were sought out to obtain pairwise comparison judgments for all possible combinations of major activities and their sub-components. Ultimately, ten experts agreed to provide inputs for the relative comparisons. Based on their input, total 135 relative matrices were recorded i.e. 10 matrices for each participant, 90 ($=9 \times 10$) set of matrices for nine major activities under nine criteria, and 45 ($=9 \times 5$) matrices for disaster management sub-activities under each major activity.

Step 3: Estimating the consistency ratio of pair-comparison matrices

According to Saaty (2008), the consistency ratio is the ratio of the consistency index (CI) of a particular evaluation matrix to the random index (RI) of a random matrix. Each comparison matrix's consistency ratio (CR) was estimated and determined to be less than the allowable threshold of 0.10. To further evaluate the consistency of the fuzzy comparative matrices, it was essential to transform these matrices into crisp values. The following sub-steps were used to obtain the corresponding crisp matrices from the recorded fuzzy matrices:

Step 3a: The average fuzzy comparison matrix

The mean fuzzy comparative matrix was obtained by aggregating the ten individuals pairwise comparison matrices using Eq. (6.1), and the results are presented in Table 6.12.

Step 3b: Establishment of a crisp comparison matrix from the average fuzzy comparison matrix

In this study, the fuzzy numbers are de-fuzzified into crisp numbers using the method obtained from Liou and Wang (1992) and Hus and Nian (1997), as stated in Eq. (6.2). Since the value of λ in this study is determined at 0.5, the assessments are neither too optimistic nor pessimistic. A higher value of α reflects a more stable decision-making environment, whereas a lower value indicates greater uncertainty. Accordingly, α is set to 0.75 to represent a relatively stable decision-making context. The resulting crisp comparison matrix is presented in Table 6.13.

Step 4: Determination of Local Priority Weights

As outlined in the solution procedure, Chang's extent analysis method is employed to compute the local priority vector from the persistent triangular fuzzy comparison matrix. In order to derive the local priority vector, the row summation for every major disaster management activity is calculated using Eq. (6.3), followed by normalization utilizing Eq. (6.4). The degree of possibility is then determined utilizing Eq. (6.5)–Eq. (6.7), and the degree of possibility of $\tilde{S}_i$ over all other $(n-1)$

fuzzy numbers is computed using Eq. (6.8). Tables 6.14, 6.15, and 6.16 present the row sums, normalized row sums, and the degree of possibility values ($S_i \geq S_j$), respectively.

The degree of possibility of $\tilde{S}_i$ over all the other (n-1) fuzzy numbers was obtained as follows:

$$\text{Min } (S_i \geq S_j) = (0.852, 0.82, 0.90, 0.765, 1.000, 0.775, 0.811, 0.747, 0.773)$$

Following the above steps, the weights of the disaster management activities were obtained using Eq no. (6.9) The weights of the criteria are as follows:

$$W' = (0.852, 0.82, 0.90, 0.765, 1.000, 0.775, 0.811, 0.747, 0.773)^T$$

Table 6.2 Preparedness criteria pairwise comparison matrix as evaluated by Expert 1.

	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>	<i>C8</i>	<i>C9</i>
<i>C1</i>	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C2</i>	(.4, 0.5, 0.667)	(1,1,1)	(.4, .5, .667)	(1, 1.5, 2)	(.4, .5, .667)	(1, 1.5, 2)	(.5, .667, 1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C3</i>	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(2, 2.5, 3)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C4</i>	(.4, .5, .667)	(.5, .667, 1)	(.33, .4, .5)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(1, 1.5, 2)	(1, 1.5, 2)
<i>C5</i>	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C6</i>	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C7</i>	(.5, .667, 1)	(1, 1.5, 2)	(.4, .5, .667)	(1,1,1)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(.5, .667, 1)	(1.5, 2, 2.5)
<i>C8</i>	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(1, 1.5, 2)	(1,1,1)	(1.5, 2, 2.5)
<i>C9</i>	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)

Table 6.3 Preparedness criteria pairwise comparison matrix as evaluated by Expert 2.

	<i>C1</i>	<i>C2</i>	<i>C3</i>	<i>C4</i>	<i>C5</i>	<i>C6</i>	<i>C7</i>	<i>C8</i>	<i>C9</i>
<i>C1</i>	(1,1,1)	(1, 1.5, 2)	(.4, .5, .667)	(.4, .5, .667)	(.33, .4, .5)	(1.5, 2, 2.5)	(.4, .5, .667)	(1, 1.5, 2)	(1, 1.5, 2)
<i>C2</i>	(.5, .667, 1)	(1,1,1)	(.5, .667, 1)	(.4, .5, .667)	(.33, .4, .5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(2, 2.5, 3)	(1.5, 2, 2.5)
<i>C3</i>	(1.5, 2, 2.5)	(1, 1.5, 2)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(2, 2.5, 3)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)
<i>C4</i>	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)	(1,1,1)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)
<i>C5</i>	(2, 2.5, 3)	(2, 2.5, 3)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1, 1.5, 2)	(1.5, 2, 2.5)
<i>C6</i>	(.4, .5, .667)	(.4, .5, .667)	(.33, .4, .5)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
<i>C7</i>	(1.5, 2, 2.5)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)
<i>C8</i>	(.5, .667, 1)	(.33, .4, .5)	(.5, .667, 1)	(.5, .667, 1)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(1,1,1)
<i>C9</i>	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(1,1,1)

Table 6.4 Preparedness criteria pairwise comparison matrix as evaluated by Expert 3.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)
C2	(.4, .5, .667)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(.4, .5, .667)	(1, 1.5, 2)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)
C3	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(2.5, 3, 3.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(2, 2.5, 3)
C4	(.4, .5, .667)	(.5, .667, 1)	(.286, .33, .4)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)	(1, 1.5, 2)
C5	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(.33, .4, .5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
C6	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.33, .4, .5)	(1,1,1)	(1, 1.5, 2)	(1, 1.5, 2)	(1.5, 2, 2.5)
C7	(.4, .5, .667)	(1,1,1)	(1,1,1)	(1,1,1)	(.5, .667, 1)	(.5, .667, 1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)
C8	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)
C9	(1,1,1)	(.5, .667, 1)	(.33, .4, .5)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)

Table 6.5 Preparedness criteria pairwise comparison matrix as evaluated by Expert 4.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(1, 1.5, 2)	(.4, .5, .667)	(1, 1.5, 2)	(.5, .667, 1)	(1.5, 2, 2.5)	(.4, .5, .667)
C2	(1.5, 2, 2.5)	(1,1,1)	(2, 2.5, 3)	(1, 1.5, 2)	(.4, .5, .667)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(.4, .5, .667)
C3	(.4, .5, .667)	(.33, .4, .5)	(1,1,1)	(2, 2.5, 3)	(.4, .5, .667)	(2, 2.5, 3)	(.4, .5, .667)	(1, 1.5, 2)	(.4, .5, .667)
C4	(.5, .667, 1)	(.5, .667, 1)	(.33, .4, .5)	(1,1,1)	(.33, .4, .5)	(1, 1.5, 2)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)
C5	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(2, 2.5, 3)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1, 1.5, 2)	(.4, .5, .667)
C6	(.5, .667, 1)	(.4, .5, .667)	(.33, .4, .5)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)
C7	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)	(2, 2.5, 3)	(.5, .667, 1)
C8	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(1.5, 2, 2.5)	(.5, .667, 1)	(.4, .5, .667)	(.33, .4, .5)	(1,1,1)	(.5, .667, 1)
C9	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1,1,1)

