Heliyon 10 (2024) e33345

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Review article

# A systematic review of cyclonic disaster: Damage-loss, consequences, adaptation strategies, and future scopes

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ARTICLE INFO

*Keywords:*
Adaptation strategy
Damage-loss
Cyclone
PRISMA
Vegetation
LULC

ABSTRACT

Tropical cyclones have direct and indirect repercussions in many coastal areas worldwide. In coastal regions, several studies have identified the driving factors of cyclonic hazards and their associated impacts. However, previous studies have focused little on cyclone-induced damage and loss, consequences, and adaptation strategies. As a result, it is critical to explore the global focus areas of cyclone-related studies. This review systematically examined cyclone-induced damage and loss, its consequences, adaptation strategies in coastal regions, and associated research gaps. Results revealed eight main types of cyclone-induced damages and losses. About 46 % of studies focused on vegetation damages, followed by water and sanitation (11 %), crop damages (8 %), income or business losses (8 %), health and injuries (8 %), land use and land cover changes (8 %), infrastructural damages (5 %), and mixed damages and losses (5 %). These damages and losses led to further consequences, including disruption of biocenoses, fish death because defoliated leaves carried carbon into the water, changes in forest structure and composition, loss of timber plantation confidence, hampering the steady supply of safe drinking water, raising drinking water costs, unsanitary circumstances, an increase in infectious diseases, a decrease in protein consumption, and business and supply chain interruptions. Approximately 35 % of the studies addressed one or more of the thirteen adaptation strategies identified in this review. Most of these studies documented the use of natural regeneration and tree planting as responses to vegetation damage and water purification and the distribution of emergency-safe water in response to water and sanitation damage. The findings have led to a proposal for an adaptation framework for cyclone-induced damage and loss. This review recommended investigating cyclone-induced land use and land cover change, damage to vegetation functional traits and patterns, health and injuries, service networks, and infrastructural damages.

## 1. Introduction

The natural environment, human lives, and societies are extremely vulnerable to the effects of current climate-induced extreme events such as heat waves, droughts, floods, river bank erosion, water logging, tropical cyclones, and wildfires [1–4]. Tropical

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https://doi.org/10.1016/j.heliyon.2024.e33345
Received 10 March 2024; Received in revised form 11 June 2024; Accepted 19 June 2024
Available online 20 June 2024
2405-8440/

cyclones, which can also be referred to as typhoons or hurricanes (those with a wind speed of 74 mph or more), are among the most debilitating extreme events because of the high risk that they pose to human life as well as the large economic downturn and environmental change [5,6]. According to Chejarla et al. [7], developing nations are especially susceptible to tropical cyclones because of the climatic unpredictability that exists there. However, North, Central, and Caribbean America, along with eastern Asia, bear the brunt of tropical cyclone damage. About 30 % of the world's cyclone-induced economic damage occurs in Eastern Asia [8]. For example, on November 15, 2007, a category 5 super cyclone named Sidr struck Bangladesh, resulting in 3,406 fatalities and affecting 2.3 million households. The total amount of losses was close to $450 million [9,10]. Similarly, category 5 super typhoon Haiyan and the accompanying storm surge caused damages of $13 billion in the coastal cities of China [11].

Tropical cyclones have direct repercussions in many coastal areas around the world [12]. These consequences might be different for different income groups. For instance, lower-income families in developing nations generally suffered greater relative physical and socio-economic losses as a result of natural catastrophes than higher-income households did in these same nations [13]. On the other hand, Abdullah et al. [14] found contradictory findings. These researchers discovered that disadvantaged households lost considerably fewer material possessions than wealthier households. According to Siddik and Moniruzzaman [15], tropical cyclones can cause damage to housing structures, home lighting systems, drinking water options, sanitation structures, and communication devices. In addition, tropical cyclones can kill livestock and disrupt livelihoods. In some instances, storm surges can cause temporary contamination of drinking water supplies with debris and salty water. Following the occurrence of a catastrophic event, individuals found themselves compelled to consume water from the surface for several months [16]. Furthermore, diseases and epidemics may create additional health hazards during the post-disaster period due to the large numbers of human and animal dead bodies and the absence of safe drinking water and sanitation options [17–19].

A cyclone can be one of the factors that change the utilization of land from one usage to another or even make it useless. It may help to the transformation of crop land into fisheries, homestead land, or other uses. It can also alter the temporary pattern of land use [20]. In addition to that, it may inflict considerable damage to the ecosystems of coastal areas [21]. Specifically, it can inflict an enormous amount of devastation on the ecosystems of coastal forests [22]. Tropical cyclones, often considered the most destructive storm type, significantly impact the diversity and growth of coastal forests, as well as their functions and structures [23]. Furthermore, despite major biological and ecological differences among animals living in the many places subjected to these repetitive disturbances, repetitive tropical cyclones create similar composition and structural trends regionally and globally [12].

Researchers have conducted several studies to identify the impact of cyclonic hazards in coastal regions. Mendelsohn et al. [8] examined the nature of global cyclone damage caused by climate change. Rahman et al. [24] developed an index for estimating cyclone-Aila induced damages to household assets. Siddik et al. [20] investigated cyclone-induced land transformation in a coastal sub-district in Bangladesh. Additionally, Chen et al. [12], Xi [22], and Sachithanandam et al. [21] explored the effects of cyclones on coastal ecosystems. Some investigated disaster-induced damages to the water supply and sanitation systems and their recovery status [19,25,26], health problems including death and injuries [17,27–30], structural damages [9,31,32], forest damages [33–35], and economic losses [13]. Furthermore, some academicians and research scholars also carried out a few reviews. Among them, Wang et al. [23] conducted a review on the effects of cyclones on wetland ecosystems in coastal regions. Doocy et al. [36] performed a review focusing on the human impacts of cyclones during 1980–2009. Salisbury et al. [3] further identified the indicators of cyclone-induced vegetation collapse in urban areas. However, to the authors' knowledge, no one has yet made an effort to conduct such a systematic review focusing on cyclone-induced damage and loss in coastal areas. This review aimed to investigate the effects of cyclonic disasters on coastal regions, their potential future consequences, the mechanisms employed to manage or lessen these impacts, and potential avenues for future research.

This systematic review will focus on the following research questions:

[1] What is the cyclone-induced damage and loss in the coastal regions?
[2] What are the consequences of cyclone-induced damage and loss?
[3] Which mechanisms have been followed to cope with or mitigate cyclone-induced damage and loss?
[4] What are the research gaps on cyclone-induced damage, loss, and associated measures?

## 2. Methodology

### 2.1. Search strategies

We conducted this critical review using the world's most familiar abstract and citation-related databases of peer-reviewed literature, Scopus and Web of Science. These databases are the foremost and most esteemed platforms for conducting reviews and meta-analyses of scholarly publications [37,38]. We carried out this systematic review using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guideline [39]. We used the key word "cyclone" including the synonyms "hurricane", and "typhoon", as well as the key word "damage" including the synonyms "loss", "impact", "consequence", and "effect". We performed the key word search on August 19, 2023.

