A Study on Natural Hazard Resilience in High-Rise Buildings in the Colombo Municipal Council Area, Sri Lanka

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ABSTRACT

High rise buildings play a pivotal role in urban development, offering solutions to land scarcity while fostering economic and social activities. The vulnerability to natural hazards poses significant challenges to urban resilience. Colombo Municipal Council (CMC) area in Sri Lanka, despite its rapid urbanization and high-rise developments, faces threats from earthquakes, tsunamis, cyclones. which can lead to structural damage and compromise occupant safety. The research aims to identify gaps in current practices and propose strategies to enhance disaster preparedness. Using a qualitative methodology, the study integrates data from expert interviews, case studies, and field observation, focusing on seismic design standards, risk assessments, and emergency systems for earthquakes and tsunamis. The study sample size is six building and key main findings reveal there was an emergent need felt regarding comprehensive design building. Despite the progress made in disaster preparedness, older buildings are still very vulnerable to natural hazards, which puts the lives of occupants and the urban environment at risk. The research provides critical insights into sustainable urban planning and disaster risk reduction, aligning with national and global agendas on urban resilience. The findings underscore the need for policy reforms, capacity building, and investment in resilient infrastructure. Recommendations include adopting and enhancing emergency preparedness and fostering collaboration among stakeholders to ensure the safety and functionality of high-rise buildings during natural disasters. The study contributes to the body of knowledge on disaster-resilient architecture, offering a framework that can be adapted to similar urban contexts. By addressing both structural and non structural aspects, this research advances sustainable and resilient high-rise development, fostering safer urban environments in Sri Lanka and beyond.

Keywords*:* Natural hazard resilience, Disaster risk reduction, Urban resilience, High-rise buildings, Sustainable architecture.

INTRODUCTION

Natural disasters have in the past decade, impacted on a global scale, resulting in the deaths of approximately 1.3 million people and 4.4 billion dollars in economic losses in recent decades (The United Nations, 2024). In global scale disasters have played a vital role in shaping human settlement pattern. A number of recent large-scale disasters underline the necessity for additional measures of resilience, including the 2004 Indian Ocean tsunami, 2005 Hurricane Katrina, 2010 Haiti earthquake, 2011 Japan earthquake and tsunami, and 2013 Typhoon Haiyan. These disasters exposed weaknesses in current risk reduction measures, underlining the necessity for combining innovative engineering solutions and policy interventions to protect human life and infrastructure.

Sri Lanka, situated in the North-Western sector of the Indo-Australian plate, is vulnerable to a range of natural hazards because of its geographical and climatic conditions. Sri Lanka is regularly affected by floods, cyclones,

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landslides, and tsunamis that risk not only human life but also impede national growth by inflicting colossal losses on key infrastructure and economic endeavours. The seismicity in Sri Lanka, while relatively lower compared to highly active areas, is still a concern, especially where tectonic activity along the Sunda Trench can initiate earthquakes and tsunamis ((Dissanayake & Rupasinghe, 2005).

As Sri Lanka, and especially Colombo, continues to urbanize rapidly today, the increasing presence of high-rise structures makes an investigation into their natural hazard resilience ever more critical. One single structural collapse in a high-rise building has the potential to cause cascading effects to adjacent buildings, thus multiplying the overall consequences of a

disaster (Sonali, 2022). The necessity for stringent building codes is understood internationally, and nations implement codes reduce disaster vulnerabilities. Sri Lanka does not have a specific high-rise building code but uses selected international codes. The lack of localized regulatory standards is a key obstacle in increasing the resilience of high-rise buildings in the Colombo Municipal Council (CMC) area (Society of Structural Engineers, 2006). Sri Lanka's disaster management system is not well equipped to deal with the special challenges of high-rise buildings (Disaster Management Centre, 2019).

Though high-rise buildings are increasing in Colombo, there is a notable lack of studies that analyse their readiness for natural disasters. Available studies predominantly concentrate on general disaster readiness without considering the particular vulnerabilities of vertical urban environment. Sri Lanka's disaster management system is not well equipped to deal with the special challenges of high-rise buildings. The fact that seismic events cannot be forecasted properly also underscores the necessity for precautionary interventions aimed at risk reduction and resilience building (Disaster Management Centre, 2019).

This study seeks to bridge these gaps by evaluating the resilience of Colombo's high-rise buildings to natural hazards and no empirical study has systematically evaluated multi-hazard resilience of high-rise buildings in Colombo Through an evaluation of structural vulnerability, existing disaster management strategies, and compliance with international building codes, the research will contribute to enhancing Sri Lanka's National Disaster Plan and align urban development with the United Nations' Sustainable Development Goals (SDGs), particularly Goal 11 making cities inclusive, safe, resilient, and sustainable.

LITERATURE REVIEW

A Hazard is a significant disruption in the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability, and capacity, leading to one or more of the following: human, material, economic, and environmental losses, and impacts (The United Nations, 2024). It tends to be a sudden accident or a natural catastrophe causing great damage or loss of life. According to the Sendai Framework Report, 2021, disaster impact involves all the negative and positive effects of hazardous events or disasters. The term "emergency" is largely used interchangeably with "Hazards," especially when dealing with biological and technological hazards or health emergencies (DAS et al., 2020).