Table 6.6 Preparedness criteria pairwise comparison matrix as evaluated by Expert 5.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1,1,1)	(.5, .667, 1)	(.4, .5, .667)	(.5, .667, 1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1,1,1)	(1,1,1)
C2	(1,1,1)	(1,1,1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)	(1,1,1)
C3	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(1,1,1)	(1,1,1)
C4	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(.5, .667, 1)	(.5, .667, 1)	(1,1,1)	(1,1,1)	(1,1,1)
C5	(1, 1.5, 2)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1, 1.5, 2)	(1,1,1)	(2, 2.5, 3)	(1,1,1)	(1,1,1)	(1,1,1)
C6	(.4, .5, .667)	(.4, .5, .667)	(1.5, 2, 2.5)	(1, 1.5, 2)	(.33, .4, .5)	(1,1,1)	(.4, .5, .667)	(1,1,1)	(1,1,1)
C7	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(.4, .5, .667)	(.4, .5, .667)
C8	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)
C9	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)

Table 6.7 Preparedness criteria pairwise comparison matrix as evaluated by Expert 6.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.5, .667, 1)	(.33, .4, .5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
C2	(1.5, 2, 2.5)	(1,1,1)	(.286, .33, .4)	(.5, .667, 1)	(.33, .4, .5)	(.5, .667, 1)	(.5, .667, 1)	(.5, .667, 1)	(1.5, 2, 2.5)
C3	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(1,1,1)	(.5, .667, 1)	(.5, .667, 1)	(.5, .667, 1)	(1, 1.5, 2)	(.5, .667, 1)	(1.5, 2, 2.5)
C4	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1,1,1)	(.4, .5, .667)	(.5, .667, 1)	(1.5, 2, 2.5)	(.5, .667, 1)	(1, 1.5, 2)
C5	(1.5, 2, 2.5)	(2, 2.5, 3)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(.4, .5, .667)	(1,1,1)	(.5, .667, 1)	(1.5, 2, 2.5)
C6	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(1, 1.5, 2)	(.4, .5, .667)	(1.5, 2, 2.5)
C7	(2, 2.5, 3)	(1, 1.5, 2)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(.5, .667, 1)	(1,1,1)	(.4, .5, .667)	(1, 1.5, 2)
C8	(.4, .5, .667)	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)
C9	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)

Table 6.8 Preparedness criteria pairwise comparison matrix as evaluated by Expert 7.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)
C2	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)	(.4, .5, .667)
C3	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)
C4	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(.4, .5, .667)	(.4, .5, .667)	(1.5, 2, 2.5)
C5	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
C6	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1, 1.5, 2)
C7	(1, 1.5, 2)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)
C8	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(1, 1.5, 2)
C9	(1,1,1)	(1.5, 2, 2.5)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.5, .667, 1)	(.5, .667, 1)	(1,1,1)

Table 6.9 Preparedness criteria pairwise comparison matrix as evaluated by Expert 8.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1,1,1)	(1,1,1)	(2, 2.5, 3)	(.4, .5, .667)	(1, 1.5, 2)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)
C2	(1,1,1)	(1,1,1)	(1,1,1)	(1, 1.5, 2)	(.5, .667, 1)	(1,1,1)	(1, 1.5, 2)	(2.5, 3, 3.5)	(1,1,1)
C3	(1,1,1)	(1,1,1)	(1,1,1)	(2.5, 3, 3.5)	(.4, .5, .667)	(1,1,1)	(1, 1.5, 2)	(1,1,1)	(.4, .5, .667)
C4	(.33, .4, .5)	(.5, .667, 1)	(.286, .33, .4)	(1,1,1)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(.5, .667, 1)
C5	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)	(.5, .667, 1)	(1, 1.5, 2)	(1,1,1)
C6	(.5, .667, 1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(1,1,1)	(1, 1.5, 2)	(1,1,1)	(.4, .5, .667)
C7	(1,1,1)	(.5, .667, 1)	(.5, .667, 1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(.5, .667, 1)	(1,1,1)	(1,1,1)	(.5, .667, 1)
C8	(.4, .5, .667)	(.286, .33, .4)	(1,1,1)	(1, 1.5, 2)	(.5, .667, 1)	(1,1,1)	(1,1,1)	(1,1,1)	(.33, .4, .5)
C9	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(2, 2.5, 3)	(1,1,1)

Table 6.10 Preparedness criteria pairwise comparison matrix as evaluated by Expert 9.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(2, 2.5, 3)	(1.5, 2, 2.5)
C2	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1, 1.5, 2)	(.4, .5, .667)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)
C3	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(2, 2.5, 3)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(1, 1.5, 2)
C4	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(1,1,1)	(.286, .33, .4)	(.5, .667, 1)	(.4, .5, .667)	(1.5, 2, 2.5)	(.4, .5, .667)
C5	(1, 1.5, 2)	(1.5, 2, 2.5)	(1,1,1)	(2.5, 3, 3.5)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)
C6	(.4, .5, .667)	(.4, .5, .667)	(.33, .4, .5)	(1, 1.5, 2)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(1, 1.5, 2)
C7	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)	(1, 1.5, 2)	(1.5, 2, 2.5)
C8	(.33, .4, .5)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(.4, .5, .667)
C9	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(.4, .5, .667)	(.5, .667, 1)	(.4, .5, .667)	(1.5, 2, 2.5)	(1,1,1)

Table 6.11 Preparedness criteria pairwise comparison matrix as evaluated by Expert 10.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(1,1,1)	(.4, .5, .667)	(1.5, 2, 2.5)	(.5, .667, 1)	(1.5, 2, 2.5)	(.5, .667, 1)	(1,1,1)	(1,1,1)
C2	(1,1,1)	(1,1,1)	(.5, .667, 1)	(1.5, 2, 2.5)	(.4, .5, .667)	(1, 1.5, 2)	(1,1,1)	(1,1,1)	(1,1,1)
C3	(1.5, 2, 2.5)	(1, 1.5, 2)	(1,1,1)	(1, 1.5, 2)	(.4, .5, .667)	(.4, .5, .667)	(1,1,1)	(1,1,1)	(1,1,1)
C4	(.4, .5, .667)	(.4, .5, .667)	(.5, .667, 1)	(1,1,1)	(.33, .4, .5)	(.4, .5, .667)	(1,1,1)	(1,1,1)	(1,1,1)
C5	(1, 1.5, 2)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(2, 2.5, 3)	(1,1,1)	(1.5, 2, 2.5)	(1, 1.5, 2)	(1,1,1)	(1,1,1)
C6	(.4, .5, .667)	(.5, .667, 1)	(1.5, 2, 2.5)	(1.5, 2, 2.5)	(.4, .5, .667)	(1,1,1)	(.4, .5, .667)	(1,1,1)	(1,1,1)
C7	(1, 1.5, 2)	(1,1,1)	(1,1,1)	(1,1,1)	(.5, .667, 1)	(1.5, 2, 2.5)	(1,1,1)	(.4, .5, .667)	(1,1,1)
C8	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)	(.4, .5, .667)
C9	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5, 2, 2.5)	(1,1,1)

