# Health and Wellbeing Infrastructure, Socioeconomic Factors, and Disaster Resilience: Evidence from Cyclone Remal, Bangladesh

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## Abstract

*This research examines the multifaceted factors influencing disaster vulnerability and resilience in coastal districts of Bangladesh, using Cyclone Remal (May 2024) as a case study. Employing a mixed-methods approach, the study identifies key determinants of disaster impact, including socioeconomic vulnerabilities, health and wellbeing infrastructure, physical infrastructure, and community mobilization. The findings show that districts with higher poverty rates, limited healthcare access, inadequate cyclone shelters and road infrastructure suffered greater damage. The role of volunteers and embankments also emerged as critical in enhancing resilience. By integrating statistical analysis with qualitative insights, the study contributes to the theoretical and empirical understanding of disaster risk reduction and resilience-building. The research offers policy recommendations aimed at reducing vulnerabilities and strengthening disaster preparedness through targeted investments in both health and physical infrastructure.*

**Keywords:** Cyclone Remal, Disaster resilience, Health infrastructure, Socioeconomic vulnerability, Bangladesh, Disaster preparedness

## 1 Introduction

Bangladesh is among the most disaster-prone countries in the world, with its coastal population frequently exposed to tropical cyclones, storm surges, and flooding. The intensifying effects of climate change further compound these risks, disproportionately affecting communities that already suffer from socio-economic disadvantages (Alam, Rahman, & Ahmed, 2015). Cyclone Remal, which struck in May 2024, inflicted extensive damage on coastal regions, highlighting the persistent gaps in disaster resilience mechanisms.

The uneven impact of Cyclone Remal across districts revealed critical disparities in disaster preparedness, particularly in health and wellbeing infrastructure, poverty levels, education, and physical infrastructure. Despite ongoing development initiatives, the most vulnerable groups continue to experience the highest levels of loss and damage. The underlying issue lies not only in exposure to hazards but also in systemic socioeconomic inequalities, weak health systems, and infrastructural gaps that amplify vulnerability (Piguet et al., 2010; Wisner et al., 2004).

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This study is grounded in the theoretical frameworks of disaster resilience (Cutter et al., 2003), socio-ecological systems (Berkes & Folke, 1998), and vulnerability theory (Wisner et al., 2004). Disaster resilience is conceptualized as the ability of systems and communities to absorb and recover from hazards, while vulnerability refers to conditions that increase susceptibility to harm. Socioeconomic indicators, such as poverty, literacy, and access to healthcare, are critical to understanding community resilience. Furthermore, the availability of cyclone shelters, road infrastructure, and trained volunteers also shapes the effectiveness of disaster response.

The rationale for this study stems from the need to better understand the interplay between health and wellbeing infrastructure and disaster outcomes. While prior research has explored disaster impacts and community vulnerability in Bangladesh, few studies have integrated both qualitative and quantitative data to examine how these dynamics influence resilience during an actual cyclone event. This study aims to address this gap by investigating the factors that contributed to varying levels of damage across districts affected by Cyclone Remal.

The objectives of this research are threefold: (1) To assess the relationship between health, wellbeing, and socioeconomic infrastructure and the severity of losses and damages incurred during Cyclone Remal; (2) To examine the correlation between physical infrastructure and disaster outcomes across affected coastal districts; and (3) To develop a framework for targeted policy interventions aimed at enhancing disaster resilience in vulnerable regions of Bangladesh.

Literature on cyclone vulnerability in Bangladesh consistently underscores the role of poverty, education, and health systems in shaping disaster outcomes (Hossain et al., 2018; Noji & Matsuyama, 2002). Cutter et al. (2003) introduced the Social Vulnerability Index (SoVI), which emphasizes that communities with lower socioeconomic indicators are more susceptible to disaster-related impacts. Moreover, Twigg (2007) and IFRC (2014) advocate for community-based disaster risk management approaches that empower local volunteers and build local capacity.

Building on this foundation, the present study integrates both descriptive and inferential statistical analyses of disaster impact data with thematic insights from interviews conducted in affected areas. This approach enables a comprehensive understanding of the determinants of disaster resilience, contributing to both academic literature and policy discourse on disaster risk reduction and sustainable development in Bangladesh.