### 2.2. Inclusion and exclusion criteria

This systematic review used several inclusion and exclusion criteria to identify the appropriate studies addressing cyclone-induced damage and loss. The main inclusion criteria were (i) the selected year of published document between 2000 and 2022; (ii) the selected original research article regarding cyclone-induced damage in the coastal region; and (iii) the only final published article in English. On the other hand, this systematic review excluded: (i) duplication; (ii) publications before 2000 and after 2022; (iii) publication other than original research article; (iv) publication other than English language; (v) regional or global focus publications; (vi) general or not focus on damage and loss related publications; (vii) partial cyclone and coastal focus publications; and (viii) multiple events impacts related publications.

### 2.3. Literature search results

We used the PRISMA 2020 guideline to conduct this systematic review. The PRISMA-2020 is an updated guideline for selected literature in systematic review. This guideline comprises three main stages, i.e., identification, screening, and inclusion (Fig. 1).

In the identification stage, we identified a total of 22,537 records, including 10,537 records from Scopus and 12,000 records from the Web of Science database. We used the find and remove duplicates formula in Microsoft Office Excel 2007 to check and remove duplicates. At this stage, we removed a total of 2932 records. After that, we performed title and abstract screening to remove irrelevant documents in the name of record screening (n = 19,605). During this stage, we removed a total of 19,315 records. The main reasons for the removal of records were documents published before 2000 and after 2022 (n = 667), global or regional focus (n = 82), review papers or publications other than journal articles (n = 51), general or not focused on damage and loss, and partial cyclone or coastal focus publications (n = 18,515). Furthermore, a retrieval issue in the stage of reports sought for retrieval led to the removal of one additional article. For full text screening, we had a total of 289 records in the stage of reports assessed for eligibility. We removed a total of 252 records due to their lack of emphasis on damage and loss, cyclone or coastal focus, single event impacts, incorrect language or document type, secondary data, or global and regional focus. Finally, we selected a total of 37 records for this systematic review.

### 2.4. Quality assessment

We used Pierson's methods to assess the quality of the included studies. There are five specific components in Pierson's methods, including documentation, uniqueness, educational value, objectivity, and interpretation. These components assessed the quality and validity of the included studies. We can rank each component on a scale ranging from 0 to 2. Therefore, the overall quality can be

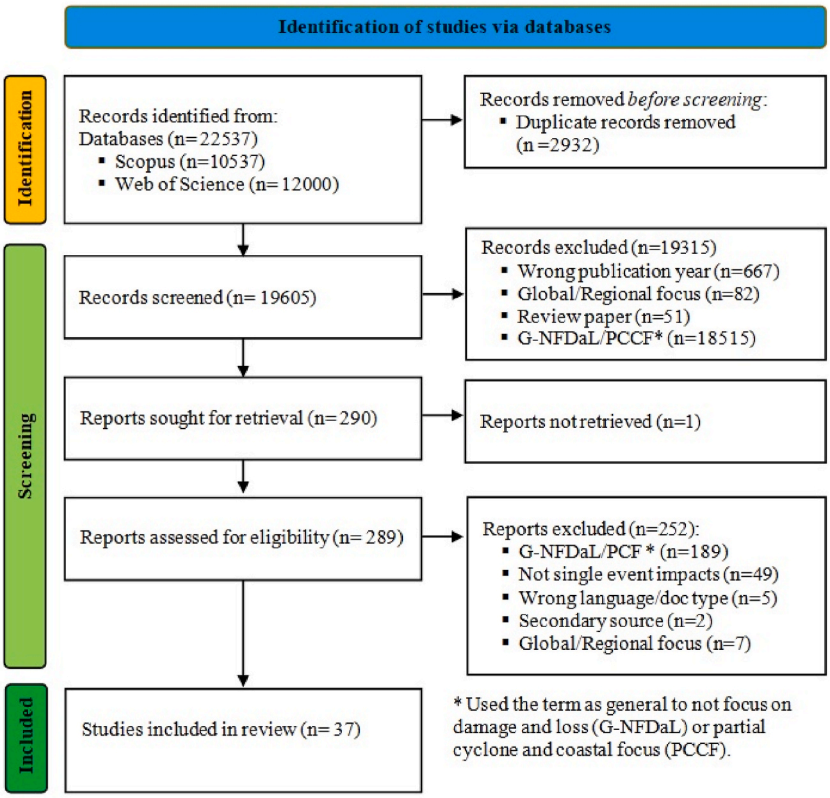


**Fig. 1.** The PRISMA strategy was applied to identify the suitable studies. It has three stages. i.e., (i) the identification stage entails calculating the total number of records present in the pertinent databases (we utilized Scopus and Web of Science databases in this instance), (ii) the screening stage entails scrutinizing the records, retrieving them, and assessing their eligibility, and (iii) the stage of inclusion studies for review encompasses the records chosen for the systematic review.

scored from 0 to 10, where 9–10 represents high quality, 6–8 represents moderate quality, and ≤5 denotes low quality [40]. Results showed that a total of 24 % of studies scored in the range of 9–10, indicating high-quality papers. Besides, a total of 57 % of studies scored in the range of 6–8, denoting moderate quality, and the rest scored ≤5, denoting low quality. Based on the average score (7.4 out of 10), we can claim that the overall quality of the papers included in this systematic review is moderate (Table S1).

### 2.5. Characteristics of scientific studies

Fig. 2 presents the year- and country-wise frequency of scientific production. Out of the 23 targeted years (2000–2022), we noticed a total of 14 publication years. We excluded the remaining nine targeted years, 2001, 2002, 2003, 2005, 2006, 2007, 2013, 2014, and 2015, as we noticed zero publications in those years. We found the most publications in 2021, and the lowest in 2000, 2010, and 2022. Thirteen countries across five continents accounted for the majority of observed scientific productions. We found that India had the highest scientific production. They found a total of seven scientific publications there. Bangladesh (n = 6) came in second place for scientific production, ahead of Australia (n = 5), the USA (n = 5), and other nations. However, based on continental distribution, Asia (n = 18) had the highest publication rate, followed by Oceania (n = 8), North America (n = 6), Africa (n = 3), and Europe (n = 2).

## 3. Results

### 3.1. Cyclone-induced damage and loss

We thoroughly checked cyclone-induced damage and loss related topics in the existing literature and found a total of eight types of damages and losses (Table S2). According to the United Nations Framework Convention on Climate Change (UNFCCC), loss and damage are climate change's negative effects that occur without mitigation or adaptation. In this review, we define the terms loss as irreversible damage, such as human death, agricultural loss, etc., and damage as reparable destruction, such as infrastructural destruction [41]. We mainly found three types of data collection methods used in the existing literature, i.e., field survey, image analysis, and both (Figs. 3 and 4). Approximately 59 % of studies completed their research solely through the field survey method. The remaining 41 % included either image analysis exclusively or field survey, which mostly used a Landsat image (47 %) and a Sentinel image (29 %).

