Assessing Social Vulnerability to Climate Change at the Coast

A report for the Resilience to Nature's Challenges National Science Challenge

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Coastal

Executive Summary

Estimates suggest that 65% of Aotearoa New Zealand's population live within 5km of the coast (Ministry for the Environment, 2019). Sea-level rise and other coastal hazards (such as erosion, inundation, and storms) are projected to magnify and become more frequent and/or severe around Aotearoa with climate change (Lawrence et al., 2018; Ministry for the Environment, 2020). In order to pursue appropriate, robust, and equitable climate adaptation to coastal hazards in Aotearoa it is essential to develop clear understandings of the regions, communities, and social groups that are most vulnerable to adverse effects.

This report examines social vulnerability indicators – a methodology widely used to assess who in society is most vulnerable to climate change. Applied in the context of climate change, social vulnerability generally means the propensity of a social group or individual(s) to be harmed by climate change on account of their relative positioning within social, cultural, economic and political systems, with greater harm generally associated to groups experiencing one or more forms of marginalisation (Adger, 2006; Barnett, 2020; Howitt et al., 2012). Social vulnerability indicators comprise a set of qualities, characteristics, or markers that are known to contribute to greater social vulnerability to climate change. They are applied to identify social vulnerability 'hotspots' or populations of concern (groups of people, communities, neighbourhoods, regions, and even countries) and assist decision-makers in prioritising the focus of climate adaptation efforts, including in coastal locations (Atyia Martin, 2015; Birkmann et al., 2022; B. E. Flanagan et al., 2018).

The purpose of this report is to provide a comprehensive overview or stocktake of indicators that are used to assess social vulnerability to climate change. It is intended as a reference document and focusses largely on indicators used in coastal locations, and reviews indicators employed in Aotearoa New Zealand in light of international indicator scholarship and practice. The report uses foundational, widely employed international indicators (such as the SoVI, SVI, and MOVE framework) as a departure point to trace the development of innovative international approaches to assessing social vulnerability to climate change in coastal locations. It discusses the limitations and opportunities for indicator-based assessments of vulnerability in Aotearoa with reference to these international and innovative approaches. A second short report (Johnson & Blackett, 2024) (Johnson and Blackett 2024) provides specific information for decision-makers intending to apply social vulnerability assessment methods.

Internationally, a range of social vulnerability indicators offer nuanced ways to assess vulnerability to coastal hazards. This includes a focus on the dynamic nature of vulnerability (accounting for shifts in vulnerability due to social change and the interaction of scales and systems) as well as consideration of heterogeneous experiences of vulnerability and adaptive capacities within (coastal) communities or regions.

Social vulnerability indicators are increasingly employed in Aotearoa in the context of risk assessment and adaptation planning, including in coastal locations. However, the majority of these indicators replicate the limitations inherent in the foundational international social vulnerability indicators (i.e. static approaches to vulnerability, and assumptions that vulnerability is experienced in the same way by all within a community). To support accurate assessment of climate vulnerability in Aotearoa's coastal communities (and therefore appropriate adaptive responses), there is a need to consider dynamism and diversity more seriously. This could be achieved by drawing on international indicators that account for changing and diverse experiences of vulnerability; making use of the growing body of qualitative and interdisciplinary research on climate vulnerability in

Aotearoa; and co-developing and/or ground-truth indicators so they align with community members' lived realities of vulnerability.

Contents

List of figures

List of tables

1. Introduction

Purpose

This report forms part of the Resilience to Nature's Challenges National Science Challenge Enabling Coastal Adaptation programme. It provides an overview or stocktake of indicators that are used to assess social vulnerability to climate change, with a focus on assessments pertaining to coastal locations. The report reviews the components and characteristics of climate-relevant social vulnerability indicators that are applied in international contexts and within Aotearoa New Zealand, and identifies areas for future growth that represent opportunities to more effectively support robust and sustainable adaptation to climate hazards in coastal Aotearoa.

The social vulnerability concepts

Social vulnerability to climate change is a contested concept that is defined, measured, and analysed differently throughout the academic literature and in policy contexts (Adger, 2006; Eakin & Lynd Luers, 2006; Faas, 2016; O'Brien et al., 2007). Social vulnerability can be understood in this context as the propensity of a social group or individual(s) to be harmed by climate change on account of their positioning within society (Adger, 2006). As opposed to focussing solely on risks arising from exposure to biophysical climate hazards (such as sea level rise), social vulnerability examines how social context (including inequalities, social and cultural norms, and economic and political systems) play a key role in shaping climate risk for different groups of people (Barnett, 2020; Howitt et al., 2012).

Box 1: International definitions of social vulnerability

Major international organisations define social vulnerability to climate change in a range of ways. The Intergovernmental Panel on Climate Change (IPCC) conceptualises vulnerability to climate change as:

"the propensity or predisposition to be adversely affected. Vulnerability encompasses a wide variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC, 2019, p. 826).

Sensitivity or susceptibility refer to factors that shape how much and how seriously a group or individual is affected by climate change, while adaptive capacity or capacity to cope and adapt refers to the ability to take actions that offset harm from climate change (Adger, 2006). The United Nations Framework Convention on Climate Change (UNFCCC) employs an older definition from the IPCC, and states that vulnerability is:

"the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity" (UNFCCC, 2022).

The United Nations Development Programme (UNDP) states that social vulnerability is the "differential capacity of groups and individuals to deal with hazards, based on their positions within physical and social worlds" (Dow 1992), whereby groups have dissimilar access to and control over

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resources, varied levels of risk exposure, and diverging abilities to manage and respond to hazards (Katic, 2017, p. 11). The International Institute for Environment and Development (IIED) and UN Office for Disaster Risk Reduction (UNDRR) add that:

"vulnerability is structured by social, economic, and political factors, particularly access to resources, social capital, and decision-making power. Vulnerability is highly differentiated by gender, sex, age, ability, ethnicity, locality, wealth, Indigenous group, and marginalisation" (Barrett et al., 2021, p. 11).

Indicators

Internationally, scholars and applied researchers have developed indicators to identify social vulnerability 'hotspots' or populations of concern (groups of people, communities, neighbourhoods, regions, and even countries) that will be adversely affected by climate change (Birkmann et al., 2013; Cutter et al., 2003; B. E. Flanagan et al., 2018; Met Office Hadley Centre, 2015). Indicators comprise a collection of qualities or characteristics of a place or population that are known to contribute to a particular outcome – in this case, social vulnerability to climate change. Indicators are able to generate quantitative measures of social vulnerability that assist in prioritising decision-making and channelling resources for hazard mitigation and climate change adaptation to appropriate locations (Atyia Martin, 2015).

Many indicators draw on Cutter et al.'s (2003) seminal work, the Social Vulnerability Index or "SoVI" (explored further below). Certain characteristics (such as age, income, education level, and housing type) are frequently employed to quantify social vulnerability to climate change around the world (see Appendix 1 for further details). However, there is no specific framework that governs selection of characteristics or design of indicators (Roukounis & Tsihrintzis, 2022). A range of scholar-practitioners seek to advance the field by incorporating participatory and/or place-based methodologies, discussions about change over time, interacting scales, a focus on adaptive assets and structural vulnerabilities that help to add nuance to conceptualisations of social vulnerability (R. Hardy & Hauer, 2018; Kashem et al., 2016; Meur-Férec et al., 2008; C. V. Nguyen et al., 2017).

In this report, we use the term 'indicator' to refer mainly to the overarching frameworks that scholars and practitioners have developed to measure social vulnerability (e.g. the SoVI) and which comprise a collection of more discrete demographic, socio-political, or place-based characteristics. However, in keeping with literature and policy discussions, we also use the term 'indicator' to reference the individual characteristics or qualities of a community or region that are used to quantify or otherwise assess vulnerability (e.g. age composition, household income, etc) and which form the component parts of overarching indicator frameworks.

This report

This report lays out how social vulnerability to climate change is framed, understood, and reported around the world and in Aotearoa New Zealand (hereafter, Aotearoa), and identifies how Aotearoa's current frameworks can be enhanced to support context-appropriate policy responses. The report is structured as follows:

- Section 2.1 identifies the theoretical concepts which have given shape to climate-related social vulnerability indicators.
- Section 2.2 explores some of the most well-known or foundational social vulnerability indicators that have been applied to assess climate/hazard vulnerability worldwide, including in coastal locations.

- examines major critiques of social vulnerability indicators, and provides an overview of the new directions emerging in international indicator scholarship and practice, especially at the coast.
- provides a summary of indicators developed by international organisations (such as UNESCO and SPC) to assess social vulnerability to climate change, and links these to the theoretical concepts, foundational indicators, and innovations discussed in sections 2.1-2.3.
- summarises the features of indicators used to assess social vulnerability to coastal climate hazards internationally.
- turns to indicators developed for the Aotearoa context.
- discusses Aotearoa-based indicators that measure concepts related to climate vulnerability (including resilience and wellbeing).
- gives an overview of indicators developed specifically for assessing social vulnerability to climate change in Aotearoa (in both coastal and non-coastal regions).
- lays out the limitations in Aotearoa's current suite of indicators.
- suggests ways to enhance social vulnerability assessment to support more robust and inclusive adaptation to climate change in coastal Aotearoa.
- concludes the report and the provides further details of indicators not otherwise discussed in the body of the report.

2. Conceptualising and reporting social vulnerability

2.1 Theoretical approaches to hazard vulnerability

There are three major "intellectual lineages" (Eakin & Lynd Luers, 2006, p. 367) that inform the study of vulnerability: risk-hazard, political economy/ecology, and human-environment/resilience (Fussel, 2007; O'Brien et al., 2007; Turner, Matson, et al., 2003). These lineages approach vulnerability in very different ways, with varied methodologies, units of analysis, and conclusions about how to overcome risk from hazards (Eakin & Lynd Luers, 2006).

The risk-hazard lineage is associated with engineering, economics, and epidemiology (Fussel, 2007). It conceptualises vulnerability as a condition that arises from exposure to a biophysical hazard and the sensitivity of the unit of exposure to that hazard, with very limited consideration of social context and its' implications for vulnerability (Eakin & Lynd Luers, 2006; Fussel, 2007). Approaching vulnerability in this way often leads to adaptation that favours technological or engineering interventions (like sea walls or irrigation schemes) that are designed to reduce the severity of impacts from the hazard but do little to address underlying causes of social vulnerability amongst those most at risk (Nightingale et al., 2020).

In contrast, the political economy/ecology lineage focusses on the social production of risk and vulnerability, and seeks to identify who is most vulnerable to hazards within a population, and why (Fussel, 2007). It is closely associated with the development, poverty, food security, and geography literature (Fussel, 2007). The political economy/ecology lineage often takes a case study approach to examine the interplay of biophysical processes with local, regional, and global socio-political, cultural, and economic factors that may deepen some peoples' exposure and sensitivity to hazards, and constrain their capacity to recover, cope, and/or adapt (Blaikie et al., 1994; Bohle et al., 1994; Eakin & Lynd Luers, 2006; Liverman, 1990; Wisner et al., 2004). As Eakin and Lynd Luers (2006, p. 370) write,

> "in this literature, vulnerability is not an outcome but rather a state or condition of being –
> and a very dynamic one at that – moderated by existing inequities in resource distribution
> and access, the control individuals can exert over choices and opportunities, and historical
> patterns of social domination and marginalisation."

Lastly, the human-environment/resilience lineage draws on ecology and conceptualises vulnerability as a product of multiple, interacting stressors impacting on coupled human-environment systems (Eakin & Lynd Luers, 2006; Turner, Matson, et al., 2003). The focus in this literature lies equally in social and ecological systems, and emphasis is given to resilience, or the ability of a system to recover, rebound, and adapt to shocks and perturbations (Fussel, 2007; O'Brien et al., 2007).

A number of commentators identify the rise of "integrative" approaches for assessing vulnerability that combine insights from two or more of the above lineages (Drakes et al., 2022; Eakin & Lynd Luers, 2006; Fussel, 2007; O'Brien et al., 2007). Integrative approaches are particularly common in assessments of climate vulnerability, and, by combining a focus on biophysical and social systems concurrently, they serve the increasing need to measure, quantify, and map vulnerable locations and populations such that adaptation resources can be channelled to those most in need (Eakin & Lynd Luers, 2006).

Another application of social vulnerability indicators is tracking the efficacy of adaptation actions and incorporating social signals into Dynamic Adaptation Policy Planning/Pathways. This is outside the scope of this report, however readers are directed to Haasnoot et al. (2013, 2018, 2019) and Lawrence et al. (2020) for further information.

2.2 Major or foundational indicators of social vulnerability to climate change

As Mustafa et al. (2011) observe, theoretical frameworks for analysing vulnerability (including some of those above) often generate nuanced, complex, qualitative information about the causal pathways involved in the production of vulnerability; however, policy-makers need simplified, actionable, and quantitative measures of vulnerability. A wide range of indicators have been developed to provide quantitative measures of social vulnerability to climate change, with many taking an integrative approach combining insights from varied theoretical perspectives and 'vulnerability lineages'. Figure 1 below shows how a sample of indicators reviewed for this report link to the different vulnerability lineages, and in turn, connect to and influence each other.

The SoVI

One of the most frequently used indicators is the Social Vulnerability Index (or SoVI) developed by geographer Susan Cutter and colleagues (Cutter et al., 2003). Influenced to an extent by Cutter's earlier 'hazard-of-place' model (1996), the SoVI conceptualises vulnerability as the combined product of exposure to biophysical hazards, as well as internal social differentiation and inequality within populations (Fussel, 2007). However, the index itself focusses exclusively on the socio-economic and demographic characteristics of a place. The SoVI was developed in order to quantify and therefore compare social vulnerability to hazards amongst US counties and its original iteration draws on the 1990 US census (Cutter et al., 2003). As well as measuring demographic and socio-economic characteristics of a population that mediate social vulnerability (including education, income, occupation, age, race, and gender) the SoVI examines the built environment (including density of housing or commercial establishments, housing stock and tenancy).

At the time of its creation, the SoVI was innovative in its attention to dynamics such as income, age, and race, which had largely been excluded from discussions of vulnerability, especially in the global

north (Adger, 1999; Adger et al., 2003; Liverman, 1999; O'Keefe et al., 1976). Cutter et al. recognised that Americans on a low income, for instance, often have limited savings and disposable income to absorb and respond to losses in the wake of disaster, whilst race-based marginalisation of African Americans, Native Americans, and those of Hispanic and/or Asian heritage can affect access to resources needed to cope and respond to hazards. The material features of a place also feature in the SoVI since they influence the number of people exposed to hazards, and the degree to which they are affected and can adapt. For instance, densely populated areas may suffer significant structural losses from hazards like floods, whilst rental homes tend be built and/or maintained to a lower quality than owner-occupied dwellings, which means they can be damaged more easily in extreme weather (Cutter et al., 2003). Full details of the SoVI (and other major indicators below) can be found in Appendix 2, Table Appendix2.

Cutter et al.'s work set the foundations for many subsequent indicators, and the SoVI (or modifications of it) are widely employed to quantify social vulnerability to climate change including in coastal locations (Boruff et al., 2005; FEMA, 2021; Kashem et al., 2016; Kirby et al., 2019; Martinich et al., 2012; Oulahen et al., 2015). Of the 71 indicators reviewed for this report 26 were influenced by or based upon the SoVI. Appendix 1 provides details of the most frequently used measures of social vulnerability to climate change within international indicators and gives an idea of the significant influence the SoVI has had on selection of variables and design of indicators.
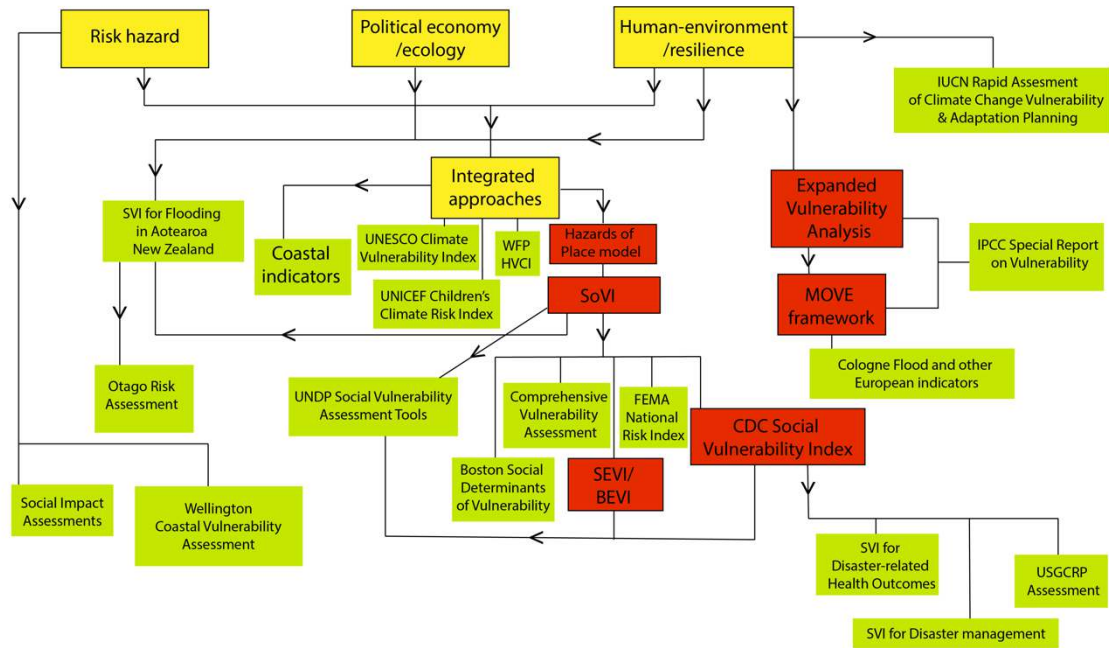
Figure 1 Linkages between vulnerability lineages and select social vulnerability indicators

Yellow boxes represent intellectual lineages

Red boxes represent foundational indicators

Green boxes represent indicators developed from foundational indicators

Expanded vulnerability analysis

At the same time the SoVI was being developed, Turner et al. (2003) proposed the expanded vulnerability analysis framework. In this framework, vulnerability of coupled human-environment systems emerges through interactions between systems as they are affected by dynamic processes and feedback loops at different spatial and temporal scales. The expanded vulnerability analysis exemplifies the human-environment/resilience lineage (above) and emerged as a critique of the political economy/ecology lineage. Turner et al. (2003) state that models of vulnerability developed within political economy/ecology, such as the Pressure and Release framework (Blaikie et al., 1994; Wisner et al., 2004), provide an incomplete picture of vulnerability. This is because such models do not account adequately for the vulnerability of biophysical systems and the effect this has on human systems, and downplay the adaptive actions and resilience of even the most marginalised and vulnerable social systems (Turner, Kasperson, et al., 2003).

In contrast, Turner et al.'s framework examines the exposure, sensitivity, and resilience of both human and environmental systems. More a set of criteria to be measured than an indicator per se, the expanded vulnerability analysis framework examines whom or what in a system is exposed (households, states, ecosystems) and the frequency, magnitude and duration of the exposure; the sensitivity of the systems under consideration (social capital, institutions, or economic structures of human systems, biophysical endowments like soil); and the ability of systems to cope, respond, adjust, and adapt (via policy, decentralised actions, etc). Whilst not an indicator itself, Turner et al.'s framework has been applied to (coastal) case studies in Mexico's Yucatan Peninsula and Yaqui Valley, and regions of the Greenland and Norwegian Arctic to generate holistic assessments of vulnerability (Turner, Matson, et al., 2003). The framework has also influenced a range of subsequent indicators including the MOVE framework below.

The MOVE framework

The Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) framework provides a heuristic tool that can be used for developing vulnerability assessments and context-appropriate indicators (Birkmann et al., 2013). Influenced by scholarship on disaster risk management, climate change adaptation, and the human-environment/resilience lineage, the MOVE framework takes an integrative, multidimensional approach to vulnerability. This accounts for both social and ecological systems and their interaction. Vulnerability emerges from exposure to natural and socio-natural hazards, susceptibility and fragility of a system (due to its physical, ecological, social, economic, cultural or institutional components), and the lack of resilience of a system (lack of capacity to anticipate, cope, and recover from hazards). Vulnerability, however, is mediated and/or offset by risk governance and adaptation (i.e. interventions that reduce exposure and susceptibility, and alter levels of resilience) and is therefore highly dynamic over both space and time (Birkmann et al., 2013).

The MOVE framework was applied to seven case studies around Europe and used to develop a series of indicators for social vulnerability that were standardised in their approach yet tailored to the specific context. These included indicators for vulnerability to flooding in Cologne and earthquakes in Barcelona (Birkmann et al., 2013), as well as landslide, avalanche, and flooding in the Danube river basin of Austria; earthquakes, floods, storms, and landslides in Italian cities; heatwaves and drought in London; forest fires, and coastal hazards in Portugal; and avalanches, flash floods, landslides, and extreme temperatures in Italy's south Tyrol (European Commission, 2013). The Cologne flood indicator examines factors such as the number of exposed people living in flood-prone areas, the percentage of people who are able to evacuate themselves based on household age structure (as a measure of sensitivity, with elderly people generally having more difficulties than those from

younger age brackets), and the ability of flood early warning systems to help those exposed to adapt (Birkmann et al., 2013).

The Social Vulnerability Index (SVI)

The SVI has been extensively applied in the US context to assist local government personnel identify communities most at risk to disasters. Originally developed in 2000 by the US government Centers for Disease Control, the SVI comprises fourteen indicators (or measures) for social vulnerability (Centres for Disease Control and Prevention (CDC), 2015). These indicators are based upon the US census and American Community Survey data and rank census tracts at either the state or national level (with county level rankings also available, like the SoVI). Different iterations of the SVI were released in 2010, 2014, 2016, and it is now updated every two years (Centres for Disease Control and Prevention (CDC), 2022; B. E. Flanagan et al., 2018).

The SVI draws heavily on Cutter et al.'s work, with indicators grouped into four themes pertaining to individual, household, and/or community level characteristics: socioeconomic status, household composition and disability, minority status and language, housing and transportation (B. E. Flanagan et al., 2018). Flanagan et al. (2018) note that the SVI has been cited over 100 times in the academic literature. Scholars and/or practitioners have applied the SVI to generate information on vulnerability to a wide range of hazards including sea-level rise, flooding, tornadoes, volcanic activity, and climate change (Fergen & Bergstrom, 2021; Horney et al., 2015; Lue & Wilson, 2017; USGCRP, 2016). Although the SVI is a quantitative indicator it has gone through multiple rounds of validation to verify the relevance of individual indicators. Case studies have, for example, focussed on vulnerability to hurricanes (B. Flanagan et al., 2011; Lavery, 2017) and extreme heat (Adams et al., 2016).

The SeVI and BeVI

The Socioeconomic Vulnerability Index (SeVI) and Built Environment Index (BeVI) were created by Holand et al. in 2011 to quantify social vulnerability to natural hazards in Norwegian municipalities and assist in hazard mitigation and climate adaptation (Holand et al., 2011). Although the SeVI and BeVI were influenced by the SoVI, Holand et al. base the design of their indices on the work of Borden et al. (2007). Whereas the SoVI combines measures of individual and household-level vulnerability alongside variables influencing vulnerability in the built environment, Borden et al. create two separate indexes: one for socioeconomic vulnerability and another for built environment vulnerability. As Holand et al. note (2011), having two separate indexes helps to create a more accurate portrayal of vulnerability. This is because combining measures related to socioeconomic and built environment into one indicator can skew the scoring and ranking process, and lead to artificially high overall measures of vulnerability when in fact a municipality only receives a high score in one set of indicators (either social or environmental).

The SeVI comprises 25 indicators and the BeVI eight. Indicators for socioeconomic vulnerability focus on income, employment, age, population change, and gender, whilst built environment indicators include housing and population density and measures of infrastructure and public services. Notably, unlike integrated approaches to vulnerability assessments, Holand et al.'s model does not include consideration of biophysical hazards or exposure but focusses solely on social and place-based characteristics. Although originally applied to Norway, the SeVI and BeVI have been used in a wide range of contexts, including in official guidance from the UNDP on how to construct a social vulnerability indicator (see below) (Katic, 2017).

2.3 Indicators advancing the field of social vulnerability

Scholars and practitioners have developed indicators of social vulnerability that respond to critiques of the above foundational models and frameworks, and therefore seek to nuance and advance the field. Below, we provide an overview of new directions that indicators are exploring. Further details are provided in [Appendix 2](), TableAppendix 3.