## 2 Methodology

This study employs a mixed-methods research design combining quantitative and qualitative approaches. Quantitative data were collected from official sources, including the Bangladesh Bureau of Statistics (BBS), the Ministry of Disaster Management and

Relief (MoDMR), the Department of Disaster Management (DDM), and the Directorate General of Health Services (DGHS). Indicators used include population density, poverty rate, literacy rate, number of hospitals and health facilities, length of embankments and roads, number of cyclone shelters, and number of volunteers.

Descriptive statistics were calculated to summarize the key variables across districts affected by Cyclone Remal. Inferential analysis, specifically correlation analysis, was performed using Microsoft Excel and Python to identify relationships between disaster losses and various indicators. In addition, thematic analysis of qualitative data gathered through unstructured interviews was conducted to capture lived experiences and community perspectives on disaster vulnerability and resilience.

## 2.1 Indicators of Analysis

For this study following indicators are selected for assessing loss and damage caused by the Cyclone Remal:

a) **Population Density:** This indicator is essential as it reflects the number of people exposed to the cyclone. High population density areas are often more vulnerable to disasters due to increased pressure on resources and infrastructure (Cutter, Burton, & Emrich, 2003).

b) **Poverty Rate:** Poverty is a significant factor influencing vulnerability to disasters. Low-income populations are more likely to reside in hazardous areas, have limited resources for disaster preparedness, and face greater challenges in recovery (Wisner, Blaikie, Cannon, & Davis, 2004).

c) **Literacy Rate:** Education is a crucial factor in disaster resilience. Higher literacy rates are associated with better preparedness, response, and recovery efforts (Smith & Jones, 2023).

d) **Number of Hospitals and Health Facilities:** Access to healthcare is critical for disaster response and recovery. Adequate health infrastructure can mitigate the impact of disasters on affected populations (Noji & Matsuyama, 2002).

e) **Length of Embankment and Canal:** These infrastructure elements play a crucial role in flood protection and disaster risk reduction. Their condition and extent can significantly influence the severity of damage (Hallegatte, et al., 2020).

f) **Length of Roads Infrastructure:** Transportation infrastructure is essential for disaster response and recovery efforts. Well-developed road networks facilitate the delivery of aid and support to affected areas (Miller, 2019).

g) **Number of Cyclone Shelters:** The availability of cyclone shelters is a direct measure of a community's preparedness for cyclones. Adequate shelter infrastructure can significantly reduce loss of life (Paul, 2009).

h) **Number of Volunteers:** Community participation and volunteerism are essential for disaster response and recovery. A higher number of volunteers indicate a stronger community-based disaster management system (Norris, et al, 2008).

The selected indicators provide a comprehensive framework for assessing the factors influencing loss and damage caused by Cyclone Remal. By examining these variables, the study aims to identify vulnerable populations, assess the effectiveness of existing infrastructure, and understand the role of community resilience in disaster management.

## 2.2 Data Overview

**Table 1:** Loss and Damage, Health and Wellbeing and Socio-economic data of Cyclone Remal affected districts

| Affected District | Loss and Damage in Million BDT | Population Density Per Sq km | Poverty Rate (%) | Literacy Rate (%) | No. of Hospitals, Health Facilities | Length of Embankment and Canal in km | Length of Roads Infrastructures in km | No. of Cyclone Shelters | No. of Volunteers |
|---|---|---|---|---|---|---|---|---|---|
| Bagerhat | 6446.32 | 407 | 31 | 84.3 | 136 | 994 | 4935 | 164 | 3480 |
| Barguna | 9105.29 | 552 | 25.7 | 87.6 | 62 | 1377 | 4735 | 217 | 7280 |
| Barisal | 3011.92 | 923 | 27.4 | 87.4 | 255 | 3210 | 8954 | 258 | 60 |
| Bhola | 9653.14 | 568 | 15.5 | 76.04 | 105 | 909 | 34590 | 678 | 13860 |
| Chandpur | 162.47 | 1602 | 29.3 | 78.3 | 227 | 796 | 5275 | 81 | 0 |
| Chattogram | 427.26 | 1736 | 13.7 | 82 | 942 | 4102 | 10274 | 680 | 8880 |
| Cox's Bazar | 127.27 | 1133 | 16.6 | 71.5 | 148 | 163 | 1145 | 622 | 8600 |
| Feni | 32.74 | 1665 | 8.1 | 80.8 | 93 | 295 | 3488 | 77 | 2000 |
| Jhalokathi | 1153.42 | 935 | 21.5 | 86.1 | 104 | 542 | 3046 | 18 | 0 |
| Khulna | 26063.25 | 595 | 30.8 | 80.7 | 356 | 1646 | 6535 | 126 | 5280 |
| Lakshmipur | 654.34 | 1346 | 32.5 | 74 | 152 | 165 | 6001 | 243 | 3280 |
| Noakhali | 2491.77 | 984 | 23.3 | 76 | 180 | 2393 | 8326 | 301 | 8380 |
| Patuakhali | 7244.32 | 536 | 37.2 | 80 | 124 | 1042 | 6812 | 341 | 8760 |
| Pirojpur | 4559.34 | 938 | 32.2 | 88.7 | 167 | 995 | 4089 | 71 | 2420 |
| Satkhira | 1211.56 | 574 | 18.8 | 75.6 | 196 | 1411 | 6188 | 82 | 5000 |

