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Assessment of composite index methods for agricultural vulnerability to climate change

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ABSTRACT

A common way of quantifying and communicating climate vulnerability is to calculate composite indices from indicators, visualizing these as maps. Inherent methodological uncertainties in vulnerability assessments, however, require greater attention. This study examines Swedish agricultural vulnerability to climate change, the aim being to review various indicator approaches for assessing agricultural vulnerability to climate change and to evaluate differences in climate vulnerability depending on the weighting and summarizing methods. The reviewed methods are evaluated by being tested at the municipal level. Three weighting and summarizing methods, representative of climate vulnerability indices in general, are analysed. The results indicate that 34 of 36 method combinations differ significantly from each other. We argue that representing agricultural vulnerability in a single composite index might be insufficient to guide climate adaptation. We emphasize the need for further research into how to measure and visualize agricultural vulnerability and into how to communicate uncertainties in both data and methods.

1. Introduction

A broader understanding of the influences of climate change and variability on social and environmental systems requires identification and evaluation of options for responding to and coping with potential impacts. The “vulnerability” concept – often used when discussing these challenges – has emerged as a central concept of research into climate and environmental change (Janssen et al., 2006). Vulnerability is an inclusive concept and therefore appealing to use, although this inclusiveness makes it complex (Polsky et al., 2007). It has repeatedly been demonstrated that there are many definitions, interpretations, and attempts to identify and conceptualize vulnerability (e.g., Adger, 2006; O'Brien et al., 2007; Soares et al., 2012). The lack of consensus regarding definitions and interpretations has resulted in various approaches to performing vulnerability assessments, both quantitative and qualitative.

One, and probably the most common, quantitative vulnerability assessment method is the employment of a composite index comprising a set of indicators. These indicators represent the vulnerability of a studied system and are mathematically combined into a single composite index (Adger et al., 2004). This indicator approach makes it possible to capture the multiple dimensions of vulnerability, which cannot be described by a single indicator (Nardo et al., 2008). This type of index is suitable for climate vulnerability as it can include both the biophysical and socioeconomic dimensions commonly used to describe vulnerability (e.g., Eakin and Luers, 2006; Füssel and Klein, 2006). Soares et al. (2012) affirm the integration of both dimensions when assessing vulnerability as the current paradigm in climate change vulnerability research. It has been claimed that a composite index may be easier to interpret than trends of single indicators (Saisana et al., 2002) and may facilitate communication with the general public, enabling users to compare complex dimensions (Nardo et al., 2008). Composite indices may, however, invite simplistic policy conclusions if they address only the “big picture” and ignore specific indicators (Saisana et al., 2002).

The process of selecting indicators, weights, and summarizing methods when constructing a composite index includes several judgement stages. Indicator selection is generally based on either a theoretical understanding of relationships (a deductive approach) or on statistical relationships (an inductive approach) (Adger et al.,

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2004). It has been argued, however, that many vulnerability studies simply use pre-existing indicators (Eriksen and Kelly, 2007). Others have emphasized the importance of contextualizing the indicator (Holand et al., 2011; Holand and Lujala, 2012). The arbitrary choice of equal weights is arguably too subjective, while the use of expert judgement can involve complications in reaching agreement among expert members (Gbetibouo et al., 2010), complications that could result, for example, in disputes between stakeholders from different regions or groups (Nardo et al., 2008). In addition to these two weighting techniques, statistical methods such as principal component analysis (PCA) can be used to assign weights to indicators (e.g., Cutter and Finch, 2008; Deressa et al., 2008; Thornton et al., 2008). Besides selecting and weighting indicators, there are various methodologies for mathematically summarizing indicators into single indices.

Quantitative vulnerability assessments are often mapped or displayed as geographic visual representations (e.g., Hameed et al., 2013; Rød et al., 2012). Geographic visualization facilitates the exploration of complex spatial and temporal aspects of continuously changing multidimensional phenomena (Harrower et al., 2000); it also facilitates the communication of complexity, which is a key to reducing vulnerability (Preston et al., 2011). Despite its benefits, vulnerability mapping entails challenges that demand the critical evaluation of both its conceptual and technical practice. Combining several types of information into a single vulnerability map can hide important underlying information regarding why a system is vulnerable and what it is vulnerable to (Preston et al., 2011). Preston et al. (2011) stress that there is a tendency to neglect uncertainty in vulnerability assessments: “as different methods of constructing indices can yield highly divergent maps of vulnerability … some assessment of the sensitivity of the distribution of vulnerability to methods is warranted” (p. 191).