According to Sendai Framework Report, (2021), during the last decade, disasters have continued to inflict severe impacts, causing loss of life and injury, and affecting well-being and security of individuals, communities, and nations. During this decade, disasters killed more than 700,000 people, injured about 1.4 million and left 23 million individuals displaced. Overall, more than 1.5 billion individuals affected by various catastrophes. Economically speaking, losses surpassing $1.3 trillion, between the years 2008 to 2012 alone, disasters caused the displacement of approximately 144 million people. (United Nations, 2015). Contemporary science defines a Hazard as a process or event which combines potentially destructive agents from natural and technological environments with a population situated in conditions of vulnerability created by social and technological factors (Smith, 1996).

Sri Lanka, a small island country located in the Indian Ocean, is highly susceptible to natural disasters owing to its physical location and weather patterns. Flooding, landslides, cyclones, and drought are the most recurring disasters that face Sri Lanka (Mendis & Fernando, 2005). Landslides are regular in the highlands of

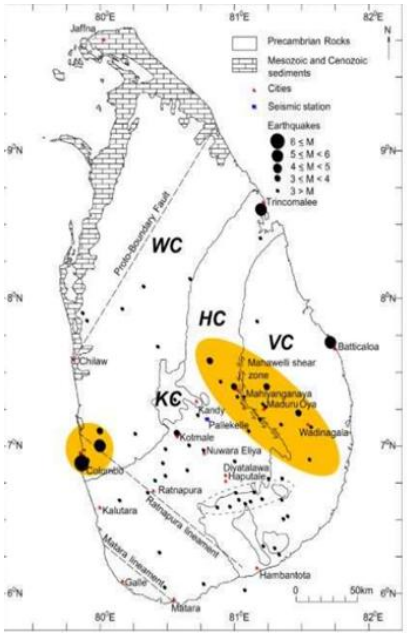
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the center, as deforestation and poor land use contribute to rising slope instability as well (Jayawardena, 2018).

Cyclones, although rarer, also bring enormous dangers to coastal communities, displacement, and damage to infrastructure (Guillermo et al., 2004). Droughts hit the desert regions, affecting farm output and water availability (Hettige, 2009). The World Bank (2017) discusses that 56% of all reported disasters in Sri Lanka are caused by floods, with droughts coming in second at 18%, landslides at 16%, and winds at 10%.

The December 7, 1993, earthquake, with its epicenter 170 km to the west of the city center of Colombo, was 4.7 on the Richter scale and had been recorded to have had seven earthquakes with epicenters close to Colombo since 1819, according to the United States Geological Survey records. Additionally, there were 88 earthquakes in the region surrounding Sri Lanka between the same dates, with magnitudes from 3.0 to 6.0 on the Richter scale, of which 18 had magnitudes from 5.0 to 6.0. These findings support the inclusion of seismic resilience in building codes to control possible risks (Abayakoon, 1998)

Figure1: Local seismicity in Sri Lanka showing reported events within the country from 1500 to 2012



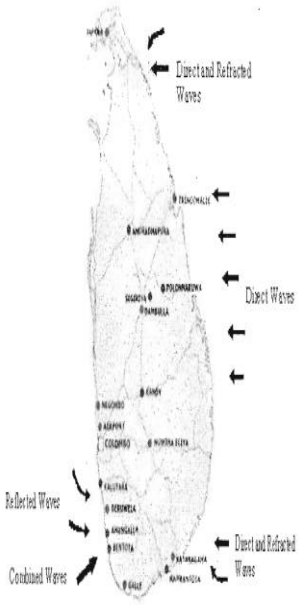
Source: (Abayakoon, 1998)

Figure 2: Wind Zones in Sri Lanka (Design manual "Design building for high winds", 1978)



Source; (Weerasuriya et al., 2016)

Figure 3: Tsunami Vulnerable Areas In Sri Lanka



Source; (Hettiarachchi & Samarawickrama, 2006)

The highlights the importance of integrating disaster resilience into urban planning. He emphasizes that risk-sensitive land-use planning and climate-resilient infrastructure are essential for minimizing disaster impacts. Despite these recommendations, studies reveal that enforcement remains weak, with many buildings failing to meet seismic and flood-resistant design standards (Jayawardena, 2018).

Resilience Theory examines how systems can absorb disturbances while maintaining their core functions. Originally developed by (Walker B et al., 2004). In the context of high-rise buildings, resilience theory underscores the importance of structures being able to withstand natural hazards and recover swiftly in the aftermath of disasters. Another key framework in disaster preparedness is the Hazard Vulnerability and Capacity Assessment (HVCA), developed by the International Federation of Red Cross and Red Crescent Societies (IFRC) in 1999. This model provides a comprehensive analysis of vulnerability, exposure, and adaptive capacity. (Cutter, 2003).

Future research should focus on assessing the effectiveness of disaster risk reduction policies in Sri Lanka, particularly in the enforcement of building codes and land-use planning. Research on the economic impact of disasters in Sri Lanka is also needed to guide resource allocation for disaster mitigation efforts.

