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THE AUSTRALIAN NATURAL DISASTER RESILIENCE INDEX

Annual project report 2016-2017

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EXECUTIVE SUMMARY

What is the Problem?

In 2010, the Council of Australian Governments (COAG) adopted resilience as one of the key guiding principles for making the nation safer. The National Strategy for Disaster Resilience (Australian Government 2011) outlines how Australia should aim to improve social and community resilience with the view that resilient communities are in a much better position to withstand adversity and to recover more quickly from extreme events. The Sendai Framework for Disaster Risk Reduction 2015-2030 also uses resilience as a key concept and calls for a people centred, multi-hazard, multi-sectoral approach to disaster risk reduction. As such each tier of government, emergency services and related NGOs have a distinct need to be able assess and monitor the ability to prevent, prepare for, respond to and recover from disasters as well as a clear baseline condition from which to measure progress.

Why is it Important?

Society has always been susceptible to extreme events. While the occurrence of these events generally cannot be prevented; the risks can often be minimised and the impacts on affected populations and property reduced. For people and communities, the capacity to cope with, adapt to, learn from, and where needed transform behaviour and social structures in response to an event and its aftermath all reduce the impact of the disaster and can broadly be considered resilience. Improving resilience and thereby reducing the effects of natural hazards has increasingly become a key goal of governments, organisations and communities within Australia and internationally.

How are we going to solve it?

The Australian Natural Disaster Resilience Index project will produce a spatial representation of the current state of disaster resilience across Australia. The index will be composed of multiple levels of information that can be reported separately and represented as colour-coded maps where each point will have a corresponding set of information about natural hazard resilience. Spatially explicit capture of data will facilitate seamless integration of the project outcomes with other types of information. The index and indicators will also be drawn together as a State of Disaster Resilience Report which will interpret resilience at multiple levels and highlight hotspots of high and low elements of natural hazard resilience.

END USER STATEMENT

Suellen Flint, Department of Fire and Emergency Services, WA

At their best resilient Communities are prepared, are able to adapt to changing situations, are connected to each other and are self-reliant.

Recent reports into disasters has identified that government has a responsibility to prepare for emergencies, however these reports also identified the notion of shared responsibility. It is clear that government bears a responsibility to support the community to build the knowledge, skills and importantly protective behaviours that are part and parcel of disaster resilience.

Emergency Services support its communities by building these characteristics in communities. Not a simple task. It involves highly complex forms of engagement based in a raft of community development based research focused on community and individual psychology, decision making under stress, physiology, knowledge exchange and information take up by the community.

The Australian Natural Disaster Resilience Index will be advantageous in many ways and support National and State and local governments. The ability to identify hot-spots of high or low disaster resilience in Australia, and identify areas of strength in coping and adaptive capacity will support the desired outcomes of the Australian Natural Disaster Resilience Strategy, and potentially help to embed disaster resilience not only into policy and legislation, but to lead to an increase in shared responsibility and resilience across Australia.

I commend the researchers for addressing the challenge in developing the Australian Natural Disaster Resilience Index.

INTRODUCTION

Natural hazard management policy directions in Australia – and indeed internationally – are increasingly being aligned to ideas of resilience. However, the definition and conceptualization of resilience in relation to natural hazards is keenly contested within academic literature (Klein et al., 2003; Wisner et al., 2004; Boin et al., 2010; Tierney, 2014). Broadly speaking, resilience to natural hazards is the ability of individuals and communities to cope with disturbances or changes and to maintain adaptive behaviour (Maguire and Cartwright, 2008). Building resilience to natural hazards requires the capacity to cope with the event and its aftermath, as well as the capacity to learn about hazard risks, change behaviour, transform institutions and adapt to a changing environment (Maguire and Cartwright, 2008).

However, an assessment of the current of resilience is needed to able identify problems and plan future resilience building actions. There are two principal approaches to assessing disaster resilience. Bottom-up approaches are locally based and locally driven and are qualitative self-assessments of disaster resilience (Committee on Measures of Community Resilience, 2015). Bottom-up approaches survey individuals or communities using a scorecard consisting of indicators of disaster resilience such as preparation, exposure to specific hazards, community resources and communication (e.g. Arbon, 2014). In contrast, top-down approaches are often intended for use at broad scales by an oversight body (Committee on Measures of Community Resilience, 2015) and use secondary spatial sources such as census data to quantitatively derive indicators that describe the inherent characteristics of a community that contribute to disaster resilience (Cutter et al., 2010).