Table 6.12 Average Fuzzy Comparison matrix for major disaster management activities.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	(1,1,1)	(0.4, 1.22, 2.5)	(0.4, 0.735, 2.5)	(0.4, 1.4, 3)	(0.33, 0.513, 1)	(0.5, 1.794, 2.5)	(0.33, 0.826, 2.5)	(1, 1839, 3)	(0.4, 1.22, 2.5)
C2	(0.4, 0.82, 2.5)	(1,1,1)	(0.286, 0.711, 3)	(0.4, 1.198, 2.5)	(0.33, 0.455, 1)	(0.5, 1.61, 2.5)	(0.4, 1.115, 2.5)	(0.4, 1.507, 3.5)	(0.4, 1.046, 2.5)
C3	(0.4, 1.361, 2.5)	(0.33, 1.407, 3.5)	(1,1,1)	(0.4, 1.826, 3.5)	(0.4, 0.694, 2.5)	(0.4, 1.4, 3)	(0.4, 1.182, 2.5)	(0.5, 1.38, 2.5)	(0.4, 1.351, 3)
C4	(0.33, 0.717, 2.5)	(0.4, 0.835, 2.5)	(0.286, 0.547, 2.5)	(1,1,1)	(0.286, 0.53, 2)	(0.4, 1.033, 2.5)	(0.4, 0.857, 2.5)	(0.4, 0.926, 2.5)	(0.4, 1.094, 2.5)
C5	(1, 1.949, 3)	(1, 2.2, 3)	(0.4, 1.442, 2.5)	(0.5, 1.885, 3.5)	(1,1,1)	(0.33, 1.47, 3)	(0.5, 1.353, 2.5)	(0.5, 1.489, 2.5)	(0.4, 1.47, 2.5)
C6	(0.4, 0.558, 2)	(0.4, 0.622, 2)	(0.33, 0.714, 2.5)	(0.4, 0.967, 2.5)	(0.33, 0.542, 2.5)	(1,1,1)	(0.4, 0.88, 2.5)	(0.4, 1.424, 2.5)	(0.4, 1.318, 2.5)
C7	(0.4, 1.212, 3)	(0.4, 0.897, 2.5)	(0.4, 0.846, 2.5)	(0.4, 1, 2.5)	(0.4, 0.74, 2)	(0.4, 1.137, 2.5)	(1,1,1)	(0.4, 1.025, 3)	(0.4, 1.22, 2.5)
C8	(0.33, 0.544, 1)	(0.286, 0.663, 2.5)	(0.4, 0.725, 2)	(0.4, 1.08, 2.5)	(0.4, 0.672, 2)	(0.4, 0.703, 2.5)	(0.33, 0.976, 2.5)	(1,1,1)	(0.33, 0.976, 2.5)
C9	(0.4, 0.82, 2.5)	(0.4, 0.956, 2.5)	(0.33, 0.635, 2.5)	(0.4, 0.914, 2.5)	(0.4, 0.68, 2.5)	(0.4, 0.76, 2.5)	(0.4, 0.82, 2.5)	(0.4, 1.025, 3)	(1,1,1)

Table 6.13 Crisp Comparison Matrix for disaster management criteria.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1.000	1.278	0.914	1.475	0.551	1.721	0.973	1.879	1.278
C2	0.978	1.000	0.944	1.261	0.508	1.583	1.199	1.618	1.147
C3	1.383	1.534	1.000	1.857	0.883	1.475	1.249	1.410	1.438
C4	0.892	0.989	0.759	1.000	0.683	1.137	1.005	1.057	1.183
C5	1.962	2.150	1.444	1.914	1.000	1.519	1.390	1.492	1.465
C6	0.719	0.767	0.889	1.088	0.760	1.000	1.023	1.431	1.351
C7	1.334	1.035	0.997	1.113	0.855	1.215	1.000	1.194	1.278
C8	0.574	0.846	0.844	1.173	0.804	0.890	1.086	1.000	1.086
C9	0.978	1.080	0.830	1.048	0.873	0.933	0.978	1.194	1.000

Determining Local Priority Weight:

Table 6.14 Row sum for each criterion.

	l_{ij}	m_{ij}	r_{ij}
RS₁	4.76	10.547	20.5
RS₂	4.116	9.462	21
RS₃	4.23	11.601	25
RS₄	3.902	7.539	20.5
RS₅	5.63	14.258	23.5
RS₆	4.06	8.025	20
RS₇	4.2	9.077	21.5
RS₈	3.876	7.339	18.5
RS₉	4.13	7.61	21.5

Table 6.15 Normalized row sum for each criterion.

	l_{ij}	m_{ij}	r_{ij}
NSC1	0.027006	0.140794	0.375156
NSC2	0.023504	0.124507	0.376425
NSC3	0.024704	0.157074	0.418943
NSC4	0.022246	0.096754	0.369356
NSC5	0.032332	0.200253	0.413922
NSC6	0.023060	0.103638	0.364671
NSC7	0.024041	0.118838	0.382535
NSC8	0.021852	0.093946	0.345614
NSC9	0.023650	0.097755	0.382059

Table 6.16 The values of degree of possibilities.

S1>S2	1.000	S2>S1	0.955	S3>S1	1.000	S4>S1	0.886	S5>S1	1	S6>S1	0.901	S7>S1	0.942	S8>S1	0.872	S9>S1	0.892
S1>S3	0.956	S2>S3	0.915	S3>S2	1.000	S4>S2	0.926	S5>S2	1	S6>S2	0.942	S7>S2	0.984	S8>S2	0.913	S9>S2	0.931
S1>S4	1.000	S2>S4	1.000	S3>S4	1.000	S4>S3	0.851	S5>S3	1	S6>S3	0.864	S7>S3	0.903	S8>S3	0.836	S9>S3	0.858
S1>S5	0.852	S2>S5	0.820	S3>S5	0.900	S4>S5	0.765	S5>S4	1	S6>S4	1.000	S7>S4	1.000	S8>S4	0.991	S9>S4	1.000
S1>S6	1.000	S2>S6	1.000	S3>S6	1.000	S4>S6	0.981	S5>S6	1	S6>S5	0.775	S7>S5	0.811	S8>S5	0.747	S9>S5	0.773
S1>S7	1.000	S2>S7	1.000	S3>S7	1.000	S4>S7	0.940	S5>S7	1	S6>S7	0.957	S7>S6	1.000	S8>S6	0.971	S9>S6	0.984
S1>S8	1.000	S2>S8	1.000	S3>S8	1.000	S4>S8	1.000	S5>S8	1	S6>S8	1.000	S7>S8	1.000	S8>S7	0.928	S9>S7	0.944
S1>S9	1.000	S2>S9	1.000	S3>S9	1.000	S4>S9	0.997	S5>S9	1	S6>S9	1.000	S7>S9	1.000	S8>S9	0.988	S9>S8	1.000

