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Approaching urban vulnerability to climate change induced risks in socio-environmentally fragmented areas – The case of Santiago de Chile –

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Foreword

This report was compiled within the Helmholtz International Research Group CLAVE[1] 'Climate change adaptation options in Santiago de Chile and other Latin American megacities: urban vulnerability on local level'. The project is a joint effort of the Helmholtz Centre for Environmental Research (UFZ) in Germany and the Pontificia Universidad Católica de Chile (PUC) in Chile and seeks to provide new insights with regard to scientific and practical climate change adaptation options on local level. CLAVE considers that projected climate change impacts, on the one hand, and the extreme concentration of economic power of decisive political and functional systems housed in Latin American megacities, on the other hand, require in-depth analyses of urban vulnerability for the development of context-specific adaptation options. This is achieved through a discussion of the two core concepts - socio-environmental fragmentation and residential vulnerability.

CLAVE acknowledges cities to be located in different climates, consuming much of the world's energy, and producing a high degree of greenhouse gas emissions. Due to the fact that cities are populated by high concentrations of people and services, they are heavily affected by the impacts of climate change. At the same time, cities possess numerous benefits and thus have significant opportunities for transition and fundamental transformations in response to climate change and other related issues. Megacities in particular are spaces of opportunities and risks, and especially vulnerable to extreme events and natural disasters. Population growth goes hand in hand with the expansion of urban areas, often into high risk environments threatened by floods or landslides, among other hazards, and it is the complexity of cities that increases overall vulnerability such as urban growth, the increasing socio-spatial fragmentation of the urban population, and governance limitations.

In this context, the aim of CLAVE is to develop and present:

- A combined methodological approach for analyzing socio-environmental fragmentation on city level and residential vulnerability at the individual/neighborhood level,
- A set of operable fragmentation and vulnerability indicators, representative for Latin American megacities,
- A proposal for specific climate change adaptation options for vulnerable urban settings.

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In practice, the project attempts to bring both concepts - fragmentation and vulnerability - together in order to allow for in-depth qualitative and quantitative analyses in selected hotspot areas based on a set of specific fragmentation and vulnerability indicators. This includes data collected from household surveys, expert interviews, workshops, census and GIS analyses, among others. As an important outcome for practical purposes, a guideline for and with municipalities to develop and implement adaptation options at the local level will be developed.

Most of the empirical research is carried out in the Metropolitan Area of Santiago de Chile (MAS), although other cities in Latin America (e.g. Buenos Aires, Bogotá and Lima) are also potential case study cities, depending on data availability and concept transferability.

The present report contains the results of the initial working steps of the CLAVE project which is a) the theoretical combination of fragmentation and vulnerability, and b) the development of a methodology for assessing socio-environmental fragmentation and residential vulnerability in order to enhance the overall knowledge of urban vulnerability. This is seen as the primary prerequisite for the subsequent elaboration and implement-tation of local adaptation measures. The different methodological steps and in-depth analyses to be undertaken are described by using selected municipalities within the MAS.

Chapter 2 focuses on describing the underlying problem of linking the theoretical approaches of fragmentation and vulnerability from a general point of view. Existing approaches presented by other authors are discussed, in order to link as well as distinguish the work presented here with/from others. **Chapter 3** shows how the concepts of fragmentation and vulnerability are interlinked from the project's point of view. **Chapter 4** describes the theoretical background of climate change adaptation and adaptive capacity in order to allow a better understanding of both the CLAVE project approach and its application. The case study, the MAS, is described and illustrated in **Chapter 5** by providing a general overview of the city together with existing findings with regard to fragmentation and vulnerability. This chapter thereby explains the context in which the approach is to be applied. **Chapter 6** presents the project's methodological framework with its three-stage approach as an integrated assessment of urban vulnerability to climate change. Options for validating the approach are likewise discussed. **Chapter 7** summarizes the main conclusions and provides an outlook by describing success stories and lessons learned for validating the theoretical approach. The development of strategies to deal with future climate change in these and other regions worldwide is discussed.

1 The core concepts: fragmentation and vulnerability

1.1 Fragmentation as a spatial approach for urban areas

There are several important and inter-related concepts involved in climate change adaptation, including the concepts of adaptive capacity and vulnerability. Each of these have varying applications in the scientific literature, with especially marked differences occurring between these concepts in ecological/natural sciences, and social science applications. While it is generally accepted that these concepts are intricately related, the nature of the relation is still subject to debate.

The concept of fragmentation is none of the 'traditional' concepts used in climate change research. It has been recurrently utilized in order to characterize and describe different socio-spatial processes associated with urban development. Significant differences regarding theoretical approaches and applications make it an ambiguous, diffuse and widespread concept with various definitions. It has been used extensively in the fields of landscape ecology and urban planning (Angel et al., 2010; Schneider and Woodcock, 2008; Schwarz, 2010). Here, fragmentation reflects the morphological, often also cited as spatial or structural, properties of different forms of an urban area (Batty et al., 2003) and is understood as a static metric. It relates to spatial patterns of discontinuity, analyzed through different indicators that determine landscape metrics and forms.

In social sciences, the concept of fragmentation often refers to the dynamics of the interdependence and division between different social groups within an area, such as a certain city. The concept relates to processes of socio-spatial segregation understood as "the degree to which two or more groups live separately from one another, in different parts of the urban environment" (Massey and Denton, 1988: 282), and thus refers to the homogeneous or heterogeneous composition of urban areas. The concept of fragmentation can include processes of segregation, as this is expressed both in physical-territorial dimensions as well as within symbolic and perception-based dimensions. Looking at large-scale social processes, the socio-spatial fragmentation of urban areas is associated with the restructuration of productive processes and is a consequence of newly emerging forms of urban spatial organization as a result of globalization, mainly through the logic of networks, nodes and centers. According to Mongin (2006), this contemplates a transformation characterized as moving from a finite and compact urban territory that makes infinite practices possible, towards an urban condition that is territorially infinite and dispersed, but results in segmented practices. The concept of fragmentation differentiates between the 'city of fragments' and the 'fragmented city', with the first referring to a spatial reconfiguration process that incorporates previously separated structural fragments into the urban system (typically urban sprawl). The latter considers a process that involves the disintegration of socio-spatial fragments within the city itself that is the dominant structure in Latin America megacities, and is therefore in the focus of the CLAVE project.

The fragmentation of urban areas is associated with a separation or distance between different spatial structures in the city. It is brought on by emergent urban dynamics involving factors such as the land market, real estate initiatives, changing lifestyle patterns, changes in the labor market, socio-spatial segregation, and increasing violence and insecurity, often leading to the separation of urban socio-spatial elements such as gated communities or business and entertainment parks into separate functional entities. According to Borsdorf et al. (2006) fragmentation is "a new concept of the city as surrounded by walls, fences, gates and security systems in order to protect its members hermetically and to exclude them from the outer world" (ibid: 324). It connects to the ideas of network urbanism (Dupuy, 1998; Salingaros, 2005), which understands the city as a reticular structure that leaves 'fragments' that can be either connected or 'out-of-bounds'. In terms of connectivity, fragmentation also relates to processes for the relocation of functional spaces within an urban area resulting in new urban districts that follow the organizational logic of capitalistic production, accompanied by new cultural and consumption patterns. These functional spaces include financial, business, industrial, cultural and service-oriented districts as well as new residential neighborhoods that enhance the tendencies of metropolization (De Mattos, 2001), urban sprawl, suburbanization and peri-urbanization (Monclús, 1998; Dematteis, 1998).

Against this background, the concept of fragmentation can be defined as a form of organizing socio-spatial elements or entities of a city, which differentiates and disintegrates space into recognizable fragments that are internally homogenous and/or heterogeneous to one another, based on different dimensions for which new borders are generated in any particular way in which such a differentiation can be defined. The various dimensions of fragmentation that have evolved within the literature are as follows:

- The **morphological** dimension, referring to characteristics of the 'urban fabric' and 'building morphology'. It considers, among other aspects, issues of physical accessibility and connectivity between territories, presence of physical barriers, homogeneity of land uses etc. (Salinas, 2010; Tella, 2005; Rodríguez and Winchester, 2004; Salingaros, 2005).
- The **economic** dimension, referring to the spatial distribution of different economic 'goods' such as economic command centers, the location of labor, the dispersion and relocation of industry, functional specialization of districts, etc. (Sánchez, 2007; Rodríguez and Winchester, 2004; Janoschka, 2002).
- The **socio-cultural** dimension, referring to both physical and symbolic aspects, and considering elements such as social inequality, symbolic barriers as well as levels of

social cohesion and victimization (Veiga, 2004; Link, 2008; Dammert, 2004; Prevot-Shapira, 2001; Villela et al., 2010; Schteingart, 2001; Sánchez, 2007).

- The diversity of administrative units and the possibilities for their articulation within an urban management scheme, connecting to the **political-administrative** dimension. This reflects issues of social organization, such as community boards, as well as variables of metropolitan urban governance (Marcuse, 1989; Sánchez, 2007; Rodríguez and Winchester, 2004; Salinas, 2010; Michelutti, 2010).
- The **ecological-environmental** dimension, relating to the distribution of ‘ecological services’, green spaces, public spaces, etc. This implies an ‘environmental’ fragmentation of the city, understood as access to and availability of these elements. It refers to the constitution of borders and the territorial limits of environmental elements within an urban area (Bizama, 2011).

Different authors in the context of urban studies have referred to the idea of fragmentation in at least one of these dimensions, which makes the formulation of a general and operational definition of the concept difficult (Link, 2008; Vidal, 1999; Borsdorf, 2003; Michelutti, 2010; Low, 2006). Differently, CLAVE project aims at applying it in various dimensions. Aiming at applying the concept empirically, it is important to overcome the dichotomy of ‘fragmented’ vs. ‘non-fragmented’, thus being able to situate the city on an *axis of fragmentation*. The methodology developed by the CLAVE project contributes to overcoming this dichotomy. The strategy for operationalizing the concept of fragmentation is described in Chapter 6.

1.2 Vulnerability in the context of climate change

Within the discussion on vulnerability many attempts have been made to conceptualize the term, leading to a diversity of approaches. Vulnerability is defined differently by various scientific disciplines. It is essentially conceptualized as the outcome of environmental, social, cultural, institutional and economic structures and processes, leading to the unequal distribution of exposure, resources and capacities (Chambers, 1989; Adger and Kelly, 1999). It is understood as “the *characteristics* of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard” (Wisner et al., 2004: 11).

Overall, there has been little effort focusing specifically on the conceptualization of ‘urban vulnerability’ to climate change, despite the fact that increasing urbanization is one of the defining phenomena of the 21st century, and cities are likely to be increasingly affected by the forecasted impacts of climate change (Romero Lankao and Qin, 2011). The few examples of available research on the subject of ‘urban vulnerability’ highlight urban complexities as well as the numerous interdependencies between the diverse spheres of urban life and the environment. By adding the notion of ‘urban’, Kuhlicke et al. (2012) provide a definition of vulnerability that refers to the degree to which individuals, infrastructures and physical assets in urban environments are exposed or susceptible to environmental hazards, as well as to their capacity to cope with and adapt to the negative impacts. According to Romero Lankao and Qin (2011) urban vulnerability refers to, "the degree to which a system (e.g. city, population, infrastructure, and economic sector) is susceptible to and is unable to cope with adverse effects of a single, or of several hazards or stresses (e.g. climate change and political instability)" (ibid: 2). In this context, urban vulnerability to climate change is generally determined by the following dimensions: *exposure*, *susceptibility*, and *coping and/or adaptive capacities*. However most recently, the IPCC (2012) introduced a new concept of vulnerability that does not consider exposure as a dimension of vulnerability, but rather as a precondition.