The Australian Natural Disaster Resilience Index will be a tool for assessing the resilience of communities to natural hazards at a large scale. Using a top down approach, the assessment will provide input to macro-level policy, strategic planning, community planning and community engagement activities at National, State and local government levels. First, it is a snapshot of the current state of natural hazard resilience at a national scale. Second, it is a layer of information for use in strategic policy development and planning. Third, it provides a benchmark against which to assess future change in resilience to natural hazards. Understanding resilience strengths and weaknesses will help communities, governments and organizations to build the capacities needed for living with natural hazards.

THE AUSTRALIAN NATURAL DISASTER RESILIENCE INDEX

The Australian Natural Disaster Resilience Index will assess resilience based on two sets of capacities – coping capacity and adaptive capacity:

- Coping capacity enables people or organizations to use available resources and abilities to face adverse consequences that could lead to a disaster (sensu UNISDR, 2009). In a practical sense, coping capacity relates to the factors influencing the ability of a community to prepare for, absorb and recover from a natural hazard event.
- Adaptive capacity is the ability of a system to modify or change its characteristics or behaviour to cope with actual or anticipated stresses (Folke et al., 2002). Adaptive capacity entails the existence of institutions and networks that learn and store knowledge and experience, create flexibility in problem solving and balance power among interest groups (Folke et al., 2002). In a practical sense, adaptive capacity relates to the factors that enable adjustment of responses and behaviours through learning, adaptation and transformation.

Together, these coping and adaptive capacities form the core of our assessment of resilience to natural hazards. Coping capacity and adaptive capacity help to answer the question 'How able is a community to prepare for, respond to and recover from a natural hazard event and return to a satisfactorily functioning state in a timely manner, and to strategically learn and adapt to improve its resilience to future natural hazard events?'

DESIGN OF THE INDEX

We have used a hierarchical structure for the Australian Natural Disaster Resilience Index (Figure 1). A hierarchical structure allows levels with similar concepts, processes and spatial/temporal organization to emerge. Lower levels can be summarized into higher levels, and higher levels constrain the elements of levels sitting within it. The first level in our hierarchy is made up of the adaptive capacities and coping capacities that make up our conceptual premise of disaster resilience. The second level in our hierarchy is made up of themes that convey the components of adaptive capacity and coping capacity. The third level is comprised of indicator sets that measure the status of a theme. It is possible that one indicator is relevant across different themes or capacities.

Figure 1. The hierarchical structure of the Australian Natural Disaster Resilience Index.

INDICATORS

Indicators provide the data for a theme – together the indicators measure the status of the theme. Many indicators have a basis in the literature and have demonstrated relationships with aspects of natural hazards or disasters. For example, there is a documented relationship between income, housing type and gender and the ability to prepare for and respond to natural hazard events (Morrow, 1999). Selecting indicators is both an art and a science, and there are tradeoffs that need to be made among the availability and quality of data at a national coverage, the latent construct of disaster resilience represented by the data and the statistical character of the indicator. Broadly, the data set contains two different types of indicators:

a) Quantitative indicators – indicators collected or compiled from exiting data sets such as census data, economic data, health data, telecommunications, infrastructure databases. These indicators are mostly continuous numbers.

b) Semi-quantitative indicators – indicators derived from assessment of policies, plans, legislation, or other reports. These indicators may be partly composed of assessments of quantitative data, such as the State of the Public Service Survey. These indicators are mostly ordinal numbers and as such have a small number of integer values.

The data collection phase of the project was completed in 2017. We collected 90 indicators across the eight coping and adaptive capacity themes. Indicators were collected at Statistical Area 2 (SA2) resolution where possible. Data collected at other resolutions (e.g. local government areas, regions, States) were disaggregated to SA2 resolution. All indicators are listed in Table 1.

Table 1. Indicators used in the eight themes of the Australian Natural Disaster Resilience Index. Q = quantitative indicator, SQ = semi-quantitative indicator.

