

## Neighbourhood Disaster Resilience Index: A Validation in the Context of Brisbane and Ipswich 2010/2011 Floods

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**Abstract:** Despite the wide use of the resilience concept in urban planning and policy making, measuring this concept at neighbourhood level has not been done. The spatial scale at which most resilience models are conducted has limited utility in mitigation planning and capacity building. Moreover, most of the indices proposed by researchers in disaster resilience fail to validate the measures, especially in terms of the incremental validity. In this study, a Neighbourhood Disaster Resilience Index (NDRI) is proposed with a refined set of variables for measuring neighbourhood level disaster resiliency. The NDRI considers varying dimensions of disaster resiliency by using different socioeconomic, spatial and place-specific indicators to measure risk and exposure, sensitivity and coping capacity.

The resilience scores and recovery outcomes are mapped and a series of regression analyses are conducted to build a robust, reliable and valid index. The mapping showed that neighbourhoods with different levels of resiliency create distinct spatial clusters that are mostly in middle and outer eastern areas along the northern side of the Brisbane River. The Damage Assessment and Reconstruction Monitoring data (DARMSys) has been utilised as a source of the real world resilience proxies to assess the external validity of NDRI. The results of analysis suggest that most of the selected indicators contribute incrementally to the recovery process and also the total score of NDRI shows consistency with expectations based on external proxies for disaster resiliency.

### Introduction

Disaster resilience is an abstract and latent characteristic of a neighbourhood rather than a concrete and observable attribute. According to Nunnally et al. (1967), the intended model in this study is a “construct” as a resilience index is literally something that we “construct” and which does not exist as an observable and directly measureable attribute. Therefore, the first step is to define the conceptual domains of the resilience construct to prevent confusion about what it does and does not refer to. In this study, neighbourhood disaster resilience is defined as: the capacity of community and its built environment at neighbourhood scale to absorb the impacts of disaster and recover in a timely manner after disaster to reach and maintain an acceptable level of functioning and structure while learning from past incidents. This outcome-oriented definition of the resilience is intentional, as it is appropriate for measurement modelling. In fact, it defines resilience in terms of the end results such as degree of recovery, time to recovery or extent of damage avoided.

There is a consensus within the research community that urban disaster resiliency includes social, economic, institutional, environment and built environment components (Bruneau et al., 2003; Cutter, Susan L. et al., 2010; Cutter, Susan L & Finch, 2008; Gunderson, 2010). Since the unit of analysis of this study is the neighbourhood, the institutional component has not been considered as it would have the same value for neighbourhoods in the same local government area. However, in the case of comparing neighbourhoods from different local government areas, a dummy variable represents the effects of institutional capacity of each local government area on disaster resiliency of neighbourhoods. Moreover, the indicators selection for the resilience construct is guided by its two distinctive essential characteristics of resilient urban systems which have the ability to both ‘absorb the impact’ and support ‘quick recovery to the previous level of functioning’. Eliminating any of these components would restrict the conceptual domain of the construct. Therefore, the intended measurement index in this study is a multidimensional model of resilience that consists of a number of interrelated attributes and dimensions including social, economic, environment and physical components.

### Research Methodology

The first step of this study on neighborhood disaster resilience was to select, a set of indicators to assess neighborhood flood resiliency. The quantitative indicators were used in a way that simplified

neighborhood's characteristics. Composite indicators, derived as a mathematical combination of this set of indicators, were used to rank and compare the overall resiliency score of the each neighborhood.

The next step of the methodology involved selecting two different proxies to measure recovery outcomes. Considering the dynamic and complicated nature of recovery, it has been approached as a multidimensional concept that includes social, economic, physical and environmental aspects. However, due to the time and data limitations, we limited the recovery outcomes to house damage and reconstruction. The calculation of recovery indicators are discussed in detail below. Finally, to link the recovery outcomes to resilience scores, a series of multivariate regression analyses were conducted. Recovery outcomes were considered as an external validation metric to calculate the extent to which the selected indicators of disaster resiliency are actually contributing to the neighborhood recovery.

### ***Research setting***

The study area for this research encompasses 76 flood-affected neighbourhoods in Brisbane and Ipswich Queensland. The neighbourhood boundary is considered the same as suburbs in this study. Most of these neighbourhoods are located along the Brisbane River on the east coast of Australia. These neighbourhoods were part of the area affected by Queensland floods in December 2010 and January 2011. The floods caused devastation throughout more than three-quarters of the council areas within Queensland and resulted in more than 56,000 insurance claims with payouts totaling \$2.55 billion. These neighbourhoods were chosen based on the availability of longitudinal data on reconstruction status of flood-affected properties from the Queensland Reconstruction Authority. To make the data set of sufficient size for conducting our statistical analysis neighbourhoods from both Brisbane and Ipswich were included. However we controlled for the effects of different local government areas by using a dummy variable in the analysis.