1.1.1. Exposure

Exposure as one dimension of vulnerability refers, in the present case, to the physical precondition to being affected by natural hazards like flooding and heat, thus acting as a bridge between the natural and social science approaches (Fuchs et al., 2011). Here, hazard exposure is not driven by physical changes to climate alone, but also by natural and anthropogenic factors such as demographics and economics, all of which have an impact on the sensitivity of places and populations to climatic change and their capacity to respond. Generally, exposure is determined by the extent to which a given socio-ecological system is physically exposed to potential risks, such as flooding, drought, extreme events, and other climate-related phenomenon. According to Messner and Meyer (2006), exposure indicators comprise the type of exposure of each element at risk (e.g. proximity to river) as well as hazard characteristics (e.g. hazard duration).

1.1.2. Susceptibility

The second dimension of the vulnerability concept is susceptibility. This refers to the extent to which a system, a person or an asset is prone to alterations or change as a result of exposure to outside pressure. For example, inadequate infrastructure, physical disconnectedness and tenuous access to basic services can lead to more susceptibility and negative alterations from a climate event. In this way, beyond mere physical aspects, susceptibility is also determined by pre-existing economic, cultural, political and environmental drivers, such as land use, settlement location and type, livelihoods, economic opportunities, among others. Thus, it is defined as the precondition to suffe-ring harm due to the fragility of constructions or to other disadvantageous conditions. Sometimes susceptibility is used interchangeably with 'sensitivity' (Smith et al., 2000), or with 'fragility' (Birkmann et al., 2013), especially when focusing on physical vulnerability. The wide range of different definitions within the literature shows that there is no clear distinction between exposure and susceptibility, and that the term susceptibility is used in different ways. There are some definitions that evolved within the risk, environmental science, climate change community, which refer to sensitivity (susceptibility) more as the "degree to which a system is affected, either adversely or beneficially, by climate-related stimuli" (IPCC, 2001: 21) which in light of Kuhlicke et al. (2012) is more related to the dimension of exposure. The definition of the European Topic Center on Climate Change Impacts, Vulnerability and Adaptation (2012) seems to be a cross between exposure and susceptibility: "Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli; it depends on biophysical or social factors or a combination of both" (ibid: 13). According to Birkmann et al. (2013: 8), "susceptibility (or fragility) describes the predisposition of elements at risk (social and ecological) to suffer harm", referring (as in the case of Kuhlicke et al. (2012)) to the reason why people and/or assets are exposed. This also holds true for Balica et al. (2012: 79), who define the term as "the elements exposed within the system, which influence the probabilities of being harmed at times of hazardous floods". Furthermore, scholars relate susceptibility to "system characteristics, including the social context of flood damage, especially the awareness and preparedness of people regarding the risk they live with (before the flood)" (ibid.). Van der Veen and Logtmeijer (2005: 70) state that, "susceptibility is the physical characteristic of the location that makes an activity vulnerable". This more or less consists with the environmental psychology perspective that, "susceptibility can be defined as the lack of the protection capacity of agents. If agents think the situation is threatening but they believe they can cope with it then this theory suggests that protection capacity is high, and subsequently, susceptibility is low" (Alcamo et al., 2002: 3). However, Alcamo et al. (2008: 138) also relate susceptibility to the concept of coping capacities: "The capability of an individual, community, or state to resist and/or recover from crises brought about by environmental stress".

To sum up, the dimension of susceptibility is important in order to justify whether exposure to hazards is necessarily a precondition to be affected. In this way, the CLAVE project follows up on those definitions that understand susceptibility as the dimension that can provide answers to the question why assets or people are exposed to climate-related hazards.

1.1.3. Coping capacity

Coping capacity is part of the formula that determines vulnerability at any given moment in time (Birkmann et al., 2013) and is generally defined as "the ability of people, organizations, and systems, using available skills, resources, and opportunities, to address, manage, and overcome adverse conditions" (IPCC 2012a: 558). Therefore it describes the immediate responses to the occurrence of a hazard (Birkmann et al., 2009) and the manner in which people, organizations and systems try to avoid potential impacts (Kelly and Adger, 2000) within the limits of existing resources (Wisner et al., 2004). Thus, coping capacity can include a set of actions or defense mechanisms, active ways of solving problems, and methods for handling stress (Wisner et al., 2004). Birkmann et al. (2013) define coping capacity as an aspect of 'resilience'. Due to its immediate character, coping capacity is a proximate, short-term and less strategic response to a hazardous event. It refers to the ability to prepare for, cope with and recover from a hazardous event. Naturally, the pre-existing conditions relevant to exposure and susceptibility are also related to and determinants of a system's ability to cope with outside pressures and climate events. This involves emergency planning and response mechanisms, as well as adequate technical and human resources to respond during and after an event. Such actions are designed to return as swiftly as possible to a state of normality, although it does not necessarily imply imposing long-term changes or adaptations to the hazard as a whole.

Coping capacity is dependent on the availability of resources, authority, human capital, and social capital, as well as the ability to manage information, the availability of technological innovation, and public perception of the risk, damage and/or harm of an event (Heinrichs et al., 2011; Yohe, 2001). Therefore, measuring coping capacities can be related to recording the actions taken by people, organizations, etc. to reduce the negative impact of a hazardous event, such as utilizing the support of social networks or financial resources, awareness raising and preparedness before the hazardous event, capabilities to cope during the hazard, and the potential to recover afterwards (Müller, 2012). Also, knowledge and awareness of the existence of protective measures and/or any emergency plan may counteract feelings of despair, contribute to residential quality of life, and spur further preventive and mitigation related initiatives. The level of awareness/ knowledge about possible resources and measures to resist or cope with a possible disaster may diminish vulnerability, especially in cases where financial resources are not a real constraint for the construction of protection measures (e.g. sandbags for short-term protection). Furthermore, social capital in terms of neighborhood trust, fears, social networks and community participation, may indicate strong community cohesion and a high degree of collective action. These are basic requirements for the resistance of a community and/or neighborhood during a hazard incident, as well as for their capability to recover from it.

2 Urban complexity as inherent to climate change adaptation: bridging the concepts of fragmentation and vulnerability

The risks to urban areas as a result of climate change impacts are transversal in nature, posing threats that have the potential to impose multiple, simultaneous pressures on the complex web of urban governance, service, infrastructure, economic and social structures all at once. In this way, an increase in the frequency and magnitude of extreme weather events, for example, may augment the vulnerability of human settlements, commercial services, health systems, transport systems, water and flood management and agricultural systems in urban environments that are less developed or unprepared for such changes. This represents a risk to cities regarding the general supply of essential urban services, as well as the public institutions and private companies that determine how such services are managed. In an emergent situation in which institutions are forced to respond to threats for which they have had no prior experience, they may find themselves with inadequate training, instruments and resources to deal with such trends. In other cases, climate events within the city or even far outside of the city can lead to cascading impacts. For example, damage to roads and transportation infrastructure from flooding or extreme heat can impede the effective operation of emergency response services, and interruption to electricity supply from outside of the city can have an impact on urban telecommunications, transportation and commercial services, among others.

The primary climate change impacts on urban systems are accentuated by varying aspects of vulnerability. Social, infrastructural, institutional and economic vulnerability are key aspects when dealing with the pressures (both long-term and more immediate) that climate change can assert over human, physical and ecological systems (Schneider et al., 2007; UN Habitat, 2011; Wilibanks et al., 2007). With regards to human populations, there are several factors that contribute to determining vulnerability to climate change. Vulnerability is understood as a composite concept that responds to the three previously described sub-dimensions: exposure, susceptibility and coping capacity. In this way, those living in areas exposed to certain hazards (due to geographic location or conditions such as low-lying areas, areas that are more prone to flooding or heat stress, etc., or as a result of maladapted human interventions) must have significant coping capacities and/or be less susceptible in order to avoid being vulnerable to such impacts. Likewise, those communities that are exposed and have lower thresholds for tolerance to external impacts, due to pre-existing social, economic, and structural conditions, are considered to be more susceptible to experiencing the negative impacts as a result of climate change (i.e. access to safe and adequate transportation, storm surge protection, access to basic services such as food, electricity and water, proximity to potentially dangerous industrial sites, etc.) (Richter, 2010; UN Habitat, 2011). At the same time, communities that do not have a developed and efficient emergency coping capacity that allows for an effective response to external shocks, and to return as quickly as possible to a state of relative normalcy, are considered to not show adequate preparation, expertise and training, existence of contingency plans, etc. In this way, vulnerability to extreme events and climate change impacts is neither evenly distributed over cities nor within cities, as it depends on varying degrees of exposure, susceptibility, and the coping capacity of the local population and governments.

Taking the two concepts of fragmentation and vulnerability into account, part of the impetus for the present research is based on the idea that urban development patterns that result in high levels of socio-environmental fragmentation may end first, in more exposure to climate change related hazards such as flood and heat, and second, negative consequences regarding susceptibility and local coping capacity. Such patterns tend to create specific fragmented areas that are more susceptible and less able to cope with the hazard related impacts. Socio-environmental fragmentation operationalizes those processes in the city that are related to socio-spatial segregation, urban growth and expansion, development patterns, and the provision and distribution of urban infrastructure and services. Therefore, we argue that the fundamentally social content of vulnerability can be strengthened by the concept of fragmentation, as the latter is used to describe how particular choices regarding the patterns and forms of changing and dynamic urban systems come to determine a preexisting city structure that plays an important role regarding urban vulnerability to climate change.

Against this background, in drawing the theoretical connections between the concepts of fragmentation and vulnerability, certain shared and interdependent elements emerge, such as physical connectedness within the city, and limited access to services and resources. In this way, it is argued that the socio-environmental fragmentation of urban areas serve as structural preconditions for varying degrees of household, neighborhood and municipal vulnerability. As such, connecting the multi-dimensional concept regarding the fragmentation of urban areas to the specific dimensions of residential vulnerability to climate change allows for a joint analysis and the super positioning of environmental and socio-spatial characteristics, in order to achieve a complementary interpretation of both fragmentation and the specific aspects of vulnerability to climate change in urban areas. By doing so, throughout the variety of spatially fragmented urban areas a number of different vulnerabilities may emerge that are influenced by a genuinely urban notion: socio-environmental fragmentation. Thus the lens of socio-environmental fragmentation of urban areas provides a contextual and analytical framework for analyzing the city through spatial logic, and a tool for understanding the dense network of complexities and interdependencies that make up the urban fabric (Kuhlicke et al., 2012).

This calls for a methodology that organizes the city into key segments necessary for a spatial comprehension of the varied urban dynamics of connectedness and disconnectedness. As such, to link socio-environmentally fragmented urban areas with residential vulnerability provides for the possibility of including categories of spatial analysis that demonstrate the processes of differentiation that make up urban complexity, which cannot be left out when studying Latin American metropolises in the context of climate change.

3 Climate change adaptation and adaptive capacity

3.1 Definition of adaptive capacity

The issue of adaptation has received considerable attention in recent years within the political and academic discourse surrounding climate change (Measham et al., 2011; Eriksen et al., 2011), in addition to mitigation of climate change. This trend has emerged in a context of growing scientific knowledge on the impending impacts of increasing climate variability on human society and governance. However, it is increasingly recognized that local scales are those less investigated although having an essential role to play in adapting to climate change, not only because of the undeniably local character of climate change impacts, but also because local institutions are those responsible for structuring responses to such impacts, mediating between individual and collective responses to vulnerability, and governing the provision of resources in order to facilitate adaptation (Agrawal et al., 2008; Measham et al., 2011).