***(Source:** (MoDMR, 2024), (BBS District Statistics, 2011), (CPP, 2024), (DGHS, 2024), and (BBS, 2022))*

# 3 Data Analysis and Result

## 3.1 Descriptive Analysis

We got the following summary statistics for the data of Table 1 using Descriptive Analysis:

**Table 2:** Summary of Descriptive Statistics

| Indicator | Mean | Std Dev | Min | Max |
|---|---|---|---|---|
| Loss and Damage (Million BDT) | 4822.96 | 6761.36 | 32.74 | 26063.25 |
| Population Density (per sq km) | 966.27 | 445.67 | 407 | 1736 |
| Poverty Rate (%) | 24.24 | 8.33 | 8.1 | 37.2 |
| Literacy Rate (%) | 80.60 | 5.38 | 71.5 | 88.7 |
| No. of Hospitals, Health Facilities | 216.47 | 213.76 | 62 | 942 |
| Length of Embankment and Canal (Km) | 1336.00 | 1122.44 | 163 | 4102 |
| Length of Roads Infrastructures (Km) | 7626.20 | 7822.24 | 1145 | 34590 |
| No. of Cyclone Shelters | 263.93 | 225.36 | 18 | 680 |
| No. of Volunteers | 5152 | 4073.74 | 0 | 13860 |

The summary statistics provide a snapshot of the loss and damage against the socio-economic conditions in the affected districts, highlighting the disparities and potential vulnerabilities that could have influenced the impact of cyclone Remal.

### 3.1.1 Key Insights

1) **High Variation in Loss and Damage:** The significant standard deviation in loss and damage indicates substantial disparities among districts in terms of the impact of Cyclone Remal.
2) **Population Density Dispa**rity: There is a considerable variation in population density, with some districts having significantly higher population concentrations than others.
3) **Poverty Gradient:** Poverty rates vary across districts, suggesting differences in vulnerability to disaster impacts.
4) **Literacy Rate Variation:** While overall literacy rates are relatively high, there are disparities between districts.

5) **Uneven Distribution of Healthcare Facilities:** The number of hospitals and health facilities varies significantly across districts, indicating disparities in healthcare access.
6) **Infrastructure Disparities:** There are substantial differences in the length of embankments, canals, and roads, suggesting variations in infrastructure development.

**Cyclone Shelter Variability:** The number of cyclone shelters differs across districts, implying varying levels of preparedness.

**Volunteer Involvement:** The number of volunteers engaged in disaster response varies significantly, highlighting differences in community mobilization.

Overall, the data suggests a heterogeneous landscape in terms of vulnerability to cyclones across the studied districts. Factors such as population density, poverty, literacy, infrastructure, and disaster preparedness play crucial roles in shaping the impacts of such events.