The neighbourhood level was chosen as it is reasonably stable in population size and is often has homogeneous population characteristics, economic status and living conditions (Sampson et al., 2002). This choice facilitated the data collection process as neighbourhoods are a geographic unit in the Australian Census database and most important socioeconomic, physical and environmental data are often available at this scale.

### ***Neighbourhood Disaster Resilience Assessment***

In this study, with recognition of the contributions and limitations of the previous resilience models at different scales, three notions seemed more suitable to conceptualize resilience within a framework: 1) Resilience attributes 2) Resilience components and 3) The 'impact absorbent' and 'quick recovery' notions. Therefore the focal construct in this study, Neighborhood Disaster Resilience Index, is considered as a function of resilience attributes (robustness, redundancy, resourcefulness and rapidity) within each component (social, economic, physical and environmental) that contribute to quick recovery after disaster or absorbing the disaster impact.

Given the definition of conceptual domains of the NDRI, the next step was to identify a set of indicators that characterize these domains. Approximately 93 indicators were selected using a matrix that guided the indicator selection process by cross-classifying the four dimensions of resiliency (social, economic, physical and environmental) by urban resilience attributes. Moreover, choices among indicators were guided by a set of criteria: the variable should be justified in the literature, should have consistent quality data publicly available and also must be scalable or available at different scales. Out of the 93 variables on the list, 51 indicators were used based on the three overarching criteria.

### ***Neighbourhood Social Resiliency Index (NSoRI)***

The social resilience captures the capacity of communities to respond during a disaster to overcome the negative effects and have the individual and social resources to recover quickly (UNISDR, 2005). Thus at individual level, literature in the field of social capital suggests that some demographic attributes of communities can enhance the social capacity of communities in terms of their response to disasters (Cutter, S.L. et al., 2003). Therefore at this level, it is important to identify the characteristics of vulnerable population and coping capacity, access to resources and human capital.

At social group level, properties that facilitate cooperative actions can influence the social resilience. Putnam (2001) suggests measuring social capital by using composite indicators containing measures of participation and involvement in social groups, civic engagement and place attachment. Therefore, social resiliency indicators in this study have been developed based on the impact of disaster on the social fabric and capacity of community to respond and recover quickly after disaster using the following six components suggested in the literature.

#### **Neighbourhood Economic Resiliency Index (NEcRI)**

Economic resilience can take place at three levels of economic systems: microeconomic (Individual behaviour of households and firms), meso-economic (economic sector and cooperative groups) and macroeconomic (all individual and markets combined and their interactive effects). In engineering-based resilience modelling approaches, four attributes of resilience are sought: robustness (loss avoidance); redundancy (untapped or excess economic capacity); resourcefulness (stabilising measures); and rapidity (optimizing recovery time). In this study, however, economic capital basically represents financial resources that people use to support their livelihoods. The next sub-component of economic resilience considered is resource equity as people with access to financial resources recover more rapidly from disasters (Mileti, 1999). Therefore exposure, sensitivity of economic assets, economic and livelihood stabilities, economic diversity and resource equity are the sub-components which best define the economic resilience of urban systems in this study.

#### **Neighbourhood Physical Resiliency Index (NPhRI)**

Existing infrastructure resiliency models that take an engineering-based approach for modelling resilience do not seem suitable for defining the physical component variables in a comprehensive resilience model. This is because an overall assessment is needed of buildings (residential/ commercial/ industrial/ public), lifelines (transport, power, water, and communication), infrastructures (roads, bridges, dams, and levees), Land and building regulations, Land use planning and also critical facilities. Four resilience attributes and additional resiliency principles extracted from urban planning literature are used to define the physical resiliency metrics: 1) robustness in built environment determines the risk avoidance measures which mainly represent the exposure and sensitivity of built environment elements; 2) redundancy characterizes measures for duplicating system, equipment and supplies which assist the system in absorbing the shock and minimize the adverse impacts on system. Temporary sheltering capacity, evacuation capacity and diversity variables will be covered by the metrics of this component; 3) resourcefulness that refers to availability of resources such as materials and skills representing reconstruction capacity and also fire, State Emergency Services and police stations representing the response capacity and 4) rapidity are the properties which help community to recover quickly. Therefore, the physical resiliency indicators are identified using six different sub-components: physical exposure, medical capacity, temporary sheltering capacity, emergency response capacity, communication capacity and transportation capacity.

#### **Neighbourhood Environmental Resiliency Index (NEnRI)**

The environment component of resiliency includes measures of risk and exposure, existence of protective resources that safeguard communities against environmental threats, and also hazard event frequency. Measures of the hazard event frequency are linked to disaster resilience since communities could become adapted to frequent disasters through mechanisms of learning from experience and selective pressure (Gunderson, 2010).