Together with the growth of interest in adaptation, the issue of vulnerability to climate change has also evolved from an initial interest in merely exposure to climate change impacts and general relevance to human society and to additional interest in non-climate factors (such as economic, demographic, political, technological and environmental factors) that play significant roles in determining differing levels of susceptibility to suffer the negative consequences of climate change. The combined interest in issues of vulnerability and adaptation led to a focus on adaptive capacity, understood as the ability of social and/or environmental systems to respond and adapt to climate hazards, stressors and overall changing patterns of variability, which in turn fed into a concentration on how to best reduce vulnerability to climate change (Füssel and Klein, 2006; Smit and Wandel, 2006).

Human communities, including homes, institutions, businesses and public authorities, respond to climatic stimuli to the degree that they are vulnerable to climate change impacts. In this way, there are several theoretical interpretations of the relationship between the concepts of adaptive capacity and vulnerability (Cutter et al., 2008; Smit and Wandel, 2006; Pelling, 2011). Some authors separate vulnerability and adaptive capacity as opposite sides of the same coin, in that a more developed adaptive capacity implies lower levels of vulnerability, while low levels of adaptive capacity may accentuate existing vulnerabilities (Kelly and Adger, 2009). Still others consider adaptive capacity to be embedded as a subset of vulnerability, defined as the characteristic of a system regarding its exposure, susceptibility and coping capacity (capacity to respond to an outside force, in this case, climate change) (IPCC, 2008; Adger et al., 2004), implying an inherent similarity or equivalence of adaptive and coping capacity. In any case, in the context of urban areas, it is appropriate to focus on adaptive capacity as the convergence of vulnerability and adaptation to climate change.

3.2 Adaptive capacity versus coping capacity

Emergent lines of research are concerned with separating out the concepts of coping capacity and adaptive capacity, although there is still no clear-cut agreement regarding the best way to do this. According to Pelling (2011), this concern arises partially from the recent mainstreaming of climate change adaptation within traditional disaster risk-reduction and preparation activities (and vice-versa), giving way to the need for a more clear-cut conceptual distinction between the two concepts. Among these distinctions, certain authors have argued that while coping capacity refers more to the actions that can be taken in response to a stressor within current structural constraints, adaptive capacity refers to the transformation of the structure, functioning and organization of a system in order to better integrate long-term restructuring and adaptation (Kelly and Adger, 2000; Eriksen et al., 2005). In the same way, authors have also highlighted the role of institutions in determining changing levels of both coping and adaptive capacity (Pelling, 2011; Berman et al., 2012). Such authors see coping capacity as determined and/or restricted by current institutional capacities for response (including resources, structure, emergency response mechanisms, etc.), while adaptive capacity implies longer-term institutional change and transformations of other underlying causes of vulnerability (susceptibility and exposure, for example).

In this way, there is still no consensus in the literature regarding the strict separation of the concept of coping capacity from that of adaptive capacity, in which some authors seem to make no distinction, while others consider it important to distinguish between the two (Nelson, 2011). Among the main and most significant differences that has been pointed out between the two concepts is that coping capacity is a concept that is suitable for integrating the aspects of vulnerability that relate to the human capacity to respond to a crisis or pressure, while adaptive capacity becomes a concept best suited for determining a wider-ranging scope for action, that can either enable or limit future actions. Both of these concepts go beyond mere exposure and susceptibility (largely determined by pre-determined factors and characteristics, such as resources, static social or economic characteristics, and infrastructure). Much research has been done on the way in which communities are coping with climate extremes and variability, whereas less work has been focused on the adaptive capacity needed to face future climate change effects (Pahl-Wostl, 2009).

In addition, both coping as well as adaptive capacities are context-specific and vary greatly between different places, differing scales as well as over time. In this way, they are not static in that they are highly flexible and respond to changes in social, economic, political and institutional conditions over time. One of the most notable distinctions, identified by Smit and Wandel (2006) and also by Gallopin (2006), is that while coping capacity refers to the ability to cope with environmental contingencies (especially regarding extreme events and climate variability), adaptive capacity refers to the ability to improve conditions related to the environment, implying systemic change and transformation aimed at adapting to changing circumstances. The latter can be achieved in many different ways, including the improvement of coping capacity (ability to respond to crises), or reducing susceptibility or exposure to climate threats. In this way, Brooks (2003: 8) define adaptive capacity as "the ability or capacity of a system to modify or change its characteristics or behavior so as to cope better with existing or anticipated external stresses. We may view reductions in social vulnerability as arising from the realization of adaptive capacity as adaptation".

For the purpose of the CLAVE project, it is considered essential to separate out the concepts of coping capacity and adaptive capacity within the subsequent stages of research and analysis, in order to determine both short and mid (coping) and long-term (adaptive) perspectives regarding local climate change adaptation and planning. In this way, we believe that the most efficient way to achieve this is to utilize the distinguishing characteristics presented in recent literature, which consider coping capacity to be connected to more immediate response capacities by individuals, communities and institutions to extreme climate events and variability (flooding, heat waves, etc.), while adaptive capacity refers primarily to institutional trends (such as the integration of climate change considerations into long-term spatial, sectoral and development planning instruments), local perceptions regarding future response capacities (considering growth and development perspectives) and general trends regarding socio-environmental fragmentation of urban areas that can either widen or constrain the capacity to adapt to the increasing frequency of extreme events and more slow-rolling climatic circumstances.

3.3 Adaptive capacity and other related concepts

The terminology relative to climate change adaptation and specifically related to concepts of vulnerability and adaptive capacity (among other similar concepts) is as of yet subject to debate. The concepts embedded in the various theoretical approaches in relation to the actual or expected impacts of global environmental change have divergent roots in both the natural and social sciences, and attempts at convergence have resulted in interesting but still undefined conceptualizations (Smit and Wandel, 2006). In the context of urban environments, communities, institutions and their corresponding power relations and agencies interact with pre-existing vulnerabilities and structural elements defined in both social and ecological terms. This complex dynamic of interactions make up the socio-ecological system, which when inserted within the context of climate change as exerting an external pressure, implies the need of all aspects of the urban system to respond either directly or indirectly, consciously or unconsciously to changing circumstances (Gallopin, 2006).

Adaptation in this sense, according to Smit and Wandel (2006), refers to processes, actions or outcomes from individual households up to regions and countries that allow coping with, managing or adjusting to changing conditions, external stresses, dangers, risks and even opportunities. This definition is the confluence of a number of varying definitions that have been utilized within the academic and scientific literature on the subject, taking into account the important idea that adaptation involves a dynamic relationship between both internal and external factors, which are both produced by and result in changing conditions. In this way, adaptation can occur in response to both the physical environment and internal stimuli, such as economic, demographic or socio-political changes. Change can occur in many different ways and take on many different forms, and in this way adaptation can be either anticipatory (taken prior to a perceived risk) or reactive (taken after a specific change or event has occurred), and can occur spontaneously or be planned.

Pelling (2011) identifies different phases of adaptation defined as resilience, transition and transformation. While resilience includes improved efficiency in planning mechanisms and improved performance of, for example, response mechanisms or building structures, it does not imply challenging the general guiding principles of development and established routines. In this way, resilience as understood by Pelling (2011) seems to be strongly linked to the concept of coping capacity, able to respond adequately to climatic events. Transition, on the other hand, involves questioning development goals and how problems are framed, and could be exemplified by a community or interest group blocking a development project that could decrease coping capacity and increase vulnerability to climate change. In this way, Pelling's concept of transition seems to be similarly linked to the concept of adaptive capacity, in looking forward at long-term growth and development trends that can be changed in response to climate change. Finally, transformation refers to irreversible fundamental change, in which shifting development paradigms and recognition of vulnerability and adaptive capacity are integrated into planning mechanisms, development schemes and political discourse. The three stages are taken to be inter-related and can occur on multiple scales, in which changes on certain levels may either drive or constrain change on others.

Other elements related to both adaptive capacity and coping capacity that must be discussed are issues of scale (Adger, 2005; Few et al., 2004) and the concept of social capital (Adger, 2003). Regarding scale, it is important to understand that adaptation to climate change means different things and implies different kinds of actions depending on the scale of application. From individuals and families, to communities, private sector organizations, municipalities, regions and countries, the development of coping capacity and adaptive capacity take on different meanings, regarding both the planning and the actions that are required. In addition, actions and plans on one scale can condition, stimulate and limit actions and planning on other scales (Adger, 2005; Urwin and Jordan, 2008). For the same reason, inter-scalar integration is extremely important when performing any kind of adaptation planning, and for the development of more robust coping and adaptive capacities (Few et al., 2004).

It is here where the issue of socio-environmental fragmentation can play a significant role, as certain areas of the city are integrated into an inter-connected network of functionalities, often scaled up to regional and global development models. These areas of urban development often exclude other areas, which are left out of the benefits of inter-scalar integration, often leading to increased social, economic and territorial marginalization, making them increasingly vulnerable to external stressors.

At the same time, in considering the particular social characteristics of actors and organizations involved in adaptation activities, social capital emerges as a very important concept for determining levels of adaptive and coping capacity. According to Adger et al. (2004), social capital is made up of the networks and relationships between individuals and social groups that facilitate economic well-being and security. Adger (2005) distinguishes between different categories of social capital, namely bonding social capital and networking social capital, as relevant concepts in the context of climate change adaptation, in that they develop different forms of horizontal integration. Here, social capital is discussed both on a local scale and on the level of organizational inter-connectivity and institutionality. Briefly, bonding social capital is developed between individuals in a family or community, based on kinship and loyalty, and is strongly tied to the ability to respond to and recover from a crisis (coping capacity). Networking social capital, on the other hand, is defined as the external connections (economic or otherwise) between individuals, communities and organizations, which are based on trust and reciprocity. Often this social capital depends on legal, formal and institutional arrangements, and thus also provides the context for the importance of vertical integration between the state and civil society in developing adaptive capacity (Adger, 2005). In this way, although the capacity of individuals to adapt to climate change is a function of their access to resources, the adaptive capacity of societies depends on the ability to act collectively in the face of the threats posed by climate variability and change (Adger et al., 2004). The issues of social learning and social capital development through vertical integration involving participation in adaptation policy dialogues and creation processes are considered to be essential for the development of long-term adaptive capacity (Collins and Ison, 2009). Thus, while the concept of adaptation and adaptive capacity ranges from technical terms to a field of research with various topics and foci, in the context of climate change, it is important to take the general well-being and livelihoods of people into account. In this way adaptive capacity, as a set of community or society skills, should consider at least issues such as environmental culture and awareness, institutional fitness and strength, citizen participation, and education and analytical skills.

Climate adaptation, in this regard, is an integral part of broader development processes, but in which development occurs by taking changing climate into consideration. Adaptive capacity involves taking how key climate and non-climate drivers of vulnerability are likely to change over a given period of time into account, so that resources can be used more effectively, maladaptation can be avoided, and communities can be enabled to carry out continuous ‘adaptive management’ of their activities. In this way, one essential characteristic of a high adaptive capacity is the linking of climate adaptation into the broader development planning process, not only to avoid parallel processes, but also to negotiate funding for adaptation activities.

