Indicators for quantifying post-disaster functionality: a neighbourhood scale

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ABSTRACT

Natural disasters, such as earthquakes and cyclones, affect people physically and mentally. They can be destructive to the built environment, hindering infrastructure, lifelines, buildings and homes, which all support the daily functioning of society. The impacts from natural disasters are commonly disproportionate to communities with vulnerabilities in their built environment or lower socio-economic attributes. Weak spots within a community can be disguised at larger spatial scales such as city, regional, or national levels. Narrowing in on smaller community units, such as neighbourhoods, will help differentiate vulnerable areas and specific sources of risk. Identifying these weak spots in a community can help focus efforts to improve community resilience. Therefore, this research aims to identify appropriate indicators to quantify functionality at a neighbourhood scale and then obtain community feedback on the relevance of these indicators in a New Zealand context. Examining 11 existing international frameworks on community resilience identified 48 potential indicators across six different dimensions, namely: 1) the physical and built environment, 2) human and health, 3) economics, 4) environmental, 5) social, and 6) governance.

1 IMPACTS OF NATURAL DISASTERS

Natural disasters such as hurricanes, earthquakes, and floods have a range of negative impacts on people and the built environment. People can be affected physically and mentally by the disaster. Some of these impacts include loss of life, injury, depression, post-traumatic stress disorder, chronic disease, and cognitive decline. (Gero et al., 2020). Natural disasters can also be destructive to the built environment, causing billions of dollars in property damages that disrupt human activities (Arumala, 2012).

Over the past decade, natural disasters have resulted in $1.7 trillion US in direct damages and nearly 240,000 fatalities (EM-DAT, 2024; Ritchie & Rosado, 2024). Among these disasters, extreme temperatures (including cold and heat waves), along with earthquakes, have claimed the largest number of lives (EM-DAT, 2024; Ritchie & Rosado, 2024). The impact of earthquakes extends beyond the loss of life, often resulting in significant damage to the built environment. For example, repairing schools, housing, and highways took up to ten years after the 1989 Loma Prieta earthquake in California. Similarly, following the 2011 Canterbury earthquake in New Zealand, the Christchurch Central Business District remained closed for two years, with 11

% of buildings remaining permanently closed (Cook et al., 2022). Reconstruction and recovery events are ongoing 13 years later, highlighting the prolonged impact of such disasters.

In addition to these impacts on the built environment, natural disasters exacerbate socio-economic disparities, disproportionately affecting vulnerable communities. For instance, on a national scale, low-income countries suffer from 3,000 deaths per disaster, in stark contrast to the 500 deaths experienced by high-income countries (Lindell & Prater, 2003). Similarly, within cities, communities with lower income levels and higher proportions of minority residents demonstrate reduced resilience to natural hazards, experiencing more extensive damage and prolonged recovery times (Deng et al., 2021; Hong et al., 2021; Nejat et al., 2022; Yabe & Ukkusuri, 2020). For example, a study on neighbourhood resilience in Texas following Hurricane Harvey in 2017 found that demographic groups characterised by lower household incomes, elevated unemployment rates, fewer homeowners, and larger minority populations experienced larger impacts after the hurricane. This included a larger initial impact on activity levels that did not return to pre-event levels throughout the duration of the study (Hong et al., 2021).

Community resilience is commonly defined geographically at a city, regional, or national scale (Kontokosta & Malik, 2018; Larimian et al., 2020; Loerzel & Dillard, 2021). Further, some of these frameworks focus on specific communities, such as coastal regions, that are less generally applicable to other areas or do not define the spatial boundary of a community, which suggests the method is spatially scalable (Kontokosta & Malik, 2018). However, when resilience is defined only at these larger scales, marginalised groups may be under or misrepresented in community-wide plans. The unique needs of these groups may be overlooked if community attributes are aggregated across a larger scale. Therefore, measuring resilience at a smaller neighbourhood scale more appropriately represents potentially vulnerable groups (Larimian et al., 2020).

