IDENTIFYING AND VISUALISING RESILIENCE TO FLOODING VIA A COMPOSITE FLOODING DISASTER RESILIENCE INDEX

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Abstract

The measurement of a community's resilience to a natural hazard is critical to the disaster management field, as its identification can assist targeted social, political, technological and economic strategies to reduce vulnerability in hot spot areas. This paper details the development of a composite flooding disaster resilience index (FDRI) by aggregating individual resilience indicators under the social, natural, built and economic categories. Via the development of the FDRI, the resilience of communities to flooding within 16 municipalities across the Greater Amsterdam region has been quantified and assessed.

Application of the FDRI to the Greater Amsterdam region revealed the multifaceted nature of the components which contribute to resilience. Further, the comparison of individual attributes with those of the surrounding area and the overall index demonstrate the ability of different municipalities to withstand and recover from adverse events and climate extremes. Indicator selection and weighting factors have been developed via a consultative process with practitioners from the public and private sector in the Netherlands. The identification of comparative resilience levels is intended to drive relevant policy actions and may assist Government organisations in identifying priority areas across the Greater Amsterdam region.

The findings of this research provide a new approach to assessing and identifying the geospatial resilience of communities to natural hazards. Thus, the work presented herein has significant implications for future studies seeking to develop a system for assessing the resilience of communities to natural hazards. Moreover, this study sheds light on the application of a resilience index internationally, such as in Australia.

Background: Resilience & Vulnerability in the 21st Century

Climate Extremes

A growing population and rising climate extremes are placing significant pressure on nations worldwide. In Australia, natural disasters cause widespread disruption, costing the Australian economy an average of $6.3 billion per year. These costs are projected to rise incrementally to $23 billion by 2050 (Australian Business Roundtable, 2013).

The PBL Netherlands Environmental Assessment Agency suggests that climate changes will be more gradual in the Netherlands compared to other regions. However, the risk of flooding, drought and precipitation extremes is likely to intensify (PBL Netherlands EAA, 2012). Annual precipitation has increased by 20% over the last century in the Netherlands and heavy rainfall has become more frequent (PBL Netherlands EAA, 2012). It is thus imperative to develop approaches and tools to increase resilience in communities which face these challenges.

Resilience & Vulnerability

Resilience has become a focal point in recent years reaching “buzzword” status, yet as a consequence of its application within multiple fields, from psychology to engineering, no single widely accepted definition exists.

Orencio and Fujii, (2013) suggest that when faced with a natural hazard, resilient communities absorb stress through resistance or adaption, manage and maintain basic functions and can recover with specific behavioural strategies for risk reduction.

The inherent resilience of a community is intrinsically linked to the impact a natural hazard may have on a community. Within the literature, “vulnerability reflects the characteristics of a person or a group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a hazard.” (Disaster Risk Analysis, 2008, p3). Cutter et.al outlines resilience as a “process linking the myriad of adaptive capacities such as social capital and economic development to responses and changes after adverse events.” (Cutter et.al, 2010, p2).

In this case study application for the Greater Amsterdam region, resilience is considered to incorporate three key functions; coping capacity, damage potential and the ability of a community to “bounce back” from a stress or disturbance. These concepts have been reflected in the indicators selected within the resilience index utilised in this study.

Measurement of Resilience

Whilst a number of metrics, standards and indicators exist for gauging resilience, currently, no consensus exists on how to measure resilience (Béné, 2013).

An extensive literature review has identified groups of social, economic and demographic indicators that could potentially be used to categorise levels of community vulnerability or resilience. The Victorian Australian Government document; ‘Assessing Resilience and Vulnerability in the Context of Emergencies: Guidelines’ (2000) provides a list of characteristics of vulnerable groups and a list of factors which support resilience. The guidelines focus on a methodology to assess resilience and vulnerability and suggest that a multitude of data sources such as local experts, focus groups, census data, surveys, questionnaires, outreach programs and group surveys be used to acquire information.