Following normalization, Eq. (6.10) was applied to compute the priority weights of the major disaster management criteria, and the results are presented as follows:

$$W_C = (0.1145, 0.1102, 0.121, 0.1028, 0.1344, 0.1041, 0.109, 0.1004, 0.1039)^T$$

Moreover, the overall priority weights of sub-activities under each major disaster management criterion are calculated by following Steps 1–4.

$$W_{SM} = (0.178, 0.189, 0.154, 0.184, 0.157, 0.137)^T$$

$$W_{NSM} = (0.465, 0.242, 0.293)^T$$

$$W_{PP} = (0.24, 0.106, 0.191, 0.115, 0.102, 0.054, 0.045, 0.146)^T$$

$$W_{EP} = (0.458, 0.542)^T$$

$$W_{EEWS} = (0.304, 0.276, 0.173, 0.247)^T$$

$$W_{Pre-R} = (0.579, 0.421)^T$$

$$W_{Post-R} = (0.185, 0.147, 0.142, 0.103, 0.14, 0.122, 0.16)^T$$

$$W_{Short-TR} = (0.316, 0.392, 0.282)^T$$

$$W_{Long-TR} = (0.164, 0.16, 0.198, 0.07, 0.114, 0.128, 0.146)^T$$

Step 5: Establishing pair-wise comparison matrix (hidden inter-relationship)

The underlying interrelationships among major disaster management criteria are represented as a network structure in Fig. 6.2, and these relationships are evaluated using the pairwise comparison scale presented in Table 6.17. Based on Fig. 6.2, interdependence matrices are constructed for C1, C2, C3, C4, C6, C7, C8 and C9 and their relative weights are subsequently calculated.

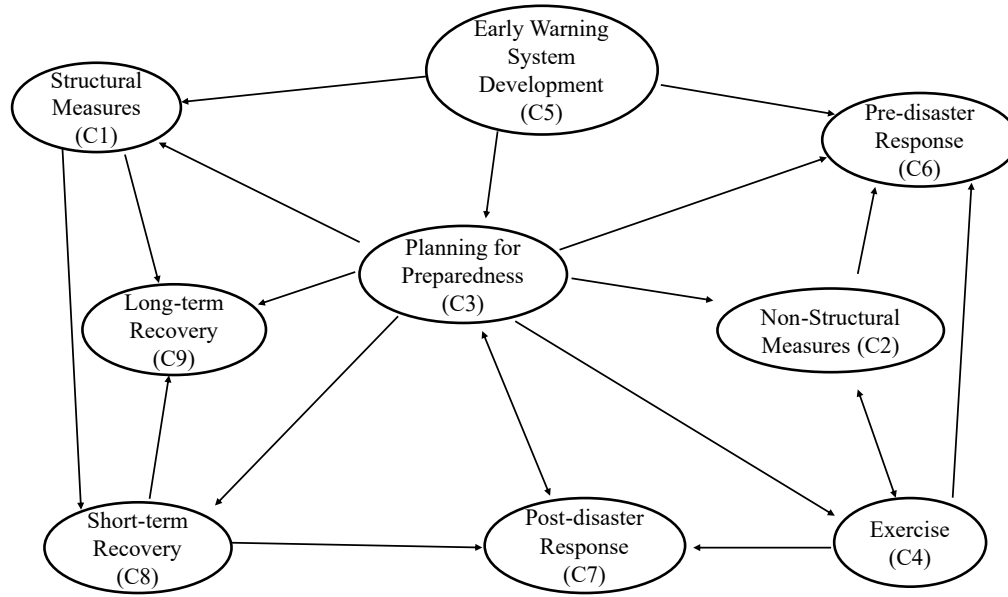


Fig. 6.2 The inter-relationship between the major disaster management activities.

Table 6.17 Interdependence matrix of nine major disaster management activities.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
Structural Measures (C1)	1	0	0	0	0	0	0	0.513	0.354
Non-Structural Measures (C2)	0	1	0	0.423	0	0.321	0	0	0
Planning for Preparedness (C3)	0.485	0.601	1	0.577	0	0.321	0.383	0.487	0.354
Exercise/Drill (C4)	0	0.399	0	1	0	0	0.255	0	0
Early Warning System Development (C5)	0.515	0	0.563	0	1	0.358	0	0	0
Pre-disaster Response (C6)	0	0	0	0	0	1	0	0	0
Post-disaster Response (C7)	0	0	0.437	0	0	0	1	0	0
Short-term Recovery (C8)	0	0	0	0	0	0	0.362	1	0.292
Long-term Recovery (C9)	0	0	0	0	0	0	0	0	1

Step 6: Aggregated local priority weight

The aggregate (normalized) weights of the criteria are computed using Eq. (6.10) by multiplying the weighted matrix that incorporates interrelationships (Table 6.18) with the weights obtained under the assumption of no interrelationships. The results of Eq. (6.10) represent the local priority weights of the major disaster management activities while accounting for interdependencies among criteria. As illustrated in Fig. 6.2, criterion C3 influences seven other criteria; consequently, its local weight is higher than that of the remaining criteria in Eq. (6.10). These weights are subsequently used to calculate the final weights of disaster management sub-components, considering interrelationships among the 42 cyclone-related disaster management activities in Bangladesh.

$$\begin{bmatrix} 0.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0.256 & 0.177 \\ 0 & 0.5 & 0 & 0.212 & 0 & 0.161 & 0 & 0 & 0 \\ 0.242 & 0.301 & 0.5 & 0.288 & 0 & 0.16 & 0.192 & 0.244 & 0.177 \\ 0 & 0.199 & 0 & 0.5 & 0 & 0 & 0.127 & 0 & 0 \\ 0.258 & 0 & 0.282 & 0 & 1 & 0.179 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.5 & 0 & 0 & 0 \\ 0 & 0 & 0.218 & 0 & 0 & 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.181 & 0.5 & 0.146 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.5 \end{bmatrix} \times \begin{bmatrix} 0.1145 \\ 0.1102 \\ 0.121 \\ 0.1028 \\ 0.1344 \\ 0.1041 \\ 0.109 \\ 0.1004 \\ 0.1039 \end{bmatrix} = \begin{bmatrix} 0.101 \\ 0.094 \\ 0.231 \\ 0.087 \\ 0.217 \\ 0.052 \\ 0.081 \\ 0.085 \\ 0.052 \end{bmatrix} \dots\dots\dots (6.11)$$

Using the method described in Steps 5 and 6, local priority values for cyclone disaster management tasks are calculated, taking into account connections among items in each sub-activity group. Revised local priority values (factoring in their interconnections) for sub-tasks under each key disaster management area appear (as detailed next):

$$W_{SM} = (0.107, 0.198, 0.143, 0.207, 0.134, 0.211)^T$$

$$W_{NSM} = (0.262, 0.438, 0.301)^T$$

$$W_{PP} = (0.146, 0.069, 0.108, 0.077, 0.035, 0.017, 0.026, 0.022)^T$$

$$W_{EP} = (0.314, 0.686)^T$$

$$W_{EEWS} = (0.250, 0.279, 0.180, 0.200)^T$$

$$W_{Pre-R} = (0.704, 0.296)^T$$

$$W_{Post-R} = (0.129, 0.085, 0.223, 0.131, 0.081, 0.025, 0.326)^T$$

$$W_{Short-TR} = (0.186, 0.347, 0.467)^T$$

$$W_{\text{Long-TR}} = (0.148, 0.487, 0.110, 0.039, 0.063, 0.071, 0.081)^T$$

Once the updated local priority weights for cyclone disaster management sub-activities within every major category have been derived, global weights are determined through multiplication of those local weights against the respective weights assigned to the major disaster management categories. The local and global weights of both sub-activities and major disaster management activities are thus derived, and the final results are presented in Table 6.18.