The results revealed that approximately 46 % of the selected publications focused on the damages and losses associated with vegetation. Field surveys formed the basis of almost 53 % of vegetation damage assessment studies, with satellite images accounting for about 29 % of these cyclone-induced damages. However, about 17 % of studies used mixed data collection tools, i.e., field surveys

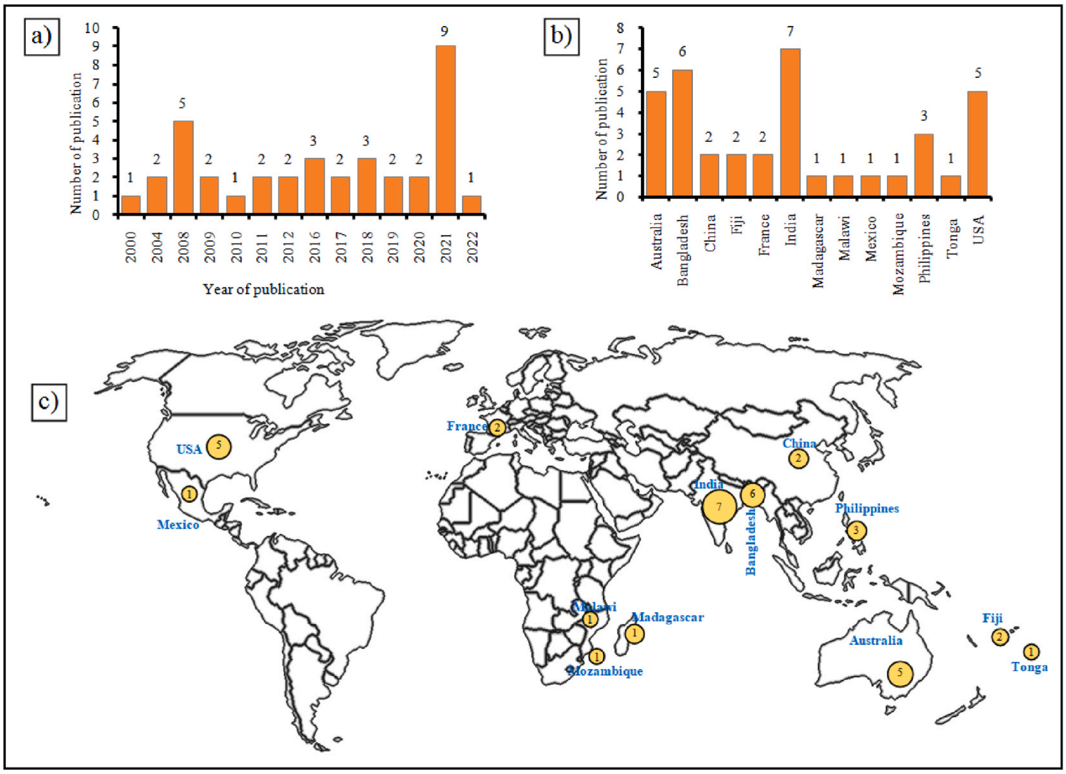


**Fig. 2.** Year-wise (a) and country-wise (b and c) frequency of scientific studies.

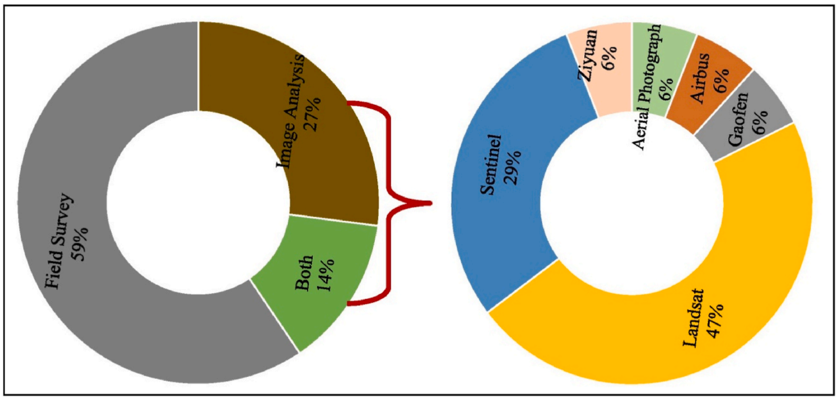


**Fig. 3.** Data collection method used in the existing literature.

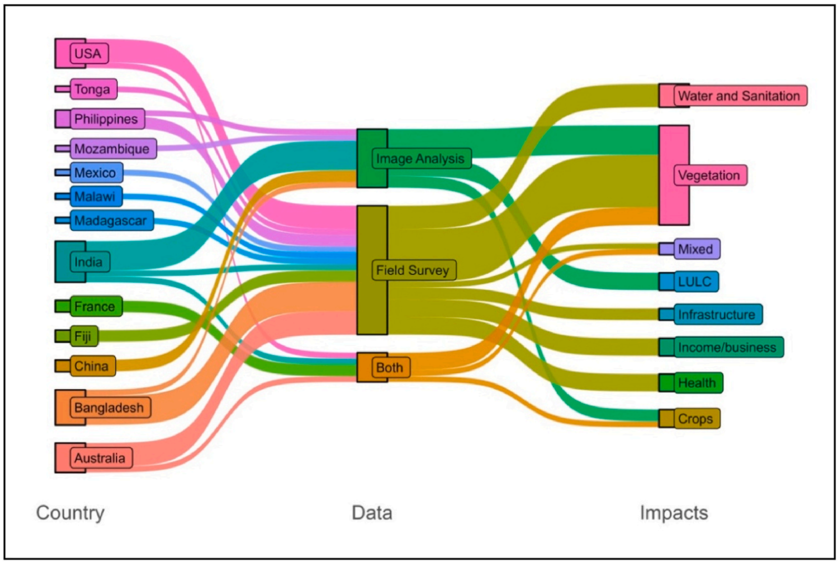


**Fig. 4.** Data collection methods (here, data) used by countries and used for damage and loss (here, impacts) assessment.

and image analysis (Fig. 4).

About 11 % of scientific publications focused on cyclone-induced water and sanitation problems. Field surveys primarily identified the damage and loss. Similarly, about 8 % of the existing literature identified agricultural crop damages, income or business-related losses, health problems, and changes in land use and land cover (LULC), with infrastructural damage coming in second at 5 %. Satellite image analysis explored crop damage and LULC changes among these damages and losses, while field survey methods investigated income- or business-related losses, health problems, and infrastructural damages. Furthermore, field surveys and mixed data collection tools focused about 5 % of the studies on cyclone-induced mixed damages and losses (Fig. 4).

Fig. 5 shows the types of cyclone-induced damages and losses by country. The results revealed that the literature focusing on Bangladesh, India, and the USA covered a maximum of four out of the eight different types of damages and losses. Conversely, the literature focusing on Australia, China, Madagascar, Malawi, Mexico, Mozambique, and Tonga covered individual types of damage and loss.