Theme	Indicator	Type
Social character	% population arrived 2001 onwards	Q
	% of total households with all or some residents not present a year ago	Q
	% speaks English not well or not at all	Q
	% population with a core activity need for assistance	Q
	% one parent families	Q
	% Households without children	Q
	% Households with children	Q
	% Lone person households	Q
	% Group households	Q
	Sex ratio	Q
	% population aged over 75	Q
	% population aged below 15	Q
	Median_age_of_persons	Q
	Median_total_household_income_weekly	Q
	Ratio of certificate/postgrad to year 8-12	Q
	% of labour force unemployed	Q
	% not in labour force	Q
	% managers and professionals	Q
Economic capital	A1a Proportion of residents owning their home outright (%)	Q
	A1b Proportion of residents owning their home with a mortgage (%)	Q
	A2 Proportion of residents renting their home (%)	Q
	A5 Median rent ($/weekly)	Q
	B7 Income/mortgage differential ($/monthly)	Q
	B8 Median weekly personal income ($)	Q
	B8 Median weekly family income ($)	Q
	Proportion of families receiving less than $600/week income (%)	Q
	Proportion of families receiving more than $3000/week income (%)	Q
	C9 Single sector employment dependence (sector unspecified) (%/workforce)	Q
	C17 Economic Diversity Index	Q
	Dwellings with one or more cars (%)	Q
	Percentage of businesses employing 20 or more people	Q
	G16 Retail/commercial establishments per 1,000 people	Q
	Population change 2001-2011 (as % of 2001 population)	Q
	GINI Coefficient TBA	Q
	Local Govt Grant Data Per Head	Q

Table 1 (cont.)

Theme	Indicator	Type
Emergency services	2011 Medical practitioners per 1000 people	Q
	2011 Registered nurses per 1000 people	Q
	2011 Psychologists per 1000 people	Q
	Available hospital beds per 1000 population	Q
	Welfare support workers per 1000 population	Q
	Ambulance officers and paramedics per 1000 population	Q
	Fire and emergency workers per 1000 population	Q
	Police per 1000 population	Q
	Fire and Emergency Services and SES organisations_Cost per 1000 population	Q
	Ambulance organisations_Cost per 1000 population	Q
	Fire service volunteers per 1000 people	Q
	SES volunteers per 1000 people	Q
	Distance to airport (km)	Q
	Road Infrastructure (%)	Q
	Distance to Medical Facility (km)	Q
Infrastructure and planning	% Caravan & improvised dwellings	Q
	% Residential pre 1980	Q
	% Residential post 1981	Q
	% Commercial & industrial pre 1980	Q
	% Commercial & industrial post 1981	Q
	Emergency plan assessment score (%)	SQ
	FTE council staff 14-15	Q
	Area km2/FTE	Q
	Population/FTE	Q
	Road Km/FTE	Q
	Dwellings/FTE	Q
	New dwellings (2012-16) as prop.of 2011 dwellings (%)	Q
	New dwellings per week (2015 - 16)	Q
	Planning assesment score	SQ
Information & engagement	ADSL%Area_ExcellentGood	Q
	ADSL%Area_SomeLimitedNone	Q
	% Area With Mobile Phone Coverage	Q
	Community engagement score	SQ
Community capital	Offences against person_2011-12_Per 100,000 population	Q
	Offences against property_2011-12_Per 100,000 population	Q
	Support in crisis_ASR per 100_2010	Q
	Safe walking in neighbourhood_ASR per 100_2010	Q
	Difficulty accessing services_ASR per 100_2010	Q
	Poor self assessed health_ASR per 100_2010	Q
	Raise 2000 in week_ASR per 100_2010	Q
	% Residents in same residence > 5 years	Q
	% Households with no motor vehicle	Q
	% Population undertaking voluntary work	Q
	% Jobless families	Q

Table 1 (cont.)

Theme	Indicator	Type
Social engagement	Life satisfaction scale 60 and below	Q
	Life satisfaction scale 70 and above	Q
	Trust_Total percent agree	Q
	MigrationEffectivenessRatio2006-11	Q
	MigrationEffectivenessRatio2006-15	Q
	Percentage of population with post school qualification	Q
	People over 15 in further education	Q
	Participation in personal interest learning	Q
Governance, leadership, innovation	Business dynamo index	Q
	Number of research organizations	Q
	Governance, policy & leadership score	SQ

STATISTICAL METHODS

Index calculation is the process of bringing together the indicators to form an index. The generalized process for computing and reporting the Australian Natural Disaster Resilience Index is shown in Figure 2. The transformation (specifically normalizing) and aggregation steps will be the focus of this section.