4 The case study city – The Metropolitan Area of Santiago de Chile (MAS)

4.1 The MAS – a general overview

The MAS – the national capital and Chile’s economic center – is currently home to about 6.6 million inhabitants (INE, 2002). According to projections, the population will exceed eight million people by 2030 (MINVU, 2008). The MAS is located between the central Andean and coastal mountain ranges, and is characterized by a dry subtropical climate with hot summers and rainy winters. Observed climate trends in recent decades show an increase in median temperatures, a decline in average precipitation rates, a greater number of days with air temperatures above 30°C, and a concentration of rainfall in extreme events (Cortés et al., 2012). Results from regional models predict higher median temperatures for the future and less precipitation as a consequence of climate change as well as more frequent and more intense extreme weather events because of its geographical and natural characteristics (CONAMA, 2006; Cortés et al., 2012). As a result, it is expected that the MAS will increasingly suffer from already existing flood and heat hazards, which frequently affect numerous people, buildings, and infrastructure across the city. In some parts, flooding occurs periodically after heavy rainfalls during the winter, and tends to inundate streets and the ground levels of dwellings. This phenomenon is directly related to intensive imperviousness as a main result of urbanization. Such events bring material losses, but are no threat to human life, as flood levels are generally moderate. Extreme heat is also closely interrelated with land use changes, as some areas tend to experience above average air temperatures during warm, dry summers. Second, it can be assumed that climate change also bears long-term, chronic effects such as water scarcity, which will affect everyday life as well as economic activities in the metropolis and its surroundings. In this context, the question of water supply can be understood as an issue related to the governance of (scarce) water resources rather than a hazard itself: How will distribution of scarce water resources be organized, and who will be affected most by the decrease in water availability? (Swyngedouw et al., 2002; Domènech and Sauri, 2010)

Since the 1930s, the MAS has seen the beginning of an important change into a modern, industrialized city. In the ensuing years, the population of the MAS has grown rapidly due to emigration from Chile's northern and southern regions. The outlying communities, and especially those located to the west, north and south of the city, have experienced dramatic expansion. In contrast, the center of Santiago has slowly decreased in population, leaving space for the development of trade, banking, and government activities. At the same time, the MAS experienced a change of its economic activities from an import substitution economy towards a global economy in terms of exports, imports and foreign capitalization (Parnreiter et al., 2003). Under this economic transition, it has experienced a deep change of its urban form. This change has included rapid horizontal expansion, particularly in recent decades, in which the built-up urban area has doubled from around 330 km² in 1980 to over 600 km² in 2004 (Petermann, 2006).

In social terms, the MAS is a traditionally anchored, polarized and polycentric city (De Ramón, 1978), and serves as a striking example of socio-spatial differentiation processes (Hidalgo, 2004; Sabatini et al., 2010; Kabisch et al., 2012). It is a highly segregated place with a clear pattern between different socio-economic groups dividing the city into the ‘rich’ northeastern municipalities and the ‘poorer’ rest of the city. As a result of economic liberalization, the emergence of new types of housing projects for higher and middle income groups by private developers in formerly poor neighborhoods has induced changes to historical segregation patterns during recent decades (Sabatini et al., 2010). Socially mixed neighborhoods have also emerged in insular parts of the MAS.

4.2 Santiago as a fragmented city

The MAS has experienced dramatic changes to the urban structure and regarding its overall development patterns in past decades, especially as a result of the overarching changes to the Chilean economic and governance systems that took place during the military dictatorship, and which have been solidified during the current democratic era. The strict neo-liberal doctrine that was implemented during the 1970's and 1980's implied a sharp withdrawal of the state from regulatory and planning powers, opting instead for the privatization of most public services and allowing market forces to determine the development of cities. As a result, a powerful real-estate industry became consolidated as the de facto urban planning and development regime, leading to accelerated urban expansion and the creation of new peripheral urban housing developments for middle and lower class segments (see section 4.1). The establishment of these urban 'dormitories' implied lacked connectivity with other residential areas and especially the urban center, and thus with the primary source of labor opportunities and access to services.

The general liberalization of the trade and labor markets in Chile implied important changes to the spatial distribution of economic opportunities, and thus to the socio-spatial distribution of various segments of the urban society. Such changes have been observed in many cases throughout the developing world, as the spatial correlation regarding the economic transformation of production and employment is presented in terms of fragmentation. Such changes also produce an image of the city that is different from the typical center-periphery urban model, under the assumption that, "what should have been expressed as a globalized operability resulted in multiple units, in which there is no longer a single unit for the city as a whole" (Prevot-Shapira, 2001: 38). De Mattos et al. (2005) identify the process of socio-spatial distribution within the MAS by pointing to:

1) A higher degree of social homogeneity in upper class residential districts, with self-segregating tendencies,
2) Tendencies towards micro-segregation and the generation of upper class islands within middle and lower class districts,
3) A heavy decrease in working class districts, and
4) Expansion of commercial and service workers throughout the territory.

The urban and individual impacts of such structural changes are of special interest to research on socio-environmental fragmentation that refers to the spatial interaction of different urban areas that are either directly or indirectly inter-connected. However, in the MAS the priorities for connections are subordinated to the interests of production and consumption. The network of connections responds mainly to links that do not represent a network per se, or 'random' connections that discriminate against some nodes and integrate others (Salingaros, 2005). The process of ongoing urbanization in the MAS over recent decades has generated an unregulated market that determines the distribution of resources, and where investments are made and urban infrastructure is developed, which has resulted in a markedly unequal development pattern within the city (Rodríguez and Winchester, 2001). This structural condition regarding the functioning of the city leads to exclusion through urban segregation and fragmentation among other processes.

In this context, there is a distinction that can be made within the concept of fragmentation, related to the scale and conceptualization of the term. On the one hand, urban fragmentation is associated with the idea of segregation. This approximation considers that the current urban dynamic, including the behavior of the land market, social polarization, and the increase in violence and insecurity, leads to a social separation that is spatially represented and reflected in the emergence of gated communities or other such phenomena. These are transversally distributed throughout the city and it is specifically in these areas where populations from differing social strata come into proximity with each other, due specifically to these new patterns of urbanization (Borsdorf et al., 2006, Sabatini et al., 2010; Welz, 2014).

On the other hand, the idea of urban fragmentation also refers to a more ample process related to the relocating of functional spaces within the city. This process is also strengthened by the tendencies towards expanded metropolization (De Mattos, 2001) and by what has been called urban dispersion, reflected by suburbanization and peri-urbanization (Monclús, 1998; Dematteis, 1998). Under this form of fragmentation, the appearance of financial, business and industrial districts (among others), as well as new residential and cultural "neighborhoods" and commercial centers (such as malls), is considered to represent new spaces of consumption. In the particular case of the MAS, this fragmentation processes can be observed in urban districts such as the Business District of Huechuraba, gated communities in Quilicura, Peñalolen and other municipal-lities, as well as the processes of urban sprawl creating socio-spatial differentiation in traditionally rural municipalities such as Colina.

In the Latin American context, the concept of fragmentation offers an interesting scheme of analysis for systematizing valuable research on socio-spatial processes in cities, as the concept reflects their dynamics within processes of globalization and transformation. Against this background, the result of the aforementioned urban development processes is the transition of Latin American cities from a colonial compact city to a structurally fragmented urban area, an idea and observation advanced by Borsdorf et al. (2006). Nevertheless, for the context of this research we found it valuable to not focus on socio-spatial fragmentation but rather broadening the perspective to socio-environmental fragmentation which is of course somehow interlinked with socio-spatial fragmentation.

4.3 Vulnerability to climate change impacts in the MAS

Especially for Latin America, research on vulnerabilities to climate change effects is motivated by research gaps identified by the IPCC (Magrin et al., 2007) regarding the social impacts of climate change but also by lacking practical response strategies (Krellenberg et al. 2014). In general, it is expected that conditions of vulnerability within cities will be altered due to climate change. The MAS is no exception, as scenarios for the coming decades predict lower medium annual precipitation rates and higher average temperatures as well as an increase in extreme events (CONAMA, 2006; Cortés et al., 2012).

The specific character of the MAS regarding climate conditions, urban expansion, patterns of socio-spatial differentiation, environmental changes etc. plays a significant role when it comes to analyzing its vulnerabilities to climate change impacts. Furthermore, initial linkages between different characteristics can be established e.g. regarding flood and heat hazards, which are in the focus of the present analysis of vulnerability.

In our understanding, urban vulnerability is also strongly related to the local living conditions of the residents of the MAS. While IPCC scenarios indicate that the primary sector in Latin America will be strongly affected by effects of climate change (Magrin et al., 2007: 597), it is specifically this sector that plays a less important role as a source of livelihood and income in urban areas. In the Province of Santiago for example, in 2002 only 1.5% of the economically active population (POA) were employed in the primary sector. In the whole MRS, 97% of the inhabitants were specified as urban population (INE, 2002). Therefore, the present investigation on vulnerability to climate change effects in urban areas focuses on the places of residence within the urban part of the city, and the corresponding factors related to everyday life and living conditions.

Keeping this place-based focus in mind, population growth and housing demand for different socio-economic groups are associated with spatial and functional changes in land use, in particular intensive land conversion from non-urban (e.g. agricultural, natural forests or wetlands) to urban uses (housing, industry and services). As previous research has shown (Ebert et al., 2010) ongoing changes in land use and land cover in the MAS are leading to the loss of environmental services such as storm water infiltration, heat mitigation and biodiversity conservation in certain areas of the city (e.g. in the Andean piedmont). As combined land-use change and changing climate conditions are already today reinforcing seasonal hydro-meteorological hazards such as heat events and flooding, these trends are likely to amplify the intensity of potentially hazardous events. Ongoing processes of urban expansion show strong linkages to hazard generation and exposure for the MAS, leading to exposure patterns that vary according to location and physical housing condition standards (Krellenberg et al., 2013). These hazards are related to high level physical, economic and social damages.

Floods in the MAS frequently affect numerous populations, buildings, and infrastructure across the city. Up to now, vulnerability assessment in the MAS has focused on land use (Müller and Höfer, 2014) and the exposure of residents and dwellings as determinants of vulnerability, showing an uneven distribution of vulnerabilities across the city depending on different types of hazards, socio-economic status and housing conditions (Welz et al., 2014). According to Welz et al. (2014), research on residential exposure to flooding and heat events is not confined to households with a specific socio-economic status or dwellings with specific physical conditions, but rather that such hazards affect all socio-economic categories. Those most exposed to hazards are not found exclusively in the lowest socio-economic strata. Rather, a comparison of exposure likelihood has demonstrated that lower socio-economic strata in the MAS are more exposed to heat, while upper classes are more prone to floods. Notwithstanding these distributional patterns, a large number of households from the middle and lower socio-economic strata were also found to be exposed to flood hazards, indicating that the need for adaptation action is not solely related to questions of exposure likelihood. More specific research on coping capacities and issues of susceptibility to further characterize and analyze vulnerability to flooding and heat has not yet been carried out and is therefore within the focus of the current investigations of the CLAVE project.

Considering the theoretical background and scientific evidence, vulnerability is an appropriate concept for discussing and evaluating risks to the population and possible countermeasures for the MAS. It is expected that the MAS is vulnerable to the consequences of climate change, even if actions were to be taken to confront the various processes of urban growth and climate change, as well as their anticipated effects. Therefore, the establishment of risk management strategies and their integration into local land use and development plans are highly necessary in order to assure sustainable, more socially and geographically stable development, and to reduce the city's overall vulnerability. How this can be enhanced, especially at the local level, is also part of current research of the CLAVE research group.

The research seizes on the previously elaborated concepts and methodologies, and analyzes all three dimensions of urban vulnerability in the MAS, thus closing an existing research gap. It will be an important step forward for case-specific and locally adjusted adaptation measures on a municipal scale, as further insights will be available regarding the susceptibility and coping capacities of people and dwellings exposed to climate change impacts. In this way, the research connected to this project contributes to a more in-depth understanding of which populations, living under which circumstances, and in which area of the MAS, are more in need of adapting. It is the municipal focus and the involvement of local investigations on individual and neighborhood level that adds to the so far more regional focus on the MRS.