Table 6.18 Ranking of disaster management activities for tropical cyclone in context of Bangladesh.

Major Disaster Management Activities	Major Activity Value (i)	Sub-Activity Name	Local Priority Weight(j)	Global Weight (ij)	Rank
Structural Mitigation Measures	0.101	Established Environmentally Sustainable Smart Cyclone Shelter (SM1)	0.107	0.010807	27
		Coastal Afforestation (SM2)	0.198	0.019998	19
		Construction of Coastal Embankment (SM3)	0.143	0.014443	25
		Reconstruction/Reinforcing Critical Infrastructure (SM4)	0.207	0.020907	18
		Construction/Renovation of Canals and Embankments for Improved Drainage (SM5)	0.134	0.013534	26
		Design and Maintenance considerations of Communication and Transmission Line Towers (SM6)	0.211	0.021311	17
Non-Structural Mitigation Measures	0.094	Building Public Awareness and Education Programs (NSM1)	0.262	0.024628	16
		Regulatory Measures (NSM2)	0.438	0.041172	5
		Hazard Mitigation Grant Program (NSM3)	0.301	0.028294	11
Planning for Preparedness	0.231	Contingency Plan (PP1)	0.146	0.033726	9
		Preparedness Guidelines (PP2)	0.069	0.015939	22
		Emergency Response Plan (PP3)	0.108	0.024948	15

		Logistics Planning (PP4)	0.077	0.017787	21
		Volunteer Management (PP5)	0.035	0.008085	30
		Recordkeeping and Reporting (PP6)	0.017	0.003927	38
		Financial Management and Plan of Reimbursement for Services and Resources (PP7)	0.026	0.006006	34
		Establishing Coordination among different Organizations (PP8)	0.022	0.005082	36
Drill and Exercises	0.087	Disaster Reduction Drills and Exercises (EP1)	0.314	0.027318	12
		Evacuation Mapping (EP2)	0.686	0.059682	2
Early Warning System Development	0.217	Cyclone Tracking and Forecasting (EEWSDP1)	0.25	0.05425	3
		Proper Information Management (EEWSDP2)	0.279	0.060543	1
		Investment in Developing Disaster Early Warning (EEWSDP3)	0.18	0.03906	7
		Public Education on Early Warning (EEWSDP4)	0.2	0.0434	4
Pre-Disaster Response	0.052	Warning and Evacuation (Pre-R1)	0.704	0.036608	8
		Pre-position Resources and Supplies (Pre-R2)	0.296	0.015392	24
Post- Disaster Response	0.081	Search and Rescue (Post-R1)	0.129	0.010449	29
		First Aid Medical Treatment (Post-R2)	0.085	0.006885	32
		Volunteer Management for Rapid Response (Post-R3)	0.223	0.018063	20
		Rapid Disaster Damage and Need Assessment (Post-R4)	0.131	0.010611	28
		Provision of Water, Food and Temporary Shelter (Post-R5)	0.081	0.006561	33
		Logistics and Supply Chain Management (Post-R6)	0.025	0.002025	42
		Coordination (Incident Command System) (Post-R7)	0.326	0.026406	13
Short-term Recovery	0.085	Provision of Temporary Early Rehabilitation (STR1)	0.186	0.01581	23

		Restoration of Critical Infrastructure (STR2)	0.347	0.029495	10
		Early Debris Clearance (but not removal or disposal) for Road Transport (STR3)	0.467	0.039695	6
Long-term Recovery	0.052	Joint Damage and Needs Assessment (LTR1)	0.148	0.007696	31
		Strategic Planning for Recovery (LTR2)	0.487	0.025324	14
		Restoration of Basic Services (LTR3)	0.11	0.00572	35
		Infrastructure Reconstruction and Development (LTR4)	0.039	0.002028	41
		Economic Recovery and Development (LTR5)	0.063	0.003276	40
		Strengthening Institutional Capacities (LTR6)	0.071	0.003692	39
		Empowering Individuals and Communities (LTR7)	0.081	0.004212	37

The assessment results, represented in Table 6.18, among the nine principal criteria for cyclone disaster management in Bangladesh, 'planning for preparedness' is identified as the most significant factor, carrying a relative weight of 0.231. Other key activities, ranked in order of decreasing importance, include 'effective early warning system development' (score: 0.217), 'structural mitigation measures' (score 0.101), 'non-structural mitigation measures' (score 0.094), 'drill or exercise' (score 0.087), 'short-term recovery' (score 0.085), 'post-disaster response' (score 0.081), and 'long-term recovery' (score 0.052). The consistency ratio in the pairwise comparison for criteria was measured below 0.10, which is within the acceptable limits of consistency as per the theory of Saaty (2008).

6.4 Discussion

According to Fuzzy ANP, the disaster management sub-components are prioritized in descending order in Fig. 6.3 from the result of Table 6.18. Proper information management (EEWSDP2) has found the most important cyclone disaster management activity in the study for Bangladesh. Following this, 'evacuation mapping (EP2)', 'cyclone tracking and forecasting (EEWSDP1)', 'public education on early warning (EEWSDP4)', 'regulatory measures (NSM2)', 'early debris cleaning for smooth transportation (STR3)', 'investment in developing disaster early warning (EEWSDP3)', 'warning and evacuation (Pre-R1)', 'contingency plan (PP1)', and 'restoration of

critical infrastructure (STR2)' respectively have appeared as the top ten disaster management activities for comprehensive cyclone disaster management in Bangladesh.

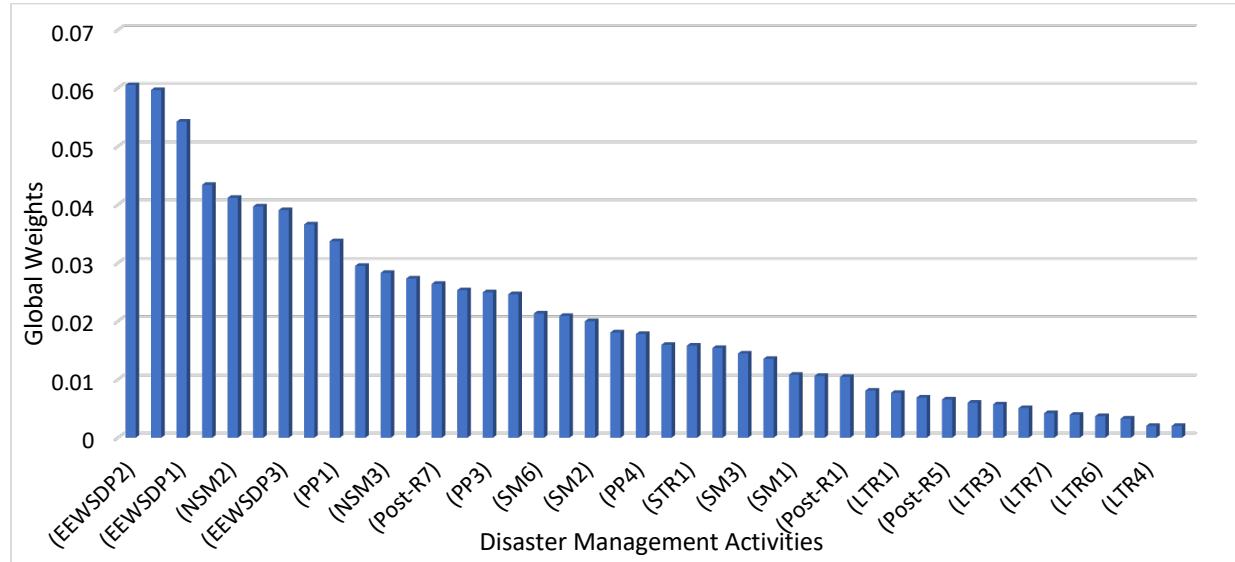


Fig. 6.3 Ranking disaster management activities for tropical cyclone in context of Bangladesh.