Greater engagement with local social context

One major critique of indicators like the SoVI is their focus on generalisability whereby a standard suite of indicators measured using quantitative methodologies and publicly available statistical data sets can be applied to a wide range of social contexts in different locations around the world. Indeed, the website of Susan Cutter's home institution, the Hazards and Vulnerability Research Institute (University of South Carolina) hosts a 'SoVI Recipe' (2016) detailing how to engage statistical methodologies like Principle Components Analysis (PCA) to enable replication of the SoVI. Whilst such standardised approaches can be useful for making comparisons between regions and rapidly assessing vulnerability, scholars like Nguyen et al. (2017) and Działek et al. (2016) note that general models, frameworks, and measurements fail to account for the highly varied and specific dynamics that influence social vulnerability in different contexts.

The same critique is applied to indicators that are developed deductively as opposed to inductively (Yoon, 2012). In deductive approaches, scholars/practitioners tend to select indicators of social vulnerability because they appear frequently in other major indicators like the SoVI (Armaş & Gavriş, 2016; Atyia Martin, 2015; Khan, 2012; Tasnuva et al., 2020), and/or because the academic literature demonstrates a well-established link between the particular characteristic or phenomena and social vulnerability (Fergen & Bergstrom, 2021; Otto et al., 2017; Parry et al., 2018; Tapia et al., 2017). Selection of indicators therefore occurs with limited consideration of whether they are pertinent to the context.

One way scholars and/or practitioners address these critiques is to draw on existing indicators or models of social vulnerability that reflect or are similar to the socio-cultural context or characteristics where the indicator is to be applied (Colburn et al., 2016; Grasso et al., 2013; Khan, 2012; Mavromatidi et al., 2018; Tuccillo & Spielman, 2022). For instance, Kirby et al. (2019) created a set of indicators for social vulnerability to flooding in Holland by selecting variables from indicators developed for similar purposes in Norway (Holand & Lujala, 2013) and Germany (Fekete, 2009). Another way to create more grounded and context-appropriate indicators is through the use of inductive, qualitative methodologies (Yoon, 2012), an approach largely taken by those within disaster risk reduction (DRR), geography, public health, anthropology, and of an interdisciplinary background. Scholars and/or practitioners employ household surveys, interviews, and workshops with affected community members, key stakeholders, and decision-makers to determine locally-relevant factors impacting vulnerability to hazards, which then informs indicator creation and design (Atyia Martin, 2015; Chang et al., 2018; Grasso et al., 2013; Guragain & Doneys, 2022; Karunarathne & Lee, 2020; Meur-Férec et al., 2008; Tasnuva et al., 2020).

Tapsell et al.'s (2002) Social Flood Vulnerability Index is a good example of this approach. The index draws on focus groups with flood-affected residents of six communities in northern England in the aftermath of flooding in the year 2000. It combines focus group data with interviews from six communities, 1991 census data, and the Townsend Index for financial deprivation. Similarly, Nguyen et al. (2017) use "expert judgement" to develop a Social Vulnerability Index in coastal Vietnam that is based upon stakeholders' views of the most salient indicators. Stakeholders included local environmental professionals and decision-makers, and local village leaders, who participated in in-depth interviews and focus groups.

Another common strategy is to begin with a list of indicators developed from existing literature and/or social vulnerability indicators, and then 'field-test', 'ground truth', or validate the indicators in collaboration with community members and/or key local stakeholders or experts (Lavoie et al., 2018; Mason et al., 2021; Su et al., 2015; Wu et al., 2016). Oulahen et al. (2015) applied this technique when developing indicators for social vulnerability to coastal climate hazards in Vancouver. The initial indicators were developed from the hazards of place model (Cutter, 1996), the SoVI (Cutter et al., 2003), and Fussel's framework for social vulnerability (2007). They were then reviewed through focus groups and surveys with local hazard-planning practitioners, and amended as necessary. Some indicators also use validation and participatory methodologies if they choose to 'weight' particular indicators to reflect their relative importance in producing vulnerability when compared with other indicators (Bukvic et al., 2020).

Portraying the dynamic, interactive nature of social vulnerability

A second major critique of social vulnerability indicators is their tendency to produce static 'snapshots' that fail to account for the dynamic nature of vulnerability as it changes over time and is influenced by multiple, interacting scales and systems (Fawcett et al., 2017; Fussel, 2007; Jozaei et al., 2022; Li & Wang, 2022; Ran et al., 2020; Roukounis & Tsihrintzis, 2022). Critics note that indicators largely attend to variability in social vulnerability across space (for example, between different communities) but not time (Li & Wang, 2022; Ran et al., 2020). As Hardy and Hauer (2018) point out, most indicators account for change over time as a purely environmental phenomena (for example, intensifying climate hazards or sea level rise) yet overlook the changing social landscape, which can lead to erroneous assumptions about vulnerability and ill-informed policies. The majority of indicators do not measure how vulnerability co-evolves and shifts with changing socio-economic, demographic and institutional dynamics (such as policy interventions, population change, behaviour change, institutional learning, or adaptation to hazards) (Fawcett et al., 2017; Ran et al., 2020).

Neglect for the temporal dynamics of vulnerability is partly a methodological issue that centres upon indicators' widespread use of large-scale, publicly-available statistical databases like the census (Boruff et al., 2005; Hemmerling & Hijuelos, 2017; Kirby et al., 2019; Kleinosky et al., 2007; Tasnuva et al., 2020) tax records (Manuel et al., 2015; Mavromatidi et al., 2018; Wu et al., 2016), and government surveys (Mason et al., 2021). Census counts (and other statistics) can be outdated and present a snapshot of a population's demographics and behaviours at a particular point in time (Armaş & Gavriş, 2016; B. Flanagan et al., 2011; Mason et al., 2021). Although many indicators of social vulnerability include measurements or counts of migrant populations, in-migration, or new residents in an area (B. Flanagan et al., 2011; Hemmerling & Hijuelos, 2017; Khan, 2012; Kleinosky et al., 2007; Mavromatidi et al., 2018), these statistics are not intended to convey population change over time. Rather, they are used to indicate the presence of a social group with higher likelihood of being exposed and sensitive to hazards and less able to cope and adapt (because of potential difficulties with language and social integration, and limited finances) (Fergen & Bergstrom, 2021; Mason et al., 2021; Otto et al., 2017).

The lack of focus on change over time also relates to the scale at which indicators are targeted. Mirroring the scale at which census data and other official statistics are collated, the majority of indicators measure social vulnerability at the community, neighbourhood (or household) scale (Fergen & Bergstrom, 2021; Fernandez & Golubiewski, 2019; Handwerger et al., 2021; Tasnuva et al., 2020; Tuccillo & Spielman, 2022). Limited attention is given to the influence of the regional, national, or international political or macro-economic sphere (institutions, governance, and policy) on local social vulnerability through time (Bukvic et al., 2020; Chakraborty et al., 2021; Guragain & Doneys, 2022; Karunarathne & Lee, 2020; T. T. X. Nguyen et al., 2016; Zou & Thomalla, 2008). Li and Wang

(2022) note that the overwhelming focus of most indicators on a single spatial scale (be it a neighbourhood, city, county, or region) and a single pressure (like climate change) magnifies the static portrayal of social vulnerability. Most indicators neglect cross-scale linkages and the interaction of multiple pressures (climate change, pandemics, adaptation policies) on a system, all of which influence and change how vulnerability is experienced, and by whom (Li & Wang, 2022).

A range of indicators have emerged that seek to provide a more dynamic portrayal of social vulnerability that accounts for both interacting scales (Kashem et al., 2016; Meur-Férec et al., 2008; Tuccillo & Spielman, 2022) and social change over time (Boruff et al., 2005; R. Hardy & Hauer, 2018; Kirby et al., 2019; Manuel et al., 2015; NOAA Fisheries, n.d.; Su et al., 2015). For instance, Hardy and Hauer's indicator for social vulnerability to sea-level rise in coastal Georgia (2018) combines sea-level rise projections and population projections for socially vulnerable populations. The indicator reveals that, when compared with existing indicators, there will be many more socially vulnerable people exposed to sea-level rise and associated hazards in the region in the future.

Combining indicators with theories of neighbourhood change, Kashem et al. (2016) account for both the spatial and temporal dynamism of social vulnerability. Applying their model to three coastal cities in the USA, Kashem et al. demonstrate how the demographic composition of particular neighbourhoods has changed over time, and become home to socially vulnerable populations, because of interacting local, regional, and global influences. Influences include policy promoting development and services designed to attract retirees and the increased need for cheap labour (provided by migrants) in an increasingly globalised world. Similarly, Meur-Férec et al. (2008) designed an indicator for measuring social vulnerability to coastal hazards in France that accounts for interacting social, economic, political, cultural, and psychological spheres over time. Indicators include pressure from real estate development, human recreational and economic activities increasing erosion, and factors mitigating risk from hazards (including policies, local initiatives, perception of risk, and remembrance of past hazards).

Accounting for adaptive capacities, strengths, and assets
A third critique of social vulnerability indicators is their tendency to overlook adaptive capacities, strengths, or assets that vulnerable groups possess (Ogie & Pradhan, 2019). Indicators overwhelmingly focus on deficits and characteristics that increase vulnerability (e.g. poverty, limited education, disability, old age, being engaged in an exposed livelihood such as farming). They tend to neglect behaviours, attitudes, life experiences, values, resources, skills, and social networks that even the most vulnerable groups may use to cope with and respond to hazards (Oliver-Smith, 2022).

Such a one-dimensional picture of vulnerable groups is unlikely to represent their lived realities of hazards (Thomas et al., 2019) and could lead to errors in policy as a result. A wealth of climate scholarship (notably the adaptive capacities literature, and studies of Indigenous peoples and climate change) attest to the complexity of vulnerability, whereby even groups experiencing severe structural vulnerability concurrently exhibit agency by engaging their strengths or assets to offset harm and secure their futures (Buchanan et al., 2016; Parsons et al., 2018; Whyte, 2018).

Scholars and/or practitioners have responded to this critique by developing indicators capable of providing a more balanced view of vulnerability. For instance, Ogie and Pradhan (2019) present a strength-based approach to measuring social vulnerability, based on a case study in Wollongong, New South Wales (Australia). The indicator includes measurements of cultural and linguistic diversity, and diverse incomes, ages, (dis)abilities, and occupations which they state enable coping and adaptation to hazards in the locale.

The MOVE framework (and indicators based upon it) combine a focus on "lack of resilience" (limitations to mobilising or accessing resources to cope and recover); "adaptation/adaptive capacities" (the ability to learn, reorganise, and change practices in light of hazards, and therefore reduce vulnerability); and "risk governance" (decisions/actions taken by government or households to prevent, prepare for, and manage disasters) (Birkmann et al., 2013). Similarly, Bergstrand et al.'s coupled social vulnerability and community resilience indicators (2015) integrates consideration for social vulnerability and community resilience. Whilst their findings in the USA corroborate a general correlation between high vulnerability and low resilience, they also find evidence that some of the most socially vulnerable US counties actually have relatively high levels of resilience (mostly because of high social capital).

Responding to under-documented dimensions of social vulnerability
Finally, a range of indicators seek to broaden measurements of social vulnerability by attending to dimensions that have traditionally been omitted from indicators. Factors that are not easily quantified (such as the effect of policy or emotion/perceptions on vulnerability) tend to feature less in indicators. In contrast, Babcicky and Seebauer (2021) develop a set of psychological indicators to measure vulnerability to river flooding. The indicators were developed from household surveys rather than traditional measurements like the census, and include factors like a belief in self-efficacy, collective efficacy, and political efficacy to prepare for, avoid, and offset damages with flooding; having a fear of flooding and being risk averse; non-protective actions or wishful thinking; and reliance on public protection of compensation.

3. Indicators for social vulnerability developed by intergovernmental organisations

A range of frameworks or indicators have been developed by intergovernmental organisations such as the United Nations Development Programme (UNDP), the World Health Organisation, and the World Food Programme in order to measure or assess social vulnerability to climate hazards. For the purpose of this report, 14 of these indicators and/or frameworks were reviewed, of which a sample are discussed below and more fully detailed in Appendix 3. It is possible to detect the influence of established social vulnerability lineages and foundational indicators on intergovernmental indicators and/or frameworks. However, intergovernmental indicators also exemplify some of the novel approaches to measuring social vulnerability discussed in section 2.3 above. This includes a focus on qualitative methodologies and validation; interacting scales; dynamism; and a more sustained emphasis on the role of political structures, institutional arrangements, policy, and governance in creating or sustaining vulnerability.

Special report of the IPCC on vulnerability (Cardona et al., 2012)

Although not an indicator, this report details a framework that can be used to understand and analyse social vulnerability to climate hazards. The framework consists of geographic, demographic, and environmental factors that increase exposure, and social and economic dimensions that influence sensitivity and/or adaptive capacity (including age, race, socio-economic class/caste, housing tenure, health status and education of the population, cultural values, policies, and risk management). The wide range of factors considered under this framework reflect an integrated, holistic approach to vulnerability. It draws on the work of Turner et al. (2003) and Birkmann (2006) and emphasises dynamism, the interaction of multiple scales, and the influence of policies and interventions in reducing vulnerability. Interdisciplinarity is a key aspect of the framework. As the authors observe (Cardona et al., 2012, p. 91),

> "quantitative approaches for assessing vulnerability need to be complemented with qualitative approaches to capture the full complexity and the various tangible and intangible aspects of vulnerability in its different dimensions. It is important to recognise that complex systems involve multiple variables (physical, social, cultural, economic, and environmental) that cannot be measured using the same methodology."

They continue,

> "an integrated and interdisciplinary focus can more consistently take into account the nonlinear relations of the parameters, the context, complexity, and dynamics of social systems, and contribute to more effective risk management by the different stakeholders involved in risk reduction or adaptation decision-making."

In keeping with the focus on dynamism, the authors emphasise the capacity of individuals and vulnerable social groups to manage vulnerability, to cope with and adapt to extremes. The framework advocates a move away from aggregations and generalisations of vulnerability and engagement of differences within social categories (like women) in order to uncover diverse experiences of vulnerability. It also advises that vulnerability analyses based on "static checklists of vulnerable groups" (Cardona et al., 2012, p. 80) are unlikely to reflect either the diversity or dynamics of peoples' changing circumstances.

UNDP Social Vulnerability Assessment Tools (Katic, 2017)

Targeted at Disaster Risk Reduction/DRR, climate risk management, and climate adaptation practitioners, the UNDP's social vulnerability assessment tools report provides a "how to" guide for developing indicators of social vulnerability to hazards (including climate change) and tailoring them to local contexts. Although the UNDP approach draws heavily on the SoVI, like the IPCC framework above, it also emphasises diversity and integration of qualitative methodologies.

The approach directs practitioners to begin the development of an indicator with review of key scholars' work, academic literature on the local context, and grey literature pertaining to policy. A set of suggested indicators from the work of Cutter et al. (2003), Holand et al. (2011) and Bergstrand et al. (2015) provides a base which can be amended as necessary according to the literature review and subsequent engagement with local stakeholders (during interviews and focus groups). Suggested indicators pertain to socioeconomic and demographic characteristics, location, and social capital. Once an initial selection has been made, the guide recommends testing and validating the

indicator using both qualitative methods (interviews, focus groups, and the Delphi[1] method) and quantitative means (using historic disasters as test cases). Ideally, the report notes, the final indicator should draw on both qualitative data (like household surveys) and quantitative (like the census).

Whilst many intergovernmental indicators rely on national-level datasets from global organisations (including the World Bank Development Indicators, the World Risk Index, or the UN Population Fund) the UNDP's approach is different in its dual focus on local and household level qualitative inputs alongside quantitative data. The report cautions against normative approaches to social vulnerability that align vulnerability with characteristics such as poverty, gender, and age, and hence overlook internal diversity and diverse experiences of vulnerability within social groups. However, as a guide for constructing indicators there is one significant drawback of the UNDP approach. The authors of the report state that indicators must be able to be verified using data available at specified geographical units, and that can be expected to be available into the future. In reality, this means that factors contributing to vulnerability which cannot be measured using these types of data (especially the least tangible aspects of vulnerability like the effects of policy, cultural heritage, or identity) are likely to be excluded from indicators even if they are deemed relevant to local people.

Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021)
The Children's Climate Risk Index is the first set of indicators dedicated to identifying children's vulnerability to climate change at a global level. The index takes a holistic, integrated approach to vulnerability. This accounts for both children's exposure to climate and environmental shocks and stresses (such as floods, heatwaves, and pollution) and their sensitivity and coping capacity. The index is especially attentive to multi-scalar social, political, economic, and cultural influences on child vulnerability.

Importantly, the index emphasises factors that both increase vulnerability (for example, low birthweight, poor nutrition, and gendered inequalities in access to education) and offset risk by elevating coping capacity (for example, social safety nets including child benefits, access to WASH[2] services, and youth literacy). Like other indicators developed by international organisations (and in contrast to the peer-reviewed literature on social vulnerability indicators) the UNICEF index has a strong focus on the policy/institutional dimension of vulnerability, reflecting elements of the political economy/ecology lineage. For example, immunisation programmes, domestic health and education expenditure, provision of WASH services, and availability of child/family benefits are all factors that influence children's vulnerability to climate change.

UNESCO Climate Vulnerability Index (Day et al., 2020)
UNESCO's Climate Vulnerability Index is the first tool to systematically assess the climate vulnerability of world heritage sites (natural, cultural, and mixed heritage) and surrounding communities. Like the UNICEF index, UNESCO's indicators take an integrated approach to vulnerability. Vulnerability of heritage sites and connected communities is linked to interacting and compounding stresses at a range of scales (such as changing land-use practices and infrastructure development), and results from economic, social, and cultural connections between the community and the site, as well as the capacity for the community to adapt to climate change. Rather than

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[1] An iterative, participatory technique to reach a decision that is based upon deliberation and consensus between experts. The technique is often used in social research to explore the implications of policy, and alternative scenarios or solutions (Glass et al., 2022).

[2] WASH stands for Water, Sanitation, and Hygiene.

relying purely on national-level quantitative data like other global indicators, the UNESCO index is intended to facilitate either rapid vulnerability assessments by property/site managers or more detailed, participatory assessments conducted through workshops with stakeholders. Another defining feature of the UNESCO index is its focus on the intangible dimensions of vulnerability which is often overlooked in indicators because of difficulties with quantifying and measuring.

The World Health Organisation: Assessing health vulnerability and adaptation to climate change (Kovats et al., 2003)

Whilst not an indicator, the World Health Organisation developed a framework for helping nations to assess vulnerability of their populations to the health impacts of climate change. The framework draws on both a risk management approach and environmental causes of disease model for assessing vulnerability (the latter echoing political ecology approaches to vulnerability). The framework treats vulnerability as dynamic. It frames risk from health impacts associated with climate change as linked to social, economic, and political systems that influence: the state of the environment and incidence of hazards, international, national, and local adaptation, mitigation, and risk management policies. In common with the UNDP approach and UNESCO indicator above and SPREP framework below, the WHO recommend an integrated approach to assessing vulnerability that draws on both quantitative and qualitative data. This includes a mixture of climate and population projections, GDP, national health or mortality data, and literature reviews on health and climate, workshops and consultations with stakeholders and experts.

The World Food Programme's Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015)

The World Food Programme has developed a number of frameworks and/or indicators for assessing and measuring climate vulnerability (Met Office Hadley Centre, 2015; Ministry of Natural Resources, Department for Disaster Management and Climate Change & World Food Programme, n.d.). One such indicator, the Hunger and Climate Change Vulnerability Index (HCVI) is based on Krishnamurthy et al.'s indicator of the same name (2014) and gives a global overview of national vulnerability to food insecurity and hunger under different emissions scenarios. The HCVI applies global meteorological data (such as the WATCH Forcing dataset) and information from organisations including the World Bank, UNDP, and UNFPA to determine the vulnerability of non-OECD and non-EU countries. The index examines a nation's exposure to flood and drought events, sensitivity of national agricultural production systems, and ability of a nation to cope with climate-related food shocks. One major limitation of the HCVI is that small countries of under 500km^2 are not included because it is difficult to access data of a fine enough resolution.

SPREP's Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016)

The Integrated Vulnerability Assessment (IVA) is a participatory tool that is based on indicators and aids community-level evaluation of climate vulnerability in the Pacific Islands. The IVA takes a sustainable livelihoods approach. This approach has primarily been employed to understand experiences of poverty and disadvantage from a holistic and community-centred perspective, and assesses the ability of livelihoods to cope with, recover, and build resilience to shocks and stresses like climate change and disasters. In contravention to other intergovernmental indicators (which tend to focus at the national level and on deficits linked to vulnerability) the IVA is specifically developed for community-level analysis and emphasises community assets that enable resilience.

As well as considering factors that enhance exposure to climatic threats (geographic, demographic, local development, and land use trends), indicators for vulnerability also assess the capacity and sensitivity of livelihoods assets, and the adaptive and risk reduction capacity of institutions. This includes having access to sufficient natural assets (water, land, etc), infrastructural assets (housing,

health services, education etc), financial assets (diversity of income, credit schemes, etc), and human assets (skills, knowledge, etc) to support and sustain livelihoods. It also includes the ability of institutions to facilitate collective action towards adaptation/risk reduction, amongst other factors. In common with the sustainable livelihoods approach, the indicators were developed in a participatory manner involving validation by local experts. Indicators can be quantified through use of databases and census data but also participatory mapping with communities and household surveys.

Rapid Assessment of Climate Change Vulnerability and Adaptation Planning – International Union for Conservation of Nature and Natural Resources (Wyatt et al., 2020)

The Rapid Assessment is intended to evaluate the socio-economic vulnerability of communities whose livelihoods depend on wetlands in the Indo-Burma region. Like the IVA above, this framework is aimed at the community level, is participatory, and focusses on local livelihoods. It draws on the human-environment/resilience lineage (above) and consequently emphasises the importance of social-ecological systems in producing vulnerability. The framework examines exposure, sensitivity, and adaptive capacity of both human and ecological systems (villages and wetlands), and their relationships to other external stressors like the encroachment of agriculture into wetland areas or dams. There is a strong qualitative element to the assessment, with focus groups and interviews comprising a key methodology to gather data about villager's livelihoods, experiences of climate change, and coping/adaptation strategies. The importance of involving women, elderly, youth, and minority groups in the assessment is also stressed.

4. International indicators for social vulnerability to coastal hazards

Many of the indicators discussed or referenced above were developed for coastal locations in both the global south and north (Grasso et al., 2013; Handwerger et al., 2021; Kleinosky et al., 2007; Mavromatidi et al., 2018; Meur-Férec et al., 2008; Tasnuva et al., 2020; Wu et al., 2016). In general, these indicators bear many similarities to indicators developed for non-coastal locations. They use largely comparable (or the same) measurements or indicators, and are often subject to the same sorts of limitations. As section 2.3 demonstrates, social vulnerability indicators developed for coastal locations are also overcoming these limitations through a focus on co-design and methods for better capturing the dynamic nature of vulnerability.

To summarise, frequently used indicators for social vulnerability in coastal locations include:

- population density and sensitive land use such as residential, commercial or agricultural (whereby high population density and sensitive land uses mean many people would be exposed to hazards and economic losses and damages could be high, and many people trying to evacuate at once may cause bottlenecks) (Boruff et al., 2005; Grasso et al., 2013; T. T. X. Nguyen et al., 2016; Oulahen et al., 2015; Su et al., 2015; Tasnuva et al., 2020),
- poverty and lack of access to resources, public services, or early warning systems (which decreases the ability of people to access items, materials, labour, facilities and information needed to prepare for and recover from coastal hazards) (Chang et al., 2018; Colburn et al., 2016; FEMA, 2021; Kirby et al., 2019; Steele et al., 2019; Tasnuva et al., 2020; Tuccillo & Spielman, 2022),
- older or younger age (which can present difficulties with mobility and evacuation, and increase reliance on others for help in emergencies and during recovery) (B. Flanagan et al.,

2011; R. Hardy & Hauer, 2018; Hemmerling & Hijuelos, 2017; Kashem et al., 2016; NOAA Fisheries, n.d.),

- migrants (especially those who do not know the area and its hazards or have limited proficiency for understanding emergency communications in the local language) (B. Flanagan et al., 2011; Hemmerling & Hijuelos, 2017; Khan, 2012),
- those working in exposed or resource-dependent industries (which are likely to be affected by hazards or put workers in harms' way) (Chang et al., 2018; Grasso et al., 2013; Hemmerling & Hijuelos, 2017; Kirby et al., 2019; NOAA Fisheries, n.d.)
- those with limited education (which impacts on income and therefore ability to cope and recover and ability to take action on official communications around hazards) (Boruff et al., 2005; B. Flanagan et al., 2011; Handwerger et al., 2021; Oulahen et al., 2015; Tasnuva et al., 2020; Wu et al., 2016).