1.1 Definition of vulnerability, resilience, and functionality

Due to a lack of universal definitions of vulnerability, resilience, and functionality within the literature (Cutter et al., 2008), it is important to define the terms within this study. Additionally, the linkages and interdependencies between these terms are crucial to understanding neighbourhood functionality.

Vulnerability is broadly defined as the potential for loss (Cutter, 1996), where groups with lower socio-economic status are more vulnerable due to a lack of access to resources such as tools and equipment, money, or human resources needed for recovery (Proag, 2014). Poor populations are more likely to depend on fragile infrastructure and housing and lose a much greater portion of income and assets after a disaster (UNDRR, 2022). Additionally, these groups are more likely to be exposed to natural hazards (Proag, 2014; UNDRR, 2022). For example, 25 % of poor households compared to 14 % of non-poor households were exposed to Cyclone Aila in Bangladesh 2009. In Vietnam, the poor have increased exposure as poor households are clustered in urban areas where they are forced to settle in higher-risk areas due to land scarcity (UNDRR, 2022). In New Zealand, vulnerable groups such as Māori, recent migrants, the elderly, and people with disabilities suffer disproportionately from natural disasters that heighten inequities (Te Uru Kahika, 2022). This was shown in the aftermath of Cyclone Gabrielle 2023 in New Zealand. Out of over 300 houses that were red stickered after the cyclone, two-thirds of these were in Auckland. Many of these were in the lower socio-economic areas of South Auckland that had also suffered from the Auckland Anniversary Weekend floods two weeks before the cyclone (Wilson et al., 2023).

Resilience can be defined as the ability of communities to withstand the stresses from a disaster through preparedness, response, and recovery (Cook et al., 2022; Doyle et al., 2015; Kwok et al., 2016). This includes the ability to mitigate the hazard, respond dynamically to reduce the consequences of any initial loss of functionality, and mobilise resources to reduce the recovery time to restore functionality to the pre-event level (Enderami et al., 2021). Therefore, due to higher vulnerability and increased exposure, groups with lower socio-economic status tend to have less resilience to disasters.

Lastly, functionality is directly linked to resilience; it measures the level to which a community is able to perform actions and operate before and after a disaster. Functionality of a community can be a measurement used to quantify community resilience (Cimellaro et al., 2010). Larger declines in functionality across a community indicate lower levels of community resilience, whereas communities with high resilience will experience a low loss of functionality after a natural disaster. Additionally, due to a lack of resources to enhance recovery efforts, vulnerable communities will have a longer recovery period to restore pre-event functionality.

1.2 Study outcomes

Due to the non-homogeneity of cities (a common geographical scale utilised for community resilience), it is necessary to refine the focus to a neighbourhood scale. This smaller scale better allows a more refined evaluation of a geographical area's strengths and weaknesses to capture its function before and after a disaster. For the purpose of this study, the scale of a 'neighbourhood' is defined as Statistical Area 2 (SA2), a geographic delineation established by Stats NZ. SA2s are designed to spatially capture communities that share social and economic interactions, and in larger urban areas, an SA2 or a group of SA2s typically corresponds to a single suburb (Stats NZ, 2023). These areas generally consist of a reasonably equal-sized resident population ranging from 1,000 to 4,000 people (Stats NZ, 2023).

Indicators are a first step to quantifying resilience at this scale. This project seeks to answer the following research question:

1. What are appropriate indicators for quantifying resilience at a neighbourhood level?

These indicators are to be identified through reviewing the literature within this section of the research. Future research aims to assess how community members value the identified indicators as measurements of community resilience using a survey.

2 INDICATOR DEVELOPMENT

Indicators are commonly used within the literature to measure and quantify resilience within communities (Cutter et al., 2008) and are defined as the factors that affect a system's ability to cope with natural disasters, either contributing to or detracting from functionality (Frazier et al., 2013).