#### **Neighbourhood Disaster Recovery Assessment**

Previous studies on disaster recovery mostly used qualitative and subjective information, obtained by social-audit techniques and participatory methods (e.g. focus group meetings, household surveys and key informant interviews). However, recently a series of quantitative, systemic and objective recovery studies were conducted using direct observation and non-participatory methods (e.g. remote sensing, repeat photography and advanced field survey techniques) that allow detailed geocoded observations. For example, Brown et al. (2010) in the Recovery Project conducted by the Centre for Risk in Built Environment at Cambridge University identified 24 recovery indicators in six major categories of vulnerability, livelihoods, housing (including drinking water access), services, environment (including vegetation and removal of floodwater sand and debris) and infrastructure (including road access and reconstruction). However, the most frequently used recovery indicators are reconstruction of houses,

critical facilities and lifelines, noncritical facilities and lifelines, transportation systems, number of building permits and population return (Bevington et al., 2011; Smith & Wenger, 2007; Stevenson et al., 2010). This study uses two sets of proxies for disaster recovery based on data from comprehensive monitoring of reconstruction status after the 2011 flood in Queensland, DARMsys (Damage Assessment and Reconstruction Monitoring system). These two sets of proxies are damage loss and reconstruction status. In this dataset, damage loss has been assessed based on the average monetary loss and categorized into four levels of property damage. 'Minor Damaged' properties are habitable but minor repairs are required (e.g. broken tiles on roof, windows damaged). 'Moderately Damaged' denotes that roughly 25%-49% of the property is damaged and occupants may need to vacate while repairs are conducting. 'Severely Damaged' properties are not habitable with 50% or more of the property damaged. In 'Totally Damaged' properties almost 100% of the property is damaged and it is unlikely to be economically feasible to repair. Considering these definitions of the damage data, in this study, the damage loss is aggregated based on the formula below:

$$\text{Damage loss} = (\# \text{minor damaged properties} + (25) * \# \text{moderately damaged properties} + (50) * \# \text{severely damaged properties} + (100) * \# \text{totally damaged properties})$$

The recovery status in each time point after the flood is calculated based on the level of change in the aggregated damage loss. As the reconstruction monitoring audits were conducted periodically after the flood for four rounds, we calculate the percentage of recovery in 10, 13 and 17 months after the flood based on the formula below (201107 indicates the survey round conducted on July 2011):

$$\% \text{ Reconstructed in 17 months} = (\text{Damage loss 201107} - \text{Damage loss 201205}) * 100 / \text{Damage loss 201202}$$

The percentage of housing stock reconstructed at each time point for each neighborhood is calculated and then directly calibrated using minimum-maximum scaling method. Four neighborhoods (Paddington, Greenslopes, Kholo and Sinnamon Park) were completely recovered within 10 months after the flood and they were rated as 1. Less than 50% of the affected properties in two neighborhoods (Goodna and Yeerongpilly) were reconstructed over 10 months and were rated as 0. This spatiotemporal assessment of the recovery following the Brisbane and Ipswich flood is used as an external validation measure to identify variables that could be sufficient to use in NDRI.

### ***Linking Recovery Outcome to Disaster Resilience Indicators***

In this study, Poisson regression models are used to identify independent variables associated with the recovery process. The Poisson regression is chosen as the response variable (recovery) inclined/truncated mostly at one value (%100) and also a primary analysis of data revealed that the assumptions of the linear regression are violated by these data. These models incorporate the percentage of properties reconstructed after 10/13/17 months as response variables and the resilience indicators in each of the four dimensions. In contrary to fitting a straight line to these data, in Poisson regression a Poisson distribution is applied to estimate the maximum likelihood from response value.

As described in recovery assessment section, recovery and reconstruction status was categorized in four categories based on the level of recovery process observed by surveyors of DARMsys. In this case, the event occurring is movement from one recovery category to the next over time toward a full recovery. Twelve regression models were calibrated to represent the association of all four resilience components' variables in each recovery time point after the flood. A Poisson regression was calibrated for the variables of each component at each time point of recovery. This calibration was based on the assumption that recovery in each neighbourhood will progress from 'no recovery' to 'full recovery' over time. A regression model is used for each recovery time point to represent the situations where particular variables might be better linked to a certain recovery stage at a different time point after the flood. This is derived from beta coefficients of regression analysis that are sensitive to the recovery values distribution. In order to make the dependent variables suitable for using in Poisson regression model, each neighbourhood's recovery status was nominally coded. Since nearly all of the neighbourhoods showed some degree of recovery, the recovery status is started from limited recovery to full recovery.