Echoing broader limitations of social vulnerability indicators, factors such as governance, policy, cultural influences, social change, social connectedness, and the perception of risk feature infrequently in coastal indicators (Meur-Férec et al., 2008; Su et al., 2015; Tonkin & Taylor Ltd, 2021; Wu et al., 2016; Zou & Thomalla, 2008). Likewise, the SoVI continues to influence the development of many social vulnerability indicators at the coast (Kashem et al., 2016; Martinich et al., 2012; Roukounis & Tsihrintzis, 2022).

A range of coastal indicators go beyond traditional models and seek to capture the dynamic nature of social vulnerability through a focus on change over time, interacting systems, qualitative methodologies, and ground-truthing indices (R. Hardy & Hauer, 2018; Lavoie et al., 2018; Meur-Férec et al., 2008; C. V. Nguyen et al., 2017).

One area where coastal indicators differ from non-coastal indicators is their propensity to focus more heavily on biophysical factors such as sea-level rise and coastal flooding (Bukvic et al., 2020; T. T. X. Nguyen et al., 2016). Reviews of coastal vulnerability indicators posit that 'integrative' or 'comprehensive' indices which merge biophysical and social vulnerability indicators are becoming increasingly common (Bevacqua et al., 2018; Bukvic et al., 2020; T. T. X. Nguyen et al., 2016; Roukounis & Tsihrintzis, 2022). Integrative approaches combine geophysical, social, and economic data (such as wave/wind data, education, unemployment, coastal infrastructure). Based on their review of over 200 studies of coastal vulnerability Bevacqua et al. (2018) note the rationale for including both biophysical and social vulnerability indicators is to provide a more holistic and complete appraisal of vulnerability at the coast. A sample of coastal indicators for social vulnerability to climate change is provided in Appendix 4.

5. Measuring social vulnerability to climate change in Aotearoa

Over the last five years efforts to evaluate the impacts of climate change on society have stepped up in Aotearoa (CCATWG, 2017). In 2018 the cross-sector, government-convened Climate Change Adaptation Technical Working Group identified gaps in knowledge about the social dimensions of climate change and a lack of action on climate adaptation (CCATWG, 2018). Since then, the first National Climate Change Risk Assessment has been undertaken (Ministry for the Environment, 2020), and the inaugural National Adaptation Plan or NAP has been developed (Ministry for the Environment, 2022). The Ministry for the Environment is also assisting local government to conduct climate change assessments for planning purposes (Ministry for the Environment, 2021). Despite these developments, there are relatively few indicators dedicated to measuring social vulnerability

to climate hazards in Aotearoa, and none that focus exclusively on vulnerability to coastal hazards at the national scale. Instead, Aotearoa's indicators tend to focus on measuring wellbeing, deprivation, or resilience of society more generally. Below, we review a range of indicators developed for the Aotearoa context and suggest how these might be enhanced to more sufficiently capture the nuances of social vulnerability to climate change and hazards.

5.1 Indicators for wellbeing, deprivation, and resilience in Aotearoa

The indicators below are not developed for measuring vulnerability to climate change. However, they either contain relevant information that could be incorporated into future indicators for measuring climate vulnerability or are used as a data source in the few extant indicators measuring climate and hazard vulnerability (see section 5.2 below).

Stats NZ: Ngā Tūtohu Aotearoa/Indicators for Aotearoa New Zealand

Aotearoa's official data agency, Stats NZ, has recently developed Ngā Tūtohu Aotearoa/Indicators for Aotearoa New Zealand. This is a set of over 100 indicators spanning 22 topics that reflects Aotearoa's progress across different dimensions of wellbeing, and is intended to help the government, local and national NGOs to improve the wellbeing of current and future generations of New Zealanders (Stats NZ, 2022). The indicators are measured using a framework comprising current wellbeing, future wellbeing, and international impacts (the impact Aotearoa is having on the rest of the world), with indicators pertaining to environmental, cultural, economic and social dimensions of wellbeing (Stats NZ, 2022). Ngā Tūtohu Aotearoa indicators align closely with and inform The New Zealand Treasury's Living Standards Framework (see below) and support The Treasury's work to embed wellbeing and sustainable development into its budget-making process, and to measure wellbeing beyond economic metrics (Stats NZ, 2019, 2022).

Although Ngā Tūtohu Aotearoa were developed collaboratively with the public (Stats NZ, 2019, 2022), and reflect the distinctive Aotearoa context within which wellbeing is experienced, at least 63 of the 100 indicators resemble components of international indicators for social vulnerability to climate change. These include measures of environmental quality and natural resources; biophysical hazards; state of infrastructure and housing; population composition and change; financial, material, and health-based inequalities; discrimination; education; employment; social networks; institutional trust; and national income. All these indicators are shown to be relevant for evaluating social vulnerability to climate change in international contexts. For instance, the NZ Stats indicators 'loneliness' and 'social support' mirror elements of indicators for social vulnerability to climate hazards including flooding, coastal hazards, and hurricanes in countries like the USA and Poland. Evidence suggests individuals and families who are connected to and supported by their neighbours, relatives, or community may have access to knowledge, services, or direct assistance that helps them navigate, recover from, or adapt to climate hazards (Atyia Martin, 2015; Działek et al., 2016; B. Flanagan et al., 2011; USGCRP, 2016). TableAppendix 6 provides a full overview of indicators within Ngā Tūtohu Aotearoa that are relevant for measuring social vulnerability to climate change.

The New Zealand Treasury: Living Standards Framework and He Ara Waiora

The Treasury has developed two frameworks for analysing wellbeing in Aotearoa: the Living Standards Framework (LSF) and He Ara Waiora. These are increasingly used together to support the objective of embedding a wellbeing approach across the public sector including through the 2019 budget, reporting on wellbeing, strategic planning, and COVID-19 advice from the Labour government (The Treasury, 2022b).

He Ara Waiora reflects a Māori perspective on wellbeing, which is intergenerational and recognises the interconnectedness of all aspects of wellbeing (The Treasury, 2021). The framework was developed alongside Ngā Pūkenga (an expert group of Māori thought leaders) in order to apply an Indigenous approach to lifting living standards in Aotearoa through policy analysis and development (The Treasury, 2021). The framework is composed of 12 dimensions of wellbeing, comprising ends and means (The Treasury, 2021). Ends refer to aspects that are important for waiora or wellbeing (such as spirituality and relationships of care with the natural world, family, and community). Means refer to principles for how to create/maintain/elevate waiora or wellbeing (such as sense of belonging and growing prosperity).

The LSF is now in its third iteration, having been developed in response to the emerging international and national literature, research, and ongoing consultation. The LSF measures wellbeing over three levels: individual and collective wellbeing, institutions and governance (and their capacity to facilitate individual and collective wellbeing and build national wealth), and the wealth of Aotearoa (both in terms of human and natural capital). The LSF Dashboard is a measurement tool for directing the Treasury's wellbeing reporting, and enables the development of policy advice to enhance wellbeing in Aotearoa (The Treasury, 2022a). The Dashboard comprises indicators that are based on the LSF framework (The Treasury, 2022a).

Like Ngā Tūtohu Aotearoa above, a significant proportion of indicators in both the LSF dashboard and He Ara Waiora are relevant for evaluating social vulnerability to climate change. This includes indicators for sense of belonging and social support; trust in government and influence over decisions; national debt and GDP; the state of the environment; climate change; health status; housing cost, quality and crowding; poverty; educational status and attainment; and employment. TableAppendix 6 provides further details.

NZDep Index of Deprivation (Atkinson et al., 2014, 2019)
NZDep is a foundational indicator for measuring deprivation in Aotearoa. Originally created in 1995, NZDep is updated every few years, and is widely used to evaluate relative socio-economic and material deprivation at the census mesh-block level around the nation. NZDep is applied to many different fields of study and serves as a primary source of data for indicators of social vulnerability to climate hazards around Aotearoa including in the Hutt Valley (Khan, 2012) and Otago (Tonkin & Taylor Ltd, 2021).

New Zealand Indices of Multiple Deprivation (Exeter, 2017)
The New Zealand Indices of Multiple Deprivation (IMD) also measures relative deprivation throughout Aotearoa, and provides an alternative to NZDep. The IMD comprises 28 indicators of deprivation grouped into seven zones and is used as a primary source of data in climate change indicators such as the Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019). Like NZDep, the IMD is wholly quantitative and draws on data such as the census and public health statistics.

Resilience Index New Zealand (Pearson et al., 2013)
The Resilience Index New Zealand (RINZ) comprises a set of indicators that can be used to assess the relative resilience of census area units around Aotearoa. Indicators are grouped into three areas: those related to the built environment, the physical environment, and social characteristics of a place. Many indicators of social vulnerability to climate change draw on the concept of resilience (Bergstrand et al., 2015; Birkmann et al., 2013; FEMA, 2021; Mason et al., 2021). Some indicators substitute measures of resilience in place of measures for adaptation and/or adaptive capacities, while other indicators treat resilience as part of adaptation. The RINZ contains indicators relevant to

measuring social vulnerability to climate change, including social cohesion, air quality, and access to healthcare.

New Zealand Resilience Index (Stevenson et al., 2018)

The New Zealand Resilience Index (NZRI) measures resilience over six areas (social, economic, built environment, natural environment, cultural, and governance of risk and resilience). As opposed to the RINZ (above), which frames resilience through a public health lens, the NZRI was specifically developed with hazard planning in mind. The six areas correspond with the approach pursued by government in recent years to build resilience to hazards and emergencies, and efforts are underway to facilitate greater involvement of the public in further developing the index. In the latest update available (from 2018), future plans for the NZRI involved eliciting public input such that it reflects the diverse capacities that different communities, households, and individuals around Aotearoa possess that enable them to manage disruption and change.

5.2 Climate change indicators and assessments in Aotearoa

A number of indicators and assessments directly address and evaluate social vulnerability to climate change and hazards in Aotearoa. The majority of indicators and assessments have been conducted by local government and are applied at the regional, city, or community level, and several reference vulnerability to coastal hazards. These indicators are discussed briefly below and more fully detailed in TableAppendix 7.

The National Climate Change Risk Assessment (Ministry for the Environment, 2020)

The National Climate Change Risk Assessment (NZCCRA) is a government-led evaluation of the most significant risks that climate change presents for Aotearoa. The NZCCRA approaches climate change from a climate adaptation and risk management perspective, and has informed Aotearoa's first NAP. Risks from climate change are evaluated according to the exposure, sensitivity, and adaptive capacity of the system or domain under consideration, and have been identified through a combination of desk-based literature reviews and consultation with the public, key stakeholders, iwi and hapū Māori (Indigenous tribes and sub-tribes), and technical experts.

The most significant risks to the 'human domain' (society) include impacts to social cohesion and community wellbeing from climate-induced displacement of individuals, families, and communities (for example, due to managed retreat), and the risk of exacerbating existing inequities or creating new inequities. Although not an indicator, the NZCCRA advances understanding of social vulnerability by identifying groups more likely to be affected by these risks (such as those of lower socio-economic status, women and children, Māori, and persons experiencing mental and physical health challenges). Echoing the wider literature on social vulnerability, the NZCCRA acknowledges that risks are dynamic, arising through the interaction of multiple factors, including risks that compound one another.

Social vulnerability indicators for flooding in Aotearoa New Zealand (Mason et al., 2019, 2021)

The social vulnerability indicators for flooding in Aotearoa New Zealand (SVI) is the only existing indicator for evaluating social vulnerability to climate change at the national level. The SVI comprises a suite of indicators pertaining to 14 dimensions of social vulnerability and is the first attempt to provide a nationally available dataset for flood vulnerability within each census mesh-block. A key aim of the SVI is to provide evidence to support (flood) risk reduction strategies (such as infrastructural upgrades and policy to address the root social drivers of vulnerability – for instance, elevating housing standards and quality). Data from the SVI is now available online for all mesh-

blocks in Aotearoa, and the project team has also created a toolkit for end users that is intended to help decision-makers incorporate indicator data into vulnerability and risk reduction planning at the local level.

Although arising from a public health and disaster risk management approach, the SVI takes a diverse and holistic approach to social vulnerability that combines major lineages of vulnerability research. The over-arching conceptual framing of social vulnerability that guides the SVI (that particular populations become vulnerable due to pre-existing conditions and characteristics affecting their ability to prepare, respond and recover from hazards) draws on Cutter et al.'s work (2003). However, the indicators themselves are influenced by the MOVE framework (above), Wisner et al.'s (2012) work on resilience, and The Treasury's LSF, thus merging SES and political economy/ecology lineages, and key work on the determinants of wellbeing in Aotearoa.

Like the MOVE framework, the SVI classifies social vulnerability as the product of dynamic interactions between exposure, susceptibility, and lack of resilience. In the SVI, exposure can be both direct or indirect and relates to the number of people residing in an area, and other factors such as use of public transport and residence in a remote community. Susceptibility is influenced by factors like age and health status of households and regions, and resilience relates to the ability to cope with disasters by having access to money, social connections, knowledge and so on. Wisner et al.'s (2012) 'circle of capacities' and the LSF inform the framing of resilience in the SVI. Accordingly, the SVI frames vulnerable populations as having reduced access to key social, economic, cognitive, political, and material capacities or capitals that enable coping and response amongst less vulnerable groups.

In addition to its emphasis on dynamism, the SVI mirrors another nascent trend in the social vulnerability indicators literature. Although the SVI still produces a quantitative measure of social vulnerability (based on datasets including the census and Ministry of Health statistics) the indicators have been subject to a collaborative design and 'ground-truthing' process. This process attempts to reconcile theory with the lived experience of vulnerability. The SVI was developed and field tested in Porirua, a city in the lower North Island, and community members, the local iwi (tribe), local decision-makers, and staff from major organisations like the District Health Board all played a part in the selection of indicators.

Auckland Council Heat Vulnerability Index (Joynt & Golubiewski, 2019)

As part of Auckland Council's climate change risk assessment, Joynt and Golubiewski developed the Heat Vulnerability Index (HVI). The HVI identifies and maps areas of Auckland where populations are more vulnerable to climate-related heat stress with a view to directing adaptation policy under Auckland's Climate Action Plan. Focussed on the census area and drawing on the 2013 census, the NZ Indices of Multiple Deprivation, the Household Economic Survey and NZ Land Cover database, the HVI is composed of ten indicators which are combined with different climate change scenarios. Several of the indicators (including deprivation, older and younger age, limited English proficiency, Indigenous/Pacific ethnicity, and rental tenure) closely resemble indicators that are employed in other major international vulnerability indices, including the SoVI.

Auckland Council Vulnerability Assessment (Fernandez & Golubiewski, 2019)

Like the HVI, the Vulnerability Assessment informs Auckland Council's climate change risk assessment. The Vulnerability Assessment seeks to identify areas of Auckland more vulnerable to dry and hot days, heavy rainfall and precipitation change, wind, changes to humidity, and exposure to inundation. It comprises two indices: the Impact Index (II) and the Adaptive Capacity Index (ACI). As with the HVI, the Vulnerability Assessment is focussed at the census area level and seeks to map

'vulnerability hotspots' in an integrated manner. It combines climate change projections with data from the NZ Deprivation Index, the 2013 census, land cover and road density data. The Impact Index comprises indicators for exposure and sensitivity that are common measures of social vulnerability (including deprivation, unemployment rate, and percentage of one-parent households). The Adaptive Capacity Index examines factors known to impact ability to cope and adapt (such as household income, rent burden, and access to economic assets).

Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021)

The Otago Climate Change Risk Assessment seeks to identify the risks that climate change poses for communities throughout Otago (including coastal areas such as Dunedin and Oamaru) in order to inform planning by Otago Regional Council. The risk assessment contains a section assessing social vulnerability of Otago communities to climate hazards. Using census area unit data, three indicators (deprivation, proportion of older adults, and social connectedness) are employed to identify socially populations. The selection of indicators was influenced by Mason et al.'s SVI (above) and stakeholder interviews and consultations, and the indicators themselves draw on the 2018 census and NZDep 2018 (see above).

Wellington Regional Coastal Vulnerability Assessment (Steele et al., 2019)

Working at the level of Greater Wellington suburbs, the Coastal Vulnerability Assessment uses a range of indicators to assess the vulnerability of particular places. Whilst the report notes that the assessment was balanced between social, economic, cultural and environmental datasets, social vulnerability is not a particularly prominent feature. Indicators of vulnerability focus primarily on exposure of population centres, businesses, lifelines, infrastructure, and sites of ecological and cultural significance to climate hazards, although community deprivation and resilience does feature on the list of indicators (based off census 2013 data and the NZ Index of Multiple Deprivation 2013).

Christchurch City Council Climate Resilient Strategy

In its Climate Resilient Strategy, Christchurch City Council (CCC) states it is working to "complete comprehensive district risk assessments to deliver local data across all domains, including updates and monitoring of hazards, exposure, and vulnerability" (Christchurch City Council, 2021, p. 18). This includes developing indicators to monitor how the climate is changing and the rate of change. Additionally, CCC will support Ngāi Tahu Papatipu Rūnanga to develop culturally relevant indicators for monitoring the impacts of climate change on mahinga kai (food gathering/harvest areas) and other cultural resources. These indicators will complement Ngāi Tahu's existing climate change risk assessment.

Comprehensive Vulnerability Assessment (Khan, 2012)

Khan's Comprehensive Vulnerability Assessment (CVA) seeks to identify social vulnerability to coastal and river flooding/inundation at the mesh block level in the Hutt Valley, near to Wellington. Khan notes that (at the time of writing) floodplain management plans often pursued a wholly risk-hazard approach that overlooked the spatial variation of social vulnerability to flooding, and instead focussed on the most physically exposed locations. The CVA comprises 38 indicators for social vulnerability to flooding. The indicators are categorised into demographic factors (like population distribution and density, age, disability and migration status); social factors (including family type such as single parents, language proficiency, ethnicity, and education); and economic (which includes income, unemployment, housing condition and access to assets like a car and telecommunications at home). The CVA was influenced by indicators employed in the SoVI (Cutter et al. (2003) and uses the 2006 census and NZDep 2006 to quantify the indicators.

Social Impact Assessments (SIA)

SIA are traditionally used to analyse the impacts to society from projects, policies, and procedures such as new infrastructure or regulatory reform. In Aotearoa, SIA have been employed since the 1970s to understand the impacts of oil and gas development, changes to agricultural subsidies, and the impact of tourism amongst other areas (Taylor & Mackay, 2016). Alongside climate change risk assessments, some councils are now making use of SIA to understand the social impacts of climate change on communities and to identify those groups who are most vulnerable to associated externalities. Although SIA identify a range of social impacts from climate change, and are sometimes framed as vulnerability assessments, most SIA do not explicitly address the social inequalities (such as socio-economic status, age, gender, ethnicity, health status and so on) at the root of social vulnerability. SIA are therefore limited in their ability to inform appropriate and transformative adaptive responses. Examples of SIA utilised to assess climate vulnerability in coastal locations around Aotearoa include:

- The Cape Coast Area Coastal Hazards Social Impact Assessment and Valuation (Maven Consulting Ltd, 2017) carried out on behalf of the Hastings District Council, Hawke's Bay Regional Council, and Napier City Council. This SIA seeks to understand the effects of climate-related coastal hazards including erosion and inundation on the small coastal communities of Te Awanga and Haumoana on Aotearoa's east coast. The report analyses the social outcomes or impacts of coastal hazards and estimates a monetary value (a "social cost" to the community) of these impacts, in order to facilitate decision-making. Impacts include decreased wellbeing amongst coastal property owners, loss of access to community facilities and services, and decreased business to local wineries reliant on foot and road traffic. Although groups like property and business owners are identified as affected by coastal hazards, the SIA takes a risk-hazard approach where vulnerability is equated with exposure to coastal hazards, rather than underlying social inequalities amongst community members.
- The Natural Hazards Social Impact Assessment for Wharekawa (EnviroStrat, 2020), conducted on behalf of the Hauraki District Council and Waikato Regional Council. Like the Cape Coast SIA above, the Wharekawa SIA assesses the social outcomes from climate-related coastal hazards based on a 'status quo' scenario where no additional interventions are taken to reduce hazard risk. The SIA focusses on coastal flooding and sea-level rise and seeks to provide information for coastal planning and hazard responses. Similar to the Cape Coast SIA, the Wharekawa SIA takes a risk-hazard approach to vulnerability. It identifies a range of people who will be affected by coastal hazards (property owners, farmers, businesses) because of their exposure to flooding rather than social dynamics that mediate sensitivity, adaptive capacity and propensity for harm.

5.3 Gaps in Aotearoa's approach to social vulnerability indicators and assessments

Although social vulnerability is receiving more attention from climate adaptation practitioners and decision-makers in Aotearoa, the limited suite of social vulnerability indicators and assessments lack the nuance that is beginning to appear in the international social vulnerability literature and policy-making sphere.

Vulnerability is equated with degree of physical exposure to hazards

Some Aotearoa-based indicators and assessments still pursue a risk-hazard model of vulnerability whereby communities, neighbourhoods, or social groups are deemed vulnerable because of heightened exposure to climate hazards (Jozaei et al., 2022). Socio-political factors and inequities

contributing to vulnerability are therefore ignored or downplayed, despite a wealth of international literature and indicators underlining the socio-political nature of vulnerability. This oversight generally applies to the SIA noted above but can also be observed in the Wellington Regional Coastal Vulnerability Assessment. Although community deprivation and resilience is included in indicators for assessing vulnerability of Wellington's coastal suburbs, the majority of indicators pertain to measures of exposure including population density, presence of important sites, lifelines, and infrastructure. Consequently, areas with the highest concentration of exposed people and assets are deemed most vulnerable, whilst groups vulnerable to coastal hazards because of their social characteristics may not be identified.

Limited range of social characteristics are considered

Although most Aotearoa-based indicators measure social vulnerability with reference to a range of characteristics and identifiers, some indicators are based off a small number of factors only, such as older age, deprivation, and social isolation (Tonkin & Taylor Ltd, 2021). This could mean that conclusions about social vulnerability are inaccurate since other relevant factors contributing to vulnerability might not be accounted for.

Static portrayals of social vulnerability

Whilst some Aotearoa-based indicators and assessments acknowledge the dynamic nature of social vulnerability (Mason et al., 2021; Ministry for the Environment, 2020), in general, indicators and assessments provide a static snapshot of vulnerability. Aotearoa-based indicators mostly rely on census data or other indices like the NZDep that were collected or compiled several years prior to the development of the indicator (Joynt & Golubiewski, 2019; Khan, 2012; Steele et al., 2019; Tonkin & Taylor Ltd, 2021). Observations (whether quantitative or qualitative) about social change (population dynamics, the shifting nature of inequalities and so on) are not a major focus of indicators and assessments in Aotearoa. Population dynamics is a case in point.

Studies of social vulnerability to climate change in Aotearoa reveal that population change and migration is a relevant factor that should be considered in both coastal and non-coastal locations (King et al., 2012; Uekusa et al., 2022). For instance, King et al. (2012) note that at Manaia, a coastal settlement in Hauraki-Waikato, in-migration from urban locations can increase vulnerability amongst Māori. Māori whānau (families) who return to Manaia after having lived in cities can sometimes have limited local environmental knowledge that leads to more risky behaviour during coastal flooding or plans to build a whare (home) in flood-prone locations. Population growth and migration is acknowledged as a driver of social vulnerability in documents such as the NCCRA (Ministry for the Environment, 2020) and Australasia chapter of the latest IPCC Working Group Two assessment (Lawrence et al., 2022), yet only features in two social vulnerability indicators in Aotearoa (Khan, 2012; Mason et al., 2021). In both cases indicators of population change draw on census data which does not always reflect the current demographics of the region, and can therefore lead to over- or under-estimations of vulnerability (R. Hardy & Hauer, 2018).

In addition, most Aotearoa-based indicators and assessments do not account for interaction between multiple scales and instead focus on the local level (be it a census mesh block, neighbourhood, or suburb). This local focus obscures understanding of how regional and national governance, planning, and even international factors like changes to global markets and the pandemic may affect social vulnerability on a local scale and how this may differ through time.

As stated in section 2.3, the replication of static measures of social vulnerability is not a new problem, and international indicators have been widely critiqued for this reason. Scholars and practitioners internationally are therefore taking steps to integrate dynamism into social

vulnerability indicators, however the same is not necessarily true for indicators and assessments in Aotearoa. A number of qualitative studies on climate and hazards vulnerability in Aotearoa present a more nuanced and dynamic picture of social vulnerability that accounts for national and international migration, patterns of population change, and the sphere of governance and policy (King et al., 2012, 2013; Matthewman & Uekusa, 2022; Oliver-Smith, 2022) yet these remain peripheral to indicator design.