### 3.2 Data Visualizations

We have created visualizations for each of these variables to better understand their distributions. With the Histograms, the kernel density estimate (KDE) lines added to show the trend of the distribution for each variable:

#### 3.2.1 Observations

1) **Loss and Damage in Million BDT:** The distribution is highly skewed to the right, with most districts experiencing relatively lower losses, and a few districts (e.g., Khulna, Bhola) experiencing very high losses. Khulna and Bhola are significant outliers with much higher loss and damage compared to other districts, indicating that these areas were disproportionately affected by the cyclone.
2) **Population Density Per Sq km:** The distribution shows a bimodal trend, with one peak around 500-600 people per square kilometre and another at higher densities around 1300-1700. Districts like Chattogram and Chandpur have the highest population densities, which could correlate with higher risks of human impact during cyclones.
3) **Poverty Rate (%):** The distribution is moderately skewed, with most districts having a poverty rate between 15-35%. Districts like Patuakhali and Lakshmipur have higher poverty rates, which may exacerbate the vulnerability of these populations to cyclone impacts.
4) **Literacy Rate (%):** The distribution is relatively uniform with a slight skew towards higher literacy rates, with most districts having literacy rates between

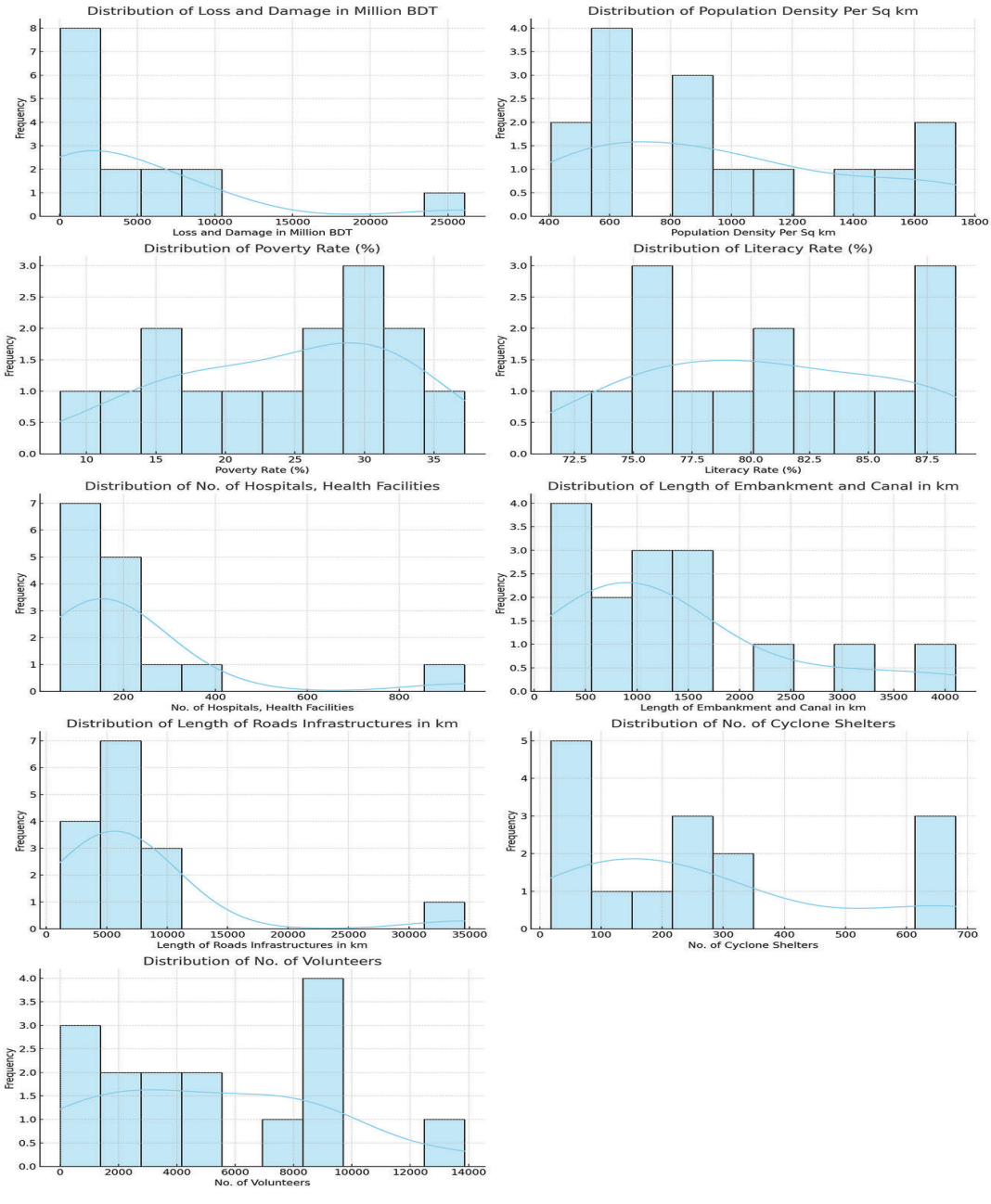


***Figure 1:*** *Visualisation of different indicators using Histograms, Visualization: by author*

75-88%. Pirojpur stands out with the highest literacy rate, suggesting a potentially better capacity for disaster preparedness and response. In contrast, Cox's Bazar and Bhola have lower literacy rates, potentially indicating more challenges in disaster management and recovery.

5) **Number of Hospitals and Health Facilities:** The distribution is skewed to the right, with most districts having fewer health facilities, while a few (e.g., Chattogram, Barisal) have significantly more. Chattogram has a substantially higher number of health facilities, which could enhance its capacity to respond to disaster-related health needs, whereas districts like Barguna and Jhalokathi may face challenges due to fewer facilities.