## Results

### ***Disaster recovery of Brisbane and Ipswich neighbourhoods***

The recovery progresses over 10, 13 and 17 months are presented in figure 1. The lighter shades of red show limited recovery in neighbourhoods. A visual assessment of these recovery maps presents a spatially variable recovery progress. Ten months after the flood, most of the neighbourhoods show a limited to medium recovery level (Figure1) except for eleven neighbourhoods (Pinjarra Hills, Newstead, Kholo, Sinnamon Park, Hawthorne, Walloon, Balmoral, Kangaroo point, Sumner, Greenslopes and Leichhardt). These neighbourhoods are mostly located in the eastern part of the city and sustained less damages comparing to other neighbourhoods. On the other hand, most of the neighbourhoods with the least level of recovery are located in a western low lying part of the study area close to Ipswich (East Ipswich, North Ipswich, Calvert, Goodna, Basin Pocket, Yeerongpilly, Westlake and Moggil). Of interest are Moggil and Calvert neighbourhoods which had very low levels of property damage and still showed very limited recovery ten months after the flood. Approximately the same sort of differential recovery is evident 13 and 17 months after the flood (Figures 1c and 1d). The least recovered neighbourhoods after 17 months are generally those with a slow recovery rate at 10 months as well.

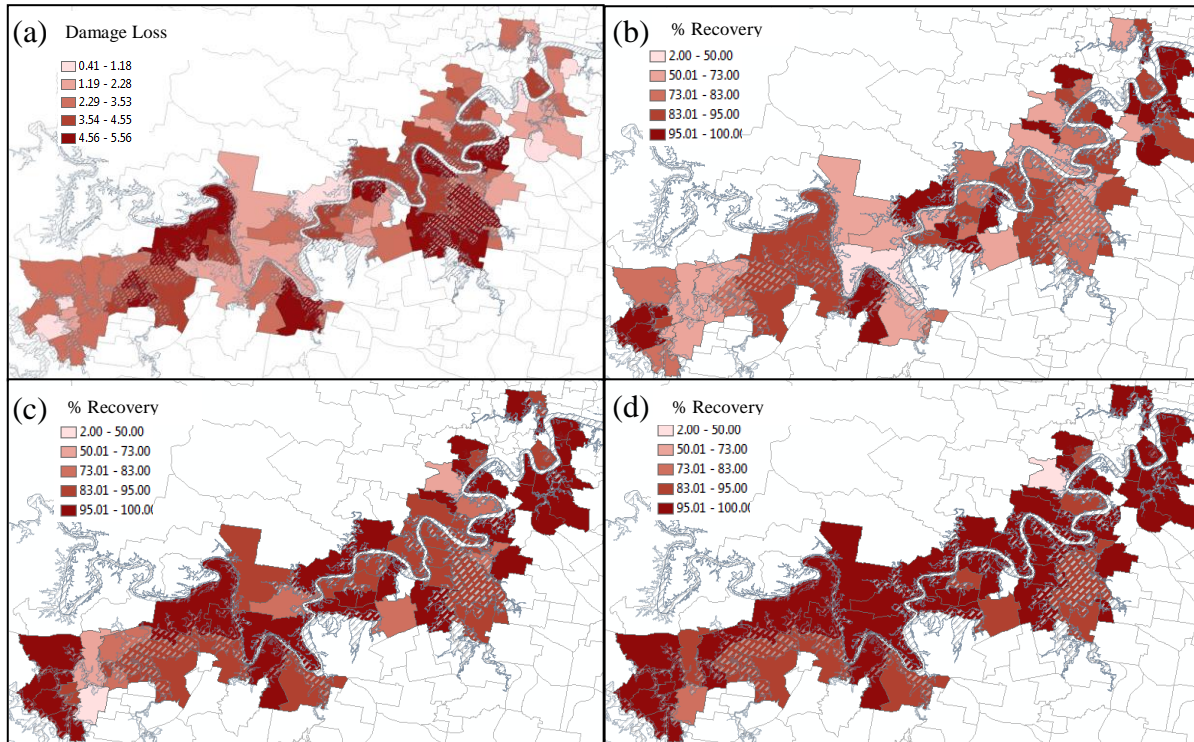


Figure1. Flood damage (a) and reconstruction status in 10 (b), 13 (c) and 17 (d) months after the flood

A set of regression analyses was conducted to find indicators suitable for comparative assessment of disaster resilience. The results revealed that twenty-two of the forty-five indicators were statistically significant ( $P < 0.05$ ) and might be suitable for measuring disaster resilience as shown in Table 1. The results of the social component show that the percentage of 'not single parent family' and the 'human capital-SEIFA' are the strongest predictors of social resilience. On the other hand, in the economic resilience component, income level is statistically significant predictor ( $p < 0.05$ ) over time, for all recovery time points. The percentage of population that is employed is also a predictor of recovery outcome. In fact, these variables show the extent to which the neighbourhood community have adequate assets and resources to recover quickly after the flood. Economic resources-SEIFA indicator only contributes to recovery after 17 months. This can be attributed to situations where just having economic resources does

not facilitate quick recovery in the first months after the flood, and differential social factors contribute to recovery in short term.

Most of the selected physical resilience variables have an impact on the disaster response phase (for example the capacity to provide temporary shelter, transportation and medical facilities) rather than disaster recovery and reconstruction. Therefore, the calibrated models for reconstruction status and physical resilience variables show relatively low R<sup>2</sup> statistics and even in some cases show negative B parameters in contribution of physical resilience variables to reconstruction progress after the flood (such as SES, police, land use mix and intersection density – see Table 1). The environment resilience variables show a predictive strength (a relatively high R<sup>2</sup> statistics). The exposure and hazard frequency sub-components within environment component have to some extent a direct impact on recovery phase and therefore there are statistically significant contributors to reconstruction progress among the environment resiliency variables (including the percentage of built up area in flood zone, percentage area not flooded in the last three floods).