Cutter et.al. (2010) focuses on resilience indicators and provides a set of indicators for measuring baseline characteristics of communities that foster resilience. Cutter’s list of disaster resilience indicators contains thirty-six variables from within the categories of social resilience, economic resilience, institutional resilience, infrastructural resilience and community capital and is to date the only single set of established indicators for quantifying disaster resilience within the literature on this topic. However, this research paper excludes ecological resilience in its formulation of indicators and therefore does not provide a completely holistic framework.

Kumpulainen (2006) establishes a list of possible indicators for measuring vulnerability. In this system, vulnerability is measured as a combination of coping capacity and damage potential. Coping capacity indicators measure the ability of the region or community to respond and prepare for a hazard, while damage potential indicators measure anything that can be damaged by a hazard (Kumpulainen, 2006), yet many of these indicators cannot be used due to a lack of data or due to difficulties in quantification. Using most of the indicators listed, Kumpulainen (2006) successfully produces an integrated vulnerability map of Europe for the ESPON hazards project. Yet it should be noted that the result does not take into account the specific impact of individual hazards and the system could be enhanced by examining damage potential on the different sectors of the economy.

Methodology: Application of a Composite Index

Use of a Composite Index

Composite indicators are widely agreed upon as significant tools in providing a holistic assessment. The vast literature on composite indicators contains many methodological approaches for index construction and most of the literature emphasises the need for a multi-step process of indicator construction. Davidson & Shah (1997) promote composite indexes as a useful tool to measure complex, multi-dimensional concepts that cannot be observed directly.

Schneiderbauer (2004) also advocates the use of composite indicators due to their ability to incorporate data from a range of fields and minimise measurement error. Moreover, the ability to synthesise a vast amount of diverse information into a simple, easily usable form has meant that indexes are widely used across many disciplines (Davidson & Shah, 1997). The plethora of existing indexes is acclaim to the usefulness of the composite index form (Cutter et.al, 2010).

What is the Flooding Disaster Resilience Index (FDRI)?

The Flooding Disaster Resilience Index (FDRI) is a single figure summarising a region's status on 11 indicators hypothesised to influence the resilience of a region to a natural hazard. The index allows comparisons of metropolitan regions to be made and thus relatively strong or vulnerable regions to be identified. The FDRI index can be summarised by Equation (1).

$$R = \sum_{C=S,N,B,E} \sum_{i=1}^{J} C_i \, x \, w_i^C \tag{1}$$

Where C represents the indicator category for the Social (S), Built (B), Natural (N) and Economic (E) environments, *i* represents the indicator and *J* represents the total number of indicators within the respective category *C*. W_i^C represents the weighting factor utilised for each indicator. Details for the complete list of indicators utilised in the index are listed in Table 1. The indicators are also visually depicted in the following schematic (Figure 1).