To ensure the broad concept of resilience can be accurately captured, the interaction between the built, social, natural, and economic environments must be represented (Norris et al., 2008). Therefore, indicators that cover a range of appropriate dimensions of resilience should be selected.

The application of these indicators at a neighbourhood level aims to identify vulnerable areas or weak spots within a community where post-disaster functionality can be improved.

2.1 Indicator selection

Existing resilience frameworks were studied to select the commonly mentioned indicators within the literature. Eleven frameworks that had thorough lists of indicators available were studied and are summarised in Table 1.

The frameworks were selected to cover a variety of dimensions. For example, some frameworks were selected that targeted specific dimensions, such as SoVI, which covered socio-economic and demographic dimensions; the NSR framework, which covered social capital dimensions; and the GRDI, which focused on ecosystems. The remaining frameworks aimed to cover broader dimensions of resilience that are not necessarily captured in targeted frameworks. Eleven frameworks were studied to minimise the number of indicators being used for future community feedback while still creating a sufficient list of indicators to cover each dimension.

Table 1: Scale and dimensions covered for each studied index.

Study	Index	Geographic Scale	Dimensions
Cutter et al. (2003)	Social Vulnerability Index (SoVI)	County	Socio-economic and demographic
Hagenlocher et al. (2018)	Global Delta Risk Index (GDRI)	Delta	Social susceptibility, ecosystem susceptibility, lack of coping and adaptive capacity, and lack of ecosystem robustness
Peduzzi et al. (2009)	Disaster Risk Index (DRI)	County	Social, economic, institutional, infrastructure, and community capital
Links et al. (2018)	Composite of Post-Event Well-Being (COPEWELL)	County	Community functioning; prevention and mitigation; population vulnerability, inequality, and deprivation
Tariq et al. (2021)	Community Disaster Resilience (CDR)	Not defined	Physical, health, economic, environmental, social, and governance
Scherzer et al. (2019)	Baseline Resilience Indicators for Communities (BRIC)	Municipal	Social, economic, institutional, community capital, infrastructure and housing, and environmental
Hung et al. (2016)	Climate Hazard Resilience Indicators for Localities (CHIRL)	Village	Inherent biophysical condition; inherent socio-economic conditions; institutional, coping, and infrastructural capacity; adaptive capacity and learning
Campbell et al. (2019)	Flood Resilience Measurement Tool (FRMT)	Not defined	Financial, human, natural, physical, and social capitals
Larimian et al. (2020)	Neighbourhood Social Resilience (NSR)	Not defined	Social capital
Cutter et al. (2010)	Disaster Resilience of Place (DROP)	County	Infrastructural, economic, environmental, social, community competence, and institutional
Lam et al. (2016)	Resilience Inference Measurement (RIM)	County	Demographic, social, economic, government, environmental, and health

Indicators were selected if they were used in more than a single study. This resulted in 43 indicators to consider for use at a neighbourhood scale. An additional five indicators were added after external consultation. This generated 48 potential indicators.

2.2 Indicators selected from the literature

The 48 potential indicators selected for each dimension of resilience are shown in Table 2. Each indicator can be quantified as a percentage, availability per 1,000 persons, or monetary value.

Indicators within each framework may have had differing wording when cross-comparing. Therefore, indicators with similar wording were grouped together and slightly re-worded to be a “percentage of” or “per 1,000 persons” statement. However, the objective of each indicator was not changed.

Table 2: Selected indicators for each dimension based on existing frameworks.