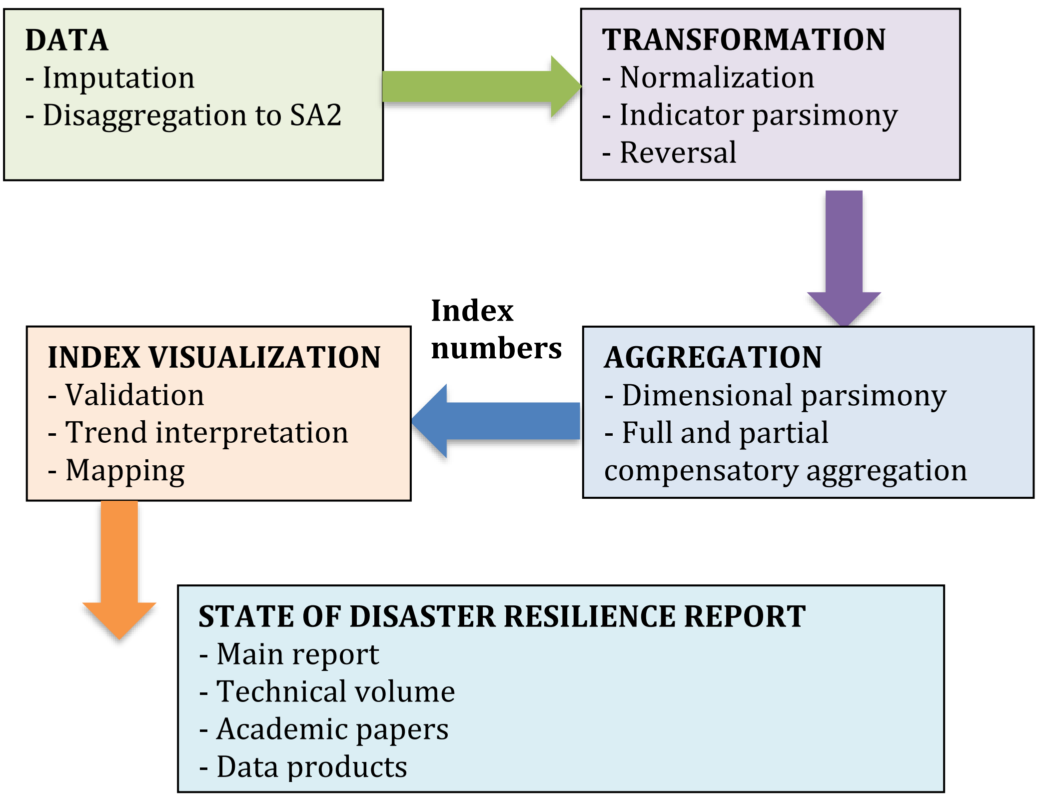


Figure 2. Generalized process of index derivation for the Australian Natural Disaster Resilience Index.

Transformation

Background

The indicators that comprise a composite index are frequently transformed for one or other, or both, of two reasons: to obtain an indicator distribution that meets the assumptions required by a statistical procedure such as Principal Components Analysis (PCA), and to give indicators equal influence in a simple additive composite index (the most common aggregation method for composite indices).

Before proceeding, it is necessary to clarify a number of terms that are used inconsistently in the indicator literature:

> *Normalise*: this can be used to refer to transformations that bring a non-normal distribution closer to a normal distribution (e.g. von Hippel, 2003), or it can refer to rescaling a variable such that it has a range of 0 – 1 (OECD, 2008).
>
> *Standardise*: this can refer to converting the values of a variable to z scores (OECD, 2008; Schmidtlein et al., 2008), or to rescaling to a range of 0 – 1 (Gall, 2007).

There appears to be a belief among some authors (e.g. Jacobs, et al., 2004; Hudrlikova and Kramulova, 2013), that converting the values of a variable to z scores:

- "… imposes a standard normal distribution onto each indicator…" (Jacobs, et al., 2004 p.37), or
- "…converts all indicators to a common scale in which they are assumed to have a normal distribution" (Jacobs, et al., 2004 p.37), or
- "Standardisation (or z-score method) converts data in order to get normal distribution." (Hudrlikova and Kramulova, 2013, p.38)

This is not the case: converting an indicator to z scores simply rescales it to have a mean of 0 and a standard deviation of 1. A skewed indicator will have exactly the same skewness, and a similar departure from normality, after conversion to z scores.

Similar inconsistencies in terminology in the composite index literature have been noted by Heinrich, et al. (in press). In addition to those noted above, "normalisation" can also be used to refer to the aggregation of a number of indicators into a single index. In this report, *normalise* means any transformation of an indicator that aims to bring its distribution closer to a normal distribution. *Rescaling* means a change to the range of an indicator, and/or its mean and standard deviation, without altering the shape of its distribution. Normalising to reduce excessive skewness and kurtosis is a step in many published composite indices (e.g. the Global Innovation Index and the Environmental Sustainability Index – Yang, 2014), and is recommended in methodological guides (e.g. OECD, 2008, Kovacevic, 2010, Hudrlikova, 2013).