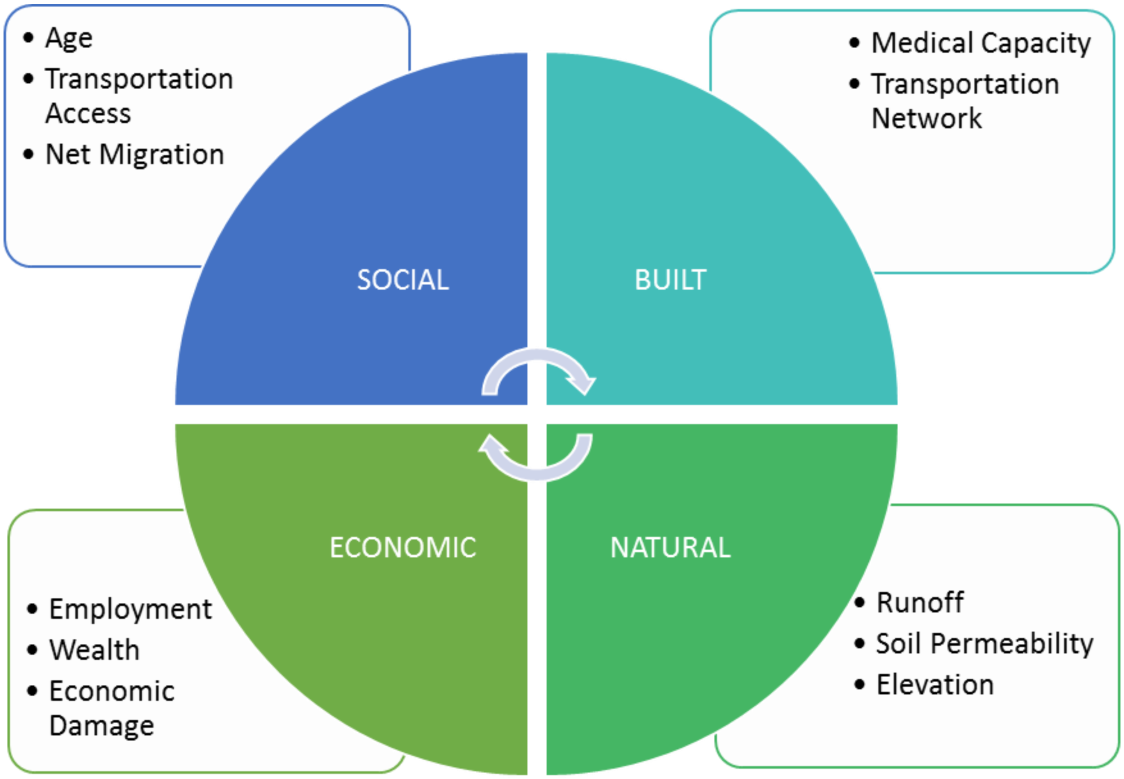


Figure 1: Indicators Utilised in the FDRI under the Social, Built, Natural & Economic Categories

Selected Indicators

All selected indicators have been grouped under one of the four resilience environments – social, built, natural or economic. The combination of these individual indicators with applied weighting factors comprises the composite FDRI. Table 1, below, details the complete list of indicators utilised in the FDRI for this case study application.

Table 1: Flooding Disaster Resilience Index (FDRI) Selected Indicators

Symbol	Category	Variable	Effect on Resilience	Justification	Weighting
S	***Social Environment***				
S_1	Age	Percent population aged 15 to 65	Positive	Morrow (2008)	$W_1^S = 11.41$
S_2	Transportation Access	Number of motor vehicles per person	Positive	Tierney (2009)	$W_2^S = 8.01$
S_3	Net Migration – Place Attachment	Percentage Net Migration	Negative	Morrow (2008)	$W_3^S = 6.03$
B	***Built Environment***				
B_1	Medical Capacity	Number of hospitals per 10000 people (within 20km)	Positive	Auf de Heide and Scanlon (2007)	$W_1^B = 9.05$
B_2	Transportation Network	Percent of total road length as highways	Positive	NRC (2006)	$W_2^B = 7.87$
N	***Natural Environment***				
N_1	Run-off	Quantified land zone use based off run off potential	Negative		$W_1^N = 6.86$
N_2	Soil Permeability	Quantification of soil types based off absorption	Positive		$W_2^N = 8.10$
N_3	Elevation (Via Water Level Map)	Scaled height above or below NAP	Negative		$W_3^N = 7.04$
E	***Economic Environment***				
E_1	Employment	Employees relative to population	Positive	Tierney et.al. 2001	$W_1^E = 9.61$
E_2	Wealth	Average household disposable income (€Euro)	Positive	Cutter et.al., 2010	$W_2^E = 11.48$
E_3	Economic Damage for Flood Volumes	Flooding economic damage indicator for 0.6m water level rise (€Euro/m^3)	Negative		$W_3^E = 14.25$

Determination of Weighting Factors

Weighting factors for each of the indicators were determined via a consultative process. A total of 18 flood experts from Waternet (Amsterdam office) and Royal HaskoningDHV (Rotterdam office) were surveyed. The participants were asked to rate the indicators within each category, with 1 being the indicator they perceived to have the highest correlation to resilience up to n (the lowest correlation with resilience), where n is the total number of indicators within the category. Each of the four categories (social, built, environmental and economic resilience) were then ranked, with 1 indicating the category with the highest significance to the concept of resilience, and 4 indicating the lowest importance to resilience. Each of the surveyed rankings for the indicators were then averaged to provide an overall averaged rank. The four categories were assigned weightings using the Rank Reciprocal Method (Buede, 2008) (Equation [2]).