Dimension	Indicator
Physical/Built Environment	Percentage of housing in mobile homes
	Access to shelter places (vacant rental units and hotels/motels per 1000 persons)
	Percentage of households without access to cell phone or landline
	Density of emergency services: hospitals, fire brigades, police stations per square km
	Percentage of households with internet service
	Percentage of households with access to power (electric and gas)
	Percentage of functioning transportation networks and public transport facilities
	Percentage of stormwater drainage in service
	Percentage of students with access to schools
	Percentage of population with access to a grocery store/dairy
	Percentage of workforce with access to the workplace
	Percentage of housing units built prior to 1970 or after 2000
Human/Health	Number of hospital beds per 1,000 persons
	Percentage of population without health insurance
	Percentage of population with sensory, physical, or mental disabilities
	Percentage of households with access to fresh drinking water
	Percentage of people with access to adequate sanitation
	Number of doctors per 1,000 persons
Economic	Percent of households receiving government income (public assistance)
	Unemployment rate (%)
	Per capita income
	Percentage of individuals earning greater than $70,000 p.a.
	Median gross rent
	Median house value
	Percentage of renter-occupied dwellings
	Percentage of population below national poverty line

	Percentage of population employed in farming, fishing, forestry, hunting, and mining
Environmental	Percentage of land in wetlands
	Percentage of total land mass in farms
	Percentage of total surface area as impervious surfaces
Social	Percentage of female population
	Percentage of female-headed households
	Percentage of population from an NZ European ethnicity
	Percentage of population from a non-NZ European ethnicity
	Percentage of population speaking English as a second language
	Percentage of population under 5 years or 65 and over
	Percentage of population with an education below high school (for people over 25 years)
	Percentage of housing units with no car
	Percentage of people affiliated with a religious group
	Percentage of residents living in nursing homes
Social – Social Capital	Percentage of population who believe their neighbourhood has cohesion (People in the neighbourhood pull together to improve the neighbourhood)
	Percentage of population with neighbourhood trust/safety and security
	Percentage of population with sense of neighbourhood belonging
	Percentage of population who feel they can influence decisions in their neighbourhood (political efficacy)
Governance	Civic organisations per 1,000 persons
	Percentage of population covered by approved hazard mitigation plan
	10-year average mitigation spending per capita
	Percentage of population involved in community volunteering

2.3 Dimensions of resilience

To ensure the wide range of needs for community functionality are represented, important dimensions of resilience must be identified. Bruneau et al. (2003) introduced the concept of four dimensions of community resilience. These included technical, organisational, social, and economic. The technical and organisational concepts cover the ability of a physical system and the capacity of an organisation to manage it to withstand external forces, and the social and economic aspects refer to the ability of a community to withstand and recover quickly from a disaster (Bruneau et al., 2003). Studies have built on this idea and used the five capital drivers of resilience defined by Majale (2002) to represent the dimensions of resilience (Campbell et al., 2019; Keating et al., 2017). The five capital drivers include social (trust, group memberships, and social networks), natural (water, land, and wildlife), physical (infrastructure such as water, sanitation, energy, transport, and housing), human (health, knowledge, skills, and information), and financial capital (savings, pensions, and credits).

Additionally, Tariq et al. (2021) built on these ideas and developed the Community Disaster Resilience framework that developed six domains of disaster resilience by analysing 36 disaster resilience frameworks. These final domains were 1) the physical and built environment, 2) human and health, 3) economics, 4) environmental, 5) social, and 6) governance. These domains are representative of the five capital drivers as well as the interactions between the built, social, natural, and economic environments. Therefore, these six domains were used for the study.

The definitions for each dimension of resilience are summarised as follows:

1. Physical: Facilities or structures that perform a vital function that contribute to the normal functioning of communities. Includes power, communication, water networks, and transportation networks (Tariq et al., 2021).
2. Human/health: The ability of communities to provide measures that promote healthy lifestyles and prevent injury and disease. Includes access to quality healthcare facilities or the management of long-term disabilities present within the community (Links et al., 2018).
3. Economic: Factors influencing the community's current economy and the ability to sustain economic growth. Includes income, employment rates, and diversity of employment types (Tariq et al., 2021).
4. Environmental: Natural resources or non-engineered structures (NASEM, 2017). Includes landforms, climate, surface types, and land use such as farms.
5. Social: The capacity of people to connect with each other as individuals, groups, and organisations (NASEM, 2017; Tariq et al., 2021). Includes culture, religion, age, gender, and ethnicity.
6. Governance: The application of laws, regulations, and the capacity of organisations to respond and assist after a natural disaster (Tariq et al., 2021). Includes volunteer groups or mitigation plans.