METHODOLOGY

The research complied to studying the resilience of high-rise buildings to natural hazards within the Colombo Municipal Council area in Sri Lanka. As the complication and importance of understanding building resilience in front of diverse natural disasters have increased. The methodology deployed integrates systematic field surveys and structured interviews with key stakeholders. These methods were selected to ensure that there is full data collected on architectural integrity, safety measures, and preparedness strategies against earthquake, tsunami, and cyclone natural hazards that are relevant to the geographical and socio-economic context of Colombo (Lee, 2020).

The case study method was identified for six high-rise buildings categorized into office, residential, and mixed-use applications, which are strategically selected for this analysis. The criteria for the selection of buildings were location within the Colombo Municipal Council area, height of over 150 meters, and a date of construction later than 1972 to keep them relevant in urban resilience studies in modern times. Collection of information has been done through direct observation, interviews with experts, and secondary information from architectural and engineering reports on the readiness of these buildings for natural disasters such as earthquakes, tsunamis, and cyclones.

Data were analysed through qualitative content analysis guided by Well-recognized conceptual frameworks of disaster resilience. The research covered the degree of structural integrity, disaster preparedness, and adherence to both local and international building codes. Confidentiality was maintained by anonymizing case study buildings and interview participants. Triangulation methods were utilized to enhance the reliability of the research by comparing insights from multiple sources. Resilience Theory and the HVCA approach are integrated in this study by using HVCA as the diagnostic lens (to identify hazard exposure, vulnerability, and capacity) and Resilience Theory as the outcome lens. Conceptually, the framework links hazards relevant to high-rise buildings in the Colombo Municipal Council area (e.g., earthquake, cyclone/high wind, flood/urban drainage, and coastal surge/tsunami where applicable) to building attributes that shape vulnerability and capacity such as site exposure and soil/drainage context, building age and structural system, façade and non-structural component stability, protection of critical services (water, power, MEP), and the strength of institutional and operational arrangements (maintenance routines, emergency plans, drills, and audits). Each variable is operationalized through a clear set of indicators and evidence sources: hazard exposure is classified using location-based references or proxies (zoning/setting, coastal proximity, flood-prone characteristics), vulnerability is assessed through observable/documented susceptibility indicators (age band, structural irregularities, non-structural risks, occupancy and egress complexity), and capacity is measured through the presence and adequacy of structural provisions, non-structural and lifeline protections (e.g., emergency water storage, backup power, secured equipment, flood protection), and preparedness practices (documented plans, training/drill frequency, and audit records). These HVCA measurements are then translated into resilience outcomes using the “4R” constructs robustness (damage resistance through structural and service protection), redundancy (availability of backups for water/power/egress), rapidity (speed of response and restoration reflected in procedures and practice), and resourcefulness (ability of management systems to mobilize resources and coordinate action) allowing each case-building to be compared through a consistent resilience profile rather than discussing hazards and preparedness as separate, unlinked themes.

The conceptual framework that guides this study incorporates the key variables aligned to the research objectives, which is on the resilience of high-rise buildings to natural hazards in the Colombo Municipal Council area. These are natural hazards, building preparedness and resilience strategies, and resilience performance outcomes.

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DATA ANALYSIS AND FINDINGS

The Selected buildings also vary greatly in their completion years from 1979 to 2025 and in the primary uses, including mixed-use developments, corporate offices, and residential. The presence of structural standards for seismic design, emergency exits, and environmental sustainability certifications is not uniform in these projects, thereby reflecting disparities in their preparedness levels. The proceed to examine these facets to ascertain the resilience of Colombo's high-rise buildings to potential natural hazards.

Table 1: basic details of the building

	Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**	**Project 6**
Date of Completion	2022	1979	2025	1985	2022	2016
Height	47Floors	15 Floors	51 Floors	32 floors	47 Floors	49 Floors
Type of Development	Mixed-Use	Cooperate Office	Mixed-use	Cooperate Office	Residential	Corporate Office
Current Status	Operational	Operational	Development stage	Operational	Operational	Operational
Ownership structure	Domestic	Domestic	Domestic	Domestic	Domestic	Domestic
Locality	Colombo CBD Area	Colombo Commercial area	Colombo CBD Area	Colombo Commercial area	Colombo Suburban Area	Colombo Commercial Area
Current population of the building	1500	1300	2000	1700	600	1,500
Seismic Design	Structural standards	No Considered	Structural standards	No Considered	Structural Standards	Structural Standards
Environmental Sustainability Certificate	No Certificate	No Certificate	Gold Certificate	No Certificate	Platinum LEED Certification	Gold LEED Certification
Parking Facility	600 parking lots with double helix parking facility	100 Parking	750 Parking	250 Parking	300 Parking Spaces	250 Parking Spaces
Number of Elevators	8 Highspeed Elevators	8 Elevators	6 passenger and 2 service	12 Elevators	4 Passenger and 1 Service	6 Elevators
Number of units	192 Luxury apartments & 48 Premium shops	Office	508 Luxury apartments & 20 Premium shops	Office	171 Apartments	Office
Average unit size	3000sqf-5000sqft	10,000-20,000	3000sqf-8000sqft	15,000-20,000	1,200sqft - 4,000sqft	2,000-10,000
Total Area (Floor)	70,000Sqft	40,000Sqft	20,000Sqft	60,000Sqft	35,000sqft	10,000sqft
Security system	CCTV, separate entrance , key card	CCTV, Key card	CCTV, separate entrance , key card	CCTV Key card	CCTV, Key Card Access	CCTV, Key Card Access
Emergency Exits	YES, every 5 floors	Yes , Ground	YES, every 5 floors	Yes , Ground	YES, Every 4 Floors	YES, Every 5 Floors

		floor		floor		
Building Management Company	Own Management	Own Management	Own Management	Own Management	Own Management	Own Management
Community services	Yes	yes	yes	yes	Yes	yes