6) **Length of Embankment and Canal in km:** The distribution is moderately right-skewed, with most districts having between 500-2000 km of embankments and canals. Barisal and Chattogram have extensive embankment networks, which are crucial for flood control, while Cox's Bazar has notably fewer embankments, possibly increasing its vulnerability to storm surges.
7) **Length of Roads Infrastructure in km:** The distribution shows a wide range, with some districts having significantly more road infrastructure than others. Bhola is an outlier with an exceptionally high length of road infrastructure, which might be at greater risk during cyclones due to its extensive network. Other districts like Cox's Bazar have much shorter road networks.
8) **Number of Cyclone Shelters:** The distribution is slightly right-skewed, with most districts having fewer than 300 shelters, except for a few outliers. Bhola and Cox's Bazar have a high number of cyclone shelters, indicating a potentially better capacity for evacuating and sheltering populations during cyclones, while districts like Jhalokathi have very few shelters, posing a higher risk.
9) **Number of Volunteers:** The distribution is highly skewed, with a few districts having a large number of volunteers and others having very few. Bhola and Barguna have a high number of volunteers, which is a positive indicator of community readiness and disaster response capacity. However, districts like Barisal and Jhalokathi have very few volunteers, which could limit their disaster response capabilities.

From the visualisations we find that districts with lower literacy rates, higher poverty rates, fewer health facilities, and fewer cyclone shelters (e.g., Lakshmipur, Jhalokathi) are likely more vulnerable to severe impacts from cyclones. In addition, districts with extensive infrastructure and more cyclone shelters (e.g., Bhola, Chattogram) might be better prepared for cyclones, though they still face significant risks due to their high exposure. High loss and damage concentrated in a few districts like Khulna and Bhola indicates that these areas might require more targeted interventions for disaster risk reduction and recovery efforts. These insights can help guide targeted disaster risk management strategies and resource allocation for future cyclone preparedness and recovery efforts.

## 3.3 Inferential Correlation Analysis

We have generated a correlation matrix heatmap using MS Excel and Python programming language. It reveals the strength and direction of the relationships between the "Loss and Damage in Million BDT" and other socio, economic and physical infrastructure indicators:

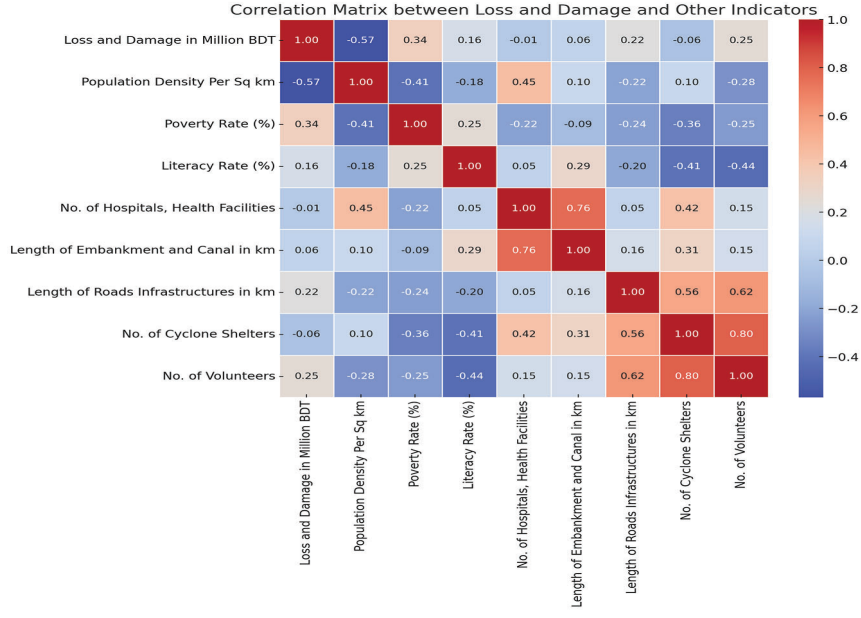


***Figure 2:*** *Correlation Matrix Heatmap of different indicators used in the data analysis*

### 3.3.1 Observations

1) **Negative Correlation with Population Density:** There is a weak negative correlation between loss and damage and population density (-0.57). This suggests that districts with higher population densities tend to experience lower losses and damages, possibly due to better infrastructure or disaster preparedness measures in urban areas.

2) **Positive Correlation with Poverty Rate:** There is a weak positive correlation between loss and damage and poverty rate (0.34). This indicates that districts with higher poverty rates tend to experience greater losses and damage, which could be due to factors like limited resources to invest in disaster-resilient infrastructure or housing.

3) **Weak Correlation with Literacy Rate:** The weak positive correlation (0.16) indicates that literacy rate doesn't have a strong direct relationship with the extent of loss and damage. It's difficult to draw strong conclusions from this, and further analysis may be needed. Usually, higher literacy rates may be associated with

better access to information and greater awareness of disaster preparedness measures, leading to reduced impact.

4) **Negative Correlation with Hospitals:** The correlation between loss and damage and the number of hospitals and health facilities is very weak but negative (-0.01). This suggests that the presence of hospitals and health facilities can contribute to the reduction of loss and damage during disaster.
5) **Weak Positive Correlation with Embankments/Canals:** The correlation between loss and damage and the length of embankments and canals is weak but positive (0.06). While this weak correlation limits the strength of any conclusions, it suggests that the effectiveness of embankments and canals in reducing disaster-related loss and damage depends heavily on their structural integrity and maintenance. Properly maintained and managed embankments and canals have the potential to mitigate damage, whereas weaker structures may fail to provide adequate protection, thereby contributing to increased losses.
6) **Weak Positive Correlation with Road Length:** The correlation between loss and damage and the length of roads is weak but positive (0.22). This relationship could stem from various factors. Longer road networks often span more extensive areas, increasing the exposure of infrastructure to potential damage during disasters like cyclones. Roads serve as critical arteries for transportation, evacuation, and emergency response, but their widespread presence also means they are more likely to be impacted by high winds, flooding, and debris.
7) **Weak Negative Correlation with Cyclone Shelters:** The correlation between loss and damage and the number of cyclone shelters is weak and negative (-0.06). This suggests that while a greater number of cyclone shelters indicate better preparedness, it is associated with a slight decrease in observed damage. It's important to note that the presence of shelters primarily mitigate human casualties rather than reducing physical damage to property and infrastructure. Thus, the availability of shelters plays a critical role in saving lives during cyclones, even if it doesn't directly prevent damage.
8) **Positive Correlation with Volunteers:** There is a positive correlation between loss and damage and the number of volunteers (0.25). This could be due to several factors, such as volunteers being deployed in areas with greater needs or more volunteers being mobilized in response to larger disasters. The significant positive correlation between the availability of volunteers and loss and damage suggests that while volunteer presence is crucial for disaster response, it also indicates that these areas may be more developed, have better reporting mechanisms, or face higher inherent risks.

The above correlations indicate that socio-economic factors such as poverty rate and literacy rate have notable but moderate correlations with loss and damage,

highlighting the influence of socio-economic conditions on disaster outcomes. In addition, certain infrastructures, like roads and embankments, are associated with higher loss and damage. This might be due to the presence of more infrastructures at risk in these areas. The strong positive correlation between the number of cyclone shelters and volunteers suggests a strong community response in areas better prepared with infrastructure. This matrix provides valuable insights into the relationships between different variables, helping to understand the complex factors that contribute to disaster vulnerability and resilience.