### 3.1.1. Health and injuries

Results revealed that 5 % of the studies included health- and injury-related damage and losses. According to Paul et al. [28], illness was one of the indirect impacts of the post-cyclonic period. They identified people who suffered cyclone-induced illnesses, including diarrheal diseases, infections of the respiratory system, typhoid, skin diseases, fever, and corneal infections. Bozick [29] asserts that cyclonic disruptions significantly heighten the strain on human health. Over the course of more than a month, people experienced difficulties with both their physical and mental health as a direct result of Hurricane Harvey. Areas of the city that sustained the greatest amount of structural damage from the storm felt these consequences most strongly. Furthermore, the majority of injuries are caused by direct impacts from cyclones. Paul [27] investigated the pattern of injuries caused by cyclones in Bangladesh. He found

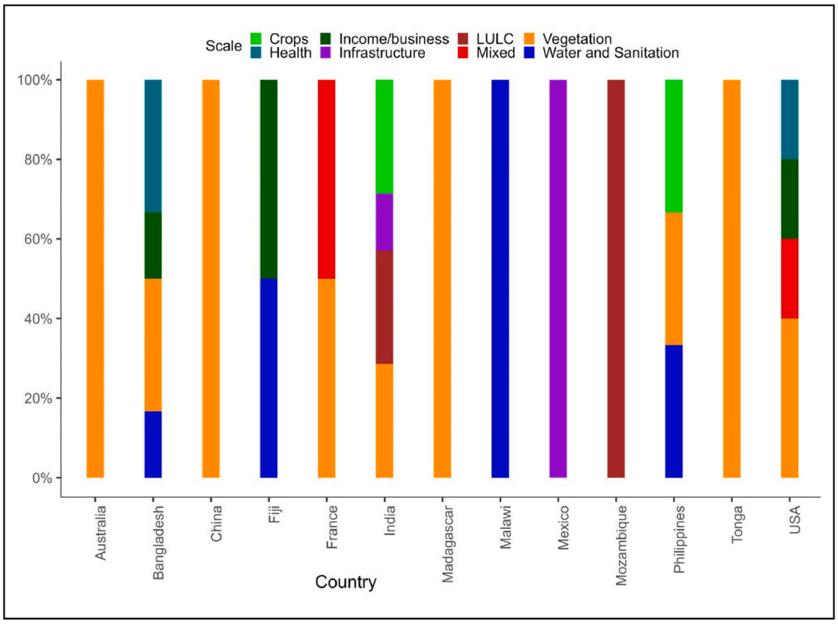


**Fig. 5.** Country wise types of cyclone-induced damages and losses.

soft-tissue damage, fractures, or dislocations to be the most prevalent injuries. Falling trees and wind-associated debris caused the majority of injuries sustained by survivors.

### *3.1.2. Vegetation damage*

Results showed that about 46 % of the selected studies focused on cyclone-induced damages and losses to vegetation. The percentage of cyclone-induced vegetation damage varies from 50 % to 95 % across the studies. Mishra et al. [42] discovered that cyclone Fani damaged nearly 50 % of the vegetation in the Balukhand Konark Wildlife Sanctuary in India. They found the sparse vegetation class to be the most damaged forest cover type. Besides, Malabrigo et al. [43] and Wang & Xu [44] found 60 % damages from cyclone Yolanda in Calauit Island, Philippines, and cyclone Meranti in Xiamen Island, China, respectively. Further, Walcker et al. [45] found almost 80 % of mangrove areas damaged by cyclone Irma in France. In addition, according to Mishra et al. [46], cyclonic storm Amphan degraded and fragmented nearly all of the Sundarbans mangrove forest in Bangladesh. However, areas with dense mangrove cover sustained the most substantial damage. Moreover, Lewis & Bannar-Martin [47] found that more than 95 % of the vegetation experienced damage from cyclone Fanele in the Kirindy Mitea National Park in Madagascar.

The vegetation plot's distance to the cyclone's eye has a significant impact on damage levels. According to Kanowski et al. [48], the severity of damage to trees decreased with greater distance from the path of the cyclone. Besides, Cook & Goyens [49] observed that where there is maximum wind speed, there is maximum uprooting or snapping of stems. They found Melaleuca spp. trees to be the most uprooted and snapped. Forests located in coastal areas act as a natural barrier against cyclones [42]. Nandi et al. [50] found that cyclonic wind direction and speed cause maximum forest damage on the seaward side. Metcalfe et al. [51] observed a contrary result. They explained that there is no association between gust direction and vegetation damage.

There are several types of vegetation damages and losses described in the existing literature, including broken branches, uprooting, snapped stems, and defoliation. This review revealed cyclonic-induced damages created larger gaps between the canopies [50,52]. Nandi et al. [50] evaluated the initial impact of cyclone Fani on plant structure and the canopy gap in Balukhand Wildlife Sanctuary in India. In addition, Wang & Xu [52] found that broad-leafed trees, especially Delonix regia, Acacia confusa, Chorisia speciosa, Bauhinia variegate, F. concinna, and Ficus benjamina, were most damaged. However, Metcalfe et al. [51] identified *C. insularis*, R. angustifolia, and Backhousiabancroftii trees as resilient species to cyclonic effects.

According to Lewis & Bannar-Martin [47], diameter at breast height determined whether or not a tree suffered damage or died. Cyclone Waka in Tonga frequently uprooted trees with a diameter of more than 20 cm, causing significant damage to their stems [53].

In the hazardous conditions created by a cyclonic storm, the root structure plays a crucial role in supporting a tree. Haq et al. [54] discovered that trees with superficial roots and a large crown suffered more damage than those with a deeper taproot and a well-shaped canopy. Lewis and Bannar-Martin [47] discovered that the death rate of understory trees and emergent-type trees was significantly higher than that of canopy trees. Curran et al. [55] found a strong correlation between the extent of defoliation and the specific leaf area and leaf length. They discovered that trees with less timber density and a large specific leaf area demonstrated poor resistance to the cyclonic effects. Furthermore, Kanowski et al. [48] investigated the correlation between cyclone-induced vegetation damage and tree size. They observed that the severity of damage to trees decreased with increasing stem density. Nonetheless, Curran et al. [55] discovered results that are debatable. They found that there is no correlation between the extent of damage and tree size or root systems.

Franklin et al. [53] observed that both the mortality rate and damage patterns were higher in the early successional trees. Pohlman et al. [56] found greater uprooting in early successional and taller trees. However, they found that damage to saplings occurred more frequently in canopy trees than in understory or shrub trees. Conversely, Middleton [57] reported that shrubs were the species most uprooted by Hurricane Katrina along the USA Gulf Coast. Kanowski et al. [48] found that planting trees with a generally open shape and large stems increases the risk of severe damage. Similarly, Xu et al. [58] observed that intentionally grown vegetation in cities, such as that located alongside roadways and in neighborhoods, is more susceptible to wind-related damage than natural vegetation.