Source: Author, (2025)

The systematic observation carried out to evaluate the disaster resilience of six approved high-rise development projects within the Colombo Municipal Council (CMC) area. Adopting a qualitative research methodology, data were collected through on-site observations, which were directed by a set checklist derived from past research studies and international safety guidelines. Table 2 presents a comparative analysis of these factors in the selected projects, indicating the strengths and weaknesses in their preparedness for natural hazards. The findings indicate disparities in compliance with seismic standards, fire safety codes, and emergency preparedness, thereby providing important data on the resilience of Colombo's high-rise buildings.

Table 2: Observation Checklist

Component	Check Item	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Foundations	Are piles in good order	✓	✓	✓	✓	✓	✓
	Is the building properly tied to pile foundations	✓	✓	✓	✓	✓	✓
	Are pile foundations supported by bracing	✗	✗	✓	✗	✓	✓
	Do foundations meet seismic standards	✓	✗	✓	✗	✓	✓
Framing /Structure	Are jack studs and wall framing braced	✗	✗	✗	✗	✓	✗
	Is the overall structural integrity certified	✓	✗	✓	✗	✓	✓
Walls	Are masonry walls reinforced	✓	✓	✓	✓	✓	✓
	Do wall materials meet fire resistance standards	✓	✗	✓	✗	✓	✓
	Are external walls impact-resistant	✗	✗	✓	✗	✗	✓
Roofs	Is the roof structure capable of withstanding high winds	✓	✗	✓	✗	✓	✓
	Is roof bracing adequate for seismic forces?	✓	✗	✓	✓	✗	✓
	Are rooftop HVAC systems secured	✓	✗	✓	✓	✓	✓
Water Storage and Supply	Are water tanks secured to withstand earthquakes	✓	✗	✓	✗	✓	✗
	Is an emergency water supply system in place	✗	✗	✓	✗	✗	✗
	Are plumbing systems tested for resilience	✗	✗	✗	✗	✗	✗
Fire Safety	Are fire sprinklers and hydrants operational	✓	✓	✓	✓	✓	✓
	Are fire doors and evacuation routes clearly marked	✓	✗	✓	✗	✗	✓
	Are smoke detection systems	✓	✓	✓	✗	✓	✓

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	functioning						
	Is there a fire drill program for residents	✗	✓	✗	✓	✗	✗
Electrical Systems	Are backup generators tested and maintained	✓	✗	✓	✗	✗	✓
	Are electrical cables secured and insulated	✗	✗	✗	✗	✓	✓
	Are electrical systems protected against flooding	✗	✗	✗	✗	✗	✗
Evacuation Preparedness	Are emergency exits easily accessible	✓	✗	✓	✗	✗	✓
	Are evacuation procedures clearly communicated	✓	✓	✗	✓	✗	✗
	Are emergency stairwells reinforced	✓	✓	✓	✗	✓	✓
Disaster Readiness Plans	Is there a natural hazard risk assessment report	✓	✗	✓	✗	✗	✗
	Is an emergency response team available	✓	✓	✓	✓	✓	✓
	Are regular preparedness audits conducted	✓	✗	✓	✗	✗	✗

Source: Author, (2025)

The Observation data was analysed to generate graphs and visualize key findings related to the basic building details of high-rise structures in the Colombo Municipal Council (MC) area. These graphical representations provided insights for evaluating the observation data throughout evaluating the level of preparedness. The findings were then assessed to evaluate the level of preparedness of these buildings against natural hazards, including tsunamis, floods, cyclones, and earthquakes.

Foundations and Structural Integrity

The structural analysis of six high-rise buildings indicates differences in compliance with foundational and seismic safety norms. All the buildings are firmly anchored to pile foundations, which facilitate effective load transfer and structural stability, especially in seismic zones (Perera, 2020). Still, it can be observed that only three projects (Projects 3, 5, and 6) include bracing to reinforce pile foundations, a vital technique of resisting lateral instability under wind and seismic loading (Perera & Wijesundara, 2021). While four structures (Projects 1, 3, 5, and 6) are compliant with seismic requirements, the lack of compliance demonstrated in Projects 2 and 4 is a cause for concern regarding their earthquake resistance. Also notable is the reality that wall framing braces are only adopted in Projects 5 and 6, yet they are necessary to resist wind and earthquake lateral loads (Perera, 2020). The absence of structural integrity certification for Projects 2 and 4 raises concerns about the necessity for greater compliance with safety protocols in engineering.

