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Vulnerability Modelling to Improve Assessment Process on Community Vulnerability

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Abstract

Most vulnerability assessment is conducted by assessing geographical areas based on their vulnerability levels with the aim of using those results for applied public policies on disaster risk management (DRM). This assessment process has been criticised as an oversimplification and because it fails to integrate vulnerability with other DRM concepts. This paper discusses the limitations of current approaches to vulnerability assessment and identifies key directions for a future research agenda to support better assessment processes at the community scale. To date, vulnerability assessment has failed to recognise the dynamic and systemic character of community vulnerability and the importance of integrating concepts of vulnerability, resilience and adaptation within the assessment process. This means it is inadequate for the purpose of assessing future vulnerability using quantitative modelling. In consequence, public policy often relies solely on assessments of current vulnerability levels for decision-making. This paper argues the need for an assessment process using vulnerability modelling. Modelling is able to emphasise characteristics of community vulnerability, assess future vulnerability, and quantitatively evaluate adaptations for specific scenarios. It integrates vulnerability with the related concepts of resilience and adaptation. As a result, this type of assessment offers a better framework for supporting more proactive public policies to reduce community vulnerability to disaster.

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1. Introduction

As an integral part of disaster risk management (DRM), the vulnerability concept has a major role to play in enhancing community capacity to respond to a particular hazard. Appreciation of the importance of DRM has increased greatly due to significant losses from disastrous events such as the Southeast Asia Tsunami 2004, the Haiti earthquake 2010 and Pakistan floods in 2010. Understanding of the concept has developed significantly since its early development in the 1980s (Gabor & Griffith, 1980) based on demography and geography perspectives. It is now a multidisciplinary approach (Marandola & Hogan, 2006); however, the vulnerability concept is still underdeveloped in certain respects, particularly in relation to assessment processes (Cutter, 1996; Adger et al., 2004; Adger, 2006; Rygel et al., 2006; Barnett et al., 2008). Much research on vulnerability has focused on mapping regions and communities that are highly vulnerable to disasters, however this approach fails to account for the dynamic and systemic characteristics of ‘community’. Some critics have argued the need to expand vulnerability research beyond the assessment of the level of vulnerability in a particular case study or region to develop predictive tools to inform policy and planning (Adger et al., 2004; Adger, 2006; Nicholls et al., 2008). However such tools require further clarification of the vulnerability concept in DRM. The review of vulnerability literature provided here aims to clarify the concept and identify key directions for a future research agenda to support more predictive assessment processes at the community scale.

2. Methods

A thematic literature review is employed to emphasize the complexity of the vulnerability literature and examine how vulnerability is understood within different bodies of research, particularly in the literature on vulnerability, resilience, and adaptation. Through this process, key dimensions of vulnerability are identified and significant gaps in current understanding of the concept are highlighted in order to suggest guidelines for a future research agenda.

In identifying the gaps in vulnerability assessment and modelling, vulnerability research has been assessed for its strengths and weaknesses based on the six themes identified in Figure 1. The discussion of gaps in the vulnerability literature draws on approaches such as single and multidiscipline, single and multi hazards and before or after disaster events. Then, the discussion also continues to integrate it with other concepts beyond vulnerability such as resilience, adaptation and social capital. Afterwards, the vulnerability literature gaps are grouped in terms of their value for developing assessment processes and further research relevant to scenario modelling. Finally, some suggestions are made based on the gaps to propose a new framework for future vulnerability assessment and modelling research.

3. Findings and Discussion

3.1. Framing Vulnerability Assessment

Equations and formulae should be typed in MathType, and numbered consecutively with Arabic numerals in parentheses on the right hand side of the page (if referred to explicitly in the text). They should also be separated from the surrounding text by one space.

Since the early 1980s, the concept of vulnerability has been discussed across many disciplines, including demography, geography, human ecology, economics, anthropology and psychology (Hogan & Marandola, 2006; Adger, 2006). It has been approached from both natural science perspectives (such as engineering and natural processes) and social science perspectives (Robert et al., 2009). Table 1 presents a range of perspectives, which are relevant in framing research on vulnerability assessment.