The aim of this study is to review indicator approaches for assessing agricultural vulnerability to climate change and to evaluate how the outcomes of climate vulnerability assessments differ as a result of varying weighting and summarizing methods. The reviewed methods are evaluated by being tested at the municipal level in Sweden. We are aware of a few studies that have performed sensitivity analyses of vulnerability indices (e.g., Jones and Andrey, 2007; Monterroso et al., 2012; Schmidtlein et al., 2008). In contrast to those studies, we use regression analysis to identify systematic differences between methods that cannot be identified using correlation analysis. Moreover, the focus on Swedish agriculture provides additional value for research into the future adaptation of Swedish agriculture.

Climate has direct and indirect impacts on many aspects of agriculture. Changing crop yields and suitability are aspects that have been extensively explored in Europe, with significant regional variation (Olesen and Bindi, 2002; Iglesias et al., 2012). Increased crop yield potential (Ewert et al., 2005; Olesen and Bindi, 2002), increased cropping areas (Trnka et al., 2011), and the introduction of new species (Tuck et al., 2006) are projected for Northern European agriculture. These opportunities could be limited by, for example, increased occurrence of plant pests (Jordbruksverket, 2012), more frost damage due to more freeze–thaw events (Høglind et al., 2007), and increased harvest loss due to greater weather variation and a higher frequency of extreme weather events (Kvalvik et al., 2011). Climate change and variability can therefore lead to higher variability in crop performance if no adaptation strategies are developed. This emphasizes the need also to consider adaptation to the positive effects of climate change on agriculture. For example, new varieties or species may need to be cultivated and more fertilizer might have to be added to the soil to facilitate the projected opportunities (Olesen et al., 2011). Research into the climate vulnerability of agriculture in the Nordic region is needed just as it is in regions where adverse effects are anticipated.

This article proceeds as follows. First, we review indices of agricultural vulnerability to climate change, classifying their constituent indicators as exposure, sensitivity, and adaptive capacity indicators. Thereafter, we describe reviewed methods and apply them at the municipal level in Sweden. Next, the data material is presented followed by methods used to analyse and compare the methods. Finally, the nine indices are presented in visualizations and comparative statistics, and then discussed.

2. Review of indicators and indices

Numerous climate vulnerability indices on different regional scales categorize areas in terms of their social and/or biophysical vulnerability to climate change-related stressors (e.g., Bjarnadottir et al., 2011; Rød et al., 2012; Brooks et al., 2005; Sullivan and Meigh, 2005; Thornton et al., 2006). Quantitative vulnerability assessments addressing agriculture involve, for example, assessments focussing on specific climate events, such as droughts (Ma et al., 2007), specific farmer groups (Zarafshani et al., 2012), or crop production (Xu et al., 2012; Simelton et al., 2012). Furthermore, the climate vulnerability of agriculture is closely linked to studies of climate-induced changes in crop yield (e.g., Fischer et al., 2002; Lobell et al., 2011; Trnka et al., 2011).

This study reviews indices treating agriculture as the vulnerable system with climate change as the stressor. It is limited to indices that take account of the socioeconomic and biophysical dimensions of vulnerability and use an indicator approach to create a composite index. Three scientific studies fulfilled these criteria: those of Gbetibouo et al. (2010), O'Brien et al. (2004), and Ravindranath et al. (2011). The spatial scales were India in O'Brien et al.'s (2004) and Ravindranath et al.'s (2011) studies and South Africa in Gbetibouo et al.'s (2010). As our study aims to test composite index methods using Sweden as a case, the grey literature on the Nordic region in particular was also searched. Carter et al. (2010) present a project report on a web-based vulnerability mapping tool for Nordic agriculture based on the method presented by O'Brien et al. (2003). The indicators used in this vulnerability mapping tool provide additional information for the present study. Although this study concentrates on Swedish agriculture, the reviewed methods are representative of vulnerability indices for human–environmental systems in general.

2.1. Indicators

An index is a weighted linear combination of indicators. All reviewed indices use the IPCC (2007) definition[1] of vulnerability for their assessments, though they appear to apply different interpretations of vulnerability and its components exposure, sensitivity, and adaptive capacity. The indices use these components to classify their indicators. Some indicators are used in more than one index, so the different interpretations of the vulnerability components have resulted in indicators being differently categorized for different indices. For example, Gbetibouo et al. (2010) categorize the “amount of irrigated land” and “soil degradation” as indicators of sensitivity, while O'Brien et al. (2004) categorize them as indicators of adaptive capacity.

We use the indicators of the reviewed indices in evaluating

[1] “Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC, 2007, p. 883).