Table1. Regression models results of the selected resilience variables and recovery outcomes

Disaster resilience variables	%Reconstructed in 10		%Reconstructed in 13		%Reconstructed in 17	
	B	sig	B	sig	B	sig
%Not single parent family	.29	.01**	.33	.004**	.33	.004**
%Same address 5 years ago	-	-	-.30	.008**	-.37	.04*
%Volunteers	-	-	-	-	.45	.000***
%Sufficient English	-	-	-	-	.31	.006**
Human Capital- SEIFA	.29	.01**	.37	.001***	.38	.001***
%Commercial Building post 1981	-	-	.28	.01**	n	-
%Employed	.39	.001***	.47	.000***	.49	.000***
Income level	.39	.001***	.47	.000***	.49	.000***
%Employed not in Primary Industries	-	-	.25	.03*	-	-
Economic diversity	-	-	-	-	-.26	.03*
Economic Resources-SEIFA	-	-	-	-	.32	.005**
%Employed in Finance and Insurance	.29	.01**	.36	.002**	-	-
%Not built up in flood zone	-.35	.002**	-.39	.000***	-	-
SES per 10,000	-	-	-	-	-.30	.009**
Police per 10,000	-	-	-.23	.04*	-	-
Road intersection	-	-	-	-	-.27	.02*
Not Single Family detached houses	.34	.003**	.32	.006**	-	-
LUM	-	-	-	-	-.25	.032*
%Residential in flood risk area	-	-	-.23	.05*	-	-
% wetland	-	-	-.23	.03*	-.27	.02*
% Impervious land	-.24	.04*	-.29	.01**	-	-
3 timesfloodedto 2011flooded	-	-	-	-	-.32	.005**

\* Significant at 0.05

\*\* Significant at 0.01

\*\*\*Significant at 0.001

### ***Disaster Resilience of Brisbane and Ipswich neighbourhoods***

The resilience indicators at the neighbourhood level and their association with recovery outcomes were investigated in previous sections of this paper. Composite indicators were used in this study to display the relative resilience of Brisbane and Ipswich neighbourhoods. To obtain a composite indicator, the scores of each sub-component (social, economic, physical and environmental) indicators were averaged to moderate the effect of different numbers of variables within each sub-component. Then, these sub-component scores were summed up to get the composite score of neighbourhood disaster resilience. To show the neighbourhoods that have very high or very low disaster resilience scores, the NDRI scores are presented in Figure 2 as standard deviations from the mean. The neighbourhoods shown in dark blue represent the most resilient neighbourhoods and those in yellow are the least resilient.

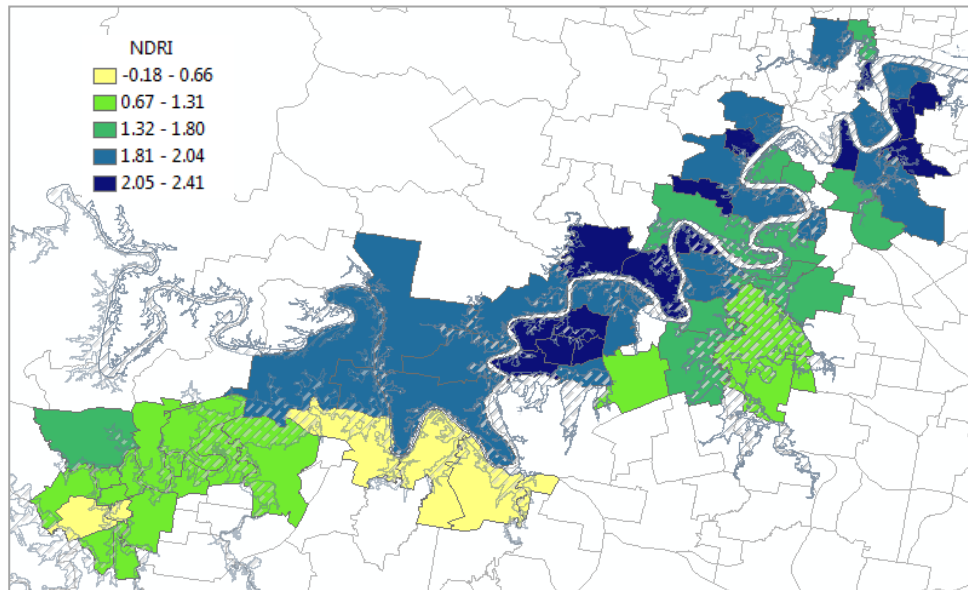


Figure2. The spatial variation of Neighbourhood Disaster Resilience scores

The NDR map shows some variations in neighbourhood disaster resilience scores. There are three groups of NDR scores; one in the outer west area around Ipswich which mostly have medium-low resiliency; another in a strip of neighbourhoods extending mostly in the north side of the Brisbane River which shows a medium-high and high level of resiliency; and finally in the southern part of this strip, the NDR is differential from very low in western neighbourhoods to higher NDR scores in the east.