Walls and Roof Systems

Fire-resistant materials in the walls are adopted in Projects 1, 3, 5, and 6, as outlined in international fire protection codes (Yuan et al., 2019). Projects No 2 failure to meet the prescribed standards is a serious fire hazard. It is also worth mentioning that only Projects 3, 5, and 6 have impact-resistant exterior walls, which are essential in regions susceptible to extreme weather conditions (Alyami et al., 2018). The roofing of Projects 1, 3, 5, and 6 is engineered to resist high winds; however, Project 2 does not have this essential component, rendering it more susceptible to damage during cyclones or storms. Roof bracing, an essential requirement for resisting wind as well as seismic loading, is also absent in Project 2 (Wang et al., 2019). Rooftop HVAC equipment is also correctly restrained in Projects 1, 3, 5, and 6, thus preventing their dislodgment under severe weather events; the problem is not addressed in Project 2 (Ryan & Chopra, 2018).

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Water Storage, Fire Safety, and Electrical Systems

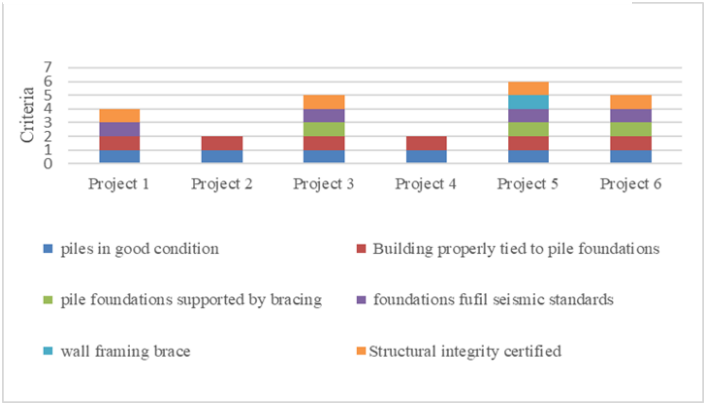
The is only Projects 1, 3, and 5 that have procured earthquake-resistant water tanks, hence ensuring a constant water supply during emergencies (He, 2019). Project 3 is the sole development with an emergency water supply system (Chavez, 2020), whereas the lack of this critical component in Projects 2, 4, and 6 is a potential hazard in the event of crises. Sprinklers and fire hydrants are operational in all the buildings apart from Project 2, a key source of worry regarding fire safety (Zhao, 2019). Projects 1, 3, and 6 have clear evacuation routes, thereby facilitating speedy emergency exit, while Projects 2, 4, and 5 are not well prepared for evacuation (Vesely, 2018). Smoke detection systems, an important feature in the early detection of fire hazards, are operational in Projects 1, 3, and 6 but are not installed in Projects 2 and 4.

Evacuation Readiness and Disaster Preparedness

Emergency preparedness measures are vital in ensuring the safety of the occupants in the event of disasters.

Projects 1, 3, and 6 have successfully implemented safety measures, which include accessible emergency exits, secured stairwells, and well-advertised evacuation procedures. Backup generators are also regularly tested in these projects to ensure that power is available in case of emergencies. Project 5 incorporates insulated electric cables, which work to negate fire hazards, whereas electrical facilities in Projects 1 and 3 are designed to be flood-resistant, thus promoting resilience in flood-prone regions (Zhao, 2019). The inability to incorporate risk analysis and disaster response systems in specific projects is an indication of their susceptibility, especially in coastal regions susceptible to flooding, wind damage, and tsunamis (Bozorg-Haddad et al., 2020).

Figure 4: Foundations and Structure Analyze



Source: Author, (2025)

Figure 5: Walls and Roofs Analysis

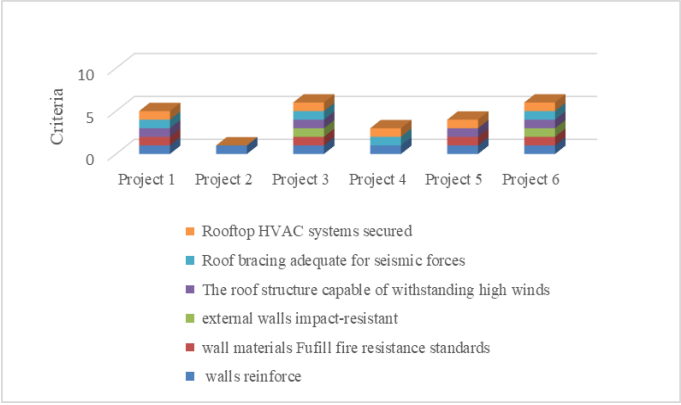
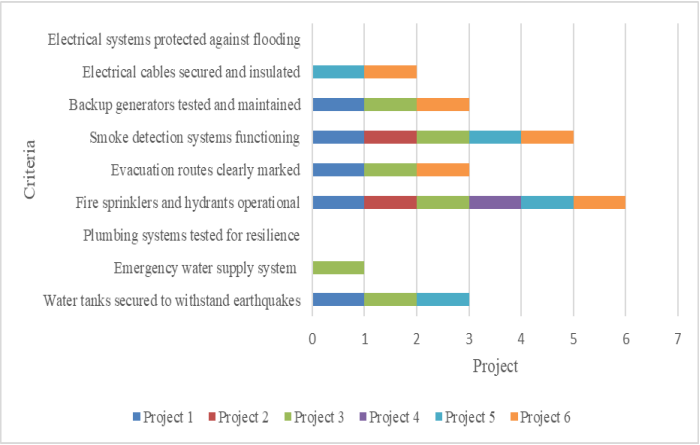
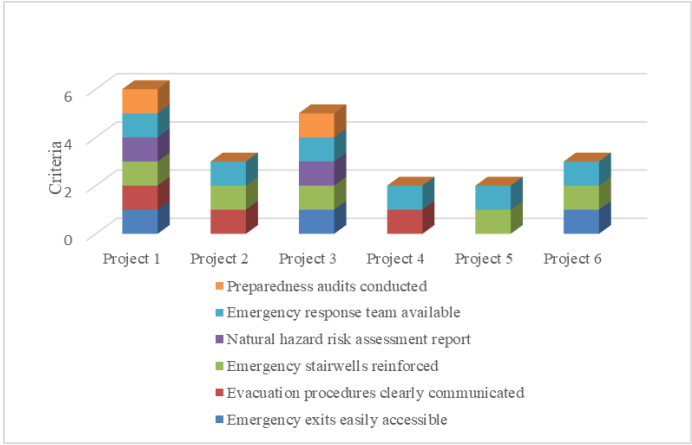