<table>
<thead>
<tr>
<th>Perspective on vulnerability</th>
<th>References</th>
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<tbody>
<tr>
<td>Demography</td>
<td>Armas (2008).</td>
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</table>
Clarity on the vulnerability concept is important as there have been different interpretations of some of its basic terminology between researchers working in different disciplinary traditions (Cutter 1996; Weichselgartner 2001). Adger (2006) argues that the variety of vulnerability interpretations indicate the importance of the concept across different disciplines and consequently should be understood as a strength rather than a weakness. However, greater definitional clarity is needed to progress research in areas requiring systemic approaches such as vulnerability assessment (Cannon, 2008; Ionescu et al. 2009), a key concern of this paper.

The concept of vulnerability is multi-layered as it includes the responses of individuals, groups of individuals and social networks to hazards. Adger & Kelly (1999) suggest that the vulnerability level reflects the state or situation of the individuals, groups or communities affected by a disaster. Moreover, Dwyer et al. (2004); Villagran de Leon (2006) suggest a broader range of research subject matter for vulnerability studies drawing on the terminology of human communities. In fact, vulnerability research has been focused on assessing individual’s and groups of individuals’ responses to any hazards (e.g. Odeh 2002; Armas 2008). Therefore, any vulnerability assessment should extend beyond individuals to larger groups of people. The larger groups of people should include groups of people within the community and also the relation between groups within and outside of the community (community network) that are stressed in the social capital literature (e.g. Putnam 2000; Woolcock & Narayan 2000; Reimer et al. 2008; Wagner & Fernandez-Gimenez 2008).

Since community is a central concern in much vulnerability literature, consideration of dynamic-systemic community characteristics is important. Bankoff et al. (2004) suggest that communities are dynamic and systemic entities. Dynamic means that characteristics may change when there is a change in specific factors over time, while systemic means all the subsystems within a community (factors) are interlinked and interact in influencing the final vulnerability level. Research by Cutter & Finch (2008) predicts future vulnerability levels based on the dynamic aspects of community vulnerability, as the level is changing from time to time, while other researchers have focused on the effect of dynamic vulnerability factors on the current vulnerability level (e.g. Odeh 2002; Armas 2008; Marfai & King 2008;). In addition, Gillespie et al. (1993) has approached the systemic aspect of community by examining the network of organizations contributing to community disaster preparedness.

Considering the points outlined above, any assessment of vulnerability should begin with clarification of terms and definitions. Since there is no universally accepted definition of vulnerability, vulnerability within this paper will be defined as: the dynamic and systemic performances of community capacities to cope with specific hazards in time and space. This definition is drawn from the dimensions discussed above that are summarised in Table 2.

<table>
<thead>
<tr>
<th>Dimensions Of Vulnerability</th>
<th>Supporting Literature</th>
</tr>
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<tbody>
<tr>
<td>Focuses on specific communities that are exposed to certain hazards (context specific).</td>
<td>Cutter et al. 2003; Schroeter et al. 2005; Brenkert &amp; Malone 2005; Messner &amp; Meyer 2006; Sharma &amp; Patwardhan 2008; Preston et al. 2008.</td>
</tr>
<tr>
<td>Covers three levels of society - individuals, groups of people and social networks - associated with a specific community.</td>
<td>Adger &amp; Kelly 1999; Dwyer et al. 2004; Villagran de Leon 2006; Carina &amp; Keskitalo 2009 urge on a need broader context of subject while Putnam 2000; Woolcock &amp; Narayan 2000 stress a power of social network in community.</td>
</tr>
<tr>
<td>Vulnerability also reflects the community’s capacity to reduce the impacts of certain hazards. This capacity can</td>
<td>Dow 1992; Adger &amp; Kelly 1999; Downing et al. 2001; Dwyer et al. 2004; Piitilakis et al. 2006; Villagran de Leon 2006; Armas</td>
</tr>
</tbody>
</table>
reduce the current vulnerability level, leading to lower future vulnerability levels. 2008.

The level of a community’s vulnerability changes as a consequence of dynamic and systemic interaction among factors as a consequence of community characteristics. Gillespie et al. 1993; Odeh 2002; Bankoff et al. 2004; Cutter & Finch 2008; Armas 2008; Marfai & King 2008.