Focus on deficits and downplaying adaptive capacities

A further issue is that Aotearoa's social vulnerability indicators and assessments primarily measure deficits amongst social groups that increase vulnerability to climate change and hazards. They largely overlook the abilities, assets, and capacities that people possess and use to offset risk and vulnerability, including in coastal locations.

Socio-economic deprivation is one of the key indicators that is used to measure social vulnerability to hazards in Aotearoa. Use of the NZDep Index, Index of Multiple Deprivation, and statistics on income thresholds below certain levels are common (Fernandez & Golubiewski, 2019; Joynt & Golubiewski, 2019; Khan, 2012; Mason et al., 2021; Steele et al., 2019). Sometimes presence of high numbers of older people, single parent households, renters, unemployed persons, and those in receipt of a government benefit are used as proxies for deprivation (Mason et al., 2021; Ministry for the Environment, 2021; Tonkin & Taylor Ltd, 2021).

Other frequently-used, deficit-focussed indicators include: older age (over 65), physical and mental impairment, disability, limited education and English proficiency, being new to the area (immigrants, recent migrants), living in poor quality or overcrowded housing, female gender, lack of access to a car or the internet at home, identifying with an ethnic minority, and being socially isolated (Joynt & Golubiewski, 2019; Khan, 2012; Mason et al., 2019; Ministry for the Environment, 2020; Tonkin & Taylor Ltd, 2021).

The focus on deficits is shared by many indicators for social vulnerability internationally (see section 2.3) and is based upon clear and well-established linkages between socio-economic, political, and culturally-mediated disadvantage and increased propensity to harm from climate change and hazards (Adger, 1999; Barnett, 2020; Bohle et al., 1994; Liverman, 1999; Sultana, 2014). Although many communities in Aotearoa (especially rurally) are low decile, and have a significant proportion of older and/or multiply disadvantaged residents, this does not automatically equate to greater climate vulnerability. In simply reproducing the deficit discourse, Aotearoa's indicators and assessments of climate and hazard vulnerability overlook more balanced assessments of vulnerability that account for adaptive capacities and strengths.

As Stephenson et al. (2018, p. 8) observe of climate vulnerability in Aotearoa,

> "just because people have a low ranking in the SocDep Index[3] does not necessarily mean they are more vulnerable to climate change impacts – they may have skills, knowledge, and networks that provide resilience which others lack."

Studies of hazard vulnerability and response amongst Māori reaffirm this assertion. Notwithstanding the heterogeneity between and amongst Māori iwi, hapū, and whānau, many Māori live with high levels of deprivation, experience ongoing marginalisation, inhabit locations and homes physically exposed to climate hazards, and engage in everyday activities affected by climate change (Carter,

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[3] The Social Deprivation Index, originally developed for the UK context by Forrest and Gordon (1995). Aotearoa-based equivalents include the NZDep and IMD.

2018; King et al., 2010; Rua et al., 2019). Despite these hardships, research demonstrates that Māori social structures, knowledge, values, and practices enable coping and adaptation during sudden-onset disasters like earthquakes, coastal flooding, and volcanic explosions as well as slower-onset climatic change, including in coastal locations (King et al., 2013). Examples of adaptation/coping capacities or strengths include whakapapa (extended family, and reciprocal relationships of care within the collective), manaakitanga (hospitality, caregiving), kotahitanga (tribal unity, reciprocity, acting collectively), and local environmental knowledge (Kenney et al., 2015; King et al., 2013; Pardo et al., 2015; Proctor, 2013).

Similarly, while recent migrants may face linguistic, socio-economic, and cultural barriers that increase their vulnerability to hazards, they may also possess specialist knowledge about hazard adaptation gained in their home community, or high levels of personal resilience that enables coping during hazard-induced emergencies (Uekusa et al., 2022). Despite these bodies of research, adaptive capacities continue to be overlooked in Aotearoa's indicators and assessments. For example, the report detailing the development of the Social Vulnerability Index for Flooding gives many examples of Māori capacities for adaptation that are drawn from existing research, yet these capacities do not feature in the final indicators (Mason et al., 2019).

Failing to examine capacities for adaptation could skew the results of vulnerability assessments, and result in unnecessary or even unwanted interventions. It also means that all members of a social group – be it Māori, renters, the elderly, or those on a low income – are assumed to be equally vulnerable, which may not be the case. An increasing volume of climate scholarship demonstrates that vulnerability is experienced differently by individuals and households whom identify with the same social group (Djoudi et al., 2016; Erwin et al., 2021; Gonda, 2017; Kaijser & Kronsell, 2014; Walker et al., 2021). For instance, women in rural Ghana have more or less access to resources and opportunities that aid climate adaptation on account of their age and marital status (Lawson et al., 2019). In an Aotearoa context, Māori households in Te Tai Tokerau (Northland) experience greater or lesser vulnerability to water shortage during drought owing to different levels of income, savings, and education, their physical location, household size, and health status (Johnson et al., 2022).

Limited engagement with the nuances of social vulnerability is a problem for most indicators, nationally and internationally. Although this is related to the minimal focus on adaptive capacities or strengths within social groups, it is also a broader problem with how indicators themselves are constructed. Indicators generally create an overall measure of social vulnerability for a community, neighbourhood, or region that is based on adding together the presence of vulnerability-enhancing characteristics (such as deprivation, employment status, ethnicity, age, and gender). There is very limited capacity within indicators to examine how different social characteristics may interact with each other, to produce diverse experiences of climate change and hazards.

Some practitioners internationally have developed ways to more accurately reflect the on-the-ground experience of climate vulnerability through indicators, and move away from heterogenous portrayals of social groups. For example, Atyia Martin (2015) developed an indicator for social vulnerability to coastal hazards in Boston that conveyed how intersecting social categories elevated vulnerability. Atyia Martin identified that gender, housing tenure, transportation access and health status clustered together, leading to greater vulnerability amongst female renters with no car and a health condition, rather than vulnerability simply arising from being a renter. Indicators in Aotearoa, however, do not take this approach and both climate change indicators and risk and vulnerability assessments treat whole social groups as equally vulnerable. For instance, the NZCCRA notes that women, children, those with mental health difficulties, and Māori are all likely to be more vulnerable to the effects of climate change (Ministry for the Environment, 2020). There is limited consideration

of how some individuals or households within these groups may have greater capacities for adaptation or be more vulnerable because of their affiliation with other characteristics and identifiers such as health status, class, or gender. Likewise, social vulnerability indicators developed for areas including the Hutt Valley, Auckland, and Otago posit that being female, aged over 65, Māori or Pacifica all elevate vulnerability, with no provision for investigating diverse experiences within these social groupings (Joynt & Golubiewski, 2019; Khan, 2012; Tonkin & Taylor Ltd, 2021).

5.4 Enhancing social vulnerability indicators and assessments in Aotearoa

There are a number of ways that social vulnerability indicators and assessments for Aotearoa could be enhanced so that they more accurately reflect peoples' lived experiences of climate vulnerability, including in coastal locations. In addition to moving away from risk-hazard approaches, indicators and assessments could be strengthened by integrating more wide-ranging measurements of social vulnerability; greater consideration of dynamism, adaptive capacities, and interaction between social categories; and elevating involvement of affected communities in the construction of indicators and assessments. Below, we draw on some of the more nuanced indicators developed for international (coastal) contexts and qualitative research pertaining to (coastal) Aotearoa to demonstrate how this can be achieved.

Wider range of social vulnerability measurements

Social vulnerability assessments and indicators that draw on a small number of factors could be enhanced by looking to the wide range of indicators in use in international social vulnerability indices. Comprehensive indicators developed for the Aotearoa context such as Mason et al.'s SVI (above) may also be useful in this regard. In addition, many of the indicators contained within Ngā Tūtohu Aotearoa (Stats NZ, 2022) and the LSF (The Treasury, 2022a) are relevant to social vulnerability to climate change (see TableAppendix 6) and could be integrated into indicators to make them more comprehensive and enhance their accuracy.

Greater emphasis on dynamism

Aotearoa's social vulnerability indicators and assessments could engage more thoroughly with the dynamic nature of vulnerability by integrating consideration for change through time and interactions between scales. One way to overcome the static portrayal of social vulnerability in Aotearoa is for indicators and assessments to build in greater consideration for population change (including future population projections) using the latest available data. Ngā Tūtohu Aotearoa contains relevant quantitative measures of population dynamics (including geographical distribution of total population by regional council area and net migration to Aotearoa) that are updated more frequently than the census (annually and even monthly). These could serve as useful data sources for future indicators. Additionally, qualitative methodologies (such as household surveys, interviews, or focus groups) could provide valuable observations about the changing nature of regional and neighbourhood demographics.

Attending to other measures of social change is also important. Again, Ngā Tūtoho Aotearoa offers a number of relevant indicators which could be incorporated into future social vulnerability indicators. These include: education equity and health equity (source and frequency under development), income adequacy, inequality, and self-reported health status (measured annually). Relevant scholarship and qualitative data could complement these measures.

Building in greater consideration for the multi-scalar and interactive nature of social vulnerability is another avenue through which indicators and assessments could be enhanced. The current limited local scale focus could be widened through including measures of: local, regional, and national climate governance, policy, and action; the state of the local and regional environment; urban

(re)development and planning; current global or national events likely to impact vulnerability; and people's attitudes towards climate hazards and adaptation.

Vulnerability scholarship demonstrates that multi-scalar biological, ecological, institutional, political, and psychological processes all feed into how social vulnerability is experienced at the individual, household, and local level (Blaikie et al., 1994; Cameron, 2017; Eriksen et al., 2015; Frank et al., 2011; Kovats et al., 2003; Thomas et al., 2019; Turner, Kasperson, et al., 2003). For instance, historical and contemporary land management practices that have modified or degraded local environments can interact with and exacerbate the impact of current and future climate hazards on both local and more distant populations, especially if these people identify with other characteristics that elevate their vulnerability (Berrueta et al., 2017; Brännlund & Axelsson, 2011; Eakin et al., 2012; Lynn et al., 2013; Mcevoy & Wilder, 2012; Rasch, 2016). Conversely, community-led climate adaptation strategies in both urban and rural locations, and participation of local governments in global climate action networks can help mitigate risk for socially vulnerable groups in neighbourhoods, communities, cities, and regions (Amorim-Maia et al., 2022; Bulkeley, 2003; Donatuto et al., 2019; Status of Tribes and Climate Change Working Group, 2021). These kinds of observations could be woven into indicators to enhance their accuracy.

There are a variety of international social vulnerability indicators that could serve as models for a more wide-ranging, multi-scalar suite of indicators in Aotearoa. Additionally, both the LSF and Ngā Tūtohu Aotearoa contain relevant indicators. TableAppendix 8 in Appendix 6 gives further details of the types of indicators that might be helpful to consider.

Engaging nuance, capacities, and interaction
In order to engage the nuances of social vulnerability and move beyond the current deficit framing of indicators and assessments in Aotearoa, it is important that future indicators and assessments include measures of the strengths, capacities, and assets that people possess and may draw on to adapt to challenges like climate change. As section 2.3 states, there are a number of international indicators that examine factors increasing vulnerability alongside characteristics that enhance coping and adaptation. Additionally, some indicators feature both a vulnerability index and a resilience or adaptive capacities index (Bergstrand et al., 2015; Su et al., 2015; Wu et al., 2016). These indicators could serve as a model for Aotearoa. TableAppendix 9 in Appendix 6 below provides examples of specific indicators that measure adaptive capacities, strengths, and assets, which are drawn from international indicators and assessments.

Although international frameworks can be helpful in expanding the focus of social vulnerability indicators and assessments in Aotearoa, it is vital that indicators for adaptive capacities and strengths are tailored to the Aotearoa context. Existing research on household, community-level, and iwi/hapū/marae responses to climate change, disasters, and hazards (including the studies mentioned in section 5.3) may be informative in this regard. Equally, frameworks for measuring wellbeing and resilience in Aotearoa (such as the LSF and New Zealand Resilience Index) contain useful indicators of strengths and capacities social groups may draw on to offset their vulnerability to climate change. TableAppendix 9 provides relevant examples from existing Aotearoa-based research and indicators. Fundamentally, however, the selection of indicators for both adaptive capacities and characteristics elevating vulnerability must be rooted in inclusive, collaborative processes involving not only technical experts and government personnel but members of communities, iwi, hapū, marae, and whānau (see below).

Integrating personas (or fictional characters) into vulnerability assessment is another way to build in consideration of people's adaptive capacities and better account for the interactive, diverse nature

of vulnerability. Personas are often employed in market research to explore the needs, desires, and experiences of potential users of a specific product or service (Pruitt, 2010). Although not widely utilised in climate research or vulnerability analysis (Morrison & Chisin, 2017), there is some evidence to suggest that personas have a role to play in highlighting the diverse experiences of climate change that exist in communities (Blackett et al., 2019; Davies et al., 2023).

In the serious game Adaptive Futures (developed by Blackett et al. 2019) players are challenged to think through the complexities of adapting to climate change in the fictional coastal community of Seaview. A key element of winning the game is to make adaptation decisions that satisfy a community panel composed of personas or 'non-player characters' whom reside in Seaview (Blackett et al., 2019). Like people in a real-life community, the personas hold a range of different values, interests, and attitudes towards climate change and adaptation options that are structured by their physical location within Seaview in combination with facets of their identity (including their age, occupation, cultural heritage, and worldview). In an evaluation of Adaptive Futures, players revealed that the presence of personas helped them to consider multiple angles on any one adaptation decision that could account for the heterogeneous experiences and perspectives of Seaview non-player characters (Davies et al., 2023).

Similarly, personas could be used in vulnerability assessment to better capture the uneven lived experiences of climate change within Aotearoa's communities. Personas could be built up from a suite of social/demographic identity-markers, the combinations of which could be selected to reflect the broad characteristics of the community under consideration (as captured in statistical data and/or qualitative research about the community). Characteristics could include: ethnicity, mobility/health status, socioeconomic status, access to social networks, political persuasion, dwelling type and location, occupation, access to local/practical knowledge, and so on. In effect, the personas could act as archetypes of different social groups residing in the community, whereby each group possesses unique experiences of climate vulnerability because of their varied degrees of sensitivity to hazards, and their different capacities to respond and adapt.

One way to operationalise personas in vulnerability assessment is through the use of agent-based modelling (ABM) tools (Johnson et al., 2023). ABM offers a way to visualise how agents – in this case, the personas – are affected by and respond to a range of climate change scenarios for a region or community. Analysing the varied impacts of climate change scenarios on personas gives a good indication of differential vulnerability within a community and goes beyond the limited conception of uniform community vulnerability perpetuated by current indicator-based systems. Approached in this way, personas offer potential to more accurately assess the diverse manifestations of social vulnerability within communities. In particular, personas allow better understanding of the largely overlooked capacities and strengths that people draw on to adapt to climate change and offset their vulnerability (even if they belong to social groups otherwise considered vulnerable).

Community-led design

The selection of variables used to assess, measure, and quantify social vulnerability must be inclusive, collaborative, and led by members of social groups and communities affected by climate change. As sections 2.3 and 3 note, international scholars and adaptation practitioners regard inductive design and validation of indicators (through methodologies like focus groups and interviews) as best practice (Katic, 2017; Kovats et al., 2003; C. V. Nguyen et al., 2017; Oulahen et al., 2015; Pacific Community (SPC) et al., 2016; Tapsell et al., 2002). In Aotearoa, stakeholder and community input informed the design of the Social Vulnerability Indicators for Flooding (Mason et

al., 2021) and social vulnerability portion of the Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021). Additionally, public consultation guided the NCCRA, National Adaptation Plan (NAP), and frameworks such as the LSF and NZRI (Ministry for the Environment, 2020, 2022; Stevenson et al., 2018; The Treasury, 2022a).

To ensure that vulnerability assessments and indicators accurately reflect the diverse experiences of social vulnerability in Aotearoa, it is important to enhance public input. Documents such as the NAP and Christchurch's Climate Resilience Strategy acknowledge the need to support Māori iwi and hapū to develop their own climate change vulnerability assessments and indicators (Christchurch City Council, 2021; Ministry for the Environment, 2021, 2022). Indigenous peoples within and beyond Aotearoa are leading efforts to analyse, monitor, and adapt to the impacts of climate change in ways that align with their lived realities, worldviews, practices, and knowledge systems (Carter, 2018; Donatuto et al., 2014; D. Hardy et al., 2019; Löw, 2020; Ranco et al., 2012; Sawatzky et al., 2020). Supporting Māori to develop iwi-, hapū-, and marae-specific climate indicators is one way to increase the likelihood that vulnerability analyses align with Te Ao Māori in all its diversity, whilst affirming tino rangatiratanga and ongoing efforts to facilitate Indigenous-led adaptation in Aotearoa (Awatere et al., 2018; Blackett et al., 2021; Henwood et al., 2019; Smith, 2020).

Participation of other social groups and identities is equally important. The development, testing and validation of social vulnerability indicators and assessments should ideally be guided by a diverse cross-section of the community or region under consideration. This might include (but is not limited to) Pacific, Asian, Māori, and members of other ethnic communities, former or recent refugees, members of the disability and LGBTQI+ communities, individuals and families from low-income backgrounds, youth, elders, women and girls, those working in industries likely to be affected by climate change, urban and rural dwellers, and those affiliated with religious or spiritual communities. Many community members will identify with more than one social group or identity.

When considering the input of community members, it is vital to go beyond tokenistic involvement (where community members are present in meetings or consultations but have little power to shape outcomes) (Arnstein, 1969). Enhancing true participation will require attention to the details of engagement (Harmsworth et al., 2015; Horney et al., 2015). This might include resourcing groups (such as Māori or Pacific community members, members of the disability community and so on) to lead their own engagement processes, in ways and spaces that are most appropriate, and at times of the day and week most suited to their participation. Face-to-face engagement presents its own challenges, and sometimes internal power dynamics (along the lines of gender, education, age and so on) can prevent equal participation of social group members (Nagoda & Nightingale, 2017; Ranjitkar, 2020). Other methods of engagement (such as online surveys or individual interviews) may help elevate participation of a diverse range of community members.

6. Conclusions

This report provides a broad overview of the types of indicators currently used to measure social vulnerability to climate change, both internationally and within Aotearoa. It reviews the theoretical foundations of social vulnerability, major indicators developed by adaptation practitioners and scholars, and identifies how the field is developing greater nuance, how it is being applied in coastal settings, and how social vulnerability is assessed in (coastal) Aotearoa.

Aotearoa currently has a limited suite of indicators for evaluating social vulnerability to climate change. Although existing indicators are helping to identify social groups, neighbourhoods, and

regions likely to experience significant risks from climate change, Aotearoa's social vulnerability indicators and assessments largely repeat the static and deficit-focussed approach to vulnerability that is pursued by the majority of international indicators. Aotearoa's social vulnerability indicators and assessments could be enhanced by paying closer attention to innovation in the international sphere. Internationally, social vulnerability indicators and assessments account more readily for dynamism of vulnerability though time and between scales, balance consideration of social inequality alongside adaptive capacities or strengths, and emphasise participation of affected community members in the selection, design, and validation of indicators.

Aotearoa's coastal communities will face a suite of impacts from climate change over the coming decades. Enacting appropriate adaptations to these hazards rests on accurate assessment of the risks, which involves a clear understanding of what and who is most vulnerable. Approaching vulnerability in a more dynamic way and better considering diverse experiences and adaptive capacities within communities is fundamental to this process. As this report lays out, there are different options for how to pursue this goal. Although many of the more innovative indicators are developed for contexts overseas, there are also a range of information sources within Aotearoa that could be tapped to enhance existing indicators and progress towards more rounded analyses of vulnerability.

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Appendix 1. Common measures of social vulnerability to climate change

Table 1 Frequently used indicators for measuring social vulnerability to climate change

Indicator	Relation of indicator to social vulnerability	Sources
Population density Measured as: population or dwelling density, number of people resident, or households in exposed area, density of housing units, number of housing units per square mile, manufacturing or commercial establishments, building permits issued, large or medium urban areas, percentage of urban residents, remoteness, people living in remote or rural communities Sometimes: population growth rate in exposed area	Areas with greater population density mean that more people are exposed to climate hazards. Additionally, in densely populated areas there can be difficulties with evacuation during emergencies if arterial roads become blocked. Heatwaves are more intense in dense urban areas with limited green infrastructure (parks, plantings, etc), and in low-income neighbourhoods where multiple-occupancy or overcrowded housing is more common (see below). Flooding can happen quickly in densely populated urban areas where hard non-porous surfaces are not broken up by green infrastructure and where storm-water drainage is poorly maintained, old, or insufficient for the number of dwellings. In urban areas, emergency services (hospitals, fire, police, lifelines like electricity, etc) can also be more stretched to provide relief to a large number of people during hazard emergencies like wildfires. Residents of sparsely populated or rural areas may also be vulnerable to climate change. There may be limited escape routes during hazards like wildfires (for example, having only one road in/out of a settlement), and emergency services (like hospitals and firefighting) can be located large distances from	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) Cologne Flood Indicators, based on MOVE framework (Birkmann et al., 2013) UNDP Social Vulnerability Indicators (Katic, 2017) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) World Food Programme Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015) University of Notre Dame Global Adaptation Index (Chen et al., 2015) Integrated method for evaluating vulnerability (Meur-Férec et al., 2008) Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Census-based SVI for Bucharest (Armaş & Gavriş, 2016)

Indicator	Relation of indicator to social vulnerability	Sources
	where people live. Residents of rural areas in Aotearoa tend to be on an independent rather than government-maintained water supply, which puts them at risk of running out of water during a drought (if supplied by roof-runoff tanks) and having to buy water (which can be very costly). Independent water supplies can also become contaminated during hot weather and floods and although regulations are being introduced to enhance the safety of independent drinking water supplies, the risk in the near-term remains. Furthermore, residents of sparsely populated rural locations may be exposed to hazards by default if they live in regions with mountainous terrain at risk of landslides, coastal areas at risk of sea-level rise and erosion, or close to pine forest plantations which are highly flammable.	NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.) Indicator Based Vulnerability Assessment (Tapia et al., 2017) Social Vulnerability Index for coastal Bangladesh (Tasnuva et al., 2020) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Comparative Vulnerability Model (Yoon, 2012) Samoa Social Vulnerability Index (Grasso et al., 2013) Social Vulnerability Index (Oulahen et al., 2015) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Sensitivity Index (social vulnerability of coastal cities in China) (Su et al., 2015) Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018) CSoVI (Boruff et al., 2005) Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017) Wellington Regional Coastal Vulnerability Assessment (Steele et al., 2019)

Indicator	Relation of indicator to social vulnerability	Sources
		Comprehensive Vulnerability Assessment (Aotearoa-based) (Khan, 2012)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Children under 5 years of age or youth Measured as percentage of population in the area under 5, 12, 15, 17, number of members in a household aged under 5, number of families with two or more children in an area, females over 15 years old with three or more children, etc	Children are dependent on adults and cannot necessarily care for themselves during climate related emergencies like floods or storms Children may lack life experiences that adults can use to prepare for, cope with, and adapt to climate change and hazard emergencies Having children in a household can increase levels of preparedness for events like floods, and therefore reduce vulnerability	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) University of Notre Dame Global Adaptation Index (Chen et al., 2015) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015) Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021)

Indicator	Relation of indicator to social vulnerability	Sources
		Flood Preparedness Index (Działek et al., 2016)
		Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020)
		Indicator Based Vulnerability Assessment (Tapia et al., 2017)
		Samoa Social Vulnerability Index (Grasso et al., 2013)
		Social Vulnerability Index (Oulahen et al., 2015)
		Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021)
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Comparative Vulnerability Model (Yoon, 2012)
		Sensitivity Index (social vulnerability of coastal cities in China) (Su et al., 2015)
		Social Vulnerability Index for Vietnam (C. V. Nguyen et al., 2017)
		Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		Social Vulnerability Index for coastal Bangladesh (Tasnuva et al., 2020)
		Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)

Indicator	Relation of indicator to social vulnerability	Sources
		NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.)
		National Risk Index (FEMA, 2021)
		Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017)
		Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016)
		Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007)
		CSoVI (Boruff et al., 2005)
		Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018)
		Comprehensive Vulnerability Assessment (Aotearoa-based) (Khan, 2012)
		Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019)
		Impact Index (Auckland climate vulnerability assessment) (Fernandez & Golubiewski, 2019)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Older adults, often over 65 years of age This includes measures of percentage of population in the area over 65, 70, 75 or 80 or number of	Older people are physiologically sensitive to heat, damp, and cold, and at increased risk of adverse health conditions when exposed to heatwaves, floods, and storms. They may also have underlying health conditions that exacerbate their sensitivity to the health impacts of climate change.	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018)