Figure 6: Water Storage, Fire Safety and Electrical Systems Analysis



Source: Author, (2025)

Figure 7: Evacuation Preparedness and Disaster Readiness Plans Analysis



Source: Author, (2025)

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The evaluation of six building projects highlights critical aspects of preparedness levels, emphasizing the importance of comprehensive safety measures across structural and non-structural elements. Projects constructed before 2000, such as Projects 2 and 3, demonstrated significant vulnerabilities, scoring the lowest due to outdated design practices and lack of adherence to modern seismic standards. These buildings fail to integrate essential components like ductile structural systems, bracing, and base isolation, posing severe risks during disasters. Conversely, Projects 1, 4, and 6 exhibited enhanced resilience, scoring higher due to their incorporation of lightweight materials, advanced structural designs, and compliance with updated building codes. Lightweight materials, as noted by Fattah (2020), reduce inertial forces, minimizing structural damage during natural hazards. However, the analysis reveals a lack of attention to critical non-structural measures, such as securing water storage, electrical systems, and plumbing, in most projects. Additionally, while evacuation preparedness was prioritized, only three projects conducted detailed natural hazard risk assessments. Older constructions' vulnerabilities, as highlighted by (Baker et al., 2022), further underscore the need for retrofitting and alignment with modern standards. The study recommends a holistic approach, integrating lightweight materials, non-structural systems, and updated engineering practices to ensure safety and resilience against natural hazards.