3.2. Vulnerability Assessments: Gaps in the Literature

While various authors have assessed the level of vulnerability based on a range of factors, the basis they use for choosing these factors is often not clearly described (first gap). Furthermore, the selection of factors is rarely linked to the characteristics or dimensions of community vulnerability. This problem is highlighted by Alwang et al. (2001); Adger et al. (2004); Downing & Patwardhan (2004) who argue the need for clearer elaboration of the factor selection process. Even though some research has considered vulnerability factors from a range of disciplinary perspectives, the selected factors have a weak correlation with the core characteristics of the vulnerability definition as outlined in Table 2 (e.g. Armas 2008; Odeh 2008). Therefore, linking these dimensions of vulnerability to the factor selection process is important.

There is a need to assess the effectiveness of adaptations in reducing vulnerability, preferably using quantitative approaches that evaluate different scenarios. To accommodate a quantitative approach, vulnerability needs to be specified into several measurable indicators, such as in Brenkert & Malone (2005); Armas (2008). The indicators are a set of subcomponents which reflect vulnerability performance within a community. The indicators are different to vulnerability factors which represent the causes of vulnerability for a community. Future research should focus on scenario modelling to identify the most effective adaptation measures to reduce future vulnerability to disasters.

3.3. Bridging the Literature Gaps in Reducing Future Vulnerability Level

The gap is in clearly identifying the dimensions of vulnerability and how aspects of the community context should inform the factor selection process. The process of selecting relevant factors can begin by making a long-list of factors from previous relevant research. Afterwards, the factors can be grouped based on different social scales from individuals to community a larger group and a multidisciplinary approach then used to assess their relevance to a specific case study location. The result can be a short-list of preliminary vulnerability factors (e.g. disadvantaged people, emergency facilities and utilities, external support and number of residents). Finally, the preliminary factors should be verified by some key stakeholders using a delphi process or focus group discussion to select the relevant final factors for vulnerability assessment in each case study. This verification is important to ensure the context specific value of vulnerability assessment.

Fig. 1. Integration of the vulnerability concept with the concepts of adaptation and resilience
The lack of consideration of two-way influences on vulnerability factors, can be represented as a process of adding or overlaying various vulnerability factors as independent variables (vulnerability factors) which influence dependent variables (vulnerability level or indicators) as shown in Figure 1.

In Section B, one of the vulnerability dimensions identified was a dynamic-systemic situation that should be reflected in the interactions among factors, adaptations and indicators. Therefore, the interaction cannot be as in Figure 2, but it should reflect dynamic and systemic situation as illustrated in Figure 5 below. In responding to these community characteristics, a dynamic system analysis can be utilized to model or simplify the community dynamic and represent systemic relationships among factors, adaptations and indicators (Sterman 2001). Moreover, in predicting levels of vulnerability, the analysis can also run certain models (based on some scenarios of adaptation) to produce various future vulnerability levels.

Since there are then some predicted levels for future vulnerability, comparison among them responds to the fifth gap, the need for assessments to evaluate the effectiveness of adaptations. The quantitative approach in dynamic system analysis could give a ranking system based on these comparisons. The rank will sort the future levels from highest to the lowest. Therefore, the most effective adaptation can be distinguished from the lowest future vulnerability level after applying certain scenarios through the modelling process. This selection process can provide a rationale for policy-making.

The number of victims, damage losses and the period of time for recovery can be utilized to respond to the last (sixth) gap around the need for measurable vulnerability indicators. Number of victims and damage losses indicators can be seen as various applications of impact assessment post hazard events. Those two kinds of valuation can also represent the vulnerability level based on the assumption of the hazards as a given variable (constant). Moreover, the period of time is drawn from the concept of resilience (the ability of community to “bounce back” (recover) after an event as in Mileti & Peek 2002; Paton et al. 2003 cited in Ronan & Johnston 2005). Those three kinds of measurements can also be set as major step to prepare a community facing negative events, as suggested by Ronan.
and Johnston (2005). Preparation itself can be made by taking adaptations to reduce the possibility of fatalities, damage losses and a long period of recovery.

In Summary, some points for a proposed vulnerability research framework are set out in Table 3 below. These points can provide a rational basis for proposing vulnerability modelling using a system dynamic analysis.