Another conclusion of this study emphasizes that the development of an effective early warning system and successful planning for preparedness can significantly enhance the awareness and readiness of vulnerable communities, enabling them to face hazards and mitigate the impacts of disasters. Similar finding has come out from a recent study by World Meteorological Organization (WMO) where stated early warnings reducing asset losses by up to 30% if a community get early warning before 24hr. Moreover, according to Global Status Report (2024) by UNDRR reveals that countries with substantive-to-comprehensive early warnings coverage have disaster mortality eight times lower than countries with limited coverage ([UNDRR, 2024](#)). It is noteworthy that cyclone disaster management experts have placed greater emphasis on conducting mock drills, pre-disaster response, preparedness planning, and structural and non-structural mitigation activities, rather than on post-disaster actions.

The study faced resource constraints in developing the DDM methodology for tropical cyclones due to the limited availability of review articles on the topic. Moreover, coordinating with experts and aligning schedules proved time-consuming. In some cases, field-level practitioners found the questionnaire tedious to complete and required clarification on certain components. Finally, the overall coastal region of Bangladesh has considered for assessing the cyclone disaster demand matrix. In the future study, researcher can focus on a specific area or micro-administrative level.

This would allow to address the local disaster risk through the demand matrix and prioritization process, ensuring more localized context and effective disaster management.

6.5 Summary

This study provides a comprehensive assessment and prioritization of cyclone disaster management activities in Bangladesh using a DDM and Fuzzy ANP method respectively. The analysis reveals substantial gaps between ideal and existing situation among nine major activities and forty-two sub-components of disaster management. The findings identify planning for preparedness and effective early warning system development as the most critical components for enhancing cyclone resilience. Sub-activities, such as proper information management, evacuation mapping, cyclone tracking and forecasting, and public education on early warning emerged as key priorities for improving coordination, communication, and community engagement in disaster response. On the other hand, poor performance in structural mitigation and long-term recovery underscores persistent weaknesses in infrastructure resilience, reconstruction, and economic recovery. Targeted investments in embankment strengthening, infrastructure reinforcement, and institutional capacity building are urgently needed. Overall, the study emphasizes a necessary shift from a reactive to a proactive disaster management approach. Strengthening preparedness, early warning dissemination, and sustainable mitigation will enhance national resilience and align Bangladesh's disaster management efforts with the Sendai Framework for Disaster Risk Reduction (2015–2030).

Chapter 7: Strategic Recommendations and Policy Roadmap

Chapter 7: Strategic Recommendations and Policy Roadmap

7.1 General

The findings of this study reveal a critical mismatch between the current state of cyclone disaster management and the ideal demand scenario, particularly in structural mitigation, preparedness planning, evacuation systems, and long-term recovery. The fuzzy ANP results further emphasize that early warning systems, preparedness planning, and evacuation-related activities are the most influential components in reducing cyclone risk. While the country has made remarkable progress in reducing cyclone-related mortality over the past three decades, the analysis demonstrates that persistent gaps remain across all phases of the disaster management cycle. Most notably, the prioritization results identify ‘proper information management’ as the single most critical activity, followed by ‘evacuation mapping’, ‘cyclone tracking and forecasting’, and ‘public education on early warning’ ([OCHA, 2025](#)).

Consistent with global disaster risk reduction (DRR) literature, effective cyclone management requires a shift from reactive response toward anticipatory, integrated, and risk-informed governance systems ([Zaman, 2022](#)). This chapter proposes a multi-dimensional policy roadmap to scale effectiveness in Bangladesh by aligning national priorities with localized implementation, technological advancement, and institutional integration.

7.2 Strengthening Early Warning Systems and Information Management

The study emphasizes that information management and accurate cyclone forecasting are the most critical pillars of risk reduction, reinforcing wider evidence that early warning systems (EWS) are central to saving lives and livelihoods. Advanced digital, AI-enabled, and people-centered EWS are increasingly seen as the ‘backbone’ of climate and cyclone risk management ([Rahman et al., 2024](#)).

Advanced, Integrated Early Warning Platforms

Integrated AI-based platforms are promoted as a way to fuse meteorological, geospatial, and societal data into multi-hazard, impact-based early warning that better anticipates complex climate risks and supports proactive adaptation ([Reichstein et al., 2025](#)).

Last-Mile Communication and Localized Warnings

Evidence from coastal Bangladesh and other contexts shows people value precise landfall timing, impact information, and voice/SMS alerts in local dialects, and are willing to pay for such improvements (Ahsan & Khatun, 2020). Studies of flood and drought EWS stress that communication and dissemination remain the weakest components, requiring multiple channels (mobile alerts, community volunteers, media, social networks) and tailored content to different user groups (Sadiq et al., 2023). Research on public alert systems and ‘last mile’ communication underlines that trusted, timely, simple, yet sufficiently detailed messages, delivered via redundant and diverse channels, are essential for warnings to trigger protective action.

Redundant and Robust Emergency Communication Networks

Reviews of emergency communication networks describe the need for redundant, multi-technology architectures combining satellite, cellular, ad hoc, and private wireless systems to maintain connectivity during extreme events. Such integrated broadband–narrowband systems are proposed to support visual dispatch, real-time data exchange, and reliable warning dissemination even when parts of the infrastructure fail. This aligns with calls in EWS literature to use multiple communication pathways and backup systems to ensure alerts reach at-risk populations despite damage to primary networks (Ahsan & Khatun, 2020).

7.3 Enhancing Preparedness Planning and Institutional Capacity

Despite its importance, preparedness planning in coastal Bangladesh performs only at an average level, revealing a persistent gap between national policy ambitions, and local implementation. Recent assessments show that Bangladesh has robust DRR policies and frameworks, yet translating plans into effective local action remains constrained by limited capacity, funding, and coordination at sub-national levels (Islam et al., 2020). Weak local institutions, external dependencies, and poor data and information management all contribute to this policy implementation gap (Quader et al., 2023).

To close this gap, standardized contingency planning frameworks should be developed for all coastal districts, supported by stronger data management, documentation, and reporting systems. Building local government capacity through training, resources, and collaborative networks is critical for operationalizing plans on the ground. Institutionalizing regular risk assessments and scenario-based planning would support anticipatory, risk-informed decision-making rather than

reactive crisis management. Researchers consistently highlight weak local capacity and fragmented governance as core reasons why well-designed DRR policies often fail in practice, both in Bangladesh and comparable contexts.