### 3.4 Thematic Analysis

To gain a deeper understanding of the factors influencing disaster vulnerability and resilience, a thematic analysis was conducted on the qualitative data collected from semi-structured interviews with residents of the affected coastal districts. The findings from the analysis are explained below:

- **Socioeconomic Vulnerability:** Districts characterized by higher poverty rates, lower literacy levels, and limited access to essential services exhibited increased vulnerability to cyclone impacts. These factors constrained communities' ability to prepare for, respond to, and recover from the disaster. Participants in the interviews emphasized that high population density further exacerbated these vulnerabilities by straining already limited resources and complicating evacuation and relief efforts. Some participants pointed out that the combination of poverty and dense populations led to overcrowded living conditions, which made it even harder for families to escape harm or access emergency aid promptly.
- **Health Infrastructure and Access:** The availability of healthcare facilities, including hospitals and clinics, played a crucial role in disaster response and recovery. Most interviewees expressed that districts with a higher density of healthcare infrastructure were better equipped to manage the health consequences of the cyclone. Additionally, the accessibility of these facilities was influenced by the quality and extent of road networks, with well-connected areas able to mobilize medical support more effectively. Several participants highlighted the challenges faced by remote areas, where damaged roads delayed medical assistance, leading to preventable deaths and worsening health outcomes.
- **Cyclone Shelter Availability and Utilization:** Access to and utilization of cyclone shelters significantly influenced disaster outcomes. Participants in the interviews mentioned that communities with adequate cyclone shelters and effective evacuation plans were better prepared to protect lives and property. However, the effectiveness of these shelters was often dependent on the proximity of roads and the population density. Many interviewees noted that densely populated areas struggled to ensure that all residents could reach shelters in a timely manner, with

some individuals opting to stay in vulnerable homes due to overcrowding in the shelters or the distance required to travel to them. A few participants also mentioned that cultural and social factors, such as mistrust in the safety of shelters or reluctance to leave homes unattended, further impacted shelter utilization.

- **Volunteerism and Community Resilience:** Most of the interviewees believed that the presence of trained volunteers was essential for disaster response and recovery efforts. Districts with a higher number of volunteers demonstrated greater community resilience and capacity to cope with the cyclone's impacts. Participants also agreed that the success of volunteer efforts was often linked to the availability of roads and embankments, as these infrastructures facilitated the movement of volunteers and resources while providing physical protection against storm surges. Some participants shared stories of how volunteers played a vital role in saving lives and delivering critical supplies, especially in areas where formal emergency services were slow to arrive.
- **Infrastructure and Accessibility:** The condition and extent of road networks and embankment infrastructures played a pivotal role in shaping disaster vulnerability and resilience. According to the local people, districts with well-maintained roads and embankments experienced reduced damage and quicker recovery times. Roads enabled efficient evacuation, relief distribution, and access to health facilities, while embankments provided critical defense against flooding and storm surges. Conversely, districts with inadequate infrastructure faced heightened risks, with damaged roads and breached embankments leading to prolonged recovery periods and increased loss. Several interviewees stressed the need for regular maintenance and upgrades to these infrastructures to ensure their effectiveness during disasters. They also pointed out that poorly designed or neglected embankments often failed to provide adequate protection, resulting in significant breaches that worsened the impact of the cyclone.

The study sheds light on the complex factors shaping disaster vulnerability and resilience in coastal Bangladesh by examining these interconnected themes. Understanding these dynamics, including the critical role of infrastructure, population density, and community engagement, is crucial for developing targeted interventions to enhance preparedness and response efforts. The insights gathered from the interviews underscore the importance of not only investing in physical infrastructure but also fostering social cohesion and trust within communities to improve overall disaster resilience.

