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Research article

# Assessing urban adaptive capacity to climate change

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ABSTRACT

Despite the growing number of studies focusing on urban vulnerability to climate change, adaptive capacity, which is a key component of the IPCC definition of vulnerability, is rarely assessed quantitatively. We examine the capacity of adaptation in the Concepción Metropolitan Area, Chile. A flexible methodology based on spatial fuzzy modelling was developed to standardise and aggregate, through a stepwise approach, seventeen indicators derived from widely available census statistical data into an adaptive capacity index. The results indicate that all the municipalities in the CMA increased their level of adaptive capacity between 1992 and 2002. However, the relative differences between municipalities did not change significantly over the studied timeframe. Fuzzy overlay allowed us to standardise and to effectively aggregate indicators with differing ranges and granularities of attribute values into an overall index. It also provided a conceptually sound and reproducible means of exploring the interplay of many indicators that individually influence adaptive capacity. Furthermore, it captured the complex, aggregated and continued nature of the adaptive capacity, favouring to deal with gaps of data and knowledge associated with the concept of adaptive capacity. The resulting maps can help identify municipalities where adaptive capacity is weak and identify which components of adaptive capacity need strengthening. Identification of these capacity conditions can stimulate dialogue amongst policymakers and stakeholders regarding how to manage urban areas and how to prioritise resources for urban development in ways that can also improve adaptive capacity and thus reduce vulnerability to climate change.


## 1. Introduction

The world is becoming increasingly urbanised, with 70% of the global population projected to live in cities by 2050 compared to 52% in 2010 (UN-DESA, 2011). It is expected that most urban growth will be concentrated in the developing world, with urban population rising from 47% in 2011 to 67% in 2050 (UN-DESA, 2011). This trend has major social and economic consequences, including the marginalisation of rural areas and a concentration of economic activity in urban centres. In a developing country as Chile, more than 25% of the population lives in nine dense coastal urban cities, covering 46% of the country's urban land surface (INE, 2012). The concentration of human, financial and manufactured capital makes cities especially vulnerable to climate change (Revi et al., 2014; Rosenzweig et al., 2011). For this reasons, knowing and understanding the baseline conditions of cities to carry out the adaptation process becomes critical to start thinking about adaptation actions.

The IPCC (2014) defines adaptive capacity (AC) as *"the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences"*. AC could thus be seen as a set of enabling conditions that help drive successful adaptation in order to ensure the viability of economic and social activity and quality of life (Gallopín, 2006; Smit and Wandel, 2006), and to reduce climate change vulnerability (Metzger et al., 2008; IPCC, 2014). Spatially explicit vulnerability studies can support governance and decision-making by providing information to know and understand the basic underlying condition that allow a city to adapt to change.

AC is a relative concept, both in terms of spatial distribution and the way it responds in different contexts (Lemos et al., 2013). AC is also an aggregated condition which can be explained through a series of determining factors and processes that affect the ability of a region, area or community to adapt (Smit and Pilifosova, 2001;

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Metzger et al., 2008, 2005). The IPCC Third Assessment Report (TAR) (Smit and Pilifosova, 2001) was prescient in being the first to list a set of AC determinants: economic resources, technology, information and skills, infrastructure, institutions and equity. Since then, many studies have sought to expand and refine this list, through focusing on social, human and political capital, health, social status, perception of society as well as spreading mechanisms (Adger et al., 2004; Armitage and Johnson, 2006; Brooks et al., 2005; Eakin and Lemos, 2006; Smit and Wandel, 2006; Tol and Yohe, 2007).

Many studies have constructed AC indices, from sectoral studies (e.g. for the agricultural industry in Australia (Fitzsimons et al., 2010) and Canada (Swanson et al., 2007)), to broader multi-sectoral national studies (e.g. the National Adaptive Capacity Index, NACI) (Vincent, 2007). Acosta et al. (2013) provided European assessments, constructing an index based on three components: awareness, ability and action, as part of wider European climate-change vulnerability assessment (Metzger et al., 2008). This method was subsequently used in others studies (Greiving, 2011; Juhola et al., 2012). It has also been adapted for cities (EEA, 2012; Swart et al., 2012), an arena where there is a strong demand for suitable methods of analysing urban AC (Schauser et al., 2010).

This paper builds on the work of Acosta et al. (2013) and Swart et al. (2012) to assess AC for the nine municipalities of the Concepción Metropolitan Area (CMA) in Chile. This research is the first to track the temporal and spatial distribution of AC in the recent past (for 1992 and 2002) through a fuzzy overlay approach with Geographic Information Systems (GIS). Using fuzzy set theory (Zadeh, 1965) in GIS allows for flexibility and transparency in the development of the AC index. Fuzzy logic is a multi-valued logic approach which involves the assignment of partial or intermediate values over a well-defined range (0–1). Thus allows the identification of varying degrees of AC (Acosta et al., 2008). Fuzzy set theory can be used to represent the continuous nature of socio-economic indicators and better addresses the inherent uncertainty and subjectivity of the data used in AC assessments (Acosta et al., 2013). In turn, it allows the straightforward comparison of the spatial objects of different values by first creating standardised value ranges for them (Espada et al., 2013). This enables a comparison of differences in the AC level between municipalities and over time. GIS makes this analysis easier to implement, whilst also allowing flexibility in the combination of maps (Pradhan, 2011).