7.4 Reforming Evacuation Systems and Disaster Drills

The study finds that evacuation mapping and drills are among the weakest components of cyclone preparedness, despite their direct role in saving lives. Risk-informed evacuation maps, optimized shelter locations, and realistic training that reflects how people actually move and decide under stress ([Rahman et al., 2021](#)).

Evacuation Mapping and Inclusive Planning

Geo-referenced evacuation maps that integrate flood/cyclone risk, road networks, and shelter capacity can greatly improve route selection and reduce evacuation time, especially for vulnerable groups such as the elderly. Reviews also highlight the need to systematically incorporate human factors, such as age, gender, disability, risk perception, and culture into evacuation models and plans.

Drills, Behavior, and Trust

Evacuation drills and training increasingly are enhanced by Volunteer Resources and serious games improve spatial navigation, decision-making, and safety compliance, including for elderly and disabled people. Behavioral studies confirm that evacuation is shaped by social norms, gendered roles, prior experience, and trust in authorities, not warnings alone; confidence in government and clear, legitimate orders are critical for compliance ([Ahsan, 2017](#)).

7.5 Strengthening Non-Structural Mitigation and Risk Governance

While public education and awareness efforts are relatively strong, regulatory and financial measures for DRR remain underdeveloped, limiting real risk reduction on the ground. Institutional silos, weak enforcement, and fragmented financing hinder a shift from knowing about risk to actually controlling and reducing it ([Islam et al., 2020](#)).

Strengthening land-use planning and building codes, especially in coastal and high-risk zones, is widely recognized as essential for reducing exposure and preventing new risk, but many systems still lack coherent spatial planning, effective enforcement, and integration of risk information into

development decisions ([Farinós-Dasí et al., 2025](#)). At the same time, scaling up public education and awareness and linking it with concrete incentives (e.g., support for safer housing, ecosystem-based DRR, or insurance uptake) may bridge the knowledge gap and lead to action. Introducing hazard mitigation grant programs to fund local adaptation and risk-reduction projects, such as nature-based solutions, resilient infrastructure, or risk-sensitive land-use plans supports locally driven, cross-sectoral implementation.

Overall, effective DRR emerges as a governance challenge: durable risk reduction requires integrated institutions, cross-sector coordination, and aligned regulatory and financial tools, rather than isolated awareness programs or siloed policies.

7.6 Improving Pre- and Post-Disaster Response Systems

The study underscores that disaster response is weakened by gaps in logistics, poor resource pre-positioning, and limited emergency response capacity. These weaknesses delay aid delivery, increase immediate losses, and slow the path to recovery ([Heng et al., 2025](#)).

To address this, it recommends establishing decentralized emergency logistics hubs so that critical supplies are closer to affected communities and less vulnerable to single-point failures. Improving disaster supply chain management systems is essential to coordinate warehouses, transport, and inventories, ensuring that pre-positioned resources can be rapidly mobilized when a crisis strikes. Strengthening rapid damage and loss assessment frameworks would enable quicker, evidence-based decisions about where and what kind of support is needed. At the same time, enhancing healthcare and first-aid response capacity helps treat casualties promptly and prevent avoidable deaths and complications. Together, efficient and well-coordinated response systems both reduce immediate human and economic losses and support faster, more sustainable recovery.

7.7 Transforming Long-Term Recovery and Resilience Building

Long-term recovery is widely recognized as the weakest part of the disaster cycle: funding, politics, and urgency favor short-term rehabilitation, while deeper social, economic, and institutional changes lag behind. Recent research argues that recovery must deliberately evolve into a pathway for resilience and development, not just a return to pre-disaster conditions ([Finucane et al., 2020](#); [Okunola & Werners, 2024](#)).

Integrated Recovery Planning Frameworks

- A multi-dimensional ‘recovery for development’ framework links six domains, communities, economy, infrastructure, environment, health, and governance into one integrated planning process, using systems thinking and stepwise strategy design.
- Project-management frameworks stress a continuous recovery lifespan, where planning, learning, and data systems span years and feed into preparedness for the next disaster.
- Long-term recovery requires inclusive deliberation, scientific data, and iterative policy revision to avoid deepening vulnerabilities and inequities.

Key elements of long-term integrated recovery planning

- Sustainable Livelihood Restoration
- Climate-Resilient Reconstruction of Infrastructure
- Community-Led and People-Centered Recovery

Evidence across contexts supports the view that long-term recovery is underdeveloped and too often reduced to short-term repair. Effective strategies knit together integrated planning, climate-resilient infrastructure, and sustained livelihood support, all grounded in community leadership and equity. When recovery is explicitly framed as a vehicle for resilience and development, it can move beyond rehabilitation and help transform vulnerable communities into more just, sustainable, and disaster-ready societies.

7.8 Enhancing Governance, Coordination, and Financing

The study highlights how institutional fragmentation, funding gaps, and coordination failures undermine effective cyclone risk management. These weaknesses manifest in overlapping mandates across agencies, limited and inconsistent financial resources for DRR, and poor communication and collaboration between key actors.

In response, the study proposes several strategic recommendations. First, it calls for the establishment of integrated disaster governance platforms that cut across ministries to ensure coherent planning and decision-making. Second, it emphasizes the need to strengthen vertical coordination between national and local governments so that policies, resources, and responsibilities are better aligned. Third, the study recommends increasing domestic funding for

DRR to reduce excessive dependence on external donors and to enable more sustainable, long-term resilience planning. Finally, it underscores the importance of promoting public–private partnerships (PPP) to mobilize additional resources and technical expertise for resilience investments. Overall, the policy insight is that adaptive governance and strong institutional collaboration are essential for managing cyclone risk effectively (Choudhury et al., 2021).

7.9 Challenges, Limitations and Future Research Directions

Although this study makes an original contribution by developing a Disaster Demand Matrix for cyclone disaster management in Bangladesh, some limitations should be acknowledged. First, the proposed DDM has been developed through a combination of literature review, policy analysis, expert judgment, and prioritization techniques. While this approach provides a structured and evidence-informed framework, the empirical validation of the matrix remains limited. Future studies may validate the DDM through field-level application in selected cyclone-prone districts and compare the findings with actual disaster preparedness, response, and recovery outcomes.

Second, the prioritization process partly depends on expert judgment. Although experts from relevant academic, government, and professional backgrounds were consulted, the results may still reflect their institutional experience, professional understanding, and subjective assessment. To reduce this limitation, the study applied the Fuzzy Analytical Network Process, which is useful for addressing uncertainty and interdependence among decision criteria. However, future research may include a larger and more diverse group of respondents, including local government representatives, community leaders, CPP volunteers, women’s groups, and disaster-affected people.

Third, the study mainly focuses on cyclone disaster management in the coastal context of Bangladesh. Therefore, the findings are most directly applicable to cyclone-prone coastal areas. Although the DDM has potential for wider application to other hazards such as floods, riverbank erosion, storm surges, landslides, and droughts, further adjustment and validation will be necessary before applying it to different disaster contexts.