Figure 8: Heatmap of Seismic Preparedness

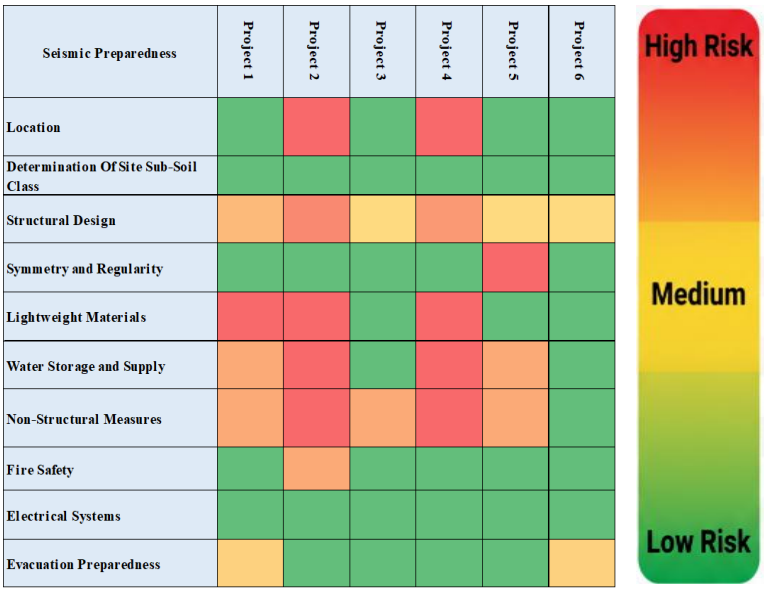


Figure 9: Heatmap of Cyclone Preparedness

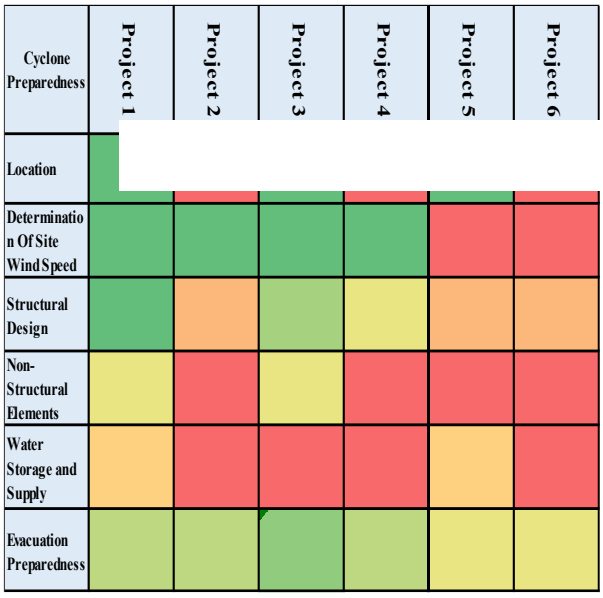
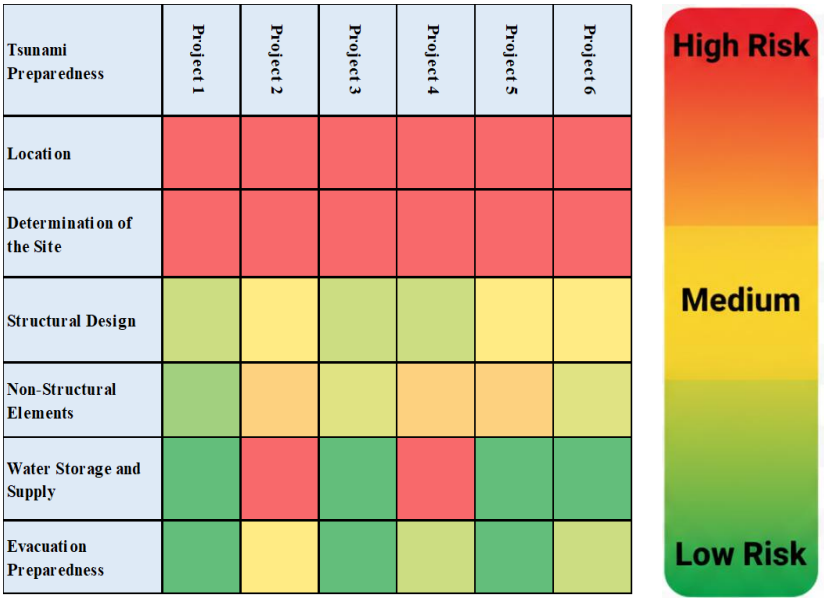


Figure 10: Heatmap of Tsunami Preparedness



Source: Author, (2025)

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RESULTS AND DISCUSSION

The observation discussion brings to the fore different levels of resilience and preparedness at the six high-rise buildings in view, determining that structural integrity, fire safety, water storage, and electrical systems do affect disaster readiness. Projects 1, 3, 5, and 6 have a better approach in terms of compliance with foundational safety features, hence being stable during any natural hazard. The buildings designed and built after 2000 tend to be in better compliance with fire safety, as international standards are met and further confirm that the need for modern fire-resistant technologies in high-rise construction is present.

Roof and water storage systems also show a wide variation in preparedness. Projects 1, 3, 5, and 6 have wind-resistant roofing and secured rooftop HVAC systems, minimizing the potential for structural damage during extreme weather events. The differences are further shown in electrical systems and evacuation preparedness, whereby Projects 1 and 3 have backup power, secured electrical cables, and indicated evacuation routes. Projects 2, 4, and 6 have poor flood protection and disaster response strategies that are required to be improved by carrying out better risk assessments and developing appropriate management plans. Overall, buildings constructed before 2000 have a low level of preparedness and pose a high risk to occupants and adjoining structures. This underlines the urgent need for renovation or reconstruction to enhance their resilience against natural hazards, ensuring the safety of both residents and surrounding infrastructure.

the study reveal significant disparities in the natural hazard resilience of high-rise buildings within the Colombo Municipal Council area, with structural integrity, fire safety systems, and emergency preparedness emerging as critical determinants of overall disaster readiness. Consistent with (Abayakoon, 1998), the analysis demonstrates that inadequate pile bracing and seismic design substantially increase vulnerability to structural failure during earthquakes, particularly in Projects 2 and 4, where non-compliance with seismic standards was evident. The structural performance observed across the six projects aligns with the theoretical framework established by (Baker et al., 2022), which emphasizes that buildings constructed after 2000 demonstrate superior resilience due to incorporation of modern engineering practices and adherence to contemporary building codes. This finding corroborates the broader literature suggesting that regulatory evolution directly translates to improved structural performance (Dissanayake & Rupasinghe, 2005).

The comparative analysis of fire safety and wall systems further highlights the critical importance of material selection and design innovation. Projects 1, 3, 5, and 6, which incorporate fire-resistant materials and reinforced wall structures, exhibit significantly better compliance with international standards than their older counterparts. However, the absence of external impact-resistant walls and structural bracing in Projects 2, 4, and 5 presents concerning vulnerabilities, contradicting contemporary resilience literature that emphasizes multi-hazard design approaches. This gap echoes findings by (Yuan et al., 2019) regarding the efficacy of fire-resistant technologies in high-rise construction, suggesting that while modern buildings progressively adopt these measures, retrofitting older structures remains inadequately addressed.

The water storage and electrical systems analysis reveals a particularly acute vulnerability in disaster recovery capacity. As noted by (Wijetunge, 2004), emergency water supply systems are essential for maintaining building operations during crises; yet, only Project 3 incorporates this critical infrastructure. Similarly, the lack of flood-resistant electrical systems in most projects contradicts resilience principles articulated by (Kodikara, 2020), which emphasize that functional electrical design is paramount for enabling urban high-rise operations during emergencies. Projects 1 and 3 demonstrate best practices through backup generators and secured electrical configurations, establishing a model for disaster resilience.