The scores of each resilience sub-component were mapped to understand the underlying factors to the trends seen in NDR scores (Figure 3). The spatial patterns of the resilience sub-components are more evident than those for the composite NDR score. Mapping the neighbourhood social, physical and environmental resiliency indicated that most of them are geographically contiguous. The cluster on northern side of the river shows very high social and physical resiliency where the recovery at all three time points had been progressed comparatively quicker. However, it has a mixed distribution of economic and environmental resilience. For example, Pinjarra Hills in this area has low economic stability and relatively high level of damages and shows a very quick recovery after the flood which could be due to its high human capital-SEIFA indicator.

The areas with low social, economic and physical resiliency are located in the southern peri-urban area between Brisbane and Ipswich. This spatial dissimilarity between the subcomponents reveals the multidimensional nature of the resilience and also shows the value of examining different dimensions of resilience different disaster management phases.

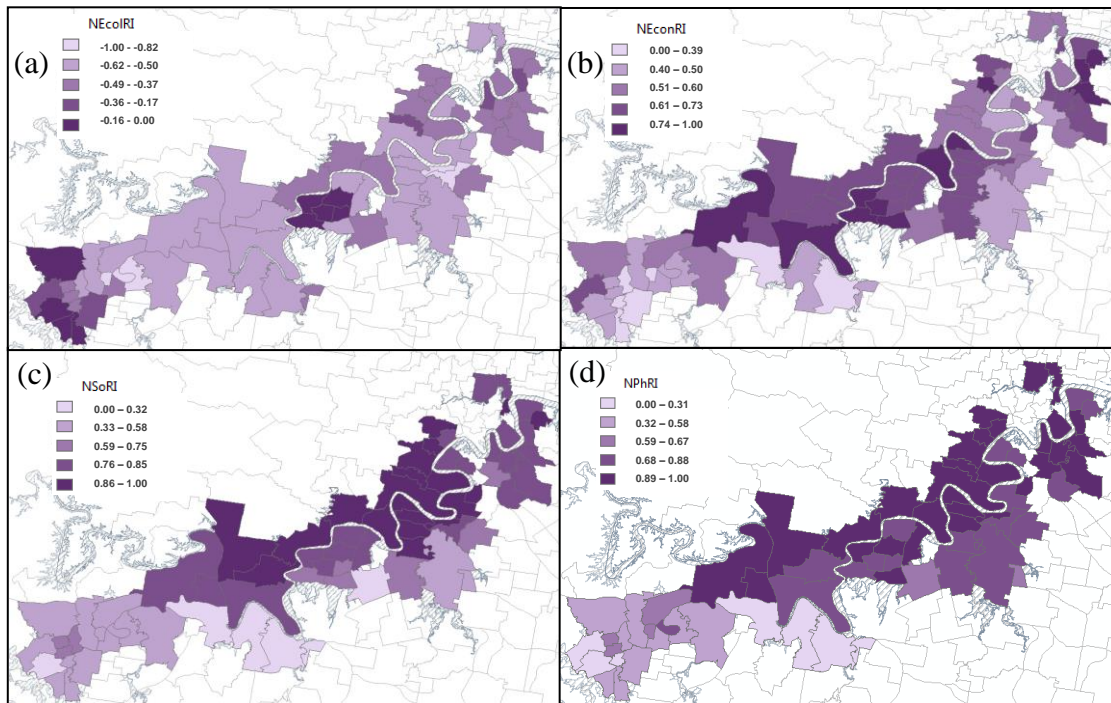


Figure3. The Neighbourhood Disaster Resilience Sub-components (a) Environmental (b) Economic (c) Social (d) Physical

***The link between disaster resilience sub-components and the recovery outcomes***

A binary logistic regression is used in this section to further understand the contributions of the four resilience components and sub-components to disaster recovery outcome in Brisbane and Ipswich neighbourhoods after the 2011 flood. For this purpose, the recovery outcome was coded to fully recovery (=100) and not fully recovered (<100). The models were calibrated for three time points of the flood recovery and the parameter estimates are shown in table 2. The explanatory powers of these models are moderately low (Adjusted R<sup>2</sup>= 0.11 to 0.32) which might be due to other post-disaster influential factors such as successful insurance claims, the governmental recovery funds (federal, state and local) (Irajifar et al., 2015). Most of the components and sub-components achieved some degree of statistical significance (<0.05) at least at one of the recovery points except from medical capacity and shelter capacity in physical component. As mentioned earlier, this non-contributory behaviour of these sub-components to some extent were predictable since the indicators in these sub-components were selected based on their contribution to the response capacity and not for the reconstruction capacity.