#### *3.1.3. Water and sanitation problems*

Water and sanitation were found to be the second-most cyclone-induced damage and loss included in the existing literature. The impacts of cyclone Glenda on water and sanitation systems in Malabon, Philippines, were evaluated by Purwar et al. [59]. The quality of the water was deteriorating due to cyclonic disruption, the water quality was deteriorating. Besides, cyclonic flooding forced informally settled people to stop toilet access for 3–4 days, resulting in the disposal of sludge in storm water and creating severely unsanitary circumstances. Similarly, Rafa et al. [25] explored the fact that almost 97 % of water and sanitation facilities were either destroyed or damaged. Cyclone Amphan disrupted water supply and sanitation systems, making them unsafe or non-operational. Mosley et al. [26] investigated the impacts of cyclone Ami on the quality of drinking water on Vanua Levu Island in Fiji. They revealed that the concentrations of turbidity and total coliform had significantly increased from the levels that existed prior to the cyclone. This was perhaps the result of massive quantities of sediment and trash entering the water supply systems during the cyclonic event. In a similar manner, Rivett et al. [60] conducted a longitudinal investigation and discovered *E. coli* concentrations in hand-pumped boreholes located close to the cyclone-induced flooded area in the Mulanje District, Malawi.

#### *3.1.4. Crop damage*

Agricultural crops are susceptible to harm from cyclone-induced wind pressure, excessive rainfall, storm surges, and flooding. This review identified two scientific publications that focused on cyclone-induced crop damage. Among them, Chejarla et al. [7] assessed cyclone-induced crop damage and associated economic losses. They observed a significant economic loss associated with agricultural crops. Besides, Rodríguez et al. [61] worked on tropical cyclone-induced coconut tree damage assessment. They found cyclone Goni caused substantial damage to over three-quarters of the perennial coconut tree crop in Camarines Sur province, Philippines. Similarly, Chakraborty et al. [62] focused on cyclone-induced damage to the jute crop. They found that the jute crop suffered extensive damage as a result of the super cyclone Amphan, particularly due to lodging and substantial inundation. The jute crop suffers from a disordered appearance due to flood-affected plants, which causes the original vertically organized canopy structure to become disorganized.

#### *3.1.5. Infrastructural damage*

About 5 % of the existing studies focused on cyclone-induced infrastructural damages. Shanmugasundaram et al. [32] evaluated Andhra Pradesh storm-damaged buildings in India. They found that the full roofing system collapsed in most of the houses. In addition, they found different types of damages in semi-engineering structures, including roofing collapse, connection failure, gable wall failure, etc. Moreover, cyclones often also blow off industrial asbestos cement roof sheets and disrupt power, communication, and transport. Similarly, Murià-Vila et al. [31] assessed hurricane Odile-induced infrastructural damages in Baja California Sur, Mexico. They explored different types of infrastructural damages, including industrial and commercial buildings, electrical infrastructure, water supply and communication infrastructure, road transport, and associated infrastructure. The makeshift housing sustained significant damage, whereas historical buildings suffered minimal damage.

#### *3.1.6. Income or business disruption*

Abdullah et al. [14] assessed cyclone Aila-induced economic impacts in a coastal sub-district of Bangladesh. They found that higher-income groups are more vulnerable to cyclone hazards. On the other hand, they are also less resilient. They identified an equal income pattern in the post-cyclone among different income groups in high-to severe-affected areas. Similarly, Thomas et al. [63] found that Hurricane Winston significantly impacted the primary source of income for most of the crab fisher-women participating in the study. Between two and three months following the cyclone, around fifty percent of the fisher-women were no longer harvesting crab fish, and those who did continue to do so experienced a variety of difficulties. Further, Sydnor et al. [64] assessed cyclone-induced small business damages. They found that cyclone Katrina disrupted more than sixty percent of small businesses. They identified a variety of types of business disruptions, including utility losses, asset damages, and losses resulting from delayed business restarts. Additionally, they discovered losses in the business environment, which included fixed customers, business employees, and goods suppliers.

#### *3.1.7. Land use and land cover change*

Disaster is one of the agents that contribute to the change in LULC. We identified three studies that addressed cyclone-induced transformations in LULC. Charrua et al. [65] analyzed cyclone Idai-induced spatio-temporal changes in land use in Sofala Province in Mozambique. They used Landsat satellite images to detect changes. According to their research, wetland vegetation and shrub land had the highest decrease in land use type. On the other hand, Kumar et al. [66] estimated the land use before and after the cyclone Amphan in West Bengal, India. They discovered that, as a result of this cyclonic event, the amount of crop and vegetation land that was subject to floods decreased. Similarly, Konda et al. [67] discovered significant damage to crop land and vegetation as a result of the cyclone. High wind pressure from the cyclone uprooted parts of the trees along the roadway and swamped the crop land with storm water.

#### 3.1.8. Mixed damages and losses

Schmidlin [68] and Duvat et al. [69] investigated a variety of damages and losses. Schmidlin [68] examined cyclone-related human tolls, injuries, electrical failure, crop damages, and insured losses in the United States. About two million clients faced power shortages during the cyclone. An interruption in electrical service further caused severe disruptions to public drinking water, wastewater treatment, and fuel supply. Besides, soybeans, corn, and tree fruit were the main losses due to Cyclone Ohio. Duvat et al. [69] investigated cyclone-induced damage to seawalls, beaches, and vegetation. Cyclonic waves damaged the coastal seawalls that protect other structural and non-structural properties. Moreover, the storm surges caused the coastlines to retreat and the beaches to sink in certain areas, while in other areas, they led to a significant increase in beach growth. In addition, they discovered that native vegetation had great resistance to the effects of the cyclone and immediate regeneration, but exotic plants were permanently harmed by the storm.

### 3.2. Consequences of cyclone-induced damage and loss

We selected a total of 37 scientific studies for this review. Of these studies, only nine focused on the consequences of cyclone-induced damages and losses. These studies primarily highlighted the additional impacts of damages and losses caused by a cyclonic event. Thomas et al. [63] reported that Hurricane Winston had a negative effect on the income of crab fishery women; therefore, most of them sold their captured mud crabs instead of consuming protein.

According to Nandi et al. [50], the evident and substantial damage to vegetation caused by cyclone Fani had further impacts on the forest structure and composition. Lewis & Bannar-Martin [47] noted that the structural damage caused by cyclones will significantly affect the biocenoses. On the other hand, Pohlman et al. [56] found that greater germination and development of plants that may impede rainforest canopy regeneration could permanently alter rainforest structure. Besides, after cyclone Yolanda, Malabrigo et al. [43] discovered over 60 % of mangrove plants defoliated. As a result, the large volume of defoliated leaves carried carbon into the water, causing a fish to die three days after the cyclone, which lasted over three weeks. Moreover, cyclones impacted people's confidence in the eventual success of timber plantations [48]. This is because the storm caused significantly more damage to tree plantations than it did to restoration plantings.