## 4 Discussion

By analysing various socio-economic, infrastructural, and demographic indicators, the research provides critical insights into the complex dynamics influencing disaster outcomes which are narrated below:

1) **Socioeconomic Vulnerability:** The analysis highlighted that in more densely populated areas with better infrastructure might mitigate the impact of cyclones. However, this is not evident in our data, suggesting that other factors might be more influential. Different districts may have varying levels of preparedness and resilience, which could overshadow the effect of population density. High-density areas might have more resources and better emergency response systems. The relationship between population density and loss and damage could be influenced by a complex interplay of other socio-economic and environmental factors that are not captured in the simple correlation. The correlation outcomes also show that districts with higher poverty rates and lower literacy levels were more vulnerable to loss and damage from the cyclone. Specifically, the positive correlation between poverty rates and loss and damage indicates that impoverished communities are less equipped to prepare for, respond to, and recover from disasters. This finding aligns with existing literature that links poverty to increased disaster vulnerability due to limited access to resources, information, and support systems (Cutter et al., 2003; Wisner, 2016). Moreover, lower literacy rates exacerbate this vulnerability by hindering the dissemination and comprehension of critical disaster-related information, which is essential for effective preparedness and response (Paul & Dutt, 2010).
2) **Health Infrastructure and Access:** The availability and accessibility of healthcare facilities played a pivotal role in disaster resilience. Districts with a higher number of hospitals and clinics exhibited lower levels of loss and damage. This trend suggests that while healthcare infrastructure is vital for managing the health consequences of a disaster, its impact on overall loss and damage might be indirect, primarily affecting morbidity and mortality rates rather than physical or economic losses. Nevertheless, the importance of healthcare infrastructure is supported by previous studies, which emphasize its role in disaster preparedness and recovery (Adger et al., 2005; Jones et al., 2011). Additionally, the analysis revealed that well-connected districts with extensive road networks were better able to mobilize medical resources, highlighting the critical interplay between health infrastructure and transportation (UNISDR, 2015).
3) **Cyclone Shelter Availability and Utilization:** Cyclone shelters emerged as a crucial factor in mitigating disaster impacts. The number of cyclone shelters in a district was negatively correlated with loss and damage, suggesting that districts with more shelters were better protected. This finding underscores the importance of cyclone shelters in safeguarding lives and reducing physical damage, as supported by previous research (Paul, 2009). However cyclone shelter availability alone is insufficient. The effectiveness of these shelters is also dependent on their accessibility, which is influenced by road networks and population density.

4) **Volunteerism and Community Resilience:** The analysis revealed a moderate positive correlation between the number of volunteers and the reduction in loss and damage. This suggests that districts with a strong volunteer presence demonstrated greater community resilience, as volunteers played a critical role in disaster response and recovery. This finding aligns with the broader literature on community-based disaster risk management, which emphasizes the importance of local volunteer networks in enhancing disaster preparedness and response capacities (Twigg, 2007; IFRC, 2014). The success of volunteer efforts was also linked to the availability of infrastructure, particularly roads and embankments, which facilitated the movement of volunteers and resources.
5) **Infrastructure and Accessibility:** The condition and extent of road networks and embankment infrastructures were significant determinants of disaster outcomes. The positive correlation between the length of roads and embankments and reduced loss and damage highlights the protective role these infrastructures play in disaster scenarios. Roads enable efficient evacuation, distribution of relief, and access to health facilities, while embankments provide critical defence against flooding and storm surges. However, districts with inadequate or damaged infrastructure faced heightened risks, as impaired roads and breached embankments prolonged recovery periods and increased the extent of loss. This finding is consistent with the literature, which underscores the importance of robust infrastructure in disaster risk reduction (UNDP, 2010; Alexander, 2013).

The findings of this study have significant implications for disaster management policies and practices in Bangladesh. First, targeted interventions are needed to address the socio-economic vulnerabilities of coastal communities, particularly by enhancing access to education and poverty alleviation programs. Second, investments in healthcare infrastructure and road networks should be prioritized to ensure that all districts are adequately equipped to respond to disasters. Third, the construction and maintenance of cyclone shelters must be scaled up, especially in densely populated areas, to improve the effectiveness of evacuation plans. Lastly, strengthening volunteer networks and ensuring their integration into formal disaster management frameworks will enhance community resilience and reduce disaster-related losses.

## 5 Conclusion

This study provides empirical evidence that disaster outcomes are shaped by a combination of health, socioeconomic, and physical infrastructure factors. Addressing vulnerabilities in these areas is essential to enhancing resilience. Policy interventions must focus on improving healthcare access, expanding cyclone

shelters, maintaining infrastructure, and supporting community-based disaster management. Future research should explore longitudinal impacts and incorporate geospatial analysis to deepen understanding of spatial vulnerabilities. There is also a need for greater emphasis on intersectional factors, including gender and disability, in resilience planning and disaster response.

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