5 Methodological framework

For the specific aims of the CLAVE project, a three-stage methodological approach was developed in order to carry out research on the issues of fragmentation and vulnerability to climate change within the MAS[2]. The three stages are the following:

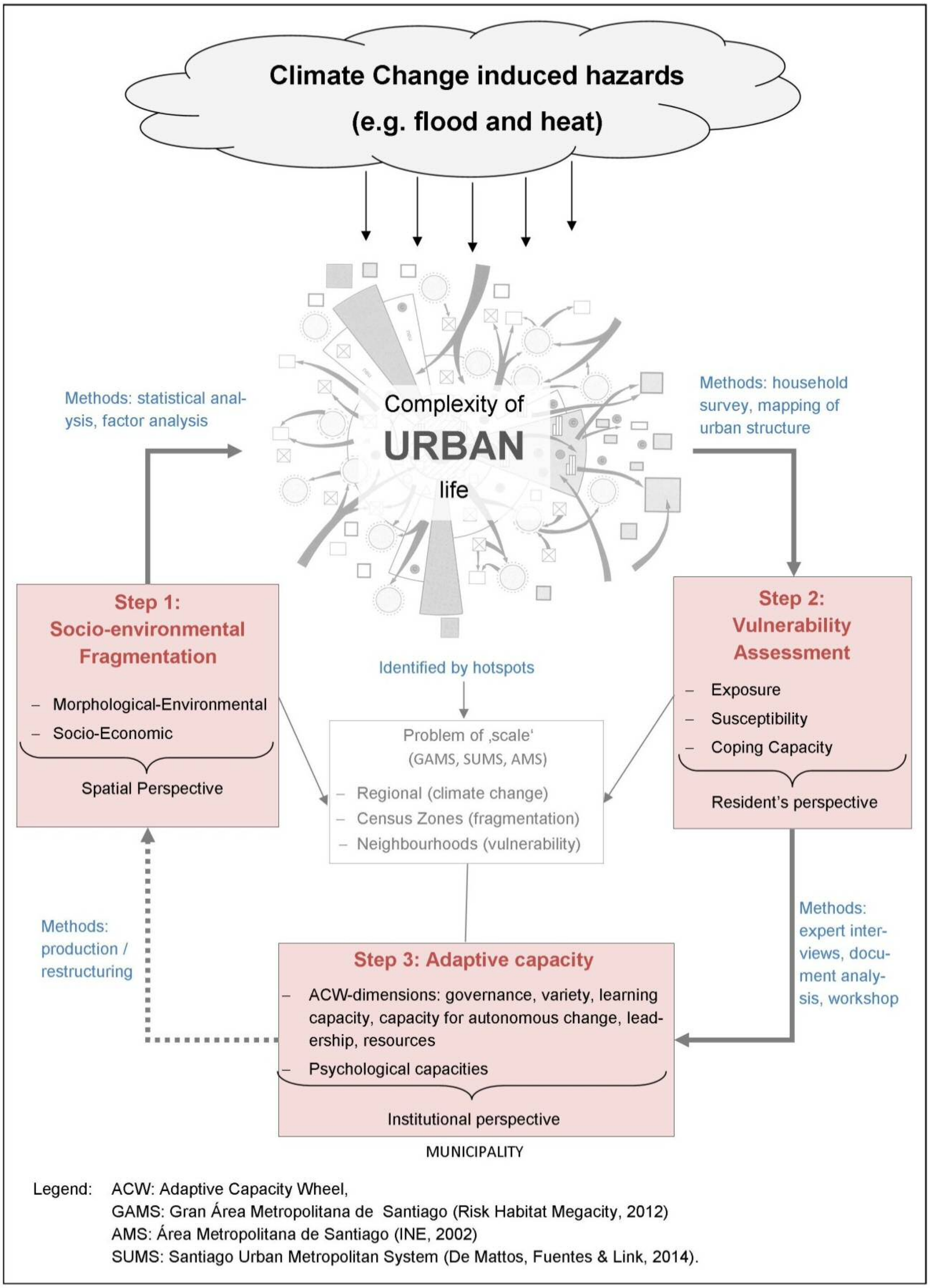
1. Operationalizing and analyzing socio-environmental fragmentation.
2. Assessing residential vulnerability to climate change related hazards in all three dimensions of exposure, susceptibility and coping capacity.
3. Evaluating the adaptive capacity of municipalities regarding climate change.

Each stage includes its own set of specific applied methodologies, with particular scales and elements of analysis, and utilizing both quantitative and qualitative methods of data collection and interpretation such as analysis of secondary statistical data, quantitative household surveys and field mapping in selected hot-spot areas, expert interviews, and analysis of remote sensing as well as Geographic Information System (GIS). Against the backdrop of the theoretical model of socio-environmental fragmentation and residential vulnerability within the MAS (see Figure 1) the proposed three stages complete one another in order to achieve an integrated assessment of urban vulnerability to climate change in the context of a socio-environmentally fragmented urban area.

The initial fragmentation stage contemplates an analysis of the entire MAS regarding different dimensions of fragmentation considered to be relevant for determining socio-environmental forms of fragmented urban areas. Characteristics of socio-environmental fragmentation are considered to be pre-determined elements of urban complexity (in the way that high levels of fragmentation indicate an imbalanced urban structure), which serve as a backdrop for varying levels of urban vulnerability to flood and heat-related hazards.

[2] See Chapter 6.4 on the issue of scale regarding the decision to use the Metropolitan Area of Santiago (MAS) for this stage of analysis.

Figure 1: Methodological approach of the CLAVE-project



Source: Authors.

Using a combination of statistical, spatial autocorrelation and hierarchical classification techniques, certain areas of the MAS that display high levels of socio-environmental fragmentation are to be identified ('hotspot' areas).

Once these socio-environmentally fragmented areas are determined, the residential vulnerability to climate change stage includes a vulnerability analysis of the selected areas on household and neighborhood scale, consisting of exposure to climate hazards, susceptibility to suffer harm as a result of such hazards, and coping capacity to effectively respond to and recover from such hazards. The three dimensions of vulnerability are analyzed in each of the selected hotspot areas, using a combination of quantitative and qualitative techniques in order to achieve a higher level of detail regarding the areas under review that result in varying degrees of urban vulnerability. The techniques include spatial mapping of socio-economic and structural variables on a local scale, a household-survey as well as in-depth interviews and focus groups with local communities and municipal officials.

The third stage, to be developed simultaneously with the second, involves an assessment of the adaptive capacity of the municipalities in which the selected hotspot areas are located. Beyond disaster preparedness and aid responses, this stage seeks to delve into the ways in which local governments and communities are integrating climate change into their development processes, and analyze the potential for more long term adaptation to increasing climate variability as well as climate change related hazards of flood and heat but also more general aspects. This stage utilizes primarily qualitative research methods, including in-depth interviews with key municipal actors and experts.

In sum, the initial stage and a portion of the second stage correspond to the systematization and analysis of secondary, statistical data, while the second and third stages correspond to the collection of primary data in order to understand the residents' opinions, perceptions and daily practices as a function of the variables defined as general indicators of urban vulnerability and adaptive capacity.

As can be observed in the methodological and conceptual model (Figure 2), the MAS is considered to be universally subject (though to varying degrees, depending on specific territorial characteristics) to certain climate hazards, in this case defined specifically as the potential for flooding and heat related threats. The three methodological stages are presented in more detail in the following sections.

5.1 Stage 1: Socio-environmental fragmentation

According to the theoretical concept of fragmentation, two dimensions were defined for the MAS that have significant influence over the varying degrees of spatially fragmented urban areas in the context of climate change related hazards: morphologic-environmental and socio-economic. Those were combined in an iterative process, and subsequently named **socio-environmental fragmentation**. The process contemplates the following specific research objectives:

1) Definition of indicators of socio-environmental fragmentation.
2) Definition of areas of socio-environmental fragmentation within the MAS.
3) Definition of hotspot areas according to socio-environmental fragmentation and exposure to flood and heat hazards.

In order to complete these specific research objectives, the analysis of socio-environmental fragmentation involves a) an analysis of secondary, quantitative data related to the social and territorial structure of the MAS, b) collection and combination information on socio-environmental fragmentation, and c) consideration of their various dimensions and variables. A set of variables was identified in terms of its relevancy and data availability regarding the morphologic-environmental and socio-economic dimension of fragmentation (Table 1).

For quantitative analysis, the National Census of Population and Housing of 2002[3] is employed. In Chile, census data can be disaggregated by different spatial scales (e.g. municipality, district, census zone, and block). In this context, the census zone is defined as the priority scale of analysis, as in terms of total area and population it is the scale that is most similar to a ‘neighborhood’ level as a category of analysis. During the initial stage of analysis the block level will not be utilized – despite the fact that it is the most detailed scale of analysis – as such a scale of analysis leads to an exceedingly high degree of dispersion and variability regarding the information to be used for analysis of the MAS. In the MAS there are approximately 55,000 blocks, meaning that differentiation at this scale is high and becomes difficult to determine varying degrees of socio-environmental fragmentation. On the other hand, there are 343 census districts in the MAS. Although this number is considerably higher than the number of municipalities (34), this scale is not capable of providing a clear distinction regarding internal differences within the territory. In this way, the census zones of the MAS (of which there are 1,125) represent a spatial division that is adequate for evaluating the distribution of different variables in order to determine differing degrees/levels of fragmentation.

[3] Data from the most recent 2012 census might be utilized, once they are available for public access.

Table 1: Fragmentation dimensions and variables

Dimension	Variable	Description
Morphologic - Environmental	Physical housing conditions (COFIVI)	The COFIVI (Physical Housing Conditions Index) is an index of material housing quality. It takes the materials used for roofing, flooring and walls into account, as well as the type of sanitation (WC) and water supply. It is weighed differently in rural and urban areas, to reflect different standards (Welz et al., 2014). The data is derived from the 2002 Chilean Population and Housing Census (INE, 2002).
	Distance to emergency support services	Based on the centroids of the polygons for each census zone, in which the distance to the emergency services represents the spatial separation between the centroids and the closest point that can be associated with emergency support services. These are understood as units oriented towards providing support services to society in situations of risk and disaster, and in this particular case both police and fire stations were considered.
	Distance to health services	Similar to the methodology for calculating the distance to emergency services, here the distance between the centroids of the census zones and the nearest medical and health centers was calculated. Health services is understood here as clinics, hospitals, health centers, health consultancies and emergency health services.
	Distance to supply centers	Centroids of each census zone were calculated, thus attaining a geometric center for each polygon. Afterwards, the distance was calculated from each centroid to different points representing supply centers. Supply centers were considered as: open air markets that operate more than twice a week, supermarkets, commercial centers and malls. The final value defined for each census zone represents the minimum distance between the centroid and the closest supply center, determined based on exploratory statistical analysis, utilizing the standard deviation as the operation to generate the divisions.
	Accessibility to main streets	As in the case of the distance to supply centers, this was performed by using the centroids of the polygons for each census zone. The main avenues were obtained from the coverage of Open Street Maps, and the streets that are categorized in the two most important categories were selected. In this way, it considers highways, avenues, and main streets. The distances represented are between the centroid of the polygon of each census zone and the closest highway, avenue or main street, which is represented by a line.