$$wt_C = \frac{\frac{1}{r_{C,avg}}}{\sum_{C=S,B,N,E}\left(\frac{1}{r_{C,avg}}\right)} \qquad \textbf{[2]}$$

Where $r_{C,\mathrm{avg}}$ represents the average rank of category C, and *C* represents each of the four indicator categories including social (S), built (B), natural (N) and economic (E) environments. As the built environment category had two indicators while each of the other categories had 3 indicators, the rankings assigned in the built environment category were altered such that the ranks of 1 and 2 were assigned a value of 1.5 and 2.5 respectively. This ensured the average of potential ranks for each of the categories remained the same and the index would not be naturally biased towards the built environment category. To determine the weighting of individual indicators (wti), the reciprocal ranking procedure was then reapplied using equation [3] below.

$$wt_i = \frac{\frac{1}{r_{i,avg} \times r_{c,i,avg}}}{\sum_{i=1}^{11}\left(\frac{1}{r_{i,avg} \times r_{c,i,avg}}\right)} \qquad \textbf{[3]}$$

Where $\mathrm{r}_{\mathrm{i,avg}}$ represents the average ranking of indicator i, and $\mathrm{r}_{\mathrm{c,i,avg}}$ represents the average ranking of the category containing indicator i..

Normalisation & Scaling of Indicators

Before computing the FDRI output, for each identified indicator the input must be converted into a normalised dimensionless number on a scale from 0 to 1. This dimensionless number is derived using the predefined minimum and maximum values from the spatial elements under consideration. Thus the final FDRI output is a value between 0 and 1. For indicators with a positive correlation with resilience, Equation [4] has been applied for normalisation. For indicators with a negative correlation with resilience, Equation [5] has been applied for normalisation.

$$NVi = \frac{RVi - Min_{i=1,n}(RVI_i)}{Max_{i=1,n}(RVI_i) - Min_{i=1,n}(RVI_i)} \qquad \textbf{[4]}$$

$$NVi = \frac{Max_{i=1,n}(RVI_i) - RVi}{Max_{i=1,n}(RVI_i) - Min_{i=1,n}(RVI_i)} \qquad \textbf{[5]}$$

where NVi represents the normalised value of the indicator *I*, RVi represents the real value of the indicator *I*, $Max_{i=1,n}(RVI_i)$ represents the maximum value from a set of *n* computed real values of the indicator *I* and $Min_{i=1,n}(RVI_i)$ represents the minimum value from a set of *n* computed real values of the indicator *I*, where *n* is the number of spatial elements under consideration.

Visualisation Via GIS Mapping

To apply the FDRI to the selected case study region, the FDRI was calculated via both the normalised indicator scores and the weighting factors (refer to Equation (1)) and visualised via GIS mapping software (ArcGIS) for 16 municipalities in the Greater Amsterdam region. Data was obtained for each of the selected indicators via the Centraal Bureau voor de Statistiek (CBS) and via Waternet (Amsterdam office) ArcGIS layers provided. ArcGIS VB scripts were used to quantify the runoff potential, soil permeability and economic damage indicators from a categorical value to a numerical value and a colour ramp was applied for the FDRI calculation using a total of 32 classes and a graduated colour scheme from red (least resilient) to green (most resilient).

Results: Visualisation of Resilience via ArcGIS

The overall output from the FDRI for the 16 municipalities in the Greater Amsterdam region is depicted in Figure 2 below, with green corresponding to regions of comparatively higher resilience to a flood.