The results show that the economic stability is the strongest predictor of recovery in 10, 13 and 17 months after the flood. After the economic component, social sub-components are the main contributors to post-flood recovery. The differences in recovery progress among neighbourhoods are distinguishable by economic stability. For example neighbourhoods such as New Farm and Paddington with high levels of economic stability recovered quickly after the flood although they sustained high levels of flood damage whereas in neighbourhoods with low economic stability such as Goodna and Archerfield the reconstruction progress was much slower. This can be attributed to their financial resources and also the probability of having the adequate flood insurance. Moreover, environment sub-components also show statistically significant negative relationships with full recovery by determining the extent of damages sustained in each neighbourhood as it includes the hazard exposure and frequency variables.



In addition to the association of social, economic and environment components with full recovery, the effect of institutional factors was examined by defining a dummy variable for the neighbourhoods located in each of Brisbane and Ipswich local government areas. The regression model show a low R<sup>2</sup> statistics (=0.08), however the variable has a statistically significant association with recovery at all three time points after the recovery (Table 2).

Table2. The models results for the resilience sub-components and recovery outcomes

	%Reconstructed10		%Reconstructed13		%Reconstructed17	
	B	sig	B	sig	B	sig
<b>NEnRI</b>	-1.8	.08	-1.8	.02*	-1.9	.015*
<b>Risk and exposure</b>	-.21	.06	-.23	.04*	-.13	.24
<b>Protection resources</b>	-.26	.02*	-.34	.003*	-.23	.04*
<b>Hazard Frequency</b>	-.20	.08	-.16	.07	-.42	.000***
<b>NEcRI</b>	.29	.01*	.49	.000***	.31	.007*
<b>Asset Exposure</b>	-	-	.28	.014*	-	-
<b>Economic stability</b>	.34	.003**	.46	.000***	.47	.000***
<b>Resource equity</b>	-	-	.20	.08	.37	.001***
<b>NPhRI</b>	-	-	-.23	.04*	-.27	.02*
<b>Physical exposure</b>	-.35	.002*	-.34	.003**	-.13	.26
<b>Response capacity</b>		-	-.23	.04*	-	-
<b>Transportation capacity</b>	.22	.05*	.26	.03*	.16	.15
<b>Urban built form</b>	.24	.04*	.25	.03*	-	-
<b>NSoRI</b>	.27	.20	.34	.003*	.39	.000***
<b>Not Vulnerable Population</b>	.18	.129	.27	.02*	.37	.001***
<b>Participation</b>	.10	.39	.24	.04*	.41	.000***
<b>Access to resources</b>	-	-	-	-	.31	.006**
<b>Human Capital</b>	.29	.01*	.37	.001**	.38	.001***
<b>NDRI</b>	.35	.002*	.43	.000***	.49	.000***
<b>Damage loss</b>	-	-	-	-	.23	.04*
<b>Brisbane/ Ipswich dummy</b>	.31	.006*	.44	.000***	.29	.01*

\*Significant at 0.05

\*\*Significant at 0.01

\*\*\*Significant at 0.001

## Conclusion

The aim of this study was to introduce a set of indicators that could represent and operationalize the concept of disaster resiliency at the neighbourhood level and validate them based on real world data as damage and recovery outcomes after Brisbane and Ipswich flood in 2011. Based on the resilience attributes framework, a list of indicators for each component of disaster resiliency was created and then the regression models suggested that twenty-two of them might be appropriate for this context based on their statistical significance. Considering the multi-faceted nature of resilience, a comprehensive validation of the indicators and composite indicators needs a comprehensive set of damage, response and recovery outcome in a real world case study. However, considering the limitations in this study, the damage level and reconstruction status of damaged properties at three different time points after the flood were used to partially validate the resilience indicators.

The selected indicators were aggregated to calculate a single score for each sub-component and also the overall resilience score. Although the composite indicators for resilience and its sub-components might simplify the complex concepts such as resilience, they capture the important factors contributing to the resilience attributes in each neighbourhood. This could show the different relationships between resilience sub-components and facilitate consideration of capacity building and risk reduction actions inclusively in all dimensions.

The resilience scores and recovery outcomes were mapped and a series of regression models were calibrated to see how the selected resilience variables contribute to recovery outcome. The mapping showed that resilient and non-resilient neighbourhoods in Brisbane and Ipswich area form distinct spatial clusters that are mostly in middle and outer eastern areas and along the northern side of the Brisbane

River. Moreover, the model calibrations showed all of the proposed components and most of the sub-components have statistically significant associations with recovery after the flood (at least in one time point). In order to have a more robust neighbourhood disaster resilience index, further research is needed to check the sensitivity and uncertainty in variable selection and aggregation methods for calculating the composite indicators.