Indicator	Relation of indicator to social vulnerability	Sources
members in a household that are aged over 65	Older people may be dependent on others for assistance in coping with and adapting to climate change (for example, help evacuating in an emergency or to make their property more secure against flooding). Not all older people can access this support as they may be socially isolated. Older people may be financially insecure and therefore less able to afford resources or services that would help them to prepare for, cope with, or adapt to climate hazards.	Cologne Flood Indicators, based on MOVE framework (Birkmann et al., 2013) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) University of Notre Dame Global Adaptation Index (Chen et al., 2015) Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015) Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) Community Asset and Social Vulnerability Mapping (Manuel et al., 2015) Social Vulnerability to Climate Change in Taiwan (Wu et al., 2016) Flood Preparedness Index (Działek et al., 2016) Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020)

Indicator	Relation of indicator to social vulnerability	Sources
		Indicator Based Vulnerability Assessment (Tapia et al., 2017)
		Samoa Social Vulnerability Index (Grasso et al., 2013)
		Sensitivity Index (social vulnerability of coastal cities in China) (Su et al., 2015)
		Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015)
		Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018)
		Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017)
		Social Vulnerability Index (for coastal Bangladesh) (Tasnuva et al., 2020)
		Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021)
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Comparative Vulnerability Model (Yoon, 2012)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)
		Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019)

Indicator	Relation of indicator to social vulnerability	Sources
		NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.)
		National Risk Index (FEMA, 2021)
		Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017)
		Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016)
		Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007)
		CSoVI (Boruff et al., 2005)
		Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019)
		Impact Index (Auckland climate vulnerability assessment) (Fernandez & Golubiewski, 2019)
		Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Low socio-economic status of household, neighbourhood, community, or region. Expressed as: low or no income, poverty ratio or percent below	Having limited access to disposable income and/or savings makes it more challenging for individuals, households and groups of people to anticipate, prepare for, cope with, recover from and adapt to climate change hazards. For example, those with	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011)

Indicator	Relation of indicator to social vulnerability	Sources
poverty line in an area, deprivation of an area, household or median income for an area below a certain threshold, median house or rent value or disposable income in an area, high rent burden, dependence on remittances or overseas aid, lack of savings, unemployment in household or levels of unemployment in an area, diversity of income, dependence of household on government benefits or levels of benefit dependence in an area, GDP per capita, per capita income, GINI index, etc	limited financial means may struggle to purchase home and/or contents insurance which leaves them vulnerable to loss of their homes and belongings during events like floods and storms, or on a longer time scale, due to coastal erosion and sea level rise. Many on a low income will not be able to afford to replace belongings and may struggle to find alternative affordable accommodation. Similarly, low-income groups and households may have difficulties purchasing extra food, drinking water, and other emergency supplies that would help them to cope with disasters like flooding or hurricanes, and they may not have the financial capacity to run fans and/or air conditioning or cooling units (if available) to help keep their home cool during heatwaves.	CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Cologne Flood Indicators, based on MOVE framework (Birkmann et al., 2013) UNDP Social Vulnerability Indicators (Katic, 2017) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) University of Notre Dame Global Adaptation Index (Chen et al., 2015) World Risk Index (Birkmann et al., 2022) IUCN Rapid Assessment of Climate Change Vulnerability and Adaptation Planning at Ramsar Sites (Wyatt et al., 2020) World Food Programme Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015) CLEAR: Consolidated Livelihood Exercise for Analysing Resilience (Ministry of Natural Resources, Department for Disaster Management and Climate Change & World Food Programme, n.d.) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015)

Indicator	Relation of indicator to social vulnerability	Sources
		Hazard Vulnerability Similarity Index (Chang et al., 2018)
		Urban Accessibility and Social Vulnerability (for Brazilian Amazon) (Parry et al., 2018)
		Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)
		Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002)
		Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022)
		Interdisciplinary Social Science Framework for Analysing and Understanding Uneven Vulnerability across Social Difference (Thomas et al., 2019)
		Samoa Social Vulnerability Index (Grasso et al., 2013)
		Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017)
		Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007)
		Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019)
		Social Vulnerability Indices for Alaska fishing communities (Lavoie et al., 2018)
		Social Vulnerability Index (for coastal Bangladesh) (Tasnuva et al., 2020)

Indicator	Relation of indicator to social vulnerability	Sources
		Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020)
		Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015)
		Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021)
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Comparative Vulnerability Model (Yoon, 2012)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		CSoVI (Boruff et al., 2005)
		Combined Vulnerability Index for Fishing Communities (Colburn et al., 2016)
		Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018)
		Sensitivity Index (social vulnerability of coastal cities in China) (Su et al., 2015)
		National Risk Index (FEMA, 2021)
		NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.)
		Social Vulnerability to Climate Change in Taiwan (Wu et al., 2016)

Indicator	Relation of indicator to social vulnerability	Sources
		Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019) Impact Index (Auckland climate vulnerability assessment) (Fernandez & Golubiewski, 2019) Wellington Regional Coastal Vulnerability Assessment (Steele et al., 2019) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Limited education of household, neighbourhood, community, or region. Expressed as: number household members or percentage of population with high school or less, minimum level of education, percentage of population or members of household aged 15+ or 25+ with no qualification or high school diploma, household head's level of education, levels of literacy or illiteracy, education expenditure of country/region etc. Sometimes indicators also include measures of	Education affects climate change vulnerability in a number of ways. Limited education is often associated with fewer opportunities for well-paid employment, and hence increases the likelihood of having a low income later in life, with associated vulnerabilities (see above). Education also increases the capacity for individuals, households, and groups to plan for and adapt to climate change, and to act upon emergency communications. For example, education can aid in understanding weather forecasting and longer-range climate projections and therefore enable people to take appropriate action. This might include cancelling travel ahead of a storm or avoiding areas	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) University of Notre Dame Global Adaptation Index (Chen et al., 2015)

Indicator	Relation of indicator to social vulnerability	Sources
more advanced education (for example, percent of people in an area in secondary or tertiary education, or percent of people with university or PhD-level education)	deemed flood or coastal erosion zones when searching for a new home. Education can also enhance the ability to diversity livelihoods as a response to climate change. For example, one member of a household may seek office work in a town or city to complement increasingly precarious family livelihoods based on natural resources (such as fishing, farming or horticulture). When education levels are limited, this can decrease the potential for household members to interpret information like climate projections and plan accordingly and may constrain the ability to pursue diversification.	Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.) Social Vulnerability Indices for Alaska fishing communities (Lavoie et al., 2018) Sensitivity Index, Capacity Index (social vulnerability of coastal cities in China) (Su et al., 2015) Social Vulnerability Index (for coastal Bangladesh) (Tasnuva et al., 2020) National Risk Index (FEMA, 2021) CSoVI (Boruff et al., 2005) Comparative Vulnerability Model (Yoon, 2012) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021) Urban Accessibility and Social Vulnerability (for Brazilian Amazon) (Parry et al., 2018) Census-based SVI for Bucharest (Armaş & Gavriş, 2016)

Indicator	Relation of indicator to social vulnerability	Sources
		Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017)
		Indicator Based Vulnerability Assessment (Tapia et al., 2017)
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Samoa Social Vulnerability Index (Grasso et al., 2013)
		Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007)
		Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015)
		Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021)
		Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018)
		Social Vulnerability to Climate Change in Taiwan (Wu et al., 2016)
		Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Presence of existing physical or mental health conditions within the household or high rates of morbidity/mortality in a neighbourhood, community, or region	Some populations that have pre-existing health conditions can be more vulnerable to climate change. For example, people with diabetes, heart conditions, and obesity may experience greater difficulties during heatwaves than otherwise healthy	Special Report of the IPCC on Vulnerability (Cardona et al., 2012) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) University of Notre Dame Global Adaptation Index (Chen et al., 2015)

Indicator	Relation of indicator to social vulnerability	Sources
Also expressed as: number of deaths per annum due to particular conditions per 1000 inhabitants of the area or at the census block level, prevalence of low birth weight	individuals. Likewise, some mental health medications increase sensitivity to heat stress. Being physically incapacitated due to a health condition can make it harder for individuals to evacuate during emergencies like wildfires, as well as presenting potential difficulties with preparing for climate hazards (such as making home repairs to strengthen the property from storms). An increasing body of evidence suggests that anxiety, depression, PTSD and other mental health conditions are associated with the impacts of climate change. For people with pre-existing experiences of mental health conditions, the mental health consequences of climate change could be more severe.	Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002) Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020) Flood Preparedness Index (Działek et al., 2016) Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Indicator Based Vulnerability Assessment (Tapia et al., 2017) The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Presence of disability within the household or high levels of disability in an area Also measured as percentage of overall population disabled, density	Disability increases vulnerability to climate change in a range of ways. For example, individuals with physical impairments can struggle to evacuate during emergencies because of mobility restrictions, and may need	CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) UNDP Social Vulnerability Indicators (Katic, 2017)

Indicator	Relation of indicator to social vulnerability	Sources
of disabled population in an area, presence of disability in household	additional assistance, support, and facilities during emergency events that are not always readily available. People with neurological or learning disabilities, or who identify as neurodiverse may experience other difficulties in the wake of climate change. For instance, autists (those living with autism) may find the experience of having to relocate to temporary accommodation after flooding or wildfire more stressful and traumatic than 'neuro-typical' people without a neurological disability. Additionally, some disabled persons have disproportionately high rates of social risk factors (low income, limited conventional education) that interact with their disability to magnify poor health outcomes with extreme events and slow-onset climate change. Many people within the disability community feel they are invisible in emergency management and climate adaptation policymaking which further intensifies potential adverse outcomes from climate change since it is unlikely that policies will be tailored to the diverse needs and/or aspirations of people with disabilities.	Special Report of the IPCC on Vulnerability (Cardona et al., 2012) The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016) Social Vulnerability Index (for coastal Bangladesh) (Tasnuva et al., 2020) Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007) Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Strengths-based approach to social vulnerability (Ogie & Pradhan, 2019) Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)

Indicator	Relation of indicator to social vulnerability	Sources
Renters or those lacking access to safe, secure housing (housing deprivation). Measured as percentage of renters or rental units in an area, percent of population living in mobile homes or percent of housing units as mobile homes in an area, presence of older buildings and those in need of repair, and homelessness or housing deprivation rates, access to climate-proof housing, slum dwelling population	Renters may be less invested in protecting their home from hazard damage due to the temporary nature of their occupancy. Additionally, even if they wanted to, renters may face financial and logistical barriers to carrying out measures like installing air conditioning, ventilation, or insulation that would make their home more climate-resilient (including restrictions on altering the property, reliance on their landlord to make changes to the building). Rental properties may also be of a generally lower quality than owner-occupied buildings, therefore increasing residents' risk from climate change. Rental properties may be damaged more easily during events like storms due to cheap construction, and may can lack basic features like ventilation and insulation that make a home more able to withstand climate extremes. Mobile homes and buildings in need of repair are more susceptible to damage during events like storms, hurricanes, floods, heavy snowfall, and can have issues with damp and mould that may intensify with climate change. Occupants are therefore more at risk of associated health impacts (respiratory conditions linked to mould, for example) and may have to evacuate and seek new accommodation. Additionally, being a renter, living in a mobile home, or building in need of repair can coincide with being	SoVI (Cutter et al., 2003) UNDP Social Vulnerability Indicators (Katic, 2017) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) University of Notre Dame Global Adaptation Index (Chen et al., 2015) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021) Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002) Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019)

Indicator	Relation of indicator to social vulnerability	Sources
	lower income. Being low income and a renter may mean that even if features like heating and cooling systems are installed in a rental property, the occupant may not be able to afford to use them, whereas occupants of mobile and damaged homes may struggle to afford alternative accommodation if needed or be unable to afford to fix or strengthen their home against potential climate-related damage. Older buildings may lack features that offset the impacts of climate change (such as adequate heating and cooling) and may be damaged more easily in extreme weather. Older buildings also may not comply with building codes and regulations (such as having escape routes in an emergency like a wildfire). Homeless, housing deprived, and slum-dwelling persons may be highly exposed to climate change. Freezing weather, heatwaves, floods, and storms present significant challenges for rough sleepers and those living in accommodation like tents and cars. Slums tend to be located in places that are at risk of climate-induced disasters like landslides, floods, and fires. Again, slum dwelling and homelessness often coincides with poverty, magnifying risk for these persons.	Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) National Risk Index (FEMA, 2021) CSoVI (Boruff et al., 2005) Comparative Vulnerability Model (Yoon, 2012) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018) Social Vulnerability Index (for coastal Bangladesh) (Tasnuva et al., 2020) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019) Impact Index (Auckland climate vulnerability assessment) (Fernandez & Golubiewski, 2019) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)

Indicator	Relation of indicator to social vulnerability	Sources
Living in overcrowded, multi-occupancy accommodation This includes numbers of people living in institutional and group living arrangements, multi-storey or multi-unit buildings in an area, average number of people per household, and measurements of average room area per person or area of living accommodation	Overcrowded or multi-occupancy buildings (such as blocks of flats, nursing homes or institutional housing) may have bottlenecks that form as people try to evacuate during emergencies like floods and wildfires. Overcrowding may also intensify the impacts of heatwaves on occupants, as more people in a room raises the temperature.	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) National Risk Index (FEMA, 2021) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Single-parent household or people living alone Measured as percent of population single-parent households, population living alone, single parents with three or more dependents, household structure or	Single-parent households can be more adversely affected by climate impacts than households with two or more caregivers. In the aftermath of an event like a flood single parents may experience greater stress from having to cope alone.	SeVI (Holand et al., 2011) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Special Report of the IPCC on Vulnerability (Cardona et al., 2012)

Indicator	Relation of indicator to social vulnerability	Sources
size, households with an older adult living alone, and so on	Single-parent households may also have limited finances to anticipate and respond to climate change and support dependents during and after disasters. Older people living alone may be socially isolated and lack a support network that might otherwise help them to prepare for, cope with, and adapt to climate change. They may also face difficulties with carrying out tasks necessary to prepare for extreme weather or make their home more climate-resilient (for example, fixing minor leaks in a roof, moving sandbags and digging drainage ditches to guard against floods, etc). Older, single people may also be on a low income and unable to afford to pay for home repairs, alternative accommodation, or to purchase sufficient emergency supplies.	UNDP Social Vulnerability Indicators (Katic, 2017) Flood Preparedness Index (Działek et al., 2016) Social Vulnerability Index (for coastal Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Comparative Vulnerability Model (Yoon, 2012) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020) Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021) Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)

Indicator	Relation of indicator to social vulnerability	Sources
		Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017)
		Indicator-based Vulnerability Assessment for European cities (Tapia et al., 2017)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019)
		Impact Index (Auckland climate vulnerability assessment) (Fernandez & Golubiewski, 2019)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Women or female-headed households Measured as percent of females or female-headed households in an area, women with dependent children, gender equality index, female labour force participation	Research suggests that women in global north contexts may be at higher risk of family and sexual violence and mental health impacts in the wake of extreme events like floods and drought. Women may also have a lower income and more caring responsibilities than men which can increase vulnerability to stress during and after climate hazards and emergencies. In some contexts, gendered social norms mean that women have fewer opportunities for education and training that would better prepare them for climate change, may face barriers to accessing resources needed for diversifying or altering their livelihoods to adapt to climate change, and can face discrimination in post-disaster recovery that	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) IUCN Rapid assessment of vulnerability at Ramsar sites (Wyatt et al., 2020) Flood Preparedness Index (Działek et al., 2016) Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007) Samoa Social Vulnerability Index (Grasso et al., 2013) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017)

Indicator	Relation of indicator to social vulnerability	Sources
	perpetuates their vulnerability. Additionally, women may be expected to fulfil responsibilities that directly expose them to climate-related hazards (fetching water during floods, for example) and may not be able to evacuate during emergencies because of socially prescribed barriers to women leaving the house without a man	CSoVI (Boruff et al., 2005) National Risk Index (FEMA, 2021) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018) Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020) Comparative Vulnerability Model (Yoon, 2012) Census-based SVI for Bucharest (Armaş & Gavriş, 2016) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)

Indicator	Relation of indicator to social vulnerability	Sources
		Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
Race or ethnicity of households, neighbourhoods, communities, and regions. Measured as percentage or number of African American, Native American, Hispanic, Asian, African, Māori, Pacific, ethnic minority residents in an area	Institutional racism can mean that individuals and households identifying with non-dominant racial or ethnic groups face barriers in education and employment which consequently influence climate vulnerability (see above). Institutional racism may also limit access to resources and opportunities needed to prepare for, cope with, and adapt to climate change, either because of discrimination in allocation or domination of policymaking by racial/ethnic majorities. Because of structural disadvantages, non-dominant racial and/or ethnic groups may also be lower income with consequences for climate vulnerability (see above)	SoVI (Cutter et al., 2003) CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021) Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016)

Indicator	Relation of indicator to social vulnerability	Sources
		CSoVI (Boruff et al., 2005) National Risk Index (FEMA, 2021) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Social Vulnerability to sea level rise (in USA) (R. Hardy & Hauer, 2018) Comparative Vulnerability Model (Yoon, 2012) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019)
Limited language skills or competency at the household level or neighbourhood, community, or regional level. This includes measures of households with limited knowledge of the local language or low English proficiency, percentage of people living in a linguistically isolated household, and those not speaking English as a first language	Populations with limited proficiency in the local language may be more vulnerable to the impacts of climate change. They may have difficulties understanding official communications during emergencies like hurricanes, floods, or wildfires which can lead them to be under-prepared or delay responses like evacuation or taking shelter. Additionally, when people do not speak the local language, they may face difficulties integrating into social networks which might otherwise provide support to prepare for, cope with and adapt to climate change (see below). They may also struggle to find employment and therefore be on a low	CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) National Risk Index (FEMA, 2021) NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.) Community vulnerability to coastal hazards (Chang et al., 2018) Strengths-based approach to social vulnerability (Ogie & Pradhan, 2019) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021)

Indicator	Relation of indicator to social vulnerability	Sources
	income which in turn elevates vulnerability (see above).	Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017)
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Social Vulnerability across the Great Lakes Basin (Fergen & Bergstrom, 2021)
		Comparative Vulnerability Model (Yoon, 2012)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Migrants, new residents of an area Measured as percentage of population as immigrants, first or second Western and non-Western immigrants, or recent immigrants, foreign-born population of an area, average length of residency in an area	People who have recently migrated to Aotearoa and/or new residents of a city, town, or community may be more vulnerable to climate change. They may be unfamiliar with the type of hazards that occur in the area, how hazards play out, the locations most at risk from hazards, and how local people have responded successfully to hazards in the past. Migrants and newcomers to an area may	SeVI (Holand et al., 2011) Special Report of the IPCC on Vulnerability (Cardona et al., 2012) UNDP Social Vulnerability Indicators (Katic, 2017) Social Vulnerability Index (Mediterranean France) (Mavromatidi et al., 2018)

Indicator	Relation of indicator to social vulnerability	Sources
	also lack social connections that serve as an important channel for informal support and information sharing on preparing for and coping with hazards (see below). Migrants may also be vulnerable to climate change because of potential language difficulties and low income (see above) and may find it challenging to access formal (government) support in the wake of hazard emergencies because of their residency/citizenship status and limited familiarity with the institutional structures and services of their new country of residence.	Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016) Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007) Sensitivity Index, Capacity Index (social vulnerability of coastal cities in China) (Su et al., 2015) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Limited social support/social cohesion Measured as social connectedness with community, sense of community, perceived level of social support Sometimes proxies for social cohesion are used, including: lone-parents or one-person households, older adults living alone, presence of	Groups with limited social support from relatives, neighbours and the wider community may be at greater risk of harm from climate change. This is because social networks provide access to informal knowledge about how to prepare for, cope with, and respond to hazards (for example, where to seek official help, which locations to avoid, how to minimise loss and disruption from hazards). Social networks are also a source of direct support (be it sharing resources needed to cope during an emergency, taking shelter in a neighbour's home,	UNDP Social Vulnerability Indicators (Katic, 2017) Multifacet Composite Social Vulnerability Index (Karunarathne & Lee, 2020) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Indicator-based Vulnerability Assessment for European cities (Tapia et al., 2017) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022)

Indicator	Relation of indicator to social vulnerability	Sources
migrants in the community, presence/absence of children in the household, membership in social networks or community organisations.	checking on elderly neighbours during extreme weather, and so on). Older adults, those living alone, migrants and new residents of the area, linguistically isolated households, those with disabilities and mental health symptoms may all be socially isolated. Additionally, children often provide a means for forming social networks (through school and extra-curricular activities), therefore households without children may be more socially isolated than those with children.	Social Vulnerability Indices for Alaska fishing communities (Lavoie et al., 2018) Flood Preparedness Index (Działek et al., 2016) Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012) Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019) Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Households lacking access to a car or communications like the internet, a phoneline, or mobile phone Measured as households with no access to a car, people dependent on public transport, number of cars per household, mobile phone subscriptions, ICT infrastructure, access to internet at home, etc	Having access to a car enables members of a household/family to evacuate quickly during an emergency like wildfires and flooding. Households with no car or that are reliant on public transport may face difficulties leaving a dangerous area quickly enough. Having access to the internet, mobile phones, or a landline is an important way for households and individuals to access information about climate change and rapid onset hazards like storms or wildfires. Being able to look at future climate projections or weather forecasts online, receive emergency alerts from authorities, and make phone calls (to neighbours, emergency services, etc) are all ways to be more prepared for climate change and	CDC Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) University of Notre Dame Global Adaptation Index (Chen et al., 2015) National Risk Index (FEMA, 2021) Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) Flood Hazard Research Centre Social Flood Vulnerability Index (Tapsell et al., 2002) Social Vulnerability to flooding (in Virginia, USA) (Kleinosky et al., 2007)

Indicator	Relation of indicator to social vulnerability	Sources
	hazard emergencies, to take appropriate action, seek and offer help to those in need.	Samoa Social Vulnerability Index (Grasso et al., 2013)
		Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019)
		Comparative Vulnerability Model (Yoon, 2012)
		Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021)
		Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015)
		Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)
		Social Vulnerability Index (for Vancouver) (Oulahen et al., 2015)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Engaging in occupations or livelihoods that increase exposure to climate hazards Measured as percentage employed in primary industries, tourism, healthcare, or lifeline services, household income generation activities involving the land or sea, natural resource or capital	Individuals, households, or communities that are engaged in occupations or livelihoods easily affected by weather and climate change are more vulnerable to adverse effects. This includes people working directly with natural resources (such as farmers, agricultural labourers, and fishers, those engaged in forestry, or producing goods like handicrafts sources from local materials) and people working in tourism or businesses that	SoVI (Cutter et al., 2003) SeVI (Holand et al., 2011) University of Notre Dame Global Adaptation Index (Chen et al., 2015) IUCN Rapid assessment of vulnerability at Ramsar sites (Wyatt et al., 2020) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016)

Indicator	Relation of indicator to social vulnerability	Sources
dependence, share of GDP comprised from agriculture, fisheries and forestry, international tourism as percentage of total exports, percentage total labour force engaging in vulnerable employment	cater to tourists (where tourism is driven by landscapes and natural features of a place or cultural/heritage entities that are sensitive to climate change). When livelihoods are easily affected by climate change people are at risk of financial loss, and in the case of subsistence livelihoods, food insecurity. People working in particular occupations may also be physically endangered by climate change. This includes people like farmers and fishers who can find themselves in hazardous conditions as part of their everyday activities, as well as employees of lifeline services (electricity, communication, water, and transport networks, etc) who may be required to work in dangerous locations and conditions to restore essential services to the public. People employed in healthcare (paramedics, ambulance drivers, hospital staff) may also face increased risk to personal safety and health when attending to the public during emergencies like wildfires or floods and may also be at risk of infectious diseases that could become more common amongst the general public with climate change.	UNESCO Climate Vulnerability Index (Day et al., 2020) World Food Programme Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015) Social Vulnerability Index (for flooding in Indigenous Canadian communities) (Chakraborty et al., 2021) Community vulnerability to coastal hazards (Chang et al., 2018) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Comparative Vulnerability Model (Yoon, 2012) Social Vulnerability Metric, Louisiana Coastal Master Plan (Hemmerling & Hijuelos, 2017) NOAA Fisheries Social Indicators for Coastal Communities (NOAA Fisheries, n.d.) Social Vulnerability Index for Alaska fishing communities (Lavoie et al., 2018) National Risk Index (FEMA, 2021) Evaluating the Changing Patterns of Social Vulnerability and Adaptation Challenges in Three Coastal Cities (Kashem et al., 2016) CSoVI (Boruff et al., 2005) Samoa Social Vulnerability Index (Grasso et al., 2013) Social Vulnerability Index for coastal Bangladesh) (Tasnuva et al., 2020)