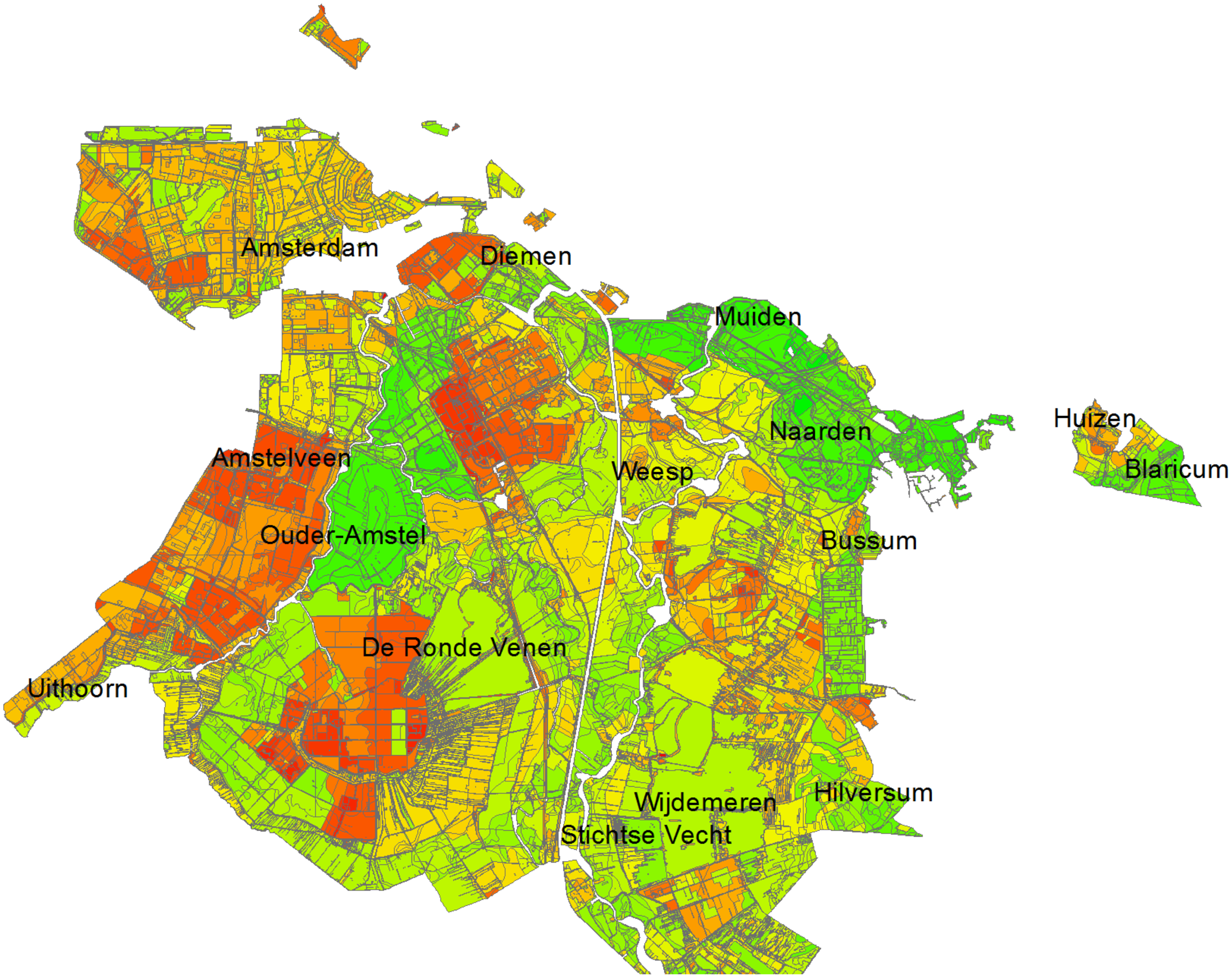
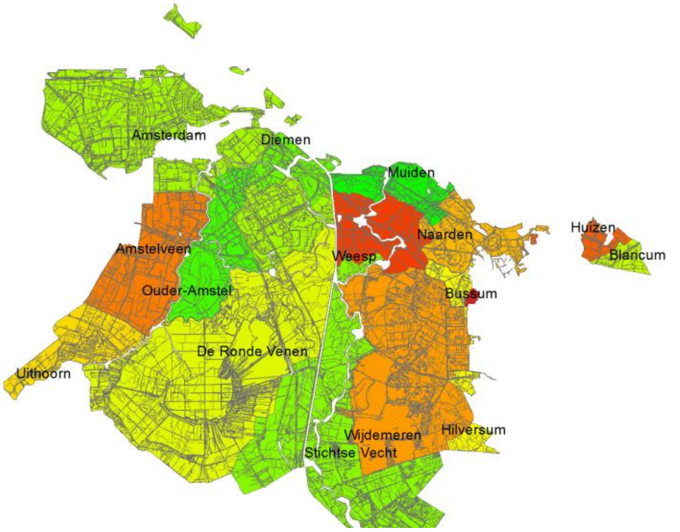
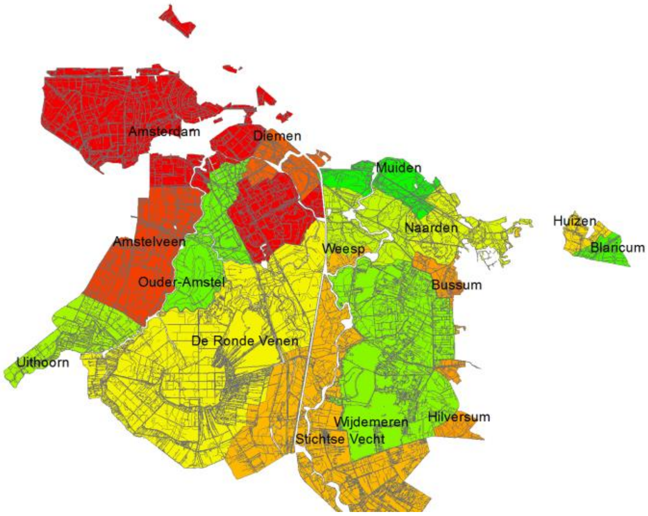