	Number of public transportation stops per inhabitant	It was decided not to work with the total number of stops, and instead to normalize this information based on the number of inhabitants (from the 2002 Census) in each zone, in order to have an estimation of total transport demand.
	Vegetation cover	Information compiled based on a Landsat satellite image from 2010, classified by applying a ‘soft’ classification methodology that allows for the identification of the probability that a pixel represents a point with vegetative cover. Each census zone in the MAS was assigned an average probability value regarding the presence of vegetation cover, based on the totality of pixels within each zone. Four categories with equal intervals of 20% were produced, grouping those zones with over 80% vegetative cover together with those that presented between 60-80% cover, due to the scarce number of cases with such characteristics.
	Percentage of impermeable surface area	The same methodology was used as in the case of vegetation cover, thus the sample sites were changed in order to perform a supervised classification. The sample sites represent built up spaces for which reason such areas were easily distinguishable from vegetative cover and bare earth areas. In addition, the same criterion was utilized in order to classify the census zones, though in this case 5 categories were formed, as all of the percentage quintiles had a significant presence of cases.
Socio-economic	Socio-occupational typology	The socio-occupational categories allow for the construction of typologies that correspond to the 9 major occupational groups defined by the International Uniform Classification of Occupations, based on the 1988 version (IUCO-88). This version was utilized by Chile for its 2002 Population and Housing Census. The classification consists of a tool for organizing the various types of jobs regarding the tasks implied by each one. Through a description of each job, the occupations are categorized into different groups, the organization of which can be understood hierarchically between those that require higher skills and imply a higher degree of authority and/or autonomy in the work process, and those that do not require much training.
	Population density	An initial division was made based on the average population density in the MAS (141.67 inhabitants/ha), and based on these two categories an additional subdivision was produced based on a distance of one standard deviation from the average. In this way, four categories of population density were formed, in order to categorize all census zones in the MAS.

Source: Authors.

Secondly, the socio-environmental fragmentation analysis contemplates the examination of the previously prioritized variables presented in table 1 by employing a Multiple Correspondence Factor Analysis (MCFA) and a hierarchical classification. This statistical analysis also includes an evaluation of the joint distribution of the variables corresponding to each dimension, in order to observe the most coherent statistical segmentation for the MAS. As a result, six clusters were identified for the MAS that are characterized by the variables included in the composition of the socio-environmental fragmentation (degree of imperviousness, vegetation, physical housing condition, population density and distances to support services) and defined by its corresponding census zones displaying similar average values related to the variables. Table 2 simplifies the calculated values to a basic scale, indicating very high (++), high (+), medium (0), low (-), and very low (--) values for each variable, in order to summarize the basic average values that define each cluster. The percentage values represent the portion of each cluster in relation to the whole MAS. Figure 2 illustrates the distribution of the six statistical clusters for the whole MAS and highlights a first outcome of large-scale socio-environmental fragmentation.

Table 2: Characterization of socio-environmental fragmentation variables

Cluster	Imperviousness	Vegetation cover	COFIVI	Population density	Distance to basic services	% of total MAS
1	-	+/-	++/+	-	0	16.7
2	--/-	+	++	--	+	5.8
3	--	+	+	--	++	7.3
4	0	-	-	+/-	-	24.7
5	+	--	-/--	++/+	-/--	32.6
6	++	--	--	++	--	12.9

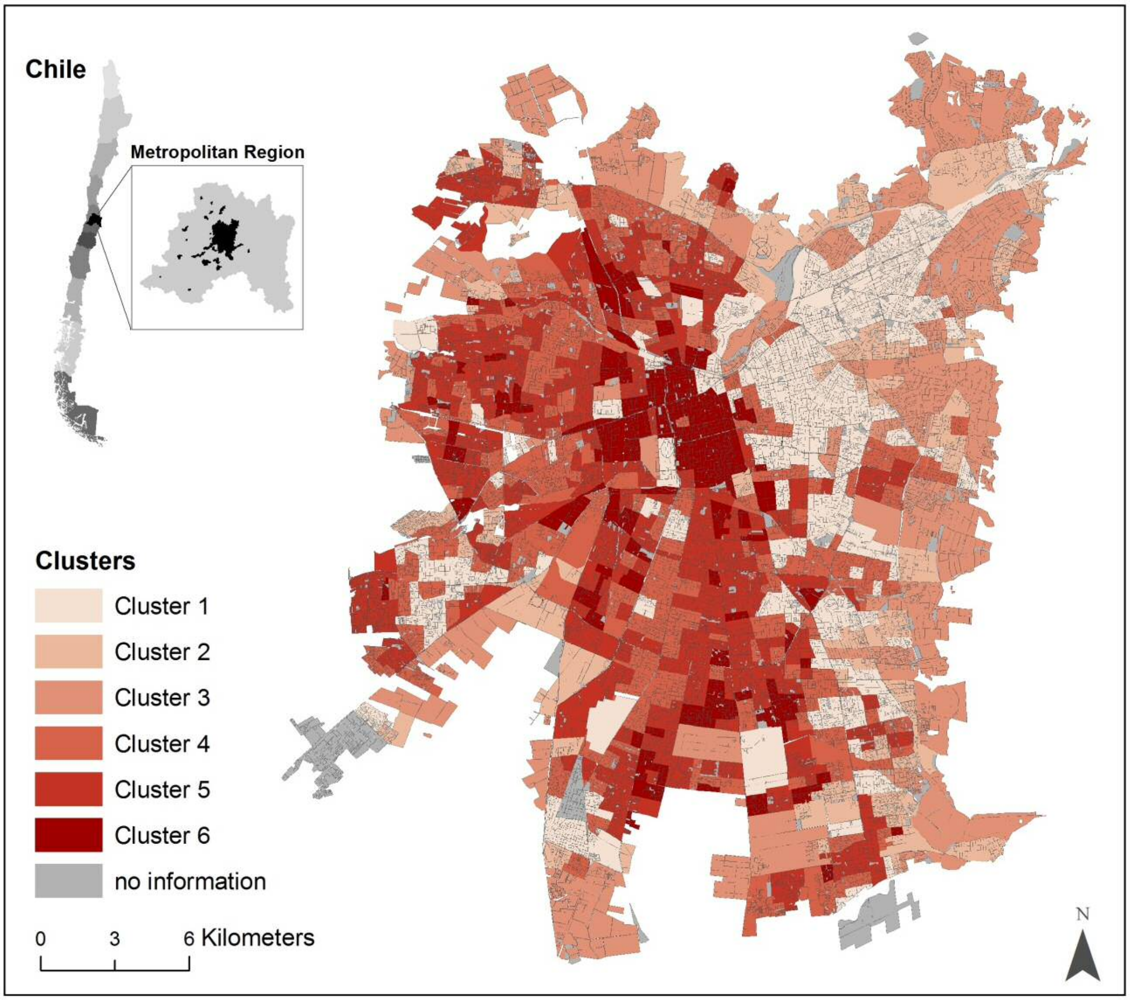
++ = very high + = high 0 = medium - = low -- = very low

Source: Authors, based on fragmentation indicators from various sources (see Table 1).

Cluster 1 represents 16.7% of the MAS and is characterized by low levels of imperviousness and population density, high levels of vegetation cover and physical housing conditions as well as ordinary distances and accessibility to public services. The most representative zones of this cluster are located in the municipalities of La Florida, Ñuñoa and Las Condes (see Figure 2).

With regards to cluster 2, 5.8% of the overall MAS zones belong to this cluster. It is characterized by very low levels of imperviousness and population density as well as high levels of vegetation cover and physical housing conditions. In contrast to cluster 1, the representative zones of cluster 2 are located at the urban periphery in the municipalities of Puente Alto, Las Condes, La Florida and Quilicura which is likewise reflected by the very high distances to basic services.

Figure 2: Six socio-environmental clusters in the MAS



Source: Authors, based on indicators of socio-environmental fragmentation from various sources (see Table 1).

Cluster 3 constitutes 7.3% of the MAS and shows also very low levels of imperviousness and population density as well as high levels of vegetation cover and physical housing conditions. The zones of this cluster are mainly located at the most peripheral urban fringe in municipalities such as Las Condes, La Reina, La Florida and San Bernardo.

Cluster 4 composes with 24.6% a high amount of the MAS and is very different from the before mentioned clusters in terms of levels of vegetation cover and physical housing conditions that are low as well as in terms of high population density. Therefore, the socio-environmental conditions are considered to be inferior to the first three clusters. Cluster 4 zones are representative in the major parts of the MAS, thus particular significant on the municipalities of Maipú, Conchalí, Penalolén and La Florida.

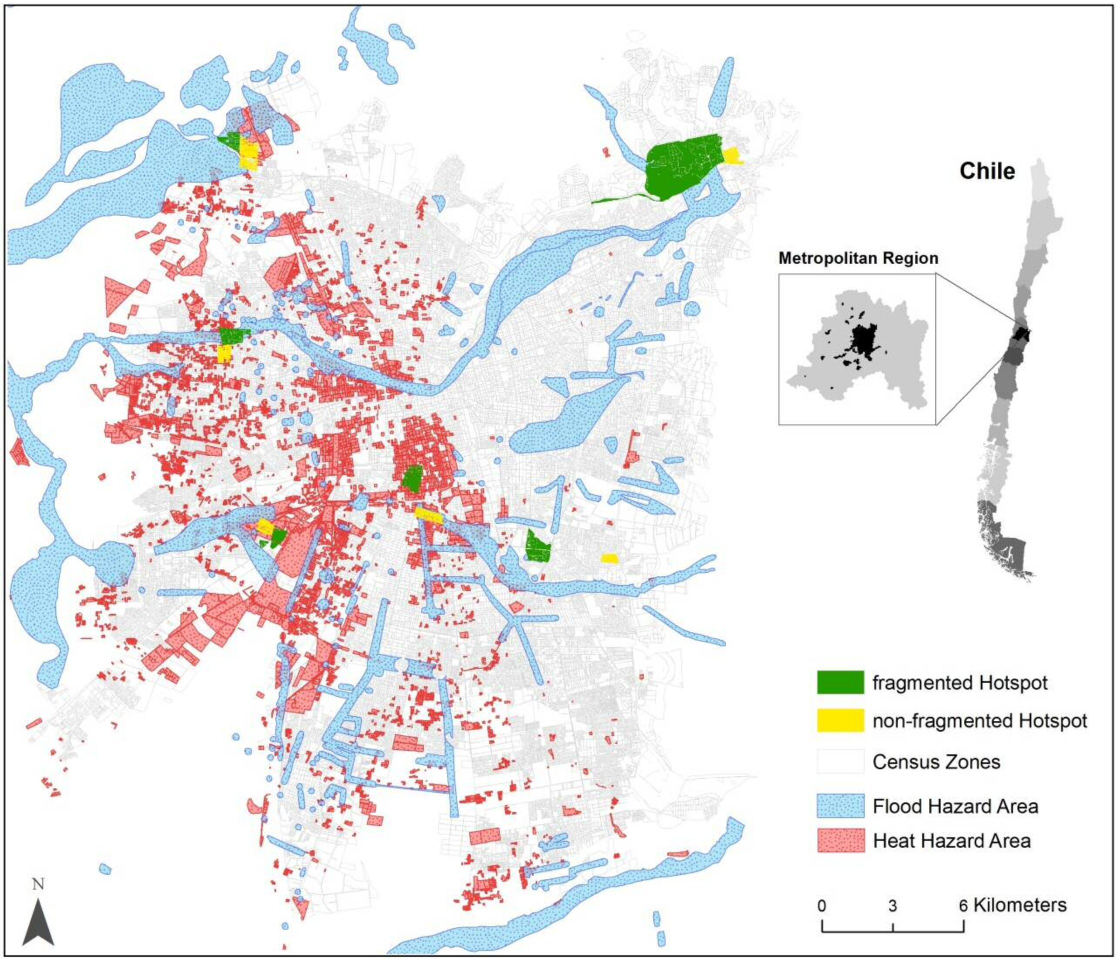
Cluster 5 represents with 32.5% the highest amount of the MAS and is characterized by very high levels of population density and imperviousness as well as very low levels of vegetation cover, physical housing conditions and distances to basic services. The zones of this cluster are located in the northern, western and southern part of the MAS.