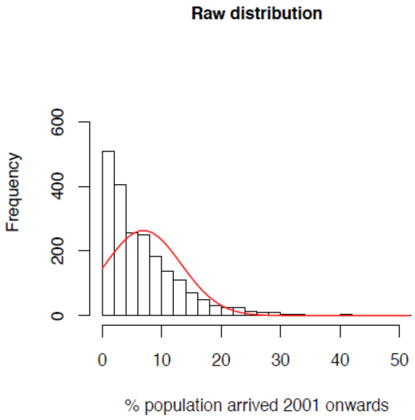
There are two reasons for normalising maldistributed indicator descriptions. Firstly, if an indicator distribution is highly skewed, then this has serious consequences when simple additive aggregation is used to form composite indices.

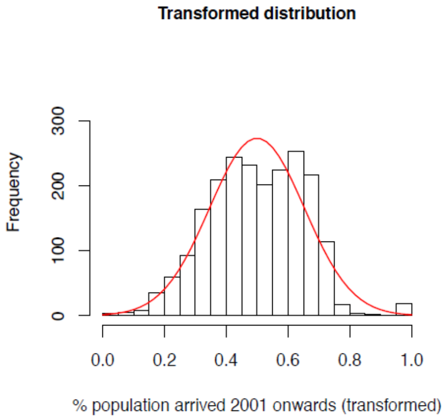
An example - social character theme transformation

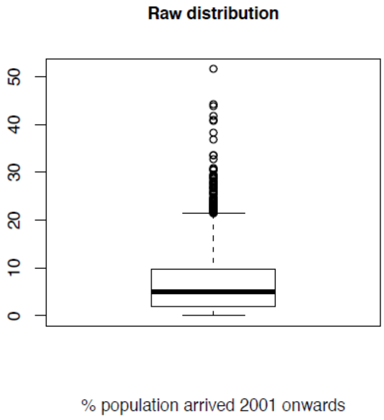
The following example shows the distribution of the raw and transformed indicator '% population arrived 2001 onwards' (with histograms and boxplots), as well as the transformation details, outlier counts before and after transformation, the functional form of the transformation and a graphic check that the transformation preserves rank order.

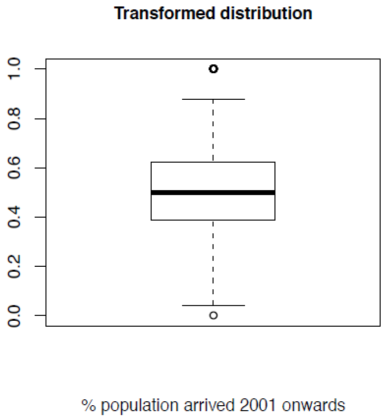
Many of the raw indicators have skewed and/or leptokurtic distributions with long tails of outliers that are likely to introduce methodological artefacts into any composite indices that allow partial or full compensibility between indicators. However, it is possible, in almost all cases, to transform these distributions to reduce the skewness, leptokurtosis and the numbers of outliers. Transformations include power transformations, log transformations and inverse power transformations.

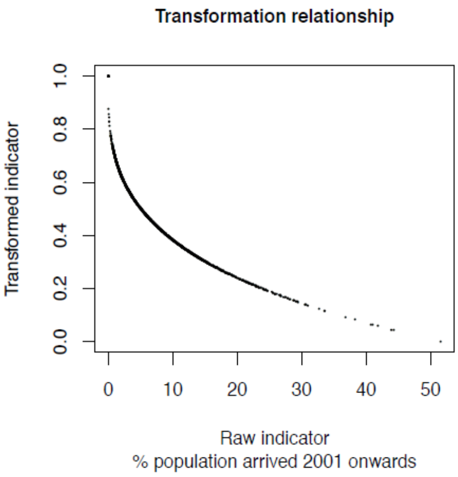
It should be noted that, while traditional outlier thresholds from inferential statistics are used to identify outliers, these outlying SA2s should not be regarded as erroneous in any way, since the data set represents a whole population of SA2s rather than a sample. There are no grounds for deleting outlying SA2s – rather the number of outliers should be reduced as much as possible by transformations and the aggregation method for constructing composite subindices should be robust to outlying SA2s. There may be slight differences in the outlier count and the outliers shown in boxplots as the former is based on absolute value of z-score greater than 3.29, while the latter is based on 1.5 times the interquartile range beyond the 1st and 3rd quartiles.