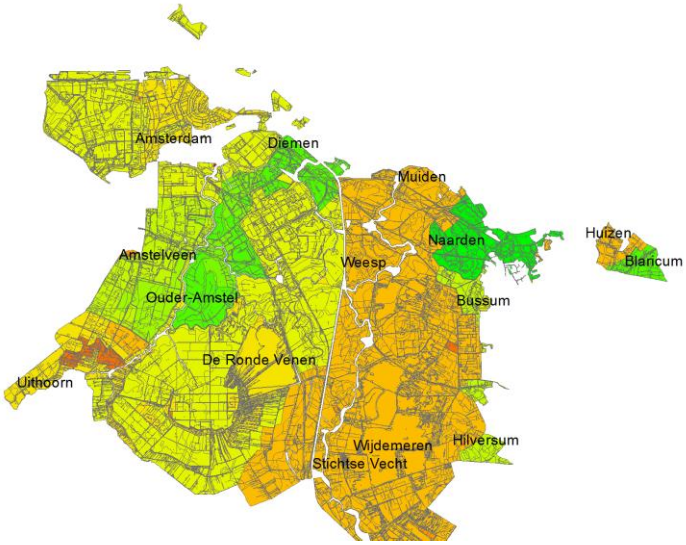
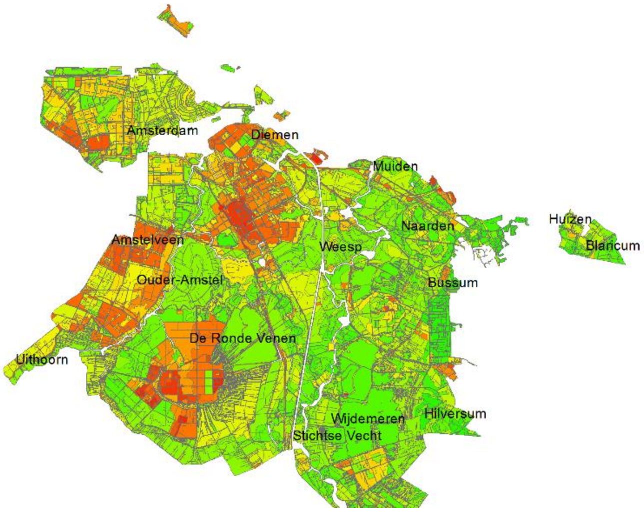