Indicators from the 11 studied frameworks were grouped into these six dimensions of resilience. While some indicators in Table 2 may have been applicable to more than one dimension, they were grouped into the chosen dimension based on the definitions provided. The dimensions of resilience that have been mentioned as important within previous studies have been recognised before the indicator selection to ensure they are represented within the chosen indicators.

3 DISCUSSION OF SELECTED INDICATORS

Physical/built environment indicators focus on access to buildings such as housing, schools, workplaces, grocery stores, and emergency services, as well as services such as transport, internet, stormwater services, and power. These facilities retain community functionality and facilitate coping responses and preparedness that minimise the risk of damage after a natural disaster (Hung et al., 2016).

The health dimension focuses on healthcare access such as hospital beds, health insurance, doctors, sanitation requirements such as fresh drinking water, and population with disabilities that may be more vulnerable. Access to healthcare services is essential after an event as it is an immediate source of relief. Access is especially important for special needs populations that are disproportionately affected during disasters and may need additional support during recovery (Cutter et al., 2003).

The economic dimension largely covers income and income types, employment types, and the number of rental-occupied homes. Income, savings, and industrial production values improve livelihoods and increase the ability of communities to mitigate disaster risk (Hung et al., 2016). Socio-economic status is important as wealth enables communities to absorb the impact from disasters more quickly. Income can also be represented through the number of renter-occupied households, as renters normally do not have the financial resources for homeownership. Additionally, some employment types, such as those within extraction industries, are more vulnerable to job losses after a disaster, which can increase recovery time (Cutter et al., 2003).

The environmental dimension relates to the land use and cover type, such as farms, wetlands, and impervious surfaces. The presence of different environmental conditions directly affects the exposure to potential disaster events. This directly affects the degree of damage and recovery time (Hung et al., 2016).

Social aspects that affect resilience include age, gender, ethnicity, education, and religion. Women, children, the elderly, and races with cultural and language barriers are considered more marginalised and socially dependent, increasing their vulnerability (Cutter et al., 2003; Hung et al., 2016).

Social capital is the norms and networks that facilitate collective action. Social capital is described as important during the emergency response, serving as a primary base for community response. Additionally, it is the only form of capital that is renewed and enhanced during this period (Dynes, 2005). Social capital can increase disaster preparedness through aspects such as social network support, emotional support, collective action, and trust (Mayer, 2019). Additionally, a sense of belonging and place attachment, safety and security, participation and influence, and local community support can increase neighbourhood resilience (Larimian & Sadeghi, 2019).

Lastly, governance factors relate to mitigation plans, community volunteering, and civic organisations. Disaster governance includes the laws, organisations, institutions, and practices that aim to reduce the impacts from natural disasters (Tierney, 2012). Within Bruneau's four dimensions of resilience, governance is covered by the "organisational" dimension, which describes the ability of organisations to manage critical disaster-related functions to remain resilient to natural disasters (Bruneau et al., 2003).

4 CONCLUSIONS

To minimise the negative impacts on communities after a natural disaster, potential indicators have been identified from the literature. These indicators will be utilised to gather community feedback in order to assess their relevance in a New Zealand context. The identification of these indicators aims to quantify functionality at a smaller neighbourhood level to identify vulnerable areas that may be disguised at the typically larger spatial scales used in previous studies. Forty-eight potential indicators were identified across six dimensions of resilience, including physical/built environment, human and health, economic, environmental, social, and governance.

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