Indicator	Relation of indicator to social vulnerability	Sources
		The Impacts of Climate Change on Human Health in the United States (USGCRP, 2016)
		Combined vulnerability index for fishing communities (Colburn et al., 2016)
		Comprehensive Vulnerability Assessment (for Hutt Valley) (Khan, 2012)
		Social Vulnerability Indicators for Flooding in Aotearoa New Zealand (Mason et al., 2021)
Lacking access to basic services or infrastructure needed for wellbeing This includes measures of availability and proximity to health services (doctors, hospitals, immunisation rates, having health insurance), sanitation (potable water, handwashing facilities, waste management), education (schools, extension services, education expenditure), paved roads, public transport, electricity, green infrastructure (parks, trees, etc), access to emergency government benefits and assistance, etc	Populations who lack access to healthcare and sanitation services may be more vulnerable to climate change impacts. They could face difficulties accessing medical attention during hazard emergencies and may be less able to prevent illness and contamination during events like floods, as well as being more exposed to water, vector- borne and infectious diseases which are projected to be more prevalent with climate change. Additionally, populations lacking access to community cooling facilities, storm shelters, and fire services may be more at-risk during climate induced emergencies, while those lacking access to green infrastructure like parks and urban landscaping may be more at risk from the urban heat island effect during heatwaves, and also more vulnerable to floods due to the capacity for vegetation to slow storm water runoff. Having access to education is important for reducing vulnerability (see above), as is being able to access	SoVI (Cutter et al., 2003) UNDP Social Vulnerability Indicators (Katic, 2017) University of Notre Dame Global Adaptation Index (Chen et al., 2015) SPREP Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016) World Food Programme Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015) Children's Climate Risk Index (United Nations Children's Fund (UNICEF), 2021) Samoa Social Vulnerability Index (Grasso et al., 2013) National Risk Index (FEMA, 2021) Zeeland Social Vulnerability Index (for flooding in Holland) (Kirby et al., 2019) Social Vulnerability Index for coastal Bangladesh) (Tasnuva et al., 2020)

Indicator	Relation of indicator to social vulnerability	Sources
	emergency government benefits and assistance, which can help people to cope with the impacts of disasters and prepare for slower onset climate hazards. Lifelines such as paved roads, public transport, and electricity services reduce climate vulnerability by enabling evacuation, employment and trade, and running fans/cooling and heating systems in the home, to cope with heatwaves and cold snaps. Populations without access to these services are likely to be more vulnerable to the impacts of climate change.	Social Vulnerability to Climate Change in Taiwan (Wu et al., 2016) Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017) Geospatial analysis of race and poverty in sea-level rise vulnerability (Handwerger et al., 2021) Coupled Individual & Social Vulnerability to Environmental Hazards (Tuccillo & Spielman, 2022) Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015) Physical, social and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021) World Risk Index (Birkmann et al., 2022) Auckland Heat Vulnerability Index (Joynt & Golubiewski, 2019) Wellington Regional Coastal Vulnerability Assessment (Steele et al., 2019)

Appendix 2. Measuring and advancing social vulnerability through indicators

Table 2 Major/foundational indicators and frameworks for measuring social vulnerability to climate change

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
The SoVI (Cutter et al., 2003) NB: There are several subsequent versions of the SoVI	42 variables • Median age • Per capita income (US$) • Median $ value of owner-occupied homes • Median rent ($) for renter-occupied housing • Number of physicians per 100,000 population • Vote cast for president • Birth rate • Net international migration (1990-1997) • Land in farms as % total land • African American • % Native American • % Asian • % Hispanic • population under 5 • % population over 65 • % civilian labour force unemployed • Average number of people per household • % households earning over $75,000 • % living in poverty • % renter-occupied housing units • % rural farm population • General local government debt to revenue ratio • % housing units that are mobile homes	(1990) US census	US county	Integrated approach combining insights from exposure, political economy/ecology lineages Draws on Cutter's (1996) Hazards of Place model

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
	• % population 25 years or older with no high school diploma • Number housing units per square mile • Number housing permits per new residential construction per square mile • Number manufacturing establishments per square mile • Earnings (in $1000) in all industries per square mile • Number of commercial establishments per square mile • Value of all property and farm products sold per square mile • % of the population participating in the labour force • % females participating in civilian labour force • % employed in primary extractive industries (farming, fishing, mining, forestry) • % employed in transportation, communication, and public utilities • % employed in service occupations • Per capita residents in nursing homes • Per capita number of community hospitals • % population change 1980/1990 • $ urban population • % females • % female-headed households, no spouse present • Per capita social security recipients			

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage

Expanded Vulnerability Analysis
 	
(Turner, Kasperson, et al., 2003)
	No set variables or indicators, but guided by the following domains
	
	Vulnerability of the coupled human-environment system depends upon:
	
	Interactions between human and environmental influences outside the place at the regional and global level:
	
	• Variability & change in human conditions (macro political economy, institutions, global trends)
	• Variability & change in environmental conditions (state of biosphere, global environmental changes)
	• Interactions of hazards (perturbations, stresses, stressors)
	• Impacts/responses as a result of hazards
	• Adjustment/adaptation responses to hazards and vulnerability
	
	Place-based vulnerability:
	
	Exposure
	
	    • Components (e.g. individuals, households, classes, ecosystems)
	    • Characteristics (e.g. frequency, magnitude, duration)
	
	Sensitivity
		Depends on the context to which the framework is applied	Analysis of vulnerability is place-based (community, regional, etc) but includes consideration of regional and global factors	Human-environment/resilience lineage

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
	• Human conditions, social capital and endowments (e.g. population, entitlements, institutions, economic structures) • Environmental conditions, natural capital, biophysical endowments (e.g. soil, water, climate, ecosystem structure) Resilience • Coping/response (e.g. extant policies, autonomous options) • Impact/response (e.g. loss of life, economic production, ecosystem services) • Adjustment and adaptation/response (e.g. new policies and autonomous options)			
The MOVE framework (Birkmann et al., 2013)	No set variables or indicators, but guided by the following domains **Environment: Hazards** • Natural events • Socio-natural events **Society: Vulnerability** Exposure • Temporal • Spatial	Depends on the context to which MOVE is applied. In the case of Cologne Flood Indicators, a mixture of census data, household surveys, expert interviews and biophysical data (hydrological models) were used	The MOVE framework can be applied to a range of scales, and has been applied at the city and regional level	Integrated approach, drawing on Disaster Risk Reduction, Climate Change Adaptation, and the Human-Environment/Resilience lineage (in particular, the work for Turner et al. 2003)

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
	Susceptibility & fragility • Physical • Ecological • Social • Economic • Cultural • Institutional Lack of resilience • Capacity to anticipate • Capacity to cope • Capacity to recover **Risk: economic/social/environmental impacts or losses** **Risk governance: organisation/planning/implementation** (by governments, institutions, households to reduce, prevent, mitigate and transfer risk) **Adaptation:** strategies or assets to reduce vulnerability Hazard intervention Vulnerability intervention • Exposure reduction			

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
	• Susceptibility reduction • Resilience improvement			
The Social Vulnerability Index (Centres for Disease Control and Prevention (CDC), 2022; B. Flanagan et al., 2011; B. E. Flanagan et al., 2018)	15 variables **Socioeconomic status** • Below poverty • Unemployed • Income • No high school diploma **Household composition & disability** • Age 65+ • Age 17 or younger • Older than age 5 with a disability • Single parent households **Minority status & language** • Minority • Speaks English "less than well" **Housing & transportation** • Multi-unit structures • Mobile homes • Crowded homes • No vehicle • Group quarters	US Census	SVI created for census level tract and United States county level	Builds directly on the work of Cutter et al. (2003) – the SoVI

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
The SeVI and BeVI (Holand et al., 2011)	**Socioeconomic Vulnerability Index (SeVI) –** 25 variables • Per capita income NOK 1000 (median) • Median per capita capital assets NOK 1000 • % households earning more than NOK 500,000 • % households with income less than NOK 150,000 • Value of housing units NOK 1000 • % with only lower secondary education • % with 4 years or more of tertiary education • % population living in nursing homes • % receiving invalidity pension • % unemployed • % employed in low-skill service sector (including retail, accommodation and food service activities, personal service and household activities) • % employed in primary sector • % participating in the labour force • % employed in health care and social services • Gender equality index • % population 5 years or younger • % population 67 years or older • % single-parent households • % out-migration per year • % first- or second-generation non-Western immigrants (countries outside of Western Europe, North America, Oceania) • % first- or second-generation Western immigrants (Western Europe, North America, Oceania) • % municipality's expenditure on debt service	(2006 data) Statistics Norway Norwegian Social Science Data Services The Norwegian Mapping Authority Gender equality index is developed by Statistics Norway and comprises measures of: Day-care availability, male-female inhabitants, education ratio, labour participation ratio, income ratio and participation in city/municipal council ratio.	Norwegian municipality	Adapted the work of Cutter et al. (2003) to the Norwegian context, but also drawing on Borden et al.'s (2007) approach which integrates measurements of socioeconomic vulnerability with built environment vulnerability

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators quantified?	Scale of application	Alignment with vulnerability lineage
	• Net debt as % of gross revenue • Municipality's disposable income per inhabitant (median = 100) • % electorate voting in local election **Built Environment Index (BeVI) –** 8 variables • Distance to nearest hospital (km) • Population density • Housing construction density • % residential building stock built after 1980 • Average age of sewer lines • Average age of water pipelines • Length of municipal roads (km per capita) • No. of exit routes from municipality, per 1000 inhabitants			

Table 3 Indicators advancing understandings of social vulnerability to climate change

Critique of major indicators	Indicators and/or approaches used to address critique	Examples	Source:
Generalisability of indicators, failure to account for varied, specific dynamics driving social vulnerability in particular place	Draw on other indicators developed for a similar social context	Creation of social vulnerability indicators for flooding in Holland by drawing off indicators developed for Norway and Germany	(Kirby et al., 2019)
Deductive selection of indicators, based on existing models like the SoVI or literature review. May obscure local dynamics of vulnerability	Use of qualitative methodologies in index design (e.g. household surveys, interviews, workshops with community members, stakeholders, decision-makers)	The Social Flood Vulnerability Index based indicator selection on focus groups with flood-affected residents in combination with census data and the Townsend Index for financial deprivation	(Tapsell et al., 2002)
		Expert judgement used to develop a SVI for coastal hazards in Vietnam, where experts gave their opinion on the most salient indicators	(C. V. Nguyen et al., 2017)
		Field-testing or validating indicators by using workshops with community members and/or hazard planning practitioners	(Mason et al., 2021; Oulahen et al., 2015)
Producing static snapshots that fail to account for dynamism in vulnerability (through time and between scales). Limited attention has been paid to how changing social dynamics and interactions between global, regional, national, and local forces affect social vulnerability.	Focus more explicitly on dynamism of vulnerability, by accounting for socio-cultural change and multi-scalar interactions	Inclusion of an indicator for measuring population change over a specified time period to determine if it affects levels of vulnerability	(Boruff et al., 2005; Cutter et al., 2003; Kirby et al., 2019; Su et al., 2015)
		Combining sea-level rise projections and population projections for socially vulnerable groups to provide insight into the growth of socially vulnerable populations in the future	(R. Hardy & Hauer, 2018)
		Combining indicators with theories of neighbourhood change to examine how interacting local, regional, and global economic/political influences have shaped neighbourhood demographics through time and led vulnerable populations to cluster in particular locations	(Kashem et al., 2016)

Critique of major indicators	Indicators and/or approaches used to address critique	Examples	Source:
		Indicators specifically designed to reflect a multi-scalar and temporally dynamic concept of vulnerability to erosion. Indicators span exposure due to biophysical factors, increased risk due to regional/national economic and social pressures increasing erosion, demographic characteristics, and individual, household, local, and regional responses to erosion	(Meur-Férec et al., 2008)
Indicators overlook adaptive capacities, strengths, or assets that vulnerable groups possess and focus overwhelmingly on deficits that increase vulnerability. Focussing solely on deficits is unlikely to convey the lived realities of vulnerable groups and could lead to inaccurate conclusions and policymaking	Development of indicators that account for strengths of vulnerable groups	Strengths-based approach to measuring vulnerability whereby indicators include measurements of factors that enhance coping/adaptation including cultural/linguistic vulnerability, diverse incomes, and ages abilities, and occupations within a neighbourhood	(Ogie & Pradhan, 2019)
		The MOVE framework combines analysis of 'lack of resilience' with 'adaptation/adaptive capacities' (ability to learn, reorganise, change practices to reduce vulnerability), and 'risk governance' (measures to prevent, prepare for, and manage disasters at the household or institutional level)	(Birkmann et al., 2013)
		The Coupled Social Vulnerability and Community Resilience Indicators integrate measures of community resilience alongside social vulnerability. Resilience includes aspects such as social capital and economic development	(Bergstrand et al., 2015)
		Alongside psychological factors that increase vulnerability, the physical, social, and psychological indicators for flooding vulnerability includes measurements of aspects such as belief in self and community efficacy which can decrease vulnerability	(Babcicky & Seebauer, 2021)

Critique of major indicators	Indicators and/or approaches used to address critique	Examples	Source:
		The Social Vulnerability Index for Vietnam includes indicators that offset vulnerability (for example, having a member of the household employed in a government office job)	(C. V. Nguyen et al., 2017)
		The Auckland Council vulnerability assessment combines an impact index (focussing on exposure and sensitivity) with an adaptive capacity index (examining factors that enable coping, absorbing shocks, and recovery from adverse events)	(Fernandez & Golubiewski, 2019)
Some aspects of social vulnerability are not sufficiently addressed in indicators (for example, factors that are not easily quantified are usually omitted from indicators, and most indicators treat categories of social vulnerability as internally homogenous)	Indicators include or focus on less tangible aspects of vulnerability	Psychological indicators of hazard preparedness, ability to cope and respond feature in indicators and are measured through methodologies such as household surveys, interviews, and focus groups	(Babcicky & Seebauer, 2021; Działek et al., 2016; Meur-Férec et al., 2008)
		UNESCO's and IUCN's vulnerability indicators examine how vulnerability emerges from not only tangible economic but less tangible social and cultural connections to heritage places and wetland landscapes	(Day et al., 2020; Wyatt et al., 2020)
	Indicators examine interactions between characteristics associated with social vulnerability	To assess vulnerability to storm surges during hurricanes in New York city, Tuccillo and Speilman create 'cohort vulnerability profiles' that represent a typology of vulnerable people and combine a range of characteristics increasing vulnerability. For example, one profile comprises families with children who lack health insurance, speak limited English, commute over one hour to work, and are exposed to freshwater intrusion	(Tuccillo & Spielman, 2022)
		Measuring 63 factors that increase social vulnerability to coastal hazards in Boston, Atyia Martin identifies	(Atyia Martin, 2015)

Critique of major indicators	Indicators and/or approaches used to address critique	Examples	Source:
		correlations between several categories. For example, social isolation often correlates with disability, low to no income, limited education, people of colour, and renters. One of the most vulnerable groups is women without a vehicle, who rent a home, and have an illness	

Appendix 3. Indicators developed by intergovernmental organisations

Table 4 Indicators and frameworks for measuring social vulnerability to climate change developed by intergovernmental organisations

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
UNDP Social Vulnerability Assessment Tools (Katic, 2017)	**Socioeconomic** including: • GDP per capita • Unemployment level • Occupation **Demographic** including: • Disabled population • Immigrants • Rapid population growth **Family structure** • Single parent households • Single-member households • Large families **Medical services** • Number of medical personnel per capita • Number of hospitals per capita • Average distance from nearest hospital	Census and other government data Household, online and telephone surveys	National, regional, local	Based on the SoVI (Cutter et al., 2003), the SeVI and BeVI (Holand et al., 2011, 2013) and the Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015)	This guidance document for constructing a social vulnerability indicator recommends a participatory approach to constructing indices that is grounded in local social context. It recommends developing a potential suite of indicators by supplementing literature review with interviews, focus groups, household surveys and consultation with local experts and stakeholders, then validating the indicators using interviews, the Delphi method or focus groups

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	Urban • Percentage of population urban **Renters** • Percentage of population renters **Built environment** including: • Population density • Quality/age of infrastructure • Average property value **Social capital** including: • Sense of community • Perceived level of social support • Civic participation				
Children's Climate Risk Index (UNICEF 2021)	**Pillar 1**: **Exposure** to (biophysical) climate and environmental shocks and stresses (such as water scarcity, coastal floods, heatwaves, soil and water pollution) **Pillar 2**: **child vulnerability and coping capacity** (including factors that increase children's sensitivity to shocks and stresses and	Pillar 2: international databases including World Bank World Development Indicators, World Bank Findex database, WHO/UNICEF Joint	National	Holistic, integrated approach (biophysical exposure, sensitivity, and adaptive capacity)	Attentive to multi-scalar social, political, economic, and cultural influences on child vulnerability, including the sphere of governance

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3

	community-, national-, and international-level capacities that offset the impacts of shocks)
	
	• Child health and nutrition
	  o Mortality, immunisation
	  o Stunting, low birthweight
	  o Maternal mortality, domestic health expenditure
	• Education
	  o Out-of-school children
	  o Youth literacy
	  o Education expenditure
	• Water, sanitation, and hygiene
	  o Access to basic or limited drinking water, unimproved or surface water
	  o Basic handwashing facilities
	• Poverty, communication assets and social protection
	  o Poverty headcount ratio, GINI index
	  o Mobile phone subscriptions
	  o Social safety nets, access to financial services or benefits
		Monitoring Programme			

UNESCO Climate Vulnerability Index (Day et al., 2020)	Assesses the vulnerability of the community (local residents, tourists, etc) to climate-related impacts on UNESCO World Heritage sites • Economic connections of the community to the site	Basic assessment by heritage site managers (2-3 hours) Comprehensive assessment with	Community level	The index draws on the work of Marshall et al. (Marshall et al., 2013)	Emphasises multi-scalar interconnections between the local and global scale (consideration of how international flows tourists may be affected by climate change impacts at a local

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	o Economic value of businesses associated with site o Estimated change in value due to climate change o How businesses will cope based on current capacity • Social connections of the community to the site (physical interactions) o Extent to which climate change impacts locals/tourists o How these groups will cope based on current capacity • Cultural connections of the community to the site (cultural affinity with site) o How climate-related impacts to site affect locals/tourists o How these groups will cope based on current capacities	stakeholders (multi-day)			scale i.e. on world heritage sites) Rather than focussing solely on deficits, the index includes consideration of capacities that local people, businesses, and tourists have with regards to coping and adapting to the impacts of climate change Considers aspects of vulnerability that are not easily quantified (such as the cultural connections to heritage sites that underlie community vulnerability)
World Health Organisation: Assessing Health Vulnerability and Adaptation to Climate Change (Kovats et al., 2003)	A comprehensive assessment of social vulnerability to climate change including: • Analysing current health issues in the region • How current disease prevalence and trends relate to climate change • Identification of strategies, policies, and measures to reduce the burden on climate-sensitive diseases	Literature review IPCC data (climate projections) National government agency data (population projections)	National	Holistic, integrated approach (biophysical exposure, sensitivity, and adaptive capacity) Draws on environmental causes of disease model (echoes political ecology lineage)	Dynamic treatment of vulnerability – risks from health impacts associated with climate change tied into social, economic, and political systems that influence the state of the environment and incidence of hazards, and international, national, and

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Reviewing the health implications of climate impacts on other sectors (such as food and water supply) • Estimate the future health impacts of climate change (using climate modelling, population change, quality of public health infrastructure)	GDP, expert consultations (adaptive capacity and policies) National statistics on mortality, air pollution, flood deaths at census area (health implications of climate change)			local adaptation, mitigation and risk management policies.
The World Food Programme's Hunger and Climate Change Vulnerability Index (Met Office Hadley Centre, 2015)	**Exposure to climate hazards** **Sensitivity of national agricultural production** to climate-related hazards, including: • Percentage total land area in forest • Percentage total land cover in rainfed agriculture **Adaptive capacity** including: • Rural and urban population with water access • Government effectiveness • Percent total labour force in vulnerable employment	WATCH Forcing dataset (exposure) International databases (sensitivity and adaptive capacity) including World Bank Governance data, FAOSTAT database	National	Integrated approach (biophysical exposure, sensitivity, and adaptive capacity) Index based on the work of Krishnamurthy et al. (2014)	N/A

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
SPREP's Integrated Vulnerability Assessment (Pacific Community (SPC) et al., 2016)	**General context (exposure)** including: • Physical geography • Demographic trends • Development & local natural resource use/management • Climatic threats, hazards and risks to key spheres (e.g. food security, housing) **Capacity and sensitivity** including: • Access to natural assets to support livelihoods (freshwater, productive land) • Physical assets (infrastructure needed for supporting livelihoods such as climate-proof housing, delivery of government services including extension services, enabling economic activity including access to transport and ICT services) • Financial assets (diversity of income, access to credit schemes, overseas development aid) • Human assets (individual and collective skills and knowledge enabling population to meet their livelihood needs, plan and implement climate adaptation including age structure, health, education and literacy, leadership skills)	Census data Health, education or other national-level databases Climate projections Participatory mapping	Athol communities in the Pacific	Sustainable livelihoods approach	Emphasises that community assets (infrastructural, financial, cognitive, socio-cultural and political) enable resilience even in vulnerable communities Indicators are grounded in local socio-cultural, political and economic context due to participatory design using validation by local experts Captures multi-scalar linkages between local, regional, and international human and environmental systems that affect vulnerability. For example, community-level vulnerability can be affected by access to national-scale credit schemes but also overseas development aid

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	Adaptive and risk reduction capacity of institutions including: • Governance structure • Ability to facilitate inclusive decisions • Ability to learn and improve previous adaptation measures • Beliefs, norms, taboos of community				
IUCN Rapid Assessment of Climate Change Vulnerability and Adaptation Planning (Wyatt et al., 2020)	**Village VA Tool** (part of the assessment used to analyse socio-economic vulnerability of wetlands communities to climate change) • Local resource use (that interacts with climate change and wetland resources) • Land tenure/rights • Governance • Important wetland resources used locally (subsistence, monetary value) • Scio-economic composition of village • Climate projections • Climate history (extreme events villagers encountered in past 10 years) • Frequency of impacts and impact on villagers' livelihoods • Current and future coping strategies (to cope with impacts of climate change on wetland resources)	Workshops with villagers Government data (socio-economic status of communities)	Village scale	Vulnerability of socio-ecological systems approach (similar to human-environment/resilience lineage)	The assessment seeks to reflect local context closely. It is carried out by and for the community, and guidance on how to conduct the assessment emphasises the importance of involving a diverse cross-section of the community. It examines cross-scale linkages that influence local social vulnerability, especially between human and ecological systems. For example, the indicator for resource use captures multi-scalar interactions whereby vulnerability of wetland-dependent communities is connected to regional-scale

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Wetland management (current and future responses to extreme weather and climate change)				land use and management practices that interact with the impacts of climate change on wetlands It considers villagers' coping and adaptation strategies alongside factors that exacerbate vulnerability
Notre Dame Global Adaptation Index - ND-GAIN (Chen et al., 2015)	Indicators for **exposure, sensitivity, and adaptive capacity** of a country's: • Food systems • Water systems • Health system and status • Ecosystem services • Human habitat • Infrastructure • Economic and social systems For example, health: **Exposure** • projected change of deaths from climate change-induced diseases • projected change of length of transmission season of vector-borne diseases	Global databases including: World Bank Health, Nutrition and Population (HNP) statistics Food and Agriculture Organisation of the United Nations statistics (FAOSTAT) World Bank World Development Indicators (WDI)	National	Integrated, holistic approach considering biophysical exposure, socio-political and economic factors affecting sensitivity and adaptive capacity	The index captures the dynamic nature of social vulnerability. It attends to change over time (for example, indicators for projected change in death rates from climate change-related health conditions) and multi-scalar interactions (for example, the indicator for a country's political stability may relate to global geopolitical factors)

Name of indicator or framework	How is vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	Sensitivity • slum population • dependence on external resources for health services **Adaptive capacity** • medical staff • access to improved sanitation facilities				

Appendix 4. Coastal indicators

Table 5 Select indicators for measuring social vulnerability to coastal hazards

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
Coastal Social Vulnerability Index – CsoVI (Boruff et al., 2005)	A Coastal Vulnerability Index (CVI) focussed on biophysical coastal hazards is combined with the SoVI to form the CSoVI. Social vulnerability indicators include: • Percent of population under five or over 65 • Per capita income • Percent unemployed • Percent living in poverty • Percent of households earning over $100,000 • Local government debt to revenue ratio • Percent of population over 25 with no high school diploma • Percent of population employed in primary industries • Percent renter-occupied units • Percent housing as mobile homes	US Census data United States Geological Survey (USGS) data on coastal hazards	County level (USA)	Integrative approach, based on indicators used in the SoVI (Cutter et al., 2003)	N/A

