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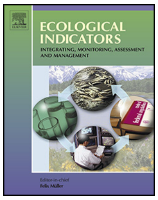

Piloting a social-ecological index for measuring flood resilience: A composite index approach

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ABSTRACT

Global increases in the magnitude and frequency of flood events have raised concerns that traditional flood management approaches may not be sufficient to deal with future uncertainties. There is a need to move towards approaches that manage the resilience of the system to floods by understanding and managing drivers of vulnerability and adaptive capacity. Here we pilot an approach to measure the resilience of a system to a flood. A method is presented in which indicators are used to measure and map the spatial distribution of the levels of flood resilience across a landscape. Using three flood affected municipalities in South Africa, 24 resilience indicators related to floods and its relevant social, ecological, infrastructural and economic aspects are selected, and integrated into a composite index using a principal components analysis (PCA). A fifth component of institutional resilience is used to explore levels of disaster planning, mitigation and public awareness capacities and where these can be increased. The PCA transformed the 24 variables into four main components, the first of which was strongly correlated with underlying social variables, while the second and third correlated well with economic and ecological variables respectively. Distinct spatial variation of flood resilience was found across the study area, with highest flood resilience in main cities, and lowest in wards located on the periphery of cities often the location of peri-urban informal settlements. The disaggregation of underlying indicators showed wards with lowest flood resilience also had the lowest social, economic and ecological resilience. The flood resilience index was sensitive to the exclusion of all three components highlighting the importance of capturing the multidimensionality of flood resilience. The approach allows for a simple, yet robust index able to include an array of datasets generally available in flood prone areas with potential to disaggregate and trace variables for management and decision making.

1. Introduction

Increases in extreme weather events combined with expanding urban populations are leading to progressively more vulnerable people and assets. High population densities, lack of urban infrastructure, ubiquitous informal settlements and urban sprawl to marginal areas mean that cities in developing countries are particularly exposed to climate change-induced disasters like floods, sea storms and wildfires (Pelling and Özerdem, 2002; Thakur et al., 2011). Studies on the impacts of severe flood events in the last decade report on unpredictable, usually rapid onset events, that lead to substantial financial losses, destruction of infrastructure, displacement, and death (Armah et al., 2010; Merz et al., 2007).

The magnitude and frequency of these events suggest that traditional approaches of flood management are no longer adequate. Resilience approaches aimed at understanding and managing the capacity of a social-ecological system (SES) to adapt to, cope with, and shape uncertainty and surprise offer a possible avenue to deal with these challenges (Adger et al., 2005; Folke et al., 2002). Social ecological systems (SES) are interdependent systems of people and nature. The way in which SES copes and adapts to changes therefore needs to be analysed in a way that accounts for social-ecological interactions (Chapin et al., 2010). In a resilient SES, dealing with disturbance such as floods present an opportunity for innovation and development in a changing environment (Folke, 2006; Turner, 2010). The ability of a SES to adapt to and benefit from change is dependent on characteristics of vulnerability and adaptive capacity (Walker et al., 2004). "Vulnerability is the degree of harm owing to exposure and sensitivity to a specific hazard and the absence of the

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capacity to adapt" (Adger, 2006). Whereas the capacity to adapt refers to the ability of actors in a system to influence resilience through collective action and learning (Walker et al., 2004).

In order to manage and foster the resilience of systems to floods, it is important to be able to measure where, and how much resilience resides in a system (Carpenter et al., 2001; Walker et al., 2002). Complex interactions between social and ecological systems, non-linear feedbacks, spatial and temporal variation, and the practical difficulties of measuring resilience, make operationalising resilience challenging (Davidson et al., 2013; Marshall and Marshall, 2007). Some of the tools and models that have been used to measure resilience include the use of ecological models (Cumming et al., 2005; Van Nes and Scheffer, 2007), indicators (Chillo et al., 2011; Dai et al., 2012), metrics (Allen et al., 2005), and resilience surrogates (Bennett et al., 2005). Due to a lack of sufficient data and capacity, uncertain model results and insufficient guidelines for use by scientists and managers, tools and models have remained substantially under-utilised in SES management (Malone and Brenkert, 2008; Nyström et al., 2008). There is therefore a need for a readily calculated and transparent method to measure resilience of a SES to stresses and events such as floods (Chapin et al., 2010).