Table 3. Literature Gaps and Basic Principles for Future Research

<table>
<thead>
<tr>
<th>No</th>
<th>Previous Research Results</th>
<th>Literature Gaps</th>
<th>Basic Principles For Future Research</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Vulnerability factors have been discussed widely (e.g. Odeh 2002; Armas 2008).</td>
<td>A need for clarity about the process for vulnerability factor selection explaining its dimensions (e.g. Alwang et al. 2001; Adger et al. 2004; Downing &amp; Patwardhan 2004).</td>
<td>Factor selection should reflect the three layers of society, specific context and multidisciplinary approach.</td>
</tr>
<tr>
<td>2</td>
<td>Vulnerability research often finishes with the assessing vulnerability levels (e.g. Gabor &amp; Griffith 1980; Odeh 2002; Rygel et al. 2006; Armas 2008).</td>
<td>There is urgency in integrating between discussing causal vulnerability factors and stakeholders actions in vulnerability assessment process.</td>
<td>The assessment process can also be expanded from assessing the levels to evaluating critical factors and stakeholders’ actions.</td>
</tr>
<tr>
<td>3</td>
<td>Factor interaction occurs in overlaying/addition process to find final level (e.g. Gabor &amp; Griffith 1980; Odeh 2002; Rygel et al. 2006 and Armas 2008).</td>
<td>The factors are interdependent and interact to reflect dynamic and systemic characteristics.</td>
<td>The use of system dynamic analysis can represent dynamic and systemic community characteristics.</td>
</tr>
<tr>
<td>4</td>
<td>Research focus on current vulnerability level (e.g. Clark et al. 1998; Odeh 2002; Armas 2008). Conversely, Little research attempts to predict future vulnerability levels (such as in; Marfai &amp; King 2008; Cutter &amp; Finch 2008; Nicholls et al. 2008).</td>
<td>A need to expand the analysis to future vulnerability and connect it with other concepts within DRM. A need to accommodate core characteristics of community when expanding vulnerability research.</td>
<td>Discussing the difference between current and future vulnerability levels links vulnerability with concepts of resilience and adaptation. Moreover, linking those concepts should accommodate the dynamic and systemic characteristics of community.</td>
</tr>
<tr>
<td>5</td>
<td>Research focus on assessing vulnerability levels (e.g. Gabor &amp; Griffith 1980; Odeh 2002; Brenkert &amp; Malone 2005; Rygel et al. 2006; Armas 2008; Preston et al. 2008).</td>
<td>The research can be expanded to evaluation of adaptation (Adger et al. 2004)</td>
<td>Linking the concepts of vulnerability, resilience, and adaptation can help to direct adaptation evaluation.</td>
</tr>
<tr>
<td>6</td>
<td>Little research uses vulnerability indicators to specify the broad concept of vulnerability (e.g. Brenkert &amp; Malone 2005; Armas 2008).</td>
<td>The specification of vulnerability indicators should be designed to highlight the results of adaptation measures.</td>
<td>Effective adaptation can be revealed by the number of victims, damage losses and recovery process.</td>
</tr>
</tbody>
</table>

3.4. Conclusion

This paper identifies gaps in the vulnerability literature and presents an approach to respond to these gaps, specifically from the perspective of improving systematic assessment processes. Since the vulnerability concept draws from a range of disciplines and there are diverse definitions, the dimensions of vulnerability were clarified first, then utilized as one of the criteria for analysing the gaps in the literature. A wide range of literature within and beyond vulnerability was then reviewed, particularly that which engages with concepts of resilience, adaptation and community in the context of vulnerability to disasters. The major gaps identified in the literature provide a basis for framing a future research agenda.

Based on these gaps, the following three main areas are proposed for future research in vulnerability modelling:

- The modelling should consider all community layers (individual, groups of people and social networks) and should focus on community case studies where vulnerability dimensions can be characterised at the community scale. It is a reflection of vulnerability dimensions.
- The context specified dimension of vulnerability modelling outlined in the first point is particularly important for selecting relevant factors and identifying interactions among them. The selection process should reflect the layers of community and be context specific in terms of hazard type, while the interaction should reflect...
the dynamic and systemic nature of the community. The end result of modelling should go beyond assessment of existing vulnerability levels to develop predictive capacity. This requires capacity to evaluate scenarios of adaptation to provide a predictive tool for reducing the level of future vulnerability.

- In responding to the last group of gaps on further developing vulnerability research, a dynamic system analysis can accommodate the issues raised in this group as well as the first and second points above. A quantitative evaluation process using dynamic system analysis can simulate several adaptation scenarios through a modelling process. By comparing the output of vulnerability modelling (future vulnerability levels) for the different adaptation scenarios the most effective adaptation scenario to reduce future vulnerability can be determined.

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