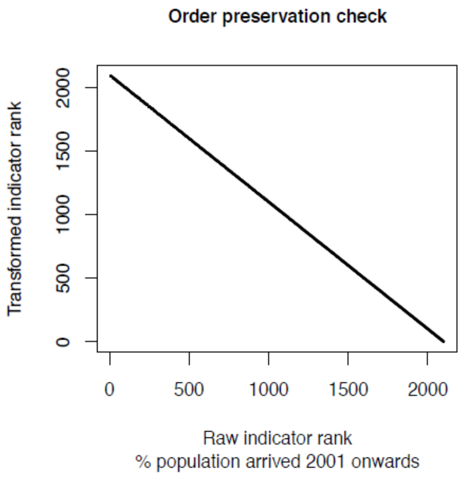












TRANSFORMATION DETAILS

Reversed

Skewness:
Power transform, exponent: 0.30
Pre–transform skewness: 1.8
Post–transform skewness: –0.0

Kurtosis:
Coefficient: 0.03
Pre–transform kurtosis: 4.9
Post–transform kurtosis: 0.0

Outliers:
Pre–transform outlier count: 26
Post–transform outlier count: 0

Aggregation methods

Background

Aggregation issues are mostly concerned with arriving at an index that somehow gives expression to the pattern of indicator values, without being unstable or misleading. The central issue, widely discussed in the literature, is compensability between indicators, i.e. whether or not low values of some indicators can be compensated for in the aggregation process by high values of other indicators. A further consideration in aggregation methodology, that has become relevant in recent times with the use of aggregation operators that allow for detailed prescription of levels of compensability between indicators, is the level of expert input required to model the compensability. In general, methods that require extensive efforts by (possibly volunteer) experts are unlikely to be practicable. An enduring issue, despite great improvements in computer processing speeds, is also the length of time required for aggregation calculations. The scoring of options in Multiple Criteria Decision Analysis (MCDA) is mathematically equivalent to constructing indices of resilience to hazards and so allows MCDA methods to be applied to the task of constructing resilience indices. However, resilience indices generally involve large numbers of indicators (MCDA criteria) and geographical units (MCDA options) in the thousands, so that the computational intensity of MCDA methods makes them infeasible for calculating resilience indices.

The hierarchical structure of the ANDRI means that there is more than one methodological choice to be made with aggregation. There are six aggregations required to calculate the various sub-indices that go to make up the Coping Capacity sub-index, and two aggregations required to calculate the sub-indices that comprise the Adaptive Capacity sub-index. This is followed by an aggregation of eight sub-indices to calculate the Coping Capacity sub-index and an aggregation of two sub-indices to calculate the Adaptive Capacity sub-index. Finally, these two sub-indices need to be aggregated to produce the ANDRI.

Having regard to wide range of aggregation methods and their varying assumptions about compensability, there is no reason that different aggregation methods cannot be used in different parts of the hierarchy. In particular, where an aggregation involves only two or three indicators or sub-indices, the demands of specifying compensatory relationships are lessened. In addition, the higher parts of the hierarchy are more conceptual in nature, which opens the possibility of specifying compensatory relationships from theoretical considerations.

Given these characteristics, the ANDRI calculation has used non-compensatory or partially non-compensatory aggregation methods where it is within the project budget to make reasonable estimates of compensatory relationships. Where the aggregation involves just a few indicators or sub-indices, compensatory relationships, if known, can be easily specified. Where there is a larger number of indicators or sub-indices to aggregate, more general methods of managing compensatory relationships can be used, as described below

No weighting at the indicator level is used in the ANDRI calculation. The critique of lack of weighting which has been levelled at fully additive aggregation methods

(De Muro et al., 2011), is less applicable to ANDRI, given the efforts made in the methods to take account of compensatory effects as much as possible within the constraints of the project.

There is no single aggregation function that is universally accepted as the correct method for aggregating indicators to calculate a composite index or composite sub-index. Choice of aggregation function depends on the indicator context, on the level of knowledge about possible indicator interactions and upon the mathematical tractability of indicator calculations. Often, a degree of subjectivity is inevitable in indicator aggregation choices. The most widely used aggregation function, the arithmetic mean, is intuitively appealing, but subject to growing criticism in the literature for allowing unconstrained compensation between indicators.

Descriptive details and selected results may include one or more of the following aggregation functions, according to the indicator context and level of understanding of indicator interactions:

- discrete Choquet integral,
- ordered weighted averaging (OWA),
- generalised mean,
- Mazziotta-Pareto index, and
- arithmetic mean.

The discrete Choquet integral requires a reasonable understanding of interactions between indicators and subsets of indicators. It provides a nuanced and mathematically valid aggregation that takes account of these interactions, but becomes intractable in its information requirements when the number of indicators exceeds three. It is rarely used in disaster resilience studies.