Evacuation preparedness and disaster response strategies exhibit considerable variation, with Projects 1, 3, and 6 implementing comprehensive measures including accessible emergency exits and clear evacuation procedures, whereas Projects 2, 4, and 5 demonstrate insufficient preparedness. This differential performance underscores the urgent necessity for holistic risk assessment and management planning. The research demonstrates that buildings constructed prior to 2000 require immediate attention through retrofitting or reconstruction to enhance resilience, ensuring occupant safety and protecting surrounding infrastructure from cascading disaster effects.

CONCLUSION AND IMPLICATIONS

The research critically analysed the preparedness for natural hazards such as earthquakes, cyclones, and tsunamis in high-rise buildings within the Colombo Municipal Council area. The findings indicated that buildings constructed prior to the year 2000 have low resiliency due to antiquity of design standards, while the ones constructed after 2000 are more prepared, with the incorporation of modern building codes. Projects 2 and 4, with execution dates prior to 2000 in the coastal area, show a special fragility: seismic activity, strong winds, and tsunamis will continue to bear high risks. Conclusively, the paper stated that in regard to fully considering both structural and non-structural measures like the use of light material, full risk assessment enhancement, 3.

Given the challenges, the study calls for a multi-stakeholder approach to enhance hazard resilience. The short-term measures involve compulsory safety audits and risk assessments, while medium-term measures involve updating building codes, retrofitting older structures, and strengthening coastal planning policies. While considering the long-term strategy, the National Resilience Framework is envisaged to be developed along with hazard-resilience certification, along with capacity building of architects and engineers. Names of institutions included in this exercise are the Urban Development Authority (UDA), National building Research Organization (NBRO), and Disaster Management Centre (DMC) for the implementation. By prioritizing the measures outlined earlier, Colombo can significantly reduce its vulnerabilities to become a model for disaster preparedness in South Asia, while ensuring urban safety and sustainability.

The implications of this study underscore a critical need for enhanced policy frameworks and stakeholder collaboration to improve the natural hazard resilience of high-rise buildings in Colombo. The uneven compliance with seismic and fire safety standards highlights gaps in regulatory enforcement and practical implementation, especially among older structures, which remain highly susceptible to disaster impacts. This finding aligns with previous research emphasizing that building codes alone are insufficient without strict enforcement and continuous monitoring. Additionally, it stresses the importance of retrofitting vulnerable buildings as an urgent priority to prevent catastrophic failures during natural hazards. Beyond physical infrastructure, the research points to the significance of integrating community awareness and education programs, which are essential for effective disaster preparedness and response. Urban resilience must thus be re-envisioned as a holistic concept that combines robust engineering, governance capacity building, and sustainable urban planning to address multifaceted risks and climate change challenges.

Looking forward, future research should focus on evaluating the real-world impact of updated building codes and their enforcement in Sri Lanka, including assessing the practicality and cost-efficiency of retrofitting strategies for existing high-rise structures. Furthermore, integrating advanced climate and hazard modeling with urban land-use planning can provide more precise risk predictions, tailoring resilience strategies to anticipated environmental changes. Longitudinal studies that examine the effects of increased municipal empowerment and public engagement on resilience outcomes would offer valuable insights into social dimensions of disaster preparedness. Comparative research between Colombo and other South Asian cities experiencing rapid urbanization could identify transferable lessons and contextual differences in resilience approaches. Lastly, analyzing the economic implications of resilience investments would guide policymakers and developers in prioritizing resource allocation, ensuring both safety and sustainable urban growth. These research directions will be instrumental in strengthening Sri Lanka's urban resilience, promoting safer, more sustainable high-rise development in the region. Based on systematic observations of six approved Highrise projects using a qualitative approach, the results show clear disparities in compliance and practice across seismic standards, fire safety, and emergency preparedness, and they highlight recurring weak points such as limited emergency water provision, inconsistent risk assessment reporting, and irregular preparedness audits. The findings should be interpreted with limitations in mind: the sample is small and geographically bounded to the CMC area, the methodology is qualitative (interviews/observations/secondary reports), and confidentiality-driven anonymization constrains external verification and broader generalization. In practical terms, the study supports four priority actions strengthen multi-hazard high-rise requirements and enforcement focused on seismic and lifeline protection, mandate periodic resilience audits and clear retrofit pathways, especially for vulnerable/older stock, require non-structural and service continuity measures (e.g.,

emergency water supply, secured systems) as minimum standards, and institutionalize building-level preparedness through routine drills, documented procedures, and recurring audits so resilience is maintained over time rather than treated as a one-time design feature.

Research also emphasizes the "Building Evaluation Framework," which needs to be developed with the inclusion of local and international standards that would assess building resilience against natural hazards. Future research could examine high-rise buildings in other parts of Sri Lanka that are rapidly urbanizing, as well as monitor the longer-term performance of structures completed post-2025. Greater geographic coverage

and monitoring over time will provide richer understanding of how measures for resilience perform and should support policy refinement. These, further on, will also help overcome some existing gaps contributing toward fuller disaster resilience frameworks and finally, safer, and more sustainable urban environments in Sri Lanka.

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