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Percent females and female-headed households • Percent African American, Native American, Hispanic • Number of housing units per square mile • Percent population change 1990-2000 • Net international migration				
Integrated method for evaluating vulnerability (Meur-Férec et al., 2008)	**Exposure** including: • Hazards • Human activities encouraging erosion (e.g. dredging, trampling) **Stakes** (human, economic and environmental value of spheres at risk from hazards) including: • Economic uses of coastal fringe (e.g. businesses submerged from floods) • Recreational use of coast (e.g. social value of coastal heritage sites)	Literature Reports Policy documents	Commune level (French equivalent of township)	Integrated approach combining physical, economic and social dimensions of vulnerability	The indicator engages dynamism by accounting for interacting social, economic, political, cultural, and psychological spheres of vulnerability, through time. In addition to analysing factors exacerbating risk, the indicator accounts for adaptive capacities and strengths (such as risk prevention planning, local and household-scale risk management) The indicator addresses one of the lesser-documented aspects of social vulnerability –

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Safety of population (number of people threatened by coastal hazards) **Management of risk** including: • Protective coastal engineering • Risk prevention plans and information distribution • Local initiatives (e.g. monitoring, local associations and management plans) **Remembrance of risk** (learning from past hazard events) including: • Frequency of hazard events • Documentation of hazards **Perceptions of risk** (local actors' perceptions of hazards/risks) including: • Population characteristics (age, education level, profession, length of time in area) • Representation of risk (awareness of risk, knowledge of risk assessment techniques, degree of competence)				psychological attitudes towards risk

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Practices when facing risk (techniques for managing risk, actions exacerbating risk)				
Social Vulnerability to Climate Change (typhoon) in Taiwan (Wu et al., 2016)	**Susceptibility** including: • Social structure (e.g. population growth rate and density) • Underprivileged groups (e.g. ratio of females, low-income earners, new residents) • Economic construction (e.g. ratio of schools and government agencies) • Movables and immovables (e.g. ratio of number of houses and automobiles) **Resistance** (ability to secure one's property based on household members' awareness of risk and precautionary action) including: • Medical relief (e.g. ratio of number of medical institutes and personnel) • Precautionary facilities (e.g. ratio of number of police and fire personnel and evacuation bases)	Taiwanese government statistics including: National Statistics Statistical Yearbook of the Interior National Taxation Bureau Ministry of Health and Welfare National Fire Agency	Township (Taiwan)		The indicator reflects local social context. The indicators were developed using a mixture of literature review and a questionnaire and consensus decision-making process conducted with local scholars familiar with the context The indicator engages with dynamism by analysing how vulnerability emerges from a range of scales including the household, community, and government-level (for example, examining policy and public service provision plus household demographics) The indicator examines adaptive capacities (in the form of resilience) as well as deficits The indicator also accounts for under-documented aspects of

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	Resilience including: • Environmental cleanliness (e.g. waste cleaning vehicles and transfer stations) • Economic structure (e.g. employment rate, average household income) • Level of education (e.g. ratio of illiterate population, ratio of population with post-secondary education or higher) • Disaster awareness (e.g. risk and prevention awareness, government emergency plans in place)				risk (psychological attitudes towards risk)
Social Vulnerability Projections to Improve Sea Level Rise Risk Assessments (Hardy & Hauer, 2018)	**Exposure** • Coastal inundation modelling **Social vulnerability** • Over 65, under 5 • Women • Minorities (Asian, African American, non-white, non-Hispanic) • Ethnicity (minorities including Hispanic)	US Census and American Community Survey (ACS) data LiDAR point data for inundation modelling	Census tract level (USA)	Integrated model, considering biophysical exposure and socio-economic, demographic factors exacerbating vulnerability. Draws on the SoVI	The indicator goes beyond static models of social vulnerability, by modelling how social vulnerability changes over time, with not only sea-level rise, but future population growth

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Low educational attainment • Poverty				
Evaluating the changing patterns of social vulnerability and adaptation challenges in three coastal cities (Kashem et al., 2016)	Social vulnerability is analysed using neighbourhood change theory with an indicator comprising 25 factors including: • Race/ethnicity (African American, Asian, Hispanic) • Over 65, under 5 • Foreign-born population • Household size • Group quarters population • Female population, female-headed households, female labour force population • Public transport dependency • Educational attainment • Unemployment rate • Employment in manufacturing, public services • Poverty rate • Average household income • Number mobile homes • Housing density	Census and ACS data (USA)	Census tract level (USA)	Political economy and ecology (work of Blaikie, 1994 and Wisner et al., 2004) SoVI (Cutter et al. 2003)	By combining neighbourhood change theories and indicators, Kashem et al. engage with the spatial and temporal dimensions of social vulnerability. Using neighbourhood changes theories, they examine how local, regional, and global influences interact (including the need for cheap labour to supply global supply chains, which funnels migrants into particular locales). Indicators then help to assess the demographic and socio-economic characteristics of neighbourhoods and support qualitative, theory-driven evidence for the presence of socially vulnerable populations.

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
Socio-economic vulnerability to coastal hazards induced by climate change in Mediterranean cities in France (Mavromatidi et al., 2018)	**Coastal Vulnerability Index** including: • Geomorphology • Coastal slope • Sea-level rise • Mean tidal range **Social Vulnerability Index** including: • Population under 14, over 75 • Women • Single-parent families • Families with two or more children • Tenants • Population density • Unemployed population • Population with no education • Overseas-born population	INSEE data (French census) Localised tax revenues	Département (largest unit of French local government)	Integrated approach analysing biophysical exposure and socio-demographic characteristics Draw on political ecology lineage (Blaikie, 1994) and the work of Cutter (2000)	N/A
Boston Social Determinants of Vulnerability Framework (Atyia Martin, 2015) – for a range of hazards	• Children • People with disabilities • Older adults (over 65) • People with chronic and acute medical illness • Social isolation • Low-to-no income	ACS (USA census) Berkman-Syme Social Network Index (for social isolation)	Census tract level (Boston, USA)	Based on the SoVI and review of other literature (Cutter et al., 2003)	Engages heterogeneity of social groups and examines how social vulnerability emerges through interactions between social categories, identities, and circumstances, rather than being a product of a single characteristic (e.g. poverty). A

Name of indicator	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
(including coastal hazards)	• People of colour • Women • Less than high school diploma • Limited English proficiency • Renters • Lack of vehicle				link analysis identified that "people who have multiple social factors of vulnerability are likely to be more exposed to negative post-incident outcomes than those who do not" (Atyia Martin 2015: 57)

Appendix 5. Measuring social vulnerability in Aotearoa

Table 6 Indicators within Ngā Tūtohu and the LSF that are relevant to measuring social vulnerability to climate change

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Illness attributable to air quality	A measure of the health impacts resulting from exposure to air pollutants	Air pollution and related health impacts (e.g. exacerbating or inducing asthma, COPD) are projected to increase with climate change. Respiratory conditions like asthma disproportionately affect groups including Māori and Pacifica communities in Aotearoa	Health impacts of PM_{10} (Stats NZ)	Ngā Tūtohu Aotearoa
Health impacts of air quality	Modelled health effects from human-made PM_{10}	As above	Ministry for the Environment, Stats NZ	LSF
Access to natural spaces	Extent to which people are satisfied with their access to natural spaces like waterfronts, parks, etc	Green space is proven to decrease the urban heat island effect and can help offset many climate change-related impacts (including effects of heatwaves, storms and flooding) especially in urban areas	TBD	Ngā Tūtohu Aotearoa
Access to the natural environment	% adults who said it was very easy to get to their nearest park or green space	As above	New Zealand General Social Survey, Stats NZ	LSF
Biodiversity/native species Biodiversity and genetic resources	Measure of state of native species populations in Aotearoa % indigenous species classified as threatened or at risk of extinction	Healthy ecosystems are more likely to be resilient to the impacts of climate change, and therefore less likely to pose a hazard to otherwise vulnerable populations in the area	TBD Ministry for the Environment Stats NZ	Ngā Tūtohu Aotearoa
Active stewardship of the land	Measure of guardianship of the land and its resources	Guardianship of the land can help elevate the health of ecosystems. Healthy ecosystems are more likely to be resilient to the impacts of climate change, and therefore less likely to pose a hazard to otherwise vulnerable populations in the area	TBD	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Waste flows in waterways and coastal marine environments	Level of waste discharged into waterways and coastal environment	Living in an area where high levels of waste are present in waterways and marine environments can elevate vulnerability to health effects during floods and storms	Litter Intelligence (Sustainable Coastlines)	Ngā Tūtohu Aotearoa
Safety of water for recreation and food gathering	Measure of water safety for recreational and food safety purposes	Many New Zealanders use freshwater and coastal environments for recreational purposes and gathering food. If water is already unsafe, events like marine heatwaves and floods can exacerbate the situation, and present further threats to people's health and wellbeing	TBD	Ngā Tūtohu Aotearoa
Swimmability of rivers	% state of the environment monitored river sites in each of the e-coli attribute bands	As above	Land, Air, Water Aotearoa	LSF
Drinking water quality	Percentage of the population served with drinking water that met all standards	Climate change (particularly storms, floods, and heatwaves) can make drinking water supplies unsafe. Populations who already have substandard drinking water or inadequate supply networks could be more adversely affected by extreme events.	Annual report on drinking-water quality (Ministry of Health)	Ngā Tūtohu Aotearoa
Drinking water management	% people with drinking water that met all treatment management standards. Indicates essential environmental amenity	As above	Ministry of Health	LSF
Modified land	Measure of land that has been changed from its natural state	Changing land uses can elevate local populations' vulnerability. For example, removing native trees for agriculture can increase erosion, landslides, and runoff during storms and heavy rain, posing risks to people living in the area	TBD	Ngā Tūtohu Aotearoa
Ecological integrity	Measure of degree to which a diverse community of organisms is maintained	Healthy ecosystems are more likely to be resilient to the impacts of climate change, and therefore less likely to pose a hazard to otherwise vulnerable populations in the area	TBD	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Perceived environmental quality	% people who rated the overall state of the natural environment in Aotearoa as good or very good	As above	Public perceptions of New Zealand's environment, Lincoln University	LSF
Health equity	Measure of the spread of health outcomes across the New Zealand population. It shows the gap between high and low health outcomes	Populations with existing health disparities and difficulties are more likely to be adversely affected by climate-induced health impacts, and, depending on the nature of the health condition, could face difficulties with evacuation during hazard emergencies, heat stress, respiratory conditions, comprehension of emergency communications, amongst other challenges	TBD	Ngā Tūtohu Aotearoa
Unmet health needs	Proportion of children under 15 with unmet need for a GP due to cost in the past 12 months	Having unmet health needs may predispose people to greater harm from climate-related health impacts	Ministry of Health	LSF
Mental health status (psychological distress)	Measure of a person's mental health symptoms including anxiety, depression, etc, in past four weeks	Populations living with mental health conditions can be more adversely affected by the effects of climate change, and may have difficulty with navigating emergency response, coping, and adapting	NZ Health Survey (Ministry of Health)	Ngā Tūtohu Aotearoa LSF
Amenable mortality	Premature deaths (under 75 years) that could be avoided given effective and timely healthcare	Populations with existing health disparities and difficulties are more likely to be adversely affected by climate-induced health impacts, and, depending on the nature of the health condition, could face difficulties with evacuation during hazard emergencies, heat stress, respiratory conditions, comprehension of emergency communications, amongst other challenges	Amenable Mortality SLM Data (Ministry of Health)	Ngā Tūtohu Aotearoa
Self-reported health status	People over 15 reporting their health to be good, very good, or excellent	Having good health can lower vulnerability as people already in good health are less likely to be adversely affected by health-related impacts from climate change	NZ Health Survey (Ministry of Health)	Ngā Tūtohu Aotearoa LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Family violence	Measure of prevalence of family violence (people over 15 exposed to violence in previous 12 months)	Family and intimate partner violence can be triggered or elevated in the wake of disasters. Living in a household where violence is already occurring may mean that occupants are at heightened risk of further violence with climate change	New Zealand Crime and Victims Survey (Ministry of Justice)	Ngā Tūtohu Aotearoa LSF
Experience of discrimination	Measure of perceived discrimination, people aged over 15, in last 12 months. Discrimination may prevent people from participating in society fully, and has effects on mental and physical wellbeing	Groups experiencing discrimination can be more vulnerable since they may have fewer opportunities in life (education, career, housing, etc), and face difficulties attaining a sustainable income, safe and secure housing, and accessing resources (financial or otherwise) for coping and adaptation to hazards	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Homelessness	Measure of stability and security of housing tenure, focusing on people without adequate shelter	People without adequate and safe shelter may be adversely affected by heatwaves, storms, heavy rain and other severe weather events that are projected to intensify with climate change	Severe Housing Deprivation Estimate (Ministry of Housing and Urban Development)	Ngā Tūtohu Aotearoa
Housing affordability	Measure of housing affordability based on the share of household income spent on housing (where a high cost of housing relative to income – over 30% income spent on housing – is associated with financial difficulty)	People experiencing financial difficulty or low income can have fewer financial resources to invest in prevention/preparation for hazards, and find it more difficult to cope with and adapt to the impacts of climate change	Household Economic Survey	Ngā Tūtohu Aotearoa
Housing cost	Deposit, mortgage, and rent affordability index; expenditure on housing as a percentage of household gross adjusted income	Spending a large portion of household income on rent, a mortgage, or a home deposit can mean that occupants have less available financial resources to invest in preparing for, coping with, and adapting to the impacts of climate change	Ministry of Housing and Urban Development	LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Housing quality	Measure of the physical condition and habitability of New Zealand houses	Poorer quality housing is known to elevate risks to occupants during storms, flooding, heatwaves and other extreme events as it is more easily damaged	TBD	Ngā Tūtohu Aotearoa
Housing quality	% adults reporting major repairs needed to their house	Living in a home that has leaks, is structurally unsound or unsafe exacerbates the risk that occupants face during storms and cyclones, floods and other emergencies	Stats NZ	LSF
Overcrowding	Measure of prevalence of household crowding (associated with increased risk of infectious disease, psychological distress, and poor educational attainment)	Overcrowded housing can increase heat stress of occupants during heatwaves, and make it more difficult to evacuate during emergencies like flooding or storms	NZ Census of Population and Dwellings (Stats NZ)	Ngā Tūtohu Aotearoa
Household crowding	Percent people living in a crowded house	As above	Stats NZ	LSF
Child poverty	Low income, material hardship, poverty persistence	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Income	Measure of the level of economic resources available for consumption (disposable income)	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Income adequacy Financial wellbeing	Self-reported measure of financial wellbeing (percentage of households reporting income not	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
	enough to meet everyday needs). Indicates deprivation	supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc		LSF
Income inequality	Measure of degree of income inequality (ratio of high-income households to low-income households based on disposable income)	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Low income	Measure of share of people living in low -income households (disposable income after housing costs below 50% of median income). Limited income restricts ability to participate in society and quality of life	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Net worth	Measure of household assets (ownership of houses) minus liabilities (mortgages)	Poverty is associated with difficulties in attaining the resources needed to prepare for, cope with, and adapt to climate hazards. This can include emergency supplies, quality and safe housing, emergency housing, strengthening or repairing property before/after events, having household or health insurance, access to a car to evacuate etc	Household Economic Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Household indebtedness	Household debt as % of household net disposable income. Indicates household resilience to financial shocks	Households with a significant debt to disposable income ratio may be adversely affected by financial shocks and impacts related to climate change. For example, households may not be able to afford to carry out emergency repairs in the wake of a cyclone, or may struggle to provide emergency necessities	OECD data	LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
		(such as hiring a generator or buying in water when power and water supply networks are disrupted)		
Food insecurity	% children aged under 15 and living in households where food sometimes or often runs out. Indicator of deprivation	Experiencing food insecurity and deprivation can put households at greater risk of hunger and malnutrition with climate change. For example, households that are partially food insecure may rely on hunting or fishing for a part of their food, which could be impacted by sea-level rise, floods, ocean acidification, marine heatwaves, or drought. Rising food prices related to climate-induced floods, droughts, pests and diseases, and disrupted global supply chains can also present further risks for food insecure households	Ministry of Health	LSF
Employment rate	Measure of prevalence of paid employment. People aged 15 or over employed one or more hours per week, seasonally adjusted % adults aged 15 years or over and who are employed	Employment can offset vulnerability by elevating income. Having access to disposable income and savings helps people navigate climate change, by enabling them to access the resources and services they need to prepare, cope and adapt (including purchasing health or housing insurance, living in safe, secure housing, making repairs, finding emergency accommodation, adjusting their way of life)	Household Labour Force Survey Stats NZ	Ngā Tūtohu Aotearoa LSF
Hourly earnings	Measure of financial return from paid employment independent of the number of hours worked. Median hourly earnings for wage and salary employees of 15 years	Higher earnings can reduce vulnerability by enabling individuals/households to access the resources and services they need to prepare, cope and adapt (including purchasing health or housing insurance, living in safe, secure housing, making repairs, finding emergency accommodation, adjusting their way of life)	Labour market statistics (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Not in employment, education, or training	Measure of the share of young people (15-24) who are disengaged from employment and training	Having limited education and being unemployed can elevate vulnerability. Those with limited education may experience difficulties finding well-paid employment and may face barriers acting upon	Household Labour Force Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
		hazards communications and climate information. Being unemployed is associated with a generally lower income and/or poverty, which elevates vulnerability by reducing people's ability to cope and adapt to climate change		
Unemployment	Measure of prevalence of unemployment (percent 15 years and over unemployed) % labour force unemployed	Being unemployed can increase vulnerability since it is associated with a generally lower income and/or poverty. This reduces people's ability to cope and adapt to climate change since they may not have access to resources, assets, savings, and so on.	Household Labour Force Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Resilience of infrastructure	Measure of resilience of infrastructure to natural and human-made hazards	Less resilient infrastructure may be damaged more easily with increasing frequency and magnitude of hazards with climate change	TBD	Ngā Tūtohu Aotearoa
Early childhood education participation	Measure of proportion of people who have participated in early childhood education prior to starting school	Education generally helps reduce vulnerability, by increasing opportunities for people to earn a higher income, and enabling them to act upon emergency warnings, prepare for, cope and adapt to hazards	Participation Intensity Measure (Ministry of Education)	Ngā Tūtohu Aotearoa
Education equity	Measure of the gap between high and low education outcomes	Limited education can elevate vulnerability by trapping people in poverty, and reducing the capacity for individuals to understand hazard communications, prepare for, cope with and adapt to hazards	TBD	Ngā Tūtohu Aotearoa
Literacy, numeracy, and science skills of 15-year-olds	Measure of skills in reading, maths, science, including digital literacy	Being able to read and navigate the digital world can enable individuals/households to access information that helps them prepare for, cope with and adapt to hazards (e.g. understanding weather forecasts, emergency communications, adaptation plans and sources of assistance)	Programme for International Student Assessment (Ministry of Education)	Ngā Tūtohu Aotearoa
Educational attainment of adult population	% adults aged 25 and over with a Batchelors degree or higher; % with upper secondary education	Education generally helps reduce vulnerability, by increasing opportunities for people to earn a higher income, and enabling them to act upon emergency warnings, prepare for, cope and adapt to hazards	Stats NZ	LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Contact with family/whānau and friends	Self-reported measure of the quality of contact people have with family and friends	Having a social network is important for preparing for, coping with and adapting to climate change and hazards. Knowledge about hazards can travel within social networks, and those within the network can offer help when needed (emergency shelter, funds, resources, loans, help evacuating, checking on safety)	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Face to face contact	% adults who had face to face contact at least once a week with friends who did not live with them. Indicates the availability of social support	As above	New Zealand General Social Survey	LSF
Māori connection to marae	% Māori adults that feel strongly connected to their ancestral marae. Intended to signify ability of Māori to connect with their culture	Research in Aotearoa shows that connections to social, whānau-based networks and cultural values (such as those fostered through marae) enable coping and response during emergencies like flooding and earthquakes.	Stats NZ	LSF
Loneliness	Self-reported measure of loneliness, which can lead to poor outcomes in other areas like mental health. Percentage people over 15 who felt lonely at least some of the time in the last four weeks	Being lonely and not having a social network to call on can elevate vulnerability. Those without a social network may lack knowledge about hazards, and have limited access to help from others (in the form of emergency shelter, funds, resources, loans, help evacuating, checking on safety)	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa LSF
Social support	Self-reported measure of people's ability to get help in times of need. People over 15 reporting they could easily ask someone they know for a place to stay urgently	Having access to emergency accommodation is an important asset for coping with and responding to climate-related hazards like storms, floods, heatwaves, etc	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Social support network	% adults who report they have friends or relatives they can count	Being able to turn to friends or relatives during emergencies like floods, storms, wildfires, and slower-	How's Life? OECD	LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
	on in times of trouble. Indicates social network support and how this compares internationally	onset disasters like sea-level rise is very important for coping and adapting. Friends and relatives provide emotional support, a place to stay in emergencies, may help with emergency supplies or access to resources needed to cope with or adapt to climate hazards, and so on		
Someone to turn to	% young people who say they have an adult they could turn to if they were going through a difficult time. Indicates social support for youth	Young people can be especially affected by mental health impacts from climate change. Research shows an increasing number of young adults are vulnerable to 'eco-anxiety' associated with the unfolding disaster of climate change. Having support from an adult may help reduce distress both in the short and long term	WhatAboutMe Survey	LSF
Sense of belonging (to Aotearoa New Zealand)	% adults and young people with a score of 7/10 or higher for sense of belonging	Having a sense of belonging within a community and wider nation (and the associated social networks) may enable people to cope with and adapt to climate hazards	New Zealand General Social Survey, WhatAboutMe Survey	LSF
Sense of control	Self-reported measure of the extent to which people over 15 feel they have control over their lives	Having some feeling of being in control of one's life can help offset vulnerability, by enabling the individual/household to plan for how they will respond to, cope with, and adapt to climate-related hazards	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Generalised trust	Self-reported measure of the trust individuals have toward other people in general	Having trust in others can facilitate participation in social networks, which reduces vulnerability. Having a social network is important for preparing for, coping with and adapting to climate change and hazards. Knowledge about hazards can travel within social networks, and those within the network can offer help when needed (emergency shelter, funds, resources, loans, help evacuating, checking on safety)	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Institutional trust	Self-reported measure of the trust individuals have towards societal institutions. Many vital services may be underutilised if trust in institutions is deficient	Trust in institutions may facilitate coping and adaptation to climate hazards. If people trust institutions to help them, and provide useful information, they are more likely to use services provided in emergencies, and act on official information (for example, on hazards or climate projections)	General Social Survey (Stats NZ)	Ngā Tūtohu Aotearoa
Trust in government institutions	% people who trust public service. Indicates health of the government sphere	As above	Public Service Commission	LSF
National income	Measure of income received by NZ residents from factors of production	Higher national income may reduce overall vulnerability by enabling more resources to be directed towards emergency responses and climate adaptation planning	Expenditure on GDP (Stats NZ)	Ngā Tūtohu Aotearoa
Net core Crown debt	Debt as % of GDP. Indicates government resilience to respond to fiscal shocks	Significant government debt may impact on availability of financial resources for long-term challenges like climate change	The Treasury	LSF
Democratic participation	Measure of people's confidence in democratic processes, and whether they feel their participation can make a difference	Public participation in designing adaptation strategies may help to ensure adaptation is tailored to the needs/aspirations of socially vulnerable groups, thereby reducing vulnerability. Conversely, exclusionary design is likely to lead to maladaptation and exacerbate vulnerability for those most at risk.	Participation in voting (Electoral Commission)	Ngā Tūtohu Aotearoa
Having a say in government	% people aged 16-65 who agree they have a say in what government does. Intended as an indicator of the capacity for the public to engage in national debates and decisions	Public participation in national adaptation planning and emergency response is an integral part of reducing vulnerability. When vulnerable groups have a say in decisions about how the government will respond to challenges like climate change it is more likely that policies and strategies will meet their needs and provide targeted support for vulnerability reduction	Programme for international assessment of adult competencies survey, OECD	LSF