Fourth, some practical challenges were encountered during data collection. Coordinating with experts and practitioners required considerable time, and some respondents needed additional explanation to understand the technical components of the questionnaire. This indicates the

importance of developing simplified and user-friendly tools for future application of the DDM at district, upazila, and union levels.

Finally, future research may strengthen the DDM by integrating real-time disaster information, GIS-based vulnerability mapping, local-level resource inventories, and community-based risk data. Application of the matrix at different administrative levels would make it more useful for localized planning, resource allocation, and evidence-based decision-making. Such future improvements would further enhance the policy relevance of the DDM and support a more inclusive, demand-driven, and resilient disaster management system in Bangladesh.

7.10 Summary

This study demonstrates that Bangladesh's cyclone disaster management system has strong foundations but critical implementation gaps. The prioritization results clearly indicate that investment in early warning systems, preparedness planning, and evacuation mechanisms yields the highest impact in reducing cyclone risks.

However, achieving long-term resilience requires a holistic transformation, integrating technology, governance, infrastructure, and community participation into a unified disaster management framework. Aligning these strategies with global frameworks such as the Sendai Framework will be essential for scaling effectiveness and ensuring sustainable disaster resilience in Bangladesh.

The DDM developed for cyclone hazards can be adapted and applied to other types of disasters in Bangladesh, as well as in different regions around the world. By providing a structured framework to identify needs, assess gaps, and prioritize actions, it offers a practical tool for strengthening disaster management systems across diverse hazard contexts. This adaptability enhances its broader relevance and usefulness beyond cyclone-prone coastal areas.

Furthermore, applying this matrix to various disaster scenarios can support more integrated and demand-driven approaches to risk reduction and emergency planning. It can assist policymakers, practitioners, and communities in making informed decisions that align resources with actual needs. Ultimately, the wider application of this framework has the potential to improve disaster preparedness and response, promote resilience, and contribute to the development of more sustainable and disaster-resilient communities globally.

This study developed a Disaster Demand Matrix (DDM) for cyclone disaster management in Bangladesh; however, its empirical validation remains limited and requires further field-level testing. The prioritization process relies partly on expert judgment, which may introduce subjectivity despite the use of the Fuzzy Analytical Network Process to address uncertainty and interdependencies. The framework is primarily designed for cyclone-prone coastal areas and therefore requires adaptation and validation before application to other disaster contexts. Data collection also faced practical challenges, including coordination with experts and the complexity of technical questionnaires. Future research should integrate real-time disaster data, GIS-based vulnerability mapping, resource inventories, and community-level information to enhance the DDM's effectiveness for localized planning and evidence-based decision-making.

Chapter 8: Conclusion

Chapter 8: Conclusion

This study develops a Disaster Demand Matrix (DDM) for Bangladesh after reviewing a specific disaster (cyclone) management scenario. In doing so, this study had to find out and address a critical gap in cyclone disaster management in Bangladesh by developing a systematic, evidence-based framework for identifying and prioritizing disaster management needs. Despite Bangladesh's internationally recognized success in reducing cyclone-related mortality through advancements in early warning systems, evacuation mechanisms, and community-based preparedness, the findings of this research demonstrate that significant structural, institutional, and operational challenges persist. These challenges are particularly evident in the areas of coordination, resource allocation, and the integration of DRR across different governance levels.

The empirical analysis of tropical cyclone trends during the modern satellite era (1982–2024) provides important insights into the evolving nature of cyclone hazards along the Bangladesh coast. Contrary to widely held assumptions of a consistent increase in cyclone frequency and intensity, the results suggest a more complex and regionally non-uniform pattern, with weak or non-significant trends in several key indicators. This finding underscores the importance of relying on data-driven, region-specific analyses rather than generalized global narratives when designing disaster management strategies. It also highlights that increasing disaster impacts in Bangladesh are not solely driven by changes in hazard characteristics, but are significantly influenced by growing exposure, socio-economic vulnerability, and limitations in adaptive capacity.

The assessment of existing disaster management practices reveals that, while Bangladesh has made considerable progress in aligning with global DRR frameworks, notable gaps remain in translating policy into effective implementation. Institutional fragmentation, limited local-level capacity, insufficient long-term recovery planning, and dependence on external funding continue to constrain the overall effectiveness of disaster management efforts. These findings reinforce the need for a more integrated, coordinated, and demand-oriented approach that bridges the gap between national policy frameworks and ground-level realities.

The DDM developed in this study offers a novel and practical tool for systematically identifying and quantifying unmet needs across the disaster management cycle. By integrating global best practices with local contextual realities, the matrix provides a structured mechanism for

benchmarking existing capacities against required standards. Furthermore, the application of the FANP enables a robust prioritization of disaster management activities by accounting for interdependencies among decision criteria, thereby overcoming the limitations of traditional linear decision-making approaches.

The prioritization results highlight that future improvements in cyclone disaster management in Bangladesh should focus on strengthening institutional coordination, enhancing local governance and technical capacity, improving resource distribution mechanisms, and ensuring the sustainability of recovery and rehabilitation efforts. In particular, greater emphasis is needed on integrating DRR into development planning, promoting inclusive and community-driven approaches, and addressing the needs of vulnerable populations who are disproportionately affected by cyclone impacts.

Finally, this research contributes both theoretically and practically to the field of disaster science and climate resilience. It advances the understanding of cyclone risk dynamics in Bangladesh through empirical analysis, while also introducing an innovative decision-support framework for improving disaster management effectiveness. The DDM developed in this study, along with its prioritization approach, offers practical and actionable guidance for policymakers, practitioners, and development partners. It supports more strategic decision-making and promotes the efficient allocation of resources by clearly linking identified needs with appropriate interventions.

When applied across different disaster contexts, the matrix can encourage more coordinated, demand-driven approaches to risk reduction, preparedness, and emergency response planning. It helps stakeholders—including government agencies, practitioners, and local communities—better understand priorities and align resources with the actual needs of affected populations. By systematically highlighting gaps between existing plans and on-the-ground realities, the framework facilitates more targeted, timely, and effective interventions.

Moreover, the broader application of this approach can significantly enhance disaster preparedness and response capacities. It strengthens resilience by ensuring that interventions are both context-specific and need-based, while also promoting long-term sustainability. Ultimately, the widespread use of the DDM can contribute to building more adaptive, inclusive, and disaster-resilient communities at both national and global levels.

Declaration on the Use of AI Tools

I hereby declare that limited use of artificial intelligence (AI)-based tools, including ChatGPT, QuillBot, Paperpal, and Grammarly, was made solely to improve the clarity, language quality, and grammatical accuracy of the written content in this thesis. These tools were used exclusively for paraphrasing, editing, and refining the presentation of text.

No data, results, analyses, figures, or interpretations presented in this research were generated, altered, or manipulated using any AI tools. All research design, data collection, analysis, and findings are entirely original and were conducted independently by the author.

I further affirm that the intellectual content, methodologies, and conclusions of this thesis are my own work, and the use of AI tools did not influence the scientific integrity or authenticity of the research.

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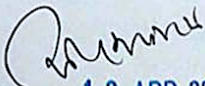
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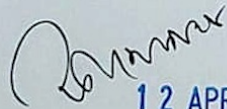
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