The OWA, generalised mean and Mazziotta-Pareto Index methods listed above have all been proposed in the literature as improvements on the arithmetic mean. They have been used in a small number of studies involving composite indices, not necessarily disaster resilience. The arithmetic mean aggregation method has been widely used but is open to serious criticism as to its validity.

The aggregation strategies pursued to obtain tractable measurement models appropriate to the level of understanding of indicator interactions may include simple formative measurement models (the model most commonly used in natural disaster resilience and vulnerability studies), as well as combined reflective and formative models. The former type is ubiquitous in studies involving latent constructs in psychology and social and educational psychology, and has the advantage that aggregation by arithmetic mean is wholly valid.

Aggregation strategies may include reducing the number of indicators if this can be done without serious information loss.

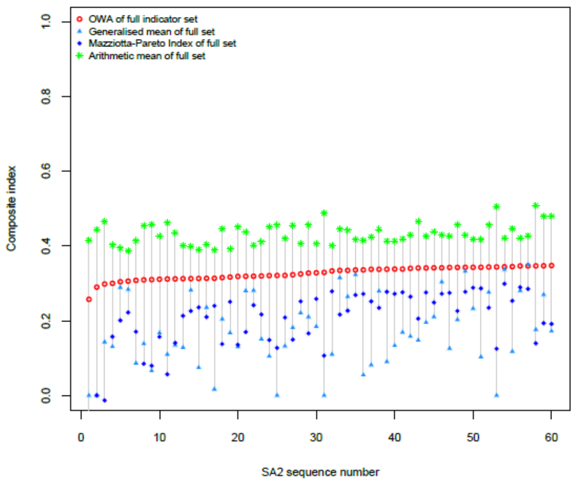
In the reporting of the theme aggregation results, one of the composite subindices and its measurement model will be identified as representing, in our opinion, the most appropriate method given the indicator context. Aggregation results for ordered weighted averaging, generalised mean, Maziotta-Pareto index and the arithmetic mean will be also provided.

The level of uncertainty attaching to the composite sub-indices is expressed through the inter-indicator variation. High inter-indicator variability leads to increased compensatory effects when indicators are aggregated. For aggregation functions other than the discrete Choquet integral, these effects will be largely uncontrolled and their basis in physical reality uncertain. For these reasons, the inter-indicator variability, as expressed by the inter-indicator coefficient of variation, is a measure of composite index uncertainty.

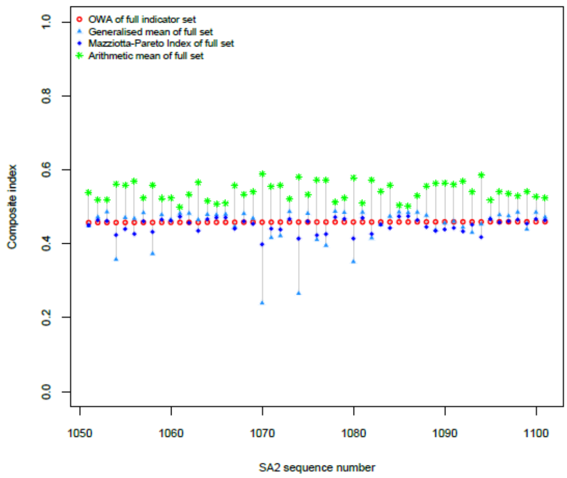
An example - social character theme aggregation

For the social character theme we used a simple formative measurement model with 17 indicators. Because no judgement could be made about the interactions between these indicators, OWA was used to aggregate the 17 indicators into the social character theme subindex. It was assumed that partial, but not full, compensatory effects between the three indicators were possible, so the OWA used a weighting vector with an orness of 0.33 (an orness of 0 corresponds to no compensatory effects allowed, and and orness of 0.5 corresponds to unrestricted compensatory effects allowed).

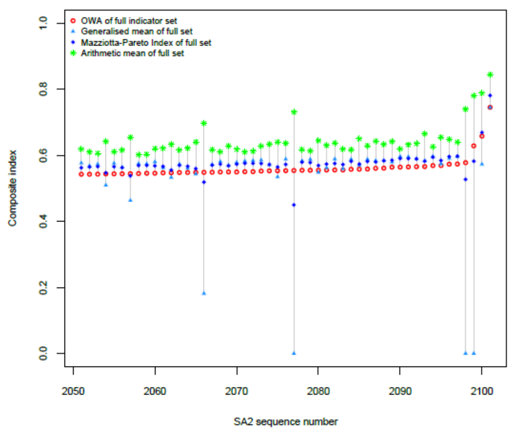
Graphed results, social character sub-index, 60 SA2s with lowest values