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Perception of public influence	% of people who say the public has some or a large influence on the decisions their local council makes. Indicates engagement of public in local debates and decisions	As above, participation of vulnerable groups in local decision-making about climate adaptation is vital for tailored and appropriate vulnerability reduction	Quality of Life Survey, Quality of life Project	LSF
Voter turnout in general elections	% enrolled electors who voted in the general election. Indicates democratic engagement	Voting is one way that the public can exert influence over national policies, institutions, and structures that reproduce, exacerbate, or offset social vulnerability	Electoral Commission	LSF
Voter turnout in local elections	% enrolled voters who voted in contested mayoral elections.	Voting is one way that the public can exert influence over local policies, institutions, and structures that reproduce, exacerbate, or offset social vulnerability	Local authority election statistics, DIA	LSF
Overseas-born population	Measure of percentage of the population who were born overseas and distribution of the overseas-born population by country of birth	High levels of migrants in a community may affect vulnerability. Migrants may be more vulnerable since they may have limited knowledge of hazards in the locale, and lack the social networks, language skills and finances needed to cope and adapt to climate hazards. However, some migrants bring with them a wealth of hazard-relevant and adaptation knowledge that could offset their own vulnerability, and assist the community to cope and adapt to hazards	NZ Census of Population and Dwellings (Stats NZ)	Ngā Tūtohu Aotearoa
Migration	Measure of net migration to New Zealand	High levels of migrants in a community may affect vulnerability. Migrants may be more vulnerable since they may have limited knowledge of hazards in the locale, and lack the social networks, language skills and finances needed to cope and adapt to climate hazards. However, some migrants bring with them a wealth of hazard-relevant and adaptation knowledge that could offset their own vulnerability, and assist the community to cope and adapt to hazards	International Migration (Stats NZ)	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Net migration by skill type	Measure of flows of people into NZ from other countries minus flows of people to other countries from NZ, by skill level	High levels of migrants in a community may affect vulnerability. Migrants may be more vulnerable since they may have limited knowledge of hazards in the locale, and lack the social networks, language skills and finances needed to cope and adapt to climate hazards. However, some migrants bring with them a wealth of hazard-relevant and adaptation knowledge that could offset their own vulnerability, and assist the community to cope and adapt to hazards	TBD	Ngā Tūtohu Aotearoa
Age and sex structure	Measure of age/sex distribution of NZ's population	Elder and younger members of the population can be more vulnerable to the impacts of climate change. Physiologically, both old and young can be more at risk of conditions like heat stress, elders can face challenges to mobility that make it hard to evacuate during emergencies, and may be socially isolated and lacking support networks needed during to cope and adapt to climate hazards.	National population estimates (Stats NZ)	Ngā Tūtohu Aotearoa
Disability status	Measure of the level of disability in the NZ population (percentage distribution by disability status and age)	Members of the disability community can face higher risks from climate change. For example, reduced mobility poses a problem during hazard emergencies and evacuations. People with learning disabilities may experience significant distress at change in surroundings or circumstances due to climate hazards, or evacuations. For those reliant on a disability allowance or other government benefit, income may be low, which elevates difficulties faced with preparing for, coping with and adapting to climate change.	Disability survey (Stats NZ)	Ngā Tūtohu Aotearoa
Ethnic composition	A measure of the ethnic diversity of NZ's population. Percentage	Ethnic diversity can affect vulnerability, as there is evidence that race- or ethnicity-based discrimination can constrain access to resources needed to cope with	Population estimates (Stats NZ)	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
	distribution of the total population by ethnic group	and adapt to climate change. Sometimes, adaptation planning and assistance can also be directed at wealthy, white regions, suburbs or communities, leaving ethnically or racially diverse and/or lower socio-economic communities with limited assistance		
Geographic distribution	Measure of the regional distribution of NZ's population. Percent distribution of total population by regional council area	High population density can elevate vulnerability, by increasing the amount of people exposed to hazards	Subnational population estimates (Stats NZ)	Ngā Tūtohu Aotearoa
Household composition	Measure of the household composition of the population. Percentage distribution of the population by household type	Household composition can affect vulnerability. Those living alone may be more vulnerable due to social isolation, whilst single parents may face greater financial burdens and stress in the wake of disasters, and experience more barriers to adaptation due to limited finances. Large families may be more vulnerable if overcrowding is a problem, or if the family has a low income. However, having children can also decrease vulnerability by increasing social connections between families and their communities, and children may be exposed to climate-relevant knowledge at school or during extra-curricular activities	NZ Census of Population and Dwellings (Stats NZ)	Ngā Tūtohu Aotearoa
Sexual identity	Measure of distribution of the population by sexual identity	There is evidence to suggest that members of the LGBTQI+ community can face discrimination and unsafe situations at emergency shelters in the wake of disasters. Evidence also suggests that members of the transgender community have a higher incidence of low income, which can be a barrier to coping and adapting to climate change	TBD	Ngā Tūtohu Aotearoa

Indicator	Rationale for inclusion in original indicator	Relevance to social vulnerability to climate change	Source of data for indicator	Source of indicator
Gender	A measure of the distribution of the population by gender	Evidence suggests that cultural norms and gender stereotypes may increase vulnerability for women. Single mothers, for example, can face greater financial burdens and stress from having to respond and adapt to climate hazards	TBD	Ngā Tūtohu Aotearoa
Urban/rural distribution	Measure of the urbanisation of NZ's population. Percentage distribution of the total population by urban/rural location	Densely populated urban areas can be more at risk of adverse effects from hazards like flooding and heatwaves. Rural populations may equally be vulnerable due to isolation from essential services and emergency assistance, as well as rural poverty and close proximity to hazardous environments like mountains and rivers (although these are equally a factor for some urban locations)	Subnational population estimates	Ngā Tūtohu Aotearoa

Table 7 Overview of indicators and assessments used to measure social vulnerability to climate change in Aotearoa

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
The National Climate Change Risk Assessment/NZCCRA (MfE 2020)	The NZCCRA identifies the top risks that climate change poses for Aotearoa, over several domains. In the human domain, key risks include threats to social cohesion and community wellbeing from displacement of individuals, households and communities, the risk of exacerbating existing inequalities or creating new ones due to differential distribution of climate impacts amongst different social groups, and risks to physical and mental health. Key factors implicated in vulnerability to these risks include: • Exposure to biophysical hazards • Age (elderly more at risk of loss of social cohesion) • Low income • Gender • Existing physical or mental health conditions • Ethnicity (Māori)	Literature review and consultation with stakeholders	Nationwide	Holistic, integrated approach that examines biophysical exposure and risk, and socio-economic, demographic and cultural components of social vulnerability	The NZCCRA engages with a dynamic conception of vulnerability. The accompanying report discusses the nature of 'compounding risk' whereby interactions between systems, processes, and characteristics heighten risk for particular groups or systems The assessment seeks to reflect the social and cultural context of Aotearoa and was subject to significant input from iwi and hapū and other relevant stakeholders including scientific and technical experts

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
Social vulnerability indicators for flooding in Aotearoa New Zealand (Mason et al., 2019, 2021)	**Exposure (direct and indirect)** • Number of households in area • People who regularly use public transport to commute to work • People living in remote/rural communities **Susceptibility** • Children • Households with at least one child • Older adults • Households with older adult living alone • Pregnant women • People with mental health needs • People with a disability **Resilience** • Enough money to cope with crisis/losses • Social connectedness • Knowledge, skills and awareness to face hazards • Safe, secure and healthy housing	Census data National health collections datasets (Ministry for Health)	Census mesh-block level, with nation-wide coverage	Conceptual framing of social vulnerability draws on Cutter et al.'s work (2003) Indicators influenced by human-environment and political economy/ecology lineages as well as key work on determinants of wellbeing in Aotearoa (drawing on MOVE framework (Birkmann et al., 2013), Wisner's (2012) work on resilience, and the Treasury's LSF)	The indicators seek to reflect context and the lived experience of vulnerability. They were developed and field tested in Porirua, and community members, the local iwi, local decision-makers and staff from major local organisations helped to select indicators

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Enough food, water and other essential to cope with shortage and survive • Decision-making and leadership • Other individual-level factors of social vulnerability (e.g. healthcare and emergency service workers)				
Auckland Council Heat Vulnerability Index/HVI (Joynt & Golubiewski, 2019)	• NZ Indices for Multiple Deprivation score (proxy for social/material deprivation) • One-person households (proxy for social isolation) • Rental tenure (proxy for houses with poor thermal performance in heat/cold) • Residents over 65 and under 5 (proxy for heightened heat sensitivity) • Population not able to speak English (proxy for limited capacity to prepare/react to hazard-related information) • Household rent burden (proxy for limited finances and adaptive capacity) • Māori and Pacific population (as proxy for chronic health conditions)	Census data NZ Indices of Multiple Deprivation Household Economic Survey NZ Land cover database	Census area (Auckland)	Many of the indicators resemble those used in other major international indicators, such as the SoVI	In the report detailing the HVI, the authors engage with an interactive model of social vulnerability that goes beyond assumptions about uniform vulnerability within social groups. The authors note that combinations of characteristics (such as ethnicity, income, and housing conditions) lead to social vulnerability, rather than pertaining to one category of identity or one factor (like being low income)

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Green infrastructure cover in area (as proxy for shelter and urban cooling capacity)				
Auckland Council Vulnerability Assessment (Fernandez & Golubiewski, 2019)	**Impact Index** Exposure including: • Coastal inundation • Dry days • Hot days • Mean wind speed Sensitivity: • Deprivation Index score • Unemployment rate • Ratio of population under 15, over 65 • Percent populated area relative to census area unit • Percent one-parent households • Road density **Adaptive capacity Index** • Average household income • Housing stress (rent burden) • Percent population owner-occupiers of home	NZDep index Census data Land cover data (LUCAS NZ)	Census area unit	Integrated approach examining biophysical exposure as well as socio-economic characteristics mediating social vulnerability	As well as analysing factors increasing vulnerability, the assessment examines strengths and capacities through the adaptive capacity index. For example, factors like being a homeowner may be an asset when compared with being a renter (with renters generally being more vulnerable due to factors including limited capacity to alter homes to make them more climate resilient)

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Percent of area in cropland, grassland, forest				
Otago Climate Change Risk Assessment (Tonkin & Taylor Ltd, 2021)	The risk assessment focusses on biophysical exposure, with a small section on social vulnerability comprising three indicators: • Deprivation • Proportion of older adults • Social connectedness	NZDep 2018 Census data	Census area unit (Otago region)	Integrated approach, but biophysical exposure is over-emphasised (therefore may align primarily with risk-hazard lineage overall)	The development of social vulnerability indicators seeks to reflect social context. It was designed by drawing on the Social Vulnerability Indicators for Flooding (Mason et al., 2021) which reflect nationally relevant factors contributing to social vulnerability. Stakeholder interviews (with members of territorial authorities and key local organisations such as lifelines provision, environment management and tourism) also informed the design of the indicators
Wellington Regional Coastal Vulnerability Assessment (Steele et al., 2019)	• Community deprivation score • Population residing in area • Mana whenua (Māori) cultural sites • Historical sites (Māori and non-Māori)	NZDep 2013 Census data Greater Wellington data (including proposed natural	Suburb (Greater Wellington)	Risk-hazard	N/A

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Business activity (percent of commercial land) • Business value • Residential value • Community services • Emergency services • Bulk fuel storage • Water mains network • Sewer mains network • Stormwater mains network • Electricity lines • Gas lines • Telecoms • Roads • Hazards mitigation structures • Erosion • Environmental sites • Significant bird sites • Coastal biodiversity	resources plan, number of schools, hospitals, defence structures) NZ Lifelines Vulnerability Assessment Department of Conservation ecosites data			
Comprehensive Vulnerability Assessment (Khan, 2012)	**Demographic** • Population distribution, density, growth, per dwelling • Gender (female population) • Age (under 5, over 65) • Disability (sickness benefit, NZ sign language)	Census data NZDep2006	Census mesh-block (Hutt Valley)	Influenced by the SoVI (Cutter et al., 2003)	N/A

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Migration (population living less than a year is current residence, population living overseas 5 years before 2006 census) **Social** • Family type (e.g. single parents, female with 3 or more children) • Education (e.g. population of 15 or older with no qualification) • Language (population not having English as first language) • Ethnicity (e.g. Māori, Pacific, Asian, Middle East) **Economic** • Income (e.g. individuals with annual income less than $10,000, families with annual income less than $20,000, population dependent on superannuation) • Employment (e.g. population dependent on unemployment benefits, population unemployed)				

Name of indicator or assessment	How is social vulnerability measured (indicators or components used)?	How are indicators or components quantified?	Scale of application	Alignment with major vulnerability lineages and indicators	Connections to novel approaches outlined in section 2.3
	• Occupation (e.g. workers in the elementary occupations) • Housing condition (e.g. dwelling not owned by residents, dwellings without fuel for heating) • Communications (e.g. households without telecommunications access, households without a car)				
Cape Coast Area Coastal Hazards SIA and Valuation (Maven Consulting Ltd, 2017)	• Property owners • Business owners	Interviews Workshops/focus groups	Cape Coast area (Hastings/Hawke's Bay)	Risk-hazard	N/A
Natural Hazards SIA for Wharekawa (EnviroStrat, 2020)	• Property owners • Farmers • Businesses		Wharekawa (Hauraki/Waikato)	Risk-hazard	N/A

Appendix 6. Enhancing social vulnerability indicators and assessments in Aotearoa

Table 8 Examples of indicators that could be used to convey the interactive, multi-scalar nature of social vulnerability to climate change

Sphere/scale of indicator	Indicator	Rationale	Source
Ecological, biological, environmental	Human activities (e.g. walking, dredging) encouraging coastal erosion	Human activities exacerbate the impacts of climate-induced erosion hazards on the local population	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008)
	Quality and health of natural capital (resources)	If natural resources the community depends upon are in good health, they are better able to support sustainable livelihoods and wellbeing through challenges like climate change	Ground-truthing social vulnerability indices of Alaska fishing communities (Lavoie et al., 2018)
	Air, soil, and water pollution	Risks from climate change are elevated for children living in areas with high levels of environmental pollution	Children's Climate Risk Index (United Nations Children's Fund, (UNICEF) 2021)
	Establishment and maintenance of conservation areas	Conservation areas can offset negative impacts of human influence, and mitigate the impact of climate change and hazards on the environment and people's livelihoods	Integrated Vulnerability Assessment for Atoll Islands (Pacific Community (SPC) et al. (including SPREP), 2016)
	Air quality: illness attributable to air quality	Measure of current wellbeing (health impacts from exposure to air pollution). If there are already high levels of illness from polluted air in a region, climate change is likely to exacerbate	Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022)

Sphere/scale of indicator	Indicator	Rationale	Source
		the problem for vulnerable groups (asthmatics, those with COPD, etc)	
	Ecological integrity	Measure of future wellbeing (degree to which diverse community of native organisms is maintained). Ecological diversity and health can help ensure environments and ecosystems are resilient to the impacts of climate change. Conversely, degraded ecosystems and environments can be more heavily impacted by climate change, with flow on effects for communities and social groups in the region	Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022)
	Perceived environmental quality	Measure of environmental amenity (percent of people who rates the overall state of the environment in Aotearoa as good/very good). As above.	The Living Standards Framework (The Treasury, 2021, 2022)
	Groundwater stocks	Measure of natural capital of Aotearoa (volume of groundwater stocks, indicates water stocks nationally). Sufficient groundwater stocks minimises impact of drought on local populations	The Living Standards Framework (The Treasury, 2021, 2022)
Governance & policy	Existence of coastal risk management and prevention documents and plans	Decreases vulnerability – minimises risk through policy	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008)
	Adaptive and risk reduction capacity of institutions including: Ability to act collectively towards adaptation/risk reduction goals Ability to facilitate inclusive decision-making	Existence of action plans, capacity of leaders to mobilise community towards adaptation goals, community trust in local leaders' ability to work together to minimised risk from climate change	Integrated Vulnerability Assessment for Atoll Islands (Pacific Community (SPC) et al. (including SPREP), 2016)

Sphere/scale of indicator	Indicator	Rationale	Source
		Sourcing knowledge and skills for adaptation from various groups in the community including women, youth, elders, technical experts	
	Current strategies, policies, measures to reduce burden of climate-sensitive diseases on population	At the individual, community and institutional/national level, what measures exist that could reduce the impact of climate change on health/disease, how effective are the policies/measures, what are the barriers to implementation, and how can strategies be made more effective in the future?	Methods of assessing human health vulnerability and public health adaptation to climate change (Kovats et al., 2003)
	Political efficacy (belief that one can understand/participate in politics, and that government acts upon citizen's demands/needs)	Person's belief about their ability to influence political processes and about authorities' responsiveness to citizen's concerns over flooding	Physical, social and psychological vulnerability indicators for flooding (Babcicky & Seebauer, 2021)
	Institutional trust	Trust individuals have towards societal institutions (police and parliament. Trust in institutions may facilitate coping and adaptation to climate hazards. If people trust institutions to help them, and provide useful information, they are more likely to use services provided in emergencies, and act on official information (for example, on hazards or climate projections)	Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022)
	Having a say in government	% people 16-65 who agree they have a say in what the government does, indicates capacity to engage in national debates and decisions. Public participation in national adaptation planning and emergency response is an integral part of reducing vulnerability. When vulnerable groups have a say in decisions about how the government will respond to challenges like climate change it is more likely that policies and	The Living Standards Framework (The Treasury, 2021, 2022)

Sphere/scale of indicator	Indicator	Rationale	Source
		strategies will meet their needs and provide targeted support for vulnerability reduction	
	Governance/policy	Local policies shape location of community infrastructure and assets, land use and age structure of the community (by encouraging retirees) therefore increasing exposure and sensitivity to climate change	Community asset and social vulnerability mapping (Manuel et al., 2015)
Local/household level action	Local initiatives to offset erosion	Decreases vulnerability	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008)
	Perception of risk	Knowledge and management of risk, practices for managing risk, effectiveness	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008)
	Disaster awareness	Risk and disaster awareness and prevention	Social Vulnerability Indicators – Taiwan (Wu et al., 2016)
	Current and future coping strategies	Actions the community takes to cope with impacts of climate change and pressure on the local environment	Integrated Vulnerability Assessment for Atoll Islands (Pacific Community (SPC) et al. (including SPREP), 2016)
	Risk aversion and fear of flooding	Increases likelihood that households will take precautionary action against flooding and reduce their vulnerability	Physical, social and psychological vulnerability indicators for flooding (Babcicky & Seebauer, 2021)

Table 9 Examples of indicators used to convey capacities, assets, and strengths used for coping with and adapting to climate change

International indicators	Indicator or characteristic	Rationale	Source
	Disaster awareness Remembrance of risk (learning from past hazards)	Being aware of where and how hazards occur, and having lived experience of responding to hazards increases preparedness, the ability to cope and adapt	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008) Social Vulnerability Indicators – Taiwan (Wu et al., 2016)
	Households with at least one person in a formal or informal social network	An important element of socio-political capital. Enhances access to knowledge, skills, and resources needed for coping and adaptation to climate change	Social Vulnerability Index (for Vietnam) (C. V. Nguyen et al., 2017)
	Linguistic diversity of neighbourhood	Multi-lingual people can be an asset for a neighbourhood, community, or region, as they may help those with language barriers to access important resources and information needed to better prepare for, cope with, and adapt to climate change	Strengths-based approach to natural hazards and social vulnerability of place (Ogie & Pradhan, 2019)
	Social capital (including household composition, civic organisations, voting behaviours, religious adherence, migration, etc)	Enables resilience of United States counties (ability to absorb, cope with, and adapt to hazards)	Coupled Social Vulnerability and Community Resilience Indicators (Bergstrand et al., 2015)
	Belief in self and community efficacy	People are more likely to be well-prepared for flooding if they believe they are able to make a different to the outcome of a flood by taking	Physical, social, and psychological indicators of flooding vulnerability (Babcicky & Seebauer, 2021)

		preventative measures and helping each other out in times of emergency	
	Social/institutional learning	The ability for social networks and institutions to observe and adapt to new circumstances brought about by climate change. For example, Arctic hunters respond to changes in sea ice over time by altering their hunting behaviour and practices, using new skills and technology	Longitudinal Vulnerability Assessment (Fawcett et al., 2017)
	Proportion of population computer literate, able to read and write, with tertiary education, practical training, or knowledge of and access to climate change and risk management information	People's knowledge, experience and skills determine their ability to respond and adapt to climate change. Being literate (computer and otherwise) enables access to information, whilst having tertiary education, practical training in relevant skills, and knowledge and access to climate management information help people to be more prepared for climate hazards and take appropriate action	Integrated Vulnerability Assessment for Atoll Islands (Pacific Community (SPC) et al. (including SPREP), 2016)
	Techniques for managing individual/collective risks Management of risk including assessment and management techniques Degree of competence and effectiveness Current coping strategies	Being versed in how to effectively manage risk at a household or community level helps to offset vulnerability Having strategies in place to cope with climate impacts helps to offset vulnerability	Integrated Method for Evaluating Vulnerability (Meur-Férec et al., 2008) IUCN Rapid assessment of vulnerability at Ramsar sites (Wyatt et al., 2020)
	Whakapapa	Reciprocal duties of care through shared genealogical connection. For example, land gifting within whakapapa networks can help whānau	Holistic Māori approach to flood management (Proctor, 2013)

Aotearoa-based indicators		(families) get a new start when a home has been destroyed during floods.	Community-led disaster risk management (Kenney et al., 2015)Community risk, vulnerability and endurance at Manaia and Mitimiti (King et al., 2012, 2013)
	Kotahitanga	Tribal unity, working collectively to overcome the impacts of hazards like flooding and earthquakes, and ensure all members of the community are safe. For example, whānau members work together to provide emergency assistance to flood-affected households, move people, livestock and valuables to safety, and provide emergency accommodation at the marae	Holistic Māori approach to flood management (Proctor, 2013)

Community-led disaster risk management (Kenney et al., 2015) |
| | Whakawhanaungatanga | Building and maintaining relationships is key for coping with and adapting to hazards. For example, in the aftermath of the earthquakes in Ōtautahi/Christchurch, intra- and extra-tribal relationships were key for facilitating a successful disaster response. These relationships provided an avenue for resource distribution, the mobilisation of iwi health teams, and access to support networks like inter-tribal and government agencies | Community-led disaster risk management (Kenney et al., 2015) |
| | Local environmental knowledge or mātauranga Māori/taiao | Hapū and whānau member awareness of local climate, hazards, and danger spots developed over time, through residency with (or lifelong visits to) ancestral homelands, and enacting kaitiakitanga (environmental guardianship). Helps households and communities to recognise when hazards are due to occur, therefore helping them to avoid and be | Holistic Māori approach to flood management (Proctor, 2013)

Community-led disaster risk management (Kenney et al., 2015)

Bridging Māori Indigenous Knowledge and western geoscience |

		prepared for emergencies, and adapt behaviour to slow-onset climate change (such as sea-level rise)	to reduce social vulnerability to volcanic hazards (Pardo et al., 2015) Community risk, vulnerability and endurance at Manaia and Mitimiti (King et al., 2012, 2013)
	Educational attainment of adult population Literacy, numeracy and science skills of 15-year-olds Early childhood participation	Education helps offset vulnerability by enhancing career prospects and therefore potential income. Education (and literacy) reduces vulnerability by enabling people to interpret and act upon hazard warning information, and make decisions about how to adapt based on climate projections, policies, and other relevant information	LSF (The Treasury, 2021, 2022) Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022)
	Resourcing, innovation and self-reliance of community	Community is able to manage threats from coastal hazards through innovation and experience of self-reliance that comes from living in a rural location and have access to mātauranga Māori. For example, being able to supplement household food supplies through fishing and hunting when community cut off due to floods	Community risk, vulnerability and endurance at Mitimiti (King et al., 2013)
	Social support network, face-to-face contact, Māori connection to marae, contact with family/whānau and friends	Support networks enhance preparedness, coping, and adaptation to climate hazards. They are valuable avenues for sharing of hazard-related information, resources needed in an emergency, and sources of emotional support that can help offset mental health risks associated with climate change	Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022) LSF (The Treasury, 2021, 2022)
	Cultural resilience	In development. One of the factors that enables resilience to emergencies	New Zealand Resilience Index (Stevenson et al., 2018)

	Migrants	Despite facing linguistic, socio-economic, and cultural barriers that might raise their vulnerability, migrants may also possess specialist knowledge about hazard adaptation gained in their home community, or high levels of personal resilience that enables coping during hazard-induced emergencies	Reflections on Studies in the Canterbury and Tohoku Disasters (Uekusa, 2019)
	Having a say in government, perception of public influence, democratic participation, voter turnout in general and local elections	When socially vulnerable groups are able to exert influence over adaptation and emergency response decision-making and policies, there is a greater chance that vulnerability reduction strategies will successfully meet their needs and reduce vulnerability	LSF (The Treasury, 2021, 2022) Ngā Tūtohu Aotearoa (Stats NZ, 2019, 2022)