Mosley et al. [26] noted that maintaining a steady supply of safe drinking water after a cyclonic event was challenging due to the damage or disruption of most water options. Purwar et al. [59] evaluated the impacts of cyclone Glenda on the water and sanitation systems in Malabon, Philippines. The quality of the water was deteriorating due to cyclonic disruption, the water quality was deteriorating. Moreover, the cyclonic flooding compelled people living in informal settlements to cease using toilets for a period of 3–4 days, leading to the accumulation of sludge in storm water and creating extremely unsanitary conditions. Cyclonic disruption, whether direct or indirect, can either destroy or damage water and sanitation facilities. Rafa et al. [25] found that the disruption of water and sanitation facilities caused further outbreaks of infectious diseases, mainly diarrhea and skin infection disease, among the cyclone-affected coastal communities in Bangladesh. Purwar et al. [59] stated that cyclone Glenda caused several damages to water and sanitation systems. Consequently, severe damages forced the dwellers to buy safe drinking water, which contributed to an increase in water prices because of the sudden crisis and huge demand. In addition, the long-term use of unsafe water led to further health-related problems and increased economic costs.

### 3.3. Adaptation strategies to cyclone-induced damage and loss

The selected 37 studies identified a total of eight types of cyclone-induced damages and losses. Approximately 35 % of these studies concentrated on adaptation strategies. These studies included a total of 13 types of coping mechanisms (Table 1). Four studies [48,53,54,56] identified natural regeneration of vegetation as one of the adaptation mechanisms for damaged vegetation. Haq et al. [54] also explored the planting of homestead vegetation with long root trees as an adaptation mechanism following Cyclone Sidr in Bangladesh.

**Table 1**
Adaptation strategies discussed in the existing literature.

| Adaptation strategies | Author(s) |
|---|---|
| Natural regeneration of vegetation | Franklin et al. [53], Kanowski et al. [48], Pohlman et al. [56], Haq et al. [54] |
| Tree plantation | Haq et al. [54], Wang & Xu [52] |
| Water purification | Mosley et al. [26], Rafa et al. [25] |
| Provision of safe drinking water and sanitation | Paul et al. [28], Rafa et al. [25] |
| Emergency power plants | Schmidlin [68], Murià-Vila et al. [31] |
| Temporary shelters | Schmidlin [68] |
| Proper medical services | Paul [27], Paul et al. [28] |
| Reduction the protein consumption of | Thomas et al. [63] |
| Borrowing money | Abdullah et al. [14] |
| Selling productive assets | Abdullah et al. [14] |
| Fishing in water-logged areas | Abdullah et al. [14] |
| Wages or money transfers | Abdullah et al. [14] |
| Sundarbans based livelihood | Abdullah et al. [14] |

Furthermore, Wang & Xu [52] discovered that both private and public efforts to plant vegetation play a significant role in rejuvenating the cyclone-damaged vegetation.

Cyclone-affected communities followed water purification methods (such as chlorination and the use of purifying tablets) to cope with the deteriorated quality of water caused by the tropical cyclone [25,26]. On the other hand, the emergency provision of safe drinking water (such as potable water or rainwater) and sanitation (newly built or available at cyclone shelters) was identified in the existing literature [25,28]. Schmidlin [68] and Murià-Vila et al. [31] further explored the development of emergency power plants for water supply, shelter lighting, and hospital treatment. Nevertheless, temporary shelters provided by non-government agencies acted as the key adaptation mechanism for cyclonic effects [68].

The government and non-government agencies identified proper medical services as the key coping mechanisms for health-related problems, including diseases and injuries. According to Paul et al.'s findings [28], a massive post-cyclone pandemic did not arise after the cyclone Sidr in Bangladesh for a number of reasons, most notably the availability of medical services and vaccination programs. Moreover, Paul [27] reported that most of the Bangladeshi Cyclone Sidr casualties received medical care onsite or at nearby medical centers. First responders or mobile medical professionals typically provide onsite treatment. Following the cyclone, medical teams and health professionals provided rapid medical assistance, opened temporary healthcare centers, and gave psychological treatment to victims.

Abdullah et al. [14] found that higher-income groups are less resilient to cyclonic effects. In addition, they investigated the most prevalent adaptation tactics in coastal Bangladesh, such as obtaining credit, selling valuable assets, catching fish in waterlogged areas, receiving wages or money transfers, and relying on the Sundarbans for people's livelihoods. Moreover, Thomas et al. [63] observed that cyclone-affected communities were supposed to reduce their seafood consumption (such as mud crab) to repair their livelihood assets.

### *3.4. Research gaps and limitations in the existing literature*

About 40 % of the existing studies included potential research gaps and limitations. Charrua et al. [65] identified future research needs for cyclone-induced changes in LULC at the local or regional level. Kumar et al. [66] also noted a lack of ground-based studies and very high-resolution satellite data to quantify cyclone-induced change in LULC. Nandi et al. [50] identified the lack of use of very high-resolution satellite images to investigate canopy gaps and variations in vegetation composition as a research limitation. Similarly, Mishra et al. [46] also advocated using high-resolution satellite images to conduct intensive research on the ecological damages of cyclones. However, Lewis and Bannar-Martin [47] and Thomas et al. [63] recommended focusing on long-term, intensive research. Most studies on cyclone-induced vegetation damage and loss focused on branch breaking, uprooting, defoliation, and snapped stems. So, previous research looked into the gaps in knowledge by looking at the links between forest functional traits and patterns [55], between scattered vegetation and cyclone damage [56], and between cyclone-resistant species [42].

Some studies identified a lack of comparative studies to address the damages and losses caused by a cyclonic event. For example, Paul et al. [28] addressed the lack of comparative health studies to investigate the health-related effects of cyclonic hazards. Besides, Murià-Vila et al. [31] observed a lack of comparative infrastructural damages. Paul [27] asserted that there is a dearth of research on disaster-related injuries, particularly in developing nations where the issue has received minimal attention. Schmidlin [68], on the other hand, observed a lack of study on how inhabitants notice warning signals and respond to them. Furthermore, Sydnor et al. [64] identified a deficiency in research regarding the collection of revenue before the cyclone and its impact on responsibilities. Moreover, Purwar et al. [59] noted a lack of research on cyclone-induced service network failure.

Existing literature has also identified research gaps based on focus areas, such as cyclone-induced damage and loss, consequences, and adaptation strategies. Results revealed that about 76 % of studies did not include the consequences of cyclone-induced damages and losses. Moreover, about 65 % did not include adaptation strategies. Moreover, about 95 % of studies did not include all three desired focus areas (Table 2).