Composite indices offer a potential avenue for dealing with the multivariate and complex nature of SES. A composite index is a mathematical aggregation of a set of indicators used to summarise the characteristics of a system (Saisana and Tarantola, 2002; Salvati and Carlucci, 2014). Indices are increasingly used to facilitate communication among scientists, policymakers, and the public (Reisi et al., 2014). Their application include the measurement of trends in poverty, human development, food security, vulnerability and biodiversity (Flanagan et al., 2011; Hahn et al., 2009; Krishnan, 2010; Scholes and Biggs, 2005; Valipour, 2014a). Part of the appeal of indices lie in their ability to provide the big picture while summarising complex or multi-dimensional issues (Saisana and Tarantola, 2002). Indices have therefore also been used to highlight strengths and weaknesses, identify suitable management strategies and to predict future scenarios (Valipour, 2014b, 2014c; Valipour et al., 2014). As decision-making tools they are not without limitations, which include challenges of disaggregation and traceability for management (Hinkel, 2011; Scholes and Biggs, 2005).

The use of composite indices to measure disaster resilience has largely been developed in social science and environmental risk and hazard communities (Cutter et al., 2010; Mayunga, 2007; Orencio and Fujii, 2013). In these indices the emphasis is on community resilience which implies that groups or communities are resilient due to social and organisational factors which enable them to respond and adapt to disasters (Cutter et al., 2008; Frazier et al., 2013; Magis, 2010). A potential shortcoming of these indices has been the absence of a biophysical component. This is an important gap as ecosystems have been shown to play a large role in determining resilience to extreme events associated with climate change impacts (Munang et al., 2013; Nel et al., 2014). In the disaster resilience index of Cutter et al. (2014) a first attempt at the inclusion of an ecological resilience component is made. The index however measures general resilience to all natural hazards, rather than specific resilience to a particular hazard. In order to account for different ecosystem features and processes associated with particular hazards a more specific resilience focused on a particular natural hazard would allow for the selection of variables relevant to the hazard while capturing more accurately the role, location and condition of ecosystem services.

To contribute to approaches and studies operationalising resilience, especially those that elaborate the social-ecological dimensions of resilience, we develop, test, and analyse the use of a flood resilience index. This study makes use of the social and ecological characteristics of three flood-prone municipalities in South Africa. The method is developed within the context of existing tools and methodological frameworks used in urban and disaster planning, in order to link to future policy and planning in the area.

2. Methods

2.1. Study site description

The study area is located in the coastal region of the Southern Cape of South Africa. The three municipalities in the study area; George, Knysna, and Bitou, consist of an interconnected system of urban centres, towns, villages, and hamlets that form part of the Eden District (Fig. 1). Municipalities are politically created boundaries, sub-divided into wards which can include part of a settlement, and one or more suburbs or residential areas depending on its size. The Eden district has been evaluated as one of the five most disaster-prone areas in South Africa as it is very mountainous, prone to flash flooding, and coastal sea storms (SALGA, 2013). It has also been the subject of long-term ecological and social data collection and analysis (Nel et al., 2014; Payet et al., 2013; Reyers et al., 2009; Sitas et al., 2013). The three municipalities chosen for the study have been the hardest hit by flood events in South Africa within the last decade (Faling et al., 2012; Macgregor, 2005).

The Eden District falls within three internationally recognised biodiversity hotspots (Vromans et al., 2010). The area hosts an extensive system of indigenous forests and is home to a number of unique lakes and estuaries that are of both scientific and economic importance (Maree, 2010; Turpie et al., 2002). The local economy is largely centred on tourism, agriculture, manufacturing, forestry, and trade (Ferreira, 2007; Pauw, 2009). Rapid population growth attributed to the net in-migration of young, low-skilled job seekers and older, high-income retirees have placed increased pressure on existing infrastructure, and demand for housing (Eden District Municipality, 2009). This urbanisation pressure is set against a backdrop of very limited developable land, a sensitive environment, and a lack of new jobs being created in the local economy (Allanson, 2000; Marker, 2003).

2.2. Construction of the index

Various methods exist to construct composite indices, with the choice of method dependent upon the type of problem, the nature of the data and the objective of the analysis (Nardo et al., 2005). The use of composite indices to measure resilience is fairly new, and the accurate characterisation of resilience still remains a challenge (Prior and Hagmann, 2013). Many disaster resilience indices use an equal weighting for reasons of simplicity and transparency (Ainuddin and Routray, 2012; Cutter et al., 2010). We rather assign an explicit and transparent weighting system to account for the range of variance in such a social-ecological dataset and conduct sensitivity analyses to make clear its impact. The statistical method of principal component analysis (PCA) is used to generate weights for the variables. PCA is a statistical model which relies on the variation and covariation of the data matrix to construct weights in the component index (Saisana and Tarantola, 2002). The weighting method is objective, computationally easy and is compatible with the type of data obtained from surveys and databases (Vyas and Kumaranayake, 2006).

2.3. Variable selection

As flood resilience is a multifaceted property, we used the principles of resilience as outlined by Biggs et al. (2012) to guide our selection of variables with which to measure resilience. These principles include maintaining diversity and redundancy, managing