Graphed results, social character sub-index, 60 SA2s with midrange values

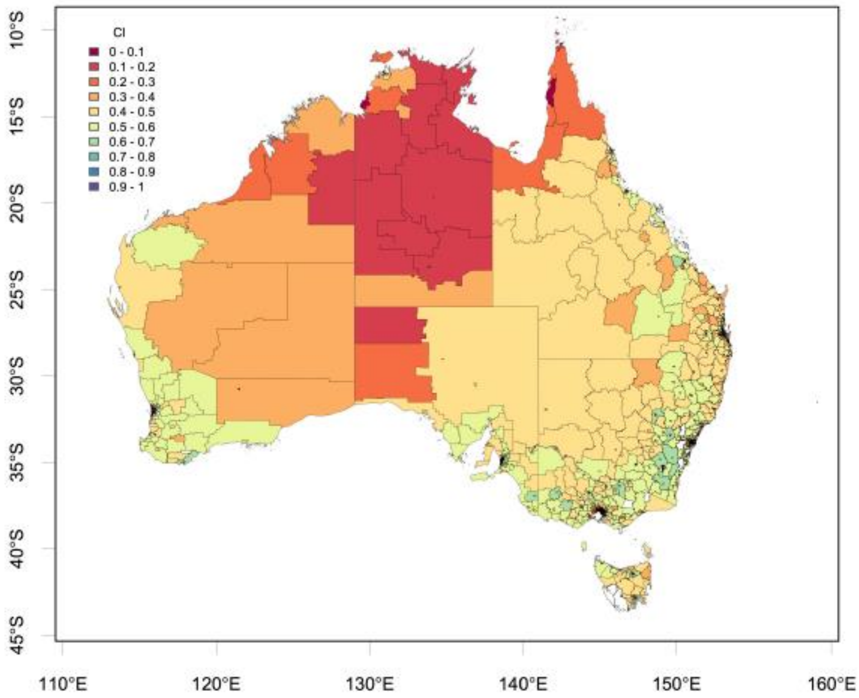


Graphed results, social character sub-index, 60 SA2s with highest values

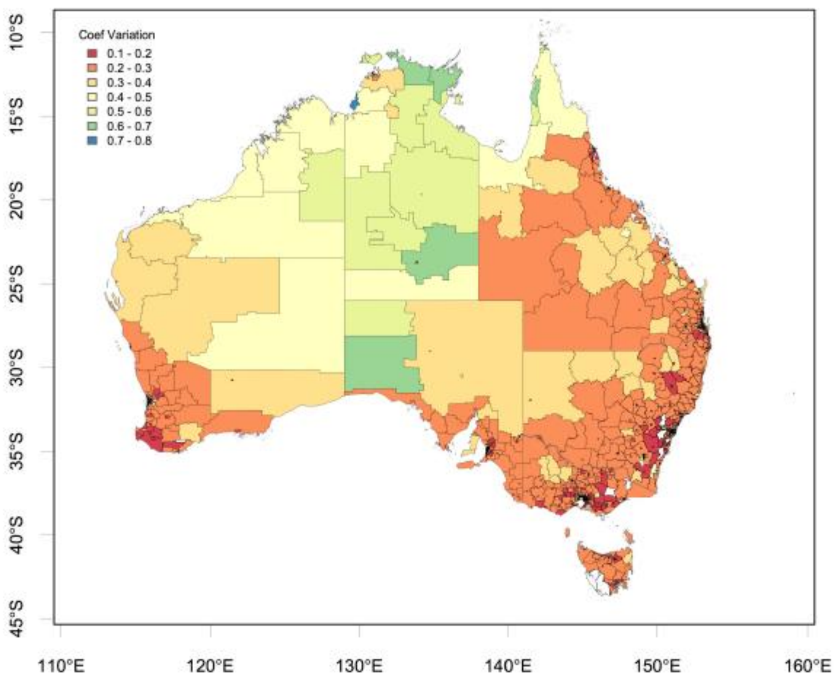


Based on the graphs above, the social character index used OWA as the aggregation method. The resulting mapped index results for the social character theme are shown below. The top map shows the index value and the lower map shows the coefficient of variation as a measure of index certainty.

Mapped results, social character sub-index, OWA with 17 indicators



Mapped results, social character composite sub-index uncertainty



PUBLICATIONS LIST

Parsons, M. and Morley, P. 2017. The Australian Natural Disaster Resilience Index. Australian Journal of Emergency Management, 32: 20-22.

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