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Appendix1. The refined set of selected variables for disaster resiliency at neighborhood level

Variable	Justification	DataSource		
<b>Social</b>				
Disaster Impact on human capital & social fabric	<b>Not Vulnerable Population</b>			
	%population aged not less than 5 or more than 65	(Cutter, Susan L. et al., 2010)	Census 2011	
	%population not need assistance	(Cutter, Susan L. et al., 2010)	NEXIS	
	%Renter renting public housings	(Cutter, Susan L. et al., 2010)	Census 2011	
Capacity of Community to respond and recover quickly	<b>%No single parent family- Family composition</b>		(Rubinoff & Courtney, 2007)	Census 2011
	<b>Place attachment</b>			
	%Residents moved more than five years ago	(Cutter, Susan L. et al., 2010)	Census 2011	
	%home owners occupancy	(Cutter, Susan L. et al., 2010)	Census 2011	
	%immigrants arrived before last two years	(Cutter, Susan L. et al., 2010)	Census 2011	
	<b>Access to resources</b>			
	%Education higher than year 8	(Cumming, 2011)	Census 2011	
	%population with sufficient English	(Cutter, Susan L. et al., 2010)	Census 2011	
	<b>Participation</b>			
	Voluntary work for an organization or group	(Cutter, Susan L. et al., 2010)	Census 2011	
	Unpaid assistance to a person with disability	(Cutter, Susan L. et al., 2010)	Census 2011	
<b>Human Capital</b>				
Human Capital-SEIFA	(Dwyer & Horney, 2013)	Census 2011		
<b>Economic</b>				
Economic Impact	<b>Sensitivity/ Vulnerability</b>			
	Commercial buildings constructed after 1981	(Rubinoff & Courtney, 2007)	NEXIS	
Economic capacity for response and recovery	<b>Economic and livelihood stability</b>			
	percent employed population	(Cutter, Susan L. et al., 2010)	Census 2011	
	Median family income	(Rose, 2007)	Census 2011	
	Percent female labor force participation	(Cutter, Susan L. et al., 2010)	Census 2011	
	<b>Resources equity</b>			
	Financial and insurance services per 10000	(Rubinoff & Courtney, 2007)	Census 2011	
Healthcare and social assistance services per 10000	(Birkmann, 2006)	Census 2011		

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	Economic Resources-SEIFA	(Dwyer & Horney, 2013)	Census 2011
	<b>Diversity</b>		
	Percent of population not employed in primary industries	(H. John Heinz III Center for Science & Environment, 2002)	Census 2011
	Retail centers per 10,000 population		QLD database
<b>Physical</b>			
Physical Impact	<b>Physical Exposure</b>		
	%Non-built up area in flood hazard areas	(Geis, 2000)	BCC database
	%services land use in flood area	(Geis, 2000)	BCC database
	%Building constructed after 1981	(Cutter, Susan L. et al., 2010)	NEXIS
	% Not single family detached houses	(Chang, S. E. & Shinozuka, 2004)	NEXIS
Physical capacity to response and recover quickly	<b>Medical capacity</b>		
	#Ambulance services per 10000	(Mayunga, 2009)	QLD database
	#Hospitals per 10000	(Mayunga, 2009)	QLD database
	<b>Temporary sheltering capacity</b>		
	# Schools per 10000	(Chang, M. S. et al., 2007)	Census 2011
	%Recreational land per 10000	(Cutter, Susan L. et al., 2010)	Census 2011
	#Sport facilities per 10000	(Cutter, Susan L. et al., 2010)	Census 2011
	# Place of worship per 10000	(Cutter, Susan L. et al., 2010)	Census 2011
	<b>Emergency response capacity</b>		
	Police stations per 10000	(Rubinoff & Courtney, 2007)	Department of Community Services
	Fire stations per 10000		
	SES stations per 10000		
	%Services Land use per 10000		
	<b>Communication capacity</b>		
	Occupied housing units with internet connection	(Cutter, Susan L. et al., 2010)	Census 2011
	<b>Transportation capacity</b>		
	% Units with motor vehicle access	(Cutter, Susan L. et al., 2010)	Census 2011
	% Occupied housing units with a vehicle available	(Mayunga, 2009)	Census 2011
	Intersection density per 10000	(Ewing and Cervero, 2010)	Census 2011
	Principal road	(Bruneau et al., 2003)	BCC database
<b>Environment</b>			
	<b>Risk and Exposure</b>		
	%land area not in a flood zone (100 &500 years)	(Mayunga, 2009)	QLD database
	%Residential land not in flood risk area	(Adger et al., 2004)	
	<b>Protection resources</b>		
	%land area that is a wetland, swamp, marsh or natural barrier	(Adger et al., 2004)	QLD database
	%land that is developed open space		
	%land area that does not contain impervious surfaces		
	<b>Disaster frequency</b>		
	% three times flooded/flooded in 2011	Adapted from (Geis, 2000)	GSA database

QLD database: Queensland government online database- GSA database: Geo-Science Australia database- BCC database: Brisbane City Council database- DCS database: Department of Community Services database