## 4. Discussion

### *4.1. Cyclone-induced damage & loss, consequence and adaptation*

This review's results showed that 41 % of studies relied on either image analysis exclusively or field surveys, with the majority using Landsat satellite images. Similarly, Gani et al. [70] and Siddik & Islam [38] found Landsat to be the most widely used satellite image for identifying the changing nature of LULC. Landsat images are the most familiar satellite images to detect changes in vegetation, crop land, built-up area, etc. because of their large coverage, enormous archive, high spectral resolution, and easy and free

**Table 2**
Focus area-based research gaps in the existing studies (for details, see Table S3).

| Focus areas | Inclusion (%) | Gaps (%) |
|---|---|---|
| Only Damage and loss (D&L) | 100 | 0 |
| D&L + Consequence (C) | 24 | 76 |
| D&L + Adaptation strategies (AS) | 35 | 65 |
| D&L + C + AS | 5 | 95 |

access [38,70,71]. Moreover, Avitabile et al. [72] and Wijedasa et al. [73] found Landsat images suitable for identifying field biomass and forest cover. Olthof et al. [74] employed Landsat images to cartographically depict the impact of ice storms on forest damage. They discovered that Landsat images worked well for identifying areas with low to medium damage. On the other hand, Bi et al. [75] determined that while Landsat or satellite image observations are useful in addition to ground observations, they cannot replace them when it comes to assessing cyclone damages and recovery in tropical forests.

Considering the findings, we proposed an adaptation framework for the comprehensive study addressing cyclone-induced damage and loss, consequences, and adaptation strategies (Fig. 6). We can classify cyclone-induced damages and losses into eight major types: death and injuries, vegetation, water and sanitation, agricultural crops, income- or business-related losses, LULC changes, infrastructural damages, and mixed damages and losses. Results revealed that the cyclone caused several direct and indirect health- and injury-related problems. There were different sorts of cyclone-induced injuries, including soft-tissue damage, fractures, and dislocations [27]. Besides, existing literature included different types of physical and mental illnesses, including diarrheal diseases, infections of the respiratory system, typhoid, skin diseases, fever, and corneal infections [28,29]. According to Bartholdson & von Schreeb [30], disasters caused >2 million dwellings in the last decade. Cyclone-induced injuries included cuts, falls, sprains, and contusions. Zadocy et al. [36] conducted a systematic review of tropical cyclone-induced human impacts. Based on their findings, the major cyclone-induced injuries were blunt trauma, wounds, lacerations, contusions, etc. Key coping mechanisms for health-related issues, such as diseases and injuries, were identified as access to proper medical services provided by government and non-government institutions [27,28]. Moreover, timely evacuation was also identified as one of the key actions that can reduce post-disaster deaths and injuries [76–78]. Acero et al. [77] found that the rate of evacuation intention is critical due to awareness of proper evacuation areas and faith in concerned authorities. Further, Moniruzzaman et al. [78] identified the reasons for late evacuation during a cyclone. They found that shifting household assets, fear of thieves, and not receiving warning signals on time were the main reasons for the late evacuation.

This review revealed that the percent of cyclone-induced vegetation damage varies from 50 % to 95 % across the globe [42–47]. Earlier studies also found similar results. On the Cobourg Peninsula in Australia, the cyclone damaged more than 50 % of the vegetation, according to Bowma & Panton [79]. However, Dittus [33] found that the cyclone-induced total vegetation loss was 40 %. Scholars found a higher rate of cyclone-induced damages and losses in the early successional trees [53,56]. People have long recognized coastal greenbelts as a cost-effective and environmentally friendly method to safeguard coastal districts and seaward islands from storm surges [80]. Planting trees was found to be more susceptible to wind-related damage than natural vegetation [48, 58]. There are several types of vegetation damage and loss described in the existing literature, including uprooting, broken branches, snapped stems, and defoliation. Trees with superficial roots and large crowns suffered more cyclone-induced damages and losses [54]. Besides, understory trees are more susceptible to cyclone-induced mortality, while saplings are less susceptible compared to canopy trees [47,56]. However, according to Dittus [33], where there is more cyclone-induced damage to tree trunks and branches, there is

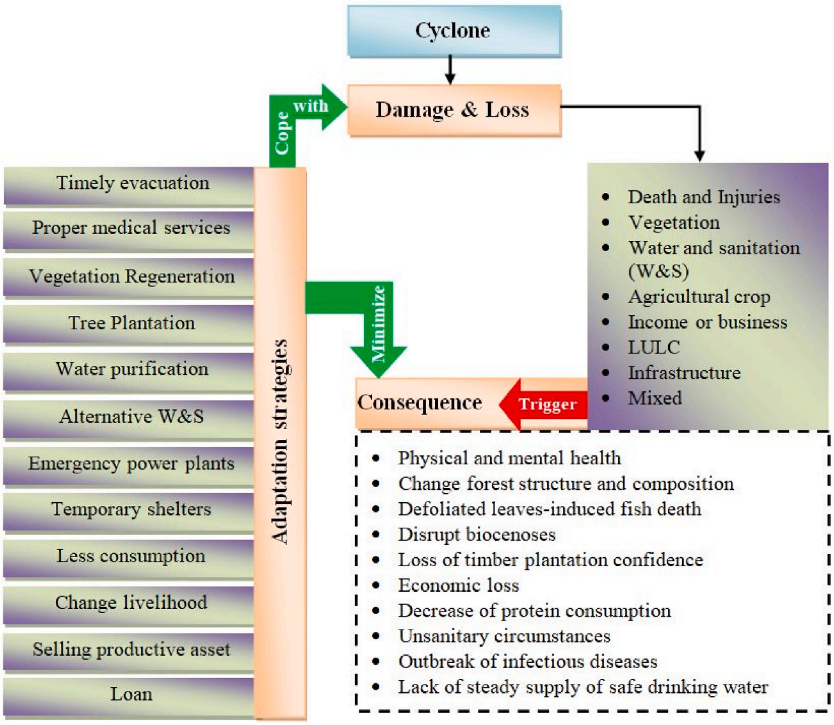


**Fig. 6.** Proposed framework for adaptation to cyclone-induced damage and loss.

greater tree mortality. Furthermore, researchers found a higher level of defoliation in the scattered upper layers of trees. Cyclone-induced forest structural damages will have considerable further impacts on species structure, composition, and forest biocenoses [47,50,56]. Tropical cyclones alter species distributions, interactions, structure, and functioning, as stated by Platt et al. [81] and Willig et al. [82]. According to Ibanez et al. [34] and Quigley & Platt [35], frequent cyclones cause changes to the forest composition and structure both regionally and globally. Two main types of forest adaptation measures were identified in this review, including forest regeneration and tree plantation [48,52–54,56]. Similarly, Rahman et al. [83] found tree plantations to be effective adaptation measures. However, they identified some drawbacks of tree plantations, including uprooted tree-induced human causalities and structural damage. Haq et al. [54] recommended planting long-root trees to minimize such drawbacks.