Cluster 6 represents 12.9% of the MAS and shows similar socio-environmental conditions as cluster 5 but stands out due to the highest levels of imperviousness. The most representative zones of this cluster are located in the central areas of the MAS (such as the municipality of Santiago) and some areas in the south such as Lo Espejo and Puente Alto.

After the definition of the six statistical clusters of socio-environmental fragmentation, a spatial correlation of these areas with their surrounding spatial units is applied through Moran´s I and LISA (Local Indicators of Spatial Association) in order to determine whether or not these areas are fragmented in relation to their surroundings. Spatial autocorrelation as the concentration or dispersion of the values of a given variable in a determined physical space is used to determine the null hypothesis regarding whether or not a variable is randomly distributed within the MAS, or to the contrary, if there is a significant association of similar or dissimilar values among neighboring spatial units. The design of this index is similar to Pearson´s correlation coefficient, as its value varies between 1 and -1, in which the former implies a perfect degree of autocorrelation (perfect concentration), and the latter implies a perfect level of negative autocorrelation (perfect dispersion). A value of zero implies a completely random pattern of spatial distribution. In order to calculate this index of correlation, it is necessary to define a methodology regarding the spatial vicinity to be used. In the case of the present research, the queen criterion is utilized, as this method allows for a correlation between a particular unit and all of the surrounding units, which diminishes the degree of randomness involved. Spatial association may not occur in the entire city, but rather only in certain areas, for which reason the local LISA indicators are applied through the use of GeoDa software.

Based on the calculation of the spatial autocorrelation, highly and lowly fragmented clusters are identified for the whole MAS. Within the final stage of the socio-environmental fragmentation analysis, specific hotspot areas are selected by considering (i) the degree of fragmentation (high vs. low), (ii) the respective cluster affiliation, and (iii) exposure to hazard such as flood, heat or both hazards. Therefore, in total 12 census zones located in six municipalities (Lo Barnechea, La Florida, San Miguel, Cerro Navia, Cerrillos, Quilicura) are selected as hotspot areas for further research. Figure 3 shows the selected areas, overlaid with flood and heat hazard zones.

Figure 3: Twelve hotspot areas in the MAS including heat and flood hazard zones



Source: Authors; Flood risk: Ayala et al. (1987) (PRMS); Heat risk: Höfer (2013).

5.2 Stage 2: Residential vulnerability to climate change

The second methodological stage is related to the assessment of residential vulnerability to climate change related hazards such as flood and heat. In order to supplement the already obsolete data basis of the last available census (dating back to the year 2012), field mapping is undertaken in all 12 hotspot areas.

The second methodological stage contemplates the following specific research objecttives:

1) Definition of indicators of residential vulnerability to climate change induced hazards within the dimensions of exposure, susceptibility and coping capacity.
2) Assessment of residential vulnerability to flood and heat hazards and evaluation of interdependencies.

While the first stage of socio-environmental fragmentation includes an analysis of the MAS in its entirety, the vulnerability analysis of stage 2 is performed only within the specific census zones identified as hotspots. In order to reach a more detailed level of spatial analysis within these areas, data is analyzed on block level or within a specific neighborhood.

Residential vulnerability to climate change induced hazards related to exposure, susceptibility, and coping capacity is dealt with through the use of empirically collected data such as:

(i) Assessment of the physical-structural conditions of the hotspot areas through field mapping.
(ii) A household survey of a randomly selected sample within the hotspot areas in order to understand the social situation as well as the experience-based knowledge and perceptions of the potentially exposed residents to flood and heat hazard within these areas.

While the former method provides information on the exposure dimension, the latter provides insights into the vulnerability dimensions of susceptibility and coping capacity. The indicators employed by field mapping are visualized by calculating an exposure index showing different levels of flood and heat hazard exposure. Data from the household survey is used to calculate susceptibility and coping capacity indices. The general outcome are three indices that allow for mapping vulnerability in the three dimensions of exposure, susceptibility and coping capacities at a) block level and b) hotspot level, and therefore lead to overall conclusions with regards to residents' vulnerability under socio-environmental fragmentation and flood and heat hazard exposure.

The variables included for the analysis of the socio-environmental hotspot areas of the MAS within the three dimensions of residential vulnerability (exposure, susceptibility, and coping capacity) are presented in table 3.

Table 3: Dimensions and indicators considered for the analysis of residential vulnerability in the MAS

Dimension	Sub-dimension	Indicator	Context
Exposure	Social	Average population density in hazard prone areas vs. non-hazard areas (population / area of hazards)	The denser the population in an area the higher the vulnerability. Climate change will be more destructive where high concentration of people (e.g. larger pressure on water resources, green spaces, more impervious spaces) (Jean-Baptiste et al., 2011).
	Environment	Types of vegetation / land cover types / structure of building use	Depending on the characteristics of the surface, it determines cover, shade, use and therefore the resistance to a flood and heat hazard (Müller, 2012).
		Level of imperviousness	This may indicate the exposure to the hazard, e.g. the higher the imperviousness, the lower the possibility of infiltration in case of flood and the higher the superficial heat storage; surface sealing reduces the absorption of rain water increasing flood incidents.
	Physical	Position of buildings in relation to street level	This may indicate the likelihood of constructions to suffer damage in case of a flood hazard (Ebert et al., 2010).
		Physical housing condition	Describes housing conditions of dwellings, may hold vital information on living standards; indicates the resistance of e.g. walls to damage/preparedness during an hazardous incident; the size of residential units may hold vital information on living standards, especially in conjunction with population figures (i.e. living space or rooms per capita); possible resistance and resilience to hazards.
Susceptibility	Social	Age (children and very elderly)	Elderly are on average more sensitive to heat, risk increases with age above ~50 years, children and babies have a more limited ability to thermo-regulate (European Topic Center on Climate Change Impacts, Vulnerability and Adaptation, 2012). Children who lack adequate family support are at a major disadvantage for disaster response (Morrow, 1999); older people tend to be more reluctant to evacuate (Gladwin and Peacock, 1997).
		Educational level	Years of school of inhabitants; the higher the educational level, the lower the vulnerability as higher educational level contributes to better knowledge about natural extreme events and the ability to anticipate and resist (Müller, 2012; Jean-Baptiste et al., 2011).

		Family / household composition	May indicate the level of support in case of a hazard.
		Physical "problems"	Affecting the ability to respond to disasters; require additional assistance in preparing for and recovering (Morrow, 1999).
	Economic	Employment status (or PEA)	Indicates the regularity of income and the possibilities of a house-hold to spare money for hazard mitigation measures or preparedness (Müller, 2012).
		Socioeconomic status (GSE)	Describes the socio-economic situation of the household; may indicate the degree of welfare; determines the possibility to prepare and cope in case of hazardous events; lower socio-economic status may be more sensitive to heat related mortality because of poorer-quality housing, lack of air conditioning (Cutter et al., 2003).
		Occupation	Whether skilled or unskilled, linked to income and financial status; some occupations, especially those involving resource extraction may be impacted by hazardous events. Workers engaged in agriculture and low skilled service jobs (housekeeping, childcare, and gardening) may similarly suffer, as disposable income fades and the need for services declines (Cutter et al., 2003).
	Environment	Knowledge of hazard warning system, Emergency Plan	Indicates the coping capacity and resistance to hazards; existence of an early warning system or/and emergency plan may counteract feelings of despair, contribute to the life quality of the inhabitants, and may spur to further preventive and mitigation initiatives (Jean-Baptiste et al., 2011; Adger, 1998).
		Occurrence of hazardous incidences (hazard return period)	Indicates potential damage levels.
Coping capacity	Social	Past experience (length of residence and experience with earlier hazards incidents)	Experience with damage has a positive influence on preparedness (Cardona, 2003); the more information available, the lower the sensitivity to a hazardous incident; percentage of people who have experience with flood/heat (estimated based on the duration of residence of a specific household in a flood/heat-exposed area) (Birkmann et al., 2013).
		Preparedness / awareness (flood & heat protection households; insurance)	Level of awareness and knowledge about possible protection measures may diminish vulnerability (Müller, 2012).

		Social network (mutual support)	Existence of diverse social networks provides information on the degree to which there is cohesion of groups in the community, may provide signals of preventive communal action and self-mobilization (Jean-Baptiste et al., 2011; Müller et al., 2011).
		Protection measures (knowledge, existence)	Coping capacity and resistance to hazardous incidents; the existence of a hazard warning system or/and emergency plan may counteract feelings of despair, contribute to the life quality of inhabitants, may spur further preventive and mitigation initiatives (Jean-Baptiste et al., 2011; Adger, 1998); Emergency plans can help facilitating evacuation activities and enhance coping capacities of cities (European Topic Center on Climate Change Impacts, Vulnerability and Adaptation, 2012).
	Economic	Employment status (or PEA)	'Stable' employment status is related to secure income and implies a certain level of preparedness or capacity to take measures against a potential risk → more resilient and better able to cope during hazards (Adger, 1998; Jean-Baptiste et al., 2011).
		Land tenure	Renters often have little autonomy and surplus for mitigation measures, may lack capacities to cope with consequences of a hazardous incident (Cutter et al., 2008; Jean-Baptiste et al., 2011).
		Insurance (for health, building, hazards)	% of residents with insurance reflects the overall level of insured assets (people/properties), degree of preparedness (European Topic Center on Climate Change Impacts, Vulnerability and Adaptation, 2012).
	Environment	Use and perception of public urban green spaces	Parks, green lands, open areas play an important role in the urban environment; green spaces along with their ecological benefits symbolize peace, help reduce stress and provide amenities for a community (Jean-Baptiste et al., 2011).
	Physical	Water supply (N° of blackouts, monthly costs, water use)	Provides information on accessibility and affordability of water being an essential component of basic technical infrastructure; indicates the type of water provision in the household (Jean-Baptiste et al., 2011).

Source: Authors.

5.3 Stage 3: Adaptive Capacity

This third stage of analysis contemplates the following specific research objectives related to the analysis of adaptive capacities of municipalities:

1) Generation of specific dimensions of adaptive capacity within the selected areas of socio-environmental fragmentation and residential vulnerability to climate change induced impacts, through the application of qualitative instruments of data collection.
2) Determination and description of the corresponding levels of adaptive capacity in each selected municipality.

The evolution in research interests on the issue of adaptive capacity since the concept was integrated in the 3rd Assessment Report of the IPCC (McCarthy et al., 2001) has been accompanied by a change in the focus from more quantitative, rigid indicators on a national-scale (for example national GDP as a measure of adaptive capacity utilized in IPCC (1996)) to more qualitative and social considerations on regional and local scales (Smit and Wandel, 2006; Erisken et al., 2011). Smit and Pilifosova (2001) point to the emergence of six general dimensions that determine adaptive capacity, as utilized in the IPCC 3rd Assessment Report: 1. economic resources; 2. technology; 3. infrastructure; 4. information and skills; 5. institutions; and 5. equity. Grothmann et al. (2013) further categorized these determinants into ‘hard social factors’ (economic resources, technology and infrastructure) and ‘soft social factors’ (information and skills, institutions and equity), in which the former are generally more static and difficult to change, and the latter more fluid, easily influenced and susceptible to change. The ‘hard social factors’ are more easily measured by quantitative indicators, while the ‘soft social factors’ are better measured by qualitative instrumentation.