This research is framed around the following questions: a) what was the AC of each of the municipality in 1992 and 2002?; b) how did the AC of each municipality change between 1992 and 2002? and c) which indicators, components and determinants have the greatest influence on the calculation of the AC index for each municipality?. This approach can be readily applied in urban municipalities worldwide with some refinements based on the use of census-based statistics to develop the indicator framework. Our findings can help stakeholders and policymakers in municipalities, contributing to their understanding of the precondition for planned adaptation, supporting the *situational analysis*, the first step in the planning process for climate change in cities (Grafakos et al., 2015).

## 2. Study area and methods

### 2.1. The Concepción Metropolitan Area

With just over 1 million inhabitants, the CMA is Chile's second city by population. Located in the coastal area of the Bío-Bío Region in the country southern-central area (Fig. 1), it covers 2077 km$^2$, has

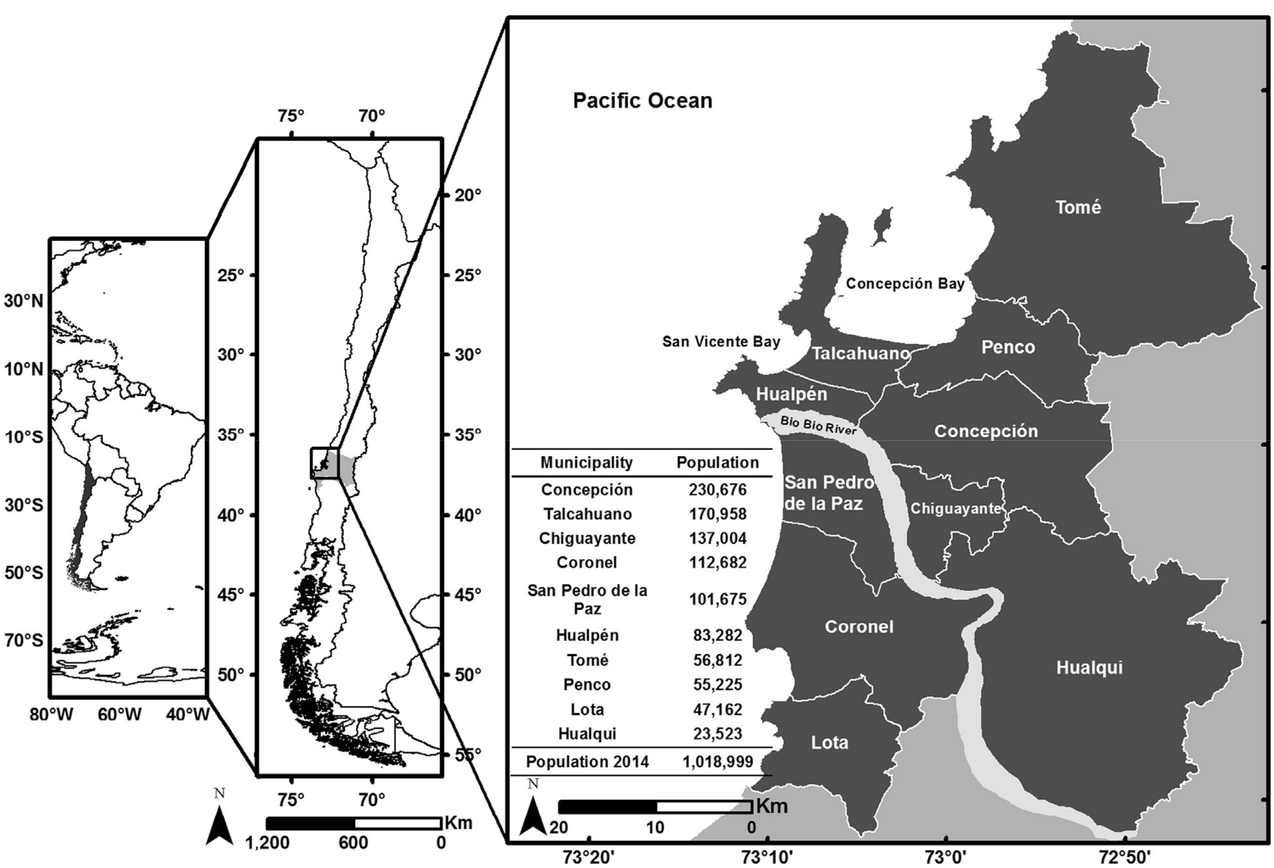


**Fig. 1.** CMA location and table of population projections of CMA municipalities for 2014 (INE, 2011).