Figure 2: Overall FDRI Output for the Greater Amsterdam Region

SOCIAL ENVIRONMENT	BUILT ENVIRONMENT
 Figure 3: Resilience in the social environment for the Greater Amsterdam Region	 Figure 4: Resilience in the built environment for the Greater Amsterdam Region
ECONOMIC ENVIRONMENT	NATURAL ENVIRONMENT
 Figure 5: Resilience in the economic environment for the Greater Amsterdam Region	 Figure 6: Resilience in the natural environment for the Greater Amsterdam Region

Discussion

Identification of Vulnerabilities

The FDRI visually identifies spatial regions which are comparatively more or less resilient across the four resilience environments. Analysing the FDRI variations between regions, both overall and within the different indicator environments, provides a broad holistic view of a regions strengths and weaknesses in relation to flood vulnerability. Visual analysis revealed that no individual municipality performs strongly in all of the 11 indicators selected, and likewise, no municipality performs weakly across all indicators. Overall, the regions of Naarden, Muiden, Blaricum and Hilversum were revealed to be more resilient to a potential flooding event. Contrasting this, the regions of Amstelveen, Amsterdam and Uithoorn were revealed to be areas of potentially higher vulnerability.

Utilisation of the FDRI

Building climate resilience is a multifaceted process which requires interaction between an array of bodies including individuals, community organisations, governments at local, state and national levels, corporations and international organisations. Thus a resilience index can be considered as a tool which can be used by a variety of stakeholders to improve resilience in any location worldwide.

By visualizing the FDRI via GIS, there is an opportunity to track the resilience index output (overall & subcategories) over time within specific geographic areas. Correlation of these changes with other initiatives, for example to the execution of new policy initiatives, or the rollout of new planning schemes, could be used as a proxy for the success of these initiatives in influencing adaptive capacity.

Through the identification of the most vulnerable areas to natural hazards, this index could also be used as a factor in the consideration of the allocation of financial spending on disaster mitigation. Financial spending on disaster mitigation measures thus could be more effectively targeted to the most vulnerable areas.

Limitations of the FDRI

The index is considered to be a useful tool for comparison purposes, however it does not provide a standalone measure for consideration. The adaption of the index to suit a particular purpose allows for greater detail and segregation between different geographic locations, however it also limits the comparative capabilities on a larger scale. To facilitate global comparison of resilience, data would be required in the same format for all regions to be studied, however in current practice this is not readily available.

The index in its current state also does not consider the risk or likelihood of a particular area experiencing a flood, however the focus is placed on the damage potential and the ability of communities to respond in the event of a flood. As this is a major limitation of the index, the FDRI is designed to be used in conjunction with existing tools and metrics, including risk analyses and flood protection ratings, to give a more thorough overview and holistic approach to flood management.

Further, the lack of an indicator directly assessing the level of community preparedness is a potential weakness in the FDRI assessment of resilience. An indicator gauging peoples' recognition, recall and actions to define a measure of natural disaster preparedness could be an important addition to the social resilience environment.

Whilst there is an inherent level of uncertainty in the FDRI, its use in operational flood risk management presents a useful tool for policy and decision makers to prioritise investments and formulate adaption plans.

Conclusion

Within the context of increasing climate extremes, it is imperative to develop approaches and tools to increase the resilience of communities which face these challenges. This paper detailed the development of a composite flooding disaster resilience index (FDRI) by aggregating individual resilience indicators under the social, natural, built and economic categories. Via the development of the FDRI, the resilience of communities to flooding within 16 municipalities across the Greater Amsterdam region has been quantified and assessed.

The identification of comparative resilience levels is intended to drive relevant policy actions and may assist Government organizations in identifying priority areas across the Greater Amsterdam region. Enhancement of the FDRI may be possible via the incorporation of a community preparedness factor and an assessment of the likelihood of a flood event to provide a more holistic approach to flood management.

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