Two of the sectors most disrupted by cyclones are water and sanitation. Cyclones mainly deteriorate water quality and damage water and sanitation structures. Such disruptions and damages further hamper the steady supply of safe drinking water and create an unhygienic environment [25,26,59,60]. Consequently, such conditions trigger further outbreaks of infectious diseases, mainly diarrhea and skin infections [25]. Flooding conditions also yielded similar results. Nyoni et al. [84] found that water-borne diseases such as typhoid and diarrhea increased after the flooding. The key adaptation mechanisms identified were water purification and emergency provision of safe water [25–28]. Related programs can help disaster victims manage the quality of their water during emergencies [85]. A vaccination program reduced the outbreak of cholera after cyclone Idai in Mozambique [86]. Moreover, during cyclone Sidr, researchers identified rainwater harvesting systems (RWHS) as adaptive measures for supplying safe drinking water [19]. Similarly, Moniruzzaman and Siddik [87] identified many effective adaptation strategies for delivering drinking water after the Aila storm. These mechanisms include pond sand filters (both conventional and raised), rainwater harvesting systems (RWHS), water desalination plants, and disaster resilience ponds.

Several researchers identified LULC as one of the cyclone-induced damage and loss areas. Charrua et al. [65] explored that dense vegetation has the highest decreased land use type, followed by wetland vegetation and shrub land. According to the findings of Kumar et al. [66] and Konda et al. [67], vegetation land is more susceptible to cyclone-induced flooding and high wind pressure. Similarly, some other scholars also identified land as the most precious physical asset in socioeconomic life and is transformed due to cyclonic effects [20,88]. In addition, agricultural crops are also susceptible to cyclone-induced wind pressure, excessive rainfall, storm surges, and flooding [7,61,62]. Similarly, Siddik et al. [20], revealed that cyclones cause the transformation of crop land into fisheries, homestead land, or other uses. It can also change the temporary pattern of land use.

Some scholars found cyclone-induced infrastructural damage. The results of the selected studies showed cyclone-induced roofing and wall collapse, power failure, and disruption in communication and transport infrastructure [31,32]. Similarly, Moniruzzaman et al. [9] discovered structural damages caused by disasters, such as houses floating on storm surges, soaring on cyclonic winds, and breaking due to fallen trees. In addition, cyclones cause huge economic losses by disrupting income options, i.e., fishing, farming, and business. Abdullah et al. [14] found that higher-income groups are more vulnerable to cyclone hazards. Thomas et al. [63] reported that Hurricane Winston significantly impacted the income of women working in the crab fishing industry. Furthermore, Sydnor et al. [64] investigated how cyclone Katrina disrupted over sixty percent of small businesses, leading to significant economic losses. Similarly, Azad et al. [89] studied disaster-induced income and economic losses. They discovered that floods hinder access to capital, labor, and land, causing large economic losses. Further, Anttila-Hughes & Hsiang [90] examined the household-level impacts of tropical cyclones in the Philippines. They found that cyclones reduce more than six percent of annual family income. Similarly, Arouri et al. [91] explored the negative effects of floods, storms, and droughts on household income. Such natural disasters reduced the incomes of households by 2 %–6 %.

Finally, future cyclone-induced damage and loss-related research can use the proposed adaptation framework as a guide. The researchers need to consider the consequences and adaptation strategies when performing a comprehensive damage and loss assessment.

### *4.2. Limitations and future scopes*

This systematic review may possess some limitations. The limitations could be related to the methods used to include the literature and the approaches used to determine the results. Therefore, we encourage future research to address these limitations.

- There are some potential biases in the review article. The potential biases of the review itself are not thoroughly explored, which deserves further investigation.
- This review included journal articles in English from two of the most familiar databases, i.e., Scopus and Web of Science. Future research may consider other databases as well as literature in other languages to incorporate more relevant literature. Further, future studies may consider regional or country reports regarding a certain tropical cyclone.
- We considered published documents from 2000 to 2022. To explore more insightful information, future research may include published papers from other years.
- Only 5 % of studies included all three focus areas (damage and loss, consequence, and adaptation strategies), which present specific research gaps. Therefore, this review warrants further comprehensive research that focuses on all the focus areas.
- Future studies may also focus on the specific cyclone-induced damage and associated consequences, as well as adaptation strategies. For example, cyclone-induced land transformation can be a specific damage-focused area for future research.
- Future studies may also focus on vegetation damages and losses, particularly the association between functional traits and patterns, scattered vegetation susceptibility to cyclonic damage, and cyclone-resistant species.

- Further studies may also include comparative studies, with a particular focus on health and injuries, as well as infrastructural damages.
- Future studies should focus on how inhabitants notice warning signals and respond to them, as well as cyclone-induced service network failures.
- Although many studies assessed the post cyclone effects on the ocean and land using satellite observation, Future studies should focus on artificial intelligence-based post cyclone impacts on the ocean and land systems.

## 5. Conclusions

Tropical cyclones have direct and indirect repercussions in many coastal areas worldwide. However, to the authors' knowledge, no one has yet tried to conduct such a systematic review focusing on cyclone-induced damage and loss in coastal areas. Using the widely used systematic review guideline, PRISMA, we selected 37 studies focusing on cyclone-induced damages and losses. Most of the studies focused on Asia, which aligns with Mendelsohn et al. [8] findings. Damage and loss assessment results revealed that vegetation was the most disrupted sector, including cyclone-induced branch breaking, uprooting, defoliation, and snapped stems. Vegetation damage and losses led to further consequences, including disruption of biocenoses, fish death because defoliated leaves carried carbon into the water, changes in forest structure and composition, and loss of timber plantation confidence. Forest regeneration and tree planting were considered adaptation measures in the studies.

Water and sanitation, precisely the quality of water and water-sanitation structures, ranks as the second most disrupted sector, with nearly 11 % of studies addressing this issue. Disruption in water and sanitation further introduced unsanitary circumstances, infectious diseases, a lack of a steady supply of safe drinking water, and raised drinking water costs. However, these consequences were managed through water purification methods, and both government and non-government entities provided emergency potable, safe drinking water. Only 8 % of studies included crop damages, income or business losses, health issues, and LULC changes. Furthermore, only a few studies have included infrastructural and mixed damages and losses in their analysis. These damages and losses led to further consequences, including economic loss, business and supply chain interruptions, decreased protein consumption, and physical and mental health.

On the other hand, government and non-government agencies provide proper medical services to help people adapt to health problems. Based on the results, this review recommends that future research should concentrate on understanding how cyclones alter land use and land cover, identifying the functional traits and damage patterns caused by cyclones, identifying the species most resistant to cyclones, assessing damage to infrastructure, addressing injuries caused by cyclones, implementing an early warning system, and establishing a service network. Future research can also use the suggested adaptation framework to get a complete picture of the damage and loss caused by cyclones and their effects and ways to adapt.

## CRediT authorship contribution statement

**Md. Abubakkor Siddik:** Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Abu Reza Md. Towfiqul Islam:** Writing – review & editing, Validation, Supervision, Resources, Funding acquisition, Data curation.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e33345.

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