In general, when seeking out a way to operationalize the concept of adaptive capacity, it is important to keep in mind that it responds to changes in economic, social, political and institutional conditions over time, and is thus far more flexible than it is static (Smit and Wandel, 2006). Eriksen et al. (2011) stressed the importance of four main principles when measuring adaptive capacity: i) recognition of the context for vulnerability with multiple and specific stressors; ii) understanding that different values and interests have an effect on adaptation outcomes; iii) the need to integrate local knowledge into adaptation responses; and iv) the importance of considering potential feedback between local and global processes.

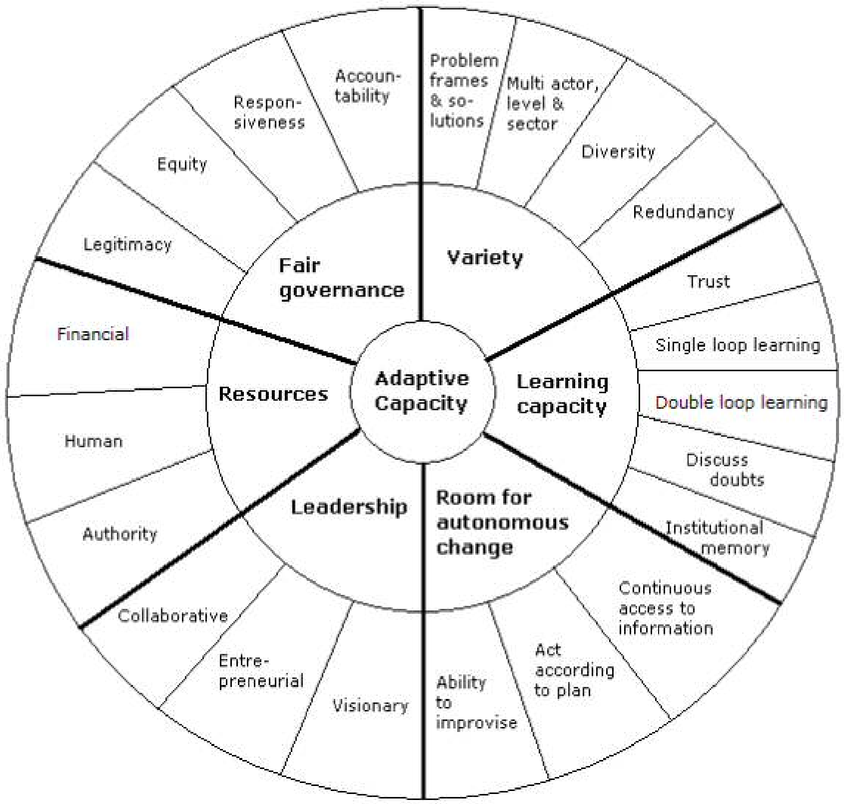
In the context of the CLAVE project, it is considered that the best way to integrate the concept of adaptive capacity, as well as a more robust analysis of coping capacity, is through posterior qualitative research on local institutional, social and socio-territorial conditions within these case study areas, utilizing in-depth interviews with key actors and surveys among public authorities, as well as document analysis of pertinent municipal policies and planning instruments. This stage is designed to determine the degree to which the local systems have integrated (or are in the process of integrating) climate change considerations into their long-term planning and development processes, through a review of local planning instruments and mechanisms, as well as the perceptions of local community leaders and inhabitants. Here it will be sought out to determine the degree to which local systems are setting the needed basis for establishing system-wide adaptation to climate change, beyond mere preparation for specific extreme events.

In order to measure the adaptive capacity of municipalities to climate change, the Adaptive Capacity Wheel (ACW) developed by Gupta et al. (2010) is utilized as a baseline instrument. All of the dimensions and criteria included in the ACW are rooted in a detailed literature review of various authors who have worked on differing approaches to the issue of institutional adaptive capacity. In this way, based on a meta-analysis of various approaches to the assessment of adaptive capacity, the ACW combines the various conceptual approaches into a single analytical tool capable of determining several dimensions. The ACW is designed to assess whether institutions, and laws and/or policy plans, are capable of promoting the adaptive capacity to climate change within society. It reflects on institutional strengths and weaknesses, as well as opportunities for improvement. In this way, the ACW measures the inherent capacity of an institution to respond to change, rather than the effectiveness of the regime in terms of whether climate change related problems are addressed well or not in technical terms (Gupta et al., 2010). It is thus a more generic instrument to evaluate whether institutions enable or inhibit adaptation to change in order to provide an assessment of how they could be reformed in order to increase their overall adaptive capacity to climate change.

The ACW is designed as a series of six dimensions of adaptive capacity (see figure 4), each with a set of sub-criteria to determine both the extent to which municipalities take climate change considerations into account in terms of municipal planning and management, and to which they have developed and acquired certain practices, perspectives and capacities that make them more or less capable of adapting to climate change in the medium-to-long term. The ACW has a strong focus on “soft” adaptive capacity indicators, related to: i) fair governance; ii) variety; iii) learning capacity; iv) room for autonomous change; v) leadership; and vi) resources.

In addition to the original dimensions, a seventh psychological dimension (psychological resources) has been added by Grothmann et al. (2013) that is related to issues of adaptation motivation, priority, and conviction. Based on prior research that has shown that a lack of these elements represents a significant obstacle to achieving adaptation their decision was motivated. Especially in the case of Chilean municipalities it is considered important to include this dimension, as although very few specific climate actions are being developed on a local level, there may be significant differences regarding potential motivation to integrate climate change into municipal activities, as well as differing reasons for not doing so. Both of these aspects can be approached through the inclusion of the psychological dimension, as well as through various criteria pertaining to the other six dimensions.

Figure 4: Adaptive Capacity Wheel (ACW) Dimensions and Criteria



Source: Gupta et al. (2010).

The ACW is applied through a review of pertinent municipal documents (policies, programs, regulations, etc.) and a series of interviews with institutional authorities and officials, in which the semi-structured interview questions correspond to the particular criteria that define each dimension. Based on this information, scores are given for each criterion, regarding whether or not the information provided demonstrates evidence of a positive or a negative impact of the institutional characteristics on fomenting higher or lower degrees of adaptive capacity. A coded and numeric scoring scale from -2 (very negative impact) to 2 (very positive impact) is used (see table 5). In the context of the CLAVE project, this methodology aids in determining aspects of structure, institutionality and management practices of the participating municipalities that are best suited for integrating climate change considerations, and which aspects require modifications in order to be able to operate more effectively.

Table 4: ACW Scoring System

Score 2	Score 1	Score 0	Score -1	Score -2
Institutional structure enhances adaptive capacity for adaptation	The structure exists, and could but is not (yet fully) applied to adaptation	Neutral score (positive nor negative effect expected)	Gap that needs to be filled to counteract negative effect on adaptive capacity	Institutional structure obstructs adaptive capacity for adaptation

Source: after Gupta et al. (2010).

In this way, the methodological approach for measuring the adaptive capacity of municipal governments in the MAS is based on adapting the ACW, together with the seventh psychological dimension proposed by Grothmann et al. (2013), to the context of Chilean municipalities and to the needs and interests of the CLAVE project. This implies the creation of an interview guideline to be applied to municipal actors from different sectors of local management. Questions related to each criterion for the seven dimensions are adopted to the particular focus of CLAVE on specific heat and flood related climate change threats and impacts. As specifically noted by Gupta et al. (2010), the application of the ACW is context-specific, and differing contexts may require changing the relative influence of different criteria over others, or even choosing to leave out certain criteria. Semi-structured interviews are held with officials from various municipal units from the previously defined hotspot municipalities. Agents responsible for the Environmental and Planning units are consulted, as well as the Mayor’s Office. Additional units may include Municipal Works, Emergency Services, Education, and/or Health.

Based on these interviews, the various criteria of the ACW are evaluated and scored, providing clear reasoning for the scores attributed to each criterion. Based on this evaluation, areas of relative strengths and weaknesses regarding adaptive capacity both within each unit and regarding the municipality are revealed, allowing for both a comparative analysis between different units/municipalities, as well as the evaluation of potential actions that could be utilized to heighten adaptive capacity by integrating climate change considerations into municipal operations, planning and development.

5.4 Methodological challenges

One of the most serious methodological challenges with regards to the work with statistical data in the MAS is that the most recent available information on demographics and housing dates back to the year 2002, as the results from Census 2012 have not been released due to technical errors. All indications point to the need to re-do the 2012 census, which implies that this information will not become available in the immediate future. As such, the available information from Census 2002 reflects the MAS as a city that was experiencing incipient processes of expansion, compared to the characteristics that are known today as the result of the intensively conducted field work, household survey, etc. If the new Census is available, there exists an interesting possibility for actualizing or contrasting the existing results with the new data. Until then, the field mapping methodology is an important tool for getting an actualized picture of the situation.

There is also the issue of the correspondence between available digital shape files for GIS analyses and statistical data, which is reflected primarily in two dimensions. When comparing the results of the analysis performed with this geo-statistical information in situ, significant differentiations were identified. For this reason, it is important to exercise caution regarding the validity of the results obtained. On-site field work thereby takes on a renewed level of importance in order to confirm the results.

6 Main conclusions and outlook

This report is compiled in order to present the research approach developed for the CLAVE project, a joint Chilean-German International Research group that focuses on climate change adaptation options in Santiago de Chile and other Latin American megacities. Key to this project is the idea that the two concepts of fragmentation and vulnerability play a major role when it comes to responding to climate change in urban areas. Accordingly, this report presents a theoretical and methodological approach that combines social-environmental fragmentation and residential vulnerability regarding context specific needs for local adaptation options to climate change related hazards of flood and heat.

What is new is the addition of the dimension of fragmentation to the most dominant extent yet regarding the discussion and analysis of urban vulnerability, in order to enlarge the existing database of more adequate response measures. It is argued that the “pre-analysis” of the city as an axis of fragmented areas can strengthen the urban dimension in the vulnerability analysis. In this way, a combination of social, economic and morphological-environmental fragmentation dimensions is used, which goes beyond traditional socio-economic fragmentation variables and allows for considerations more closely associated to climate change related vulnerabilities. Coping and adaptive capacities are considered as two separate but complementary concepts, addressing different scales in a selected urban area.

Within the report, the MAS is presented as the first case study, in which fragmentation and vulnerability to flood and heat hazards are prevailing. The report presents the state of the art regarding knowledge of these phenomena in the context of climate change, and argues that a combination of both fragmentation and vulnerability makes a significant contribution to existing frameworks. Taking this as a basis, the report details the methodological approach for a combined fragmentation and vulnerability analysis. In this context, data availability plays a role when it came to selecting both fragmentation as well as vulnerability indicators. As the latest official statistical data base (“Census”) dates back to the year 2002, field mapping for the vulnerability analysis of exposure represents an important contribution, but requires several prior methodological steps: development of a mapping sheet, field work and the following digitalizing steps. Regarding the analysis of susceptibility and coping capacities, the only reasonable procedure was by conducting a household survey. Both the mapping sheet as well as the questionnaire developed are now available and can be used for other geographical contexts.

What became apparent is that scale is important for developing context-specific urban adaptation responses, as both vulnerabilities to climate change and the capacities to cope and adapt vary at household, neighborhood and municipality level. Whereas the household links to individual coping capacities, the neighborhood level allows for more collaborative activities related to coping with hazards. It is expected that by applying the methodological approach in the selected hotspot areas, information regarding the influence of existing networks and varying level of trust (among other factors) on the coping capacities at the neighborhood level will emerge. Including the municipal level in the analysis allows for conclusions regarding the adaptive capacity of institutions. In this way, it is expected that research results will point to whether or not the overall consideration of temporal and spatial responses to flood and heat hazards can lead to more robust adaptive capacities of the overall population.

After having fully applied the methodological approach to the case of MAS, the results will be used in order to discuss and adapt the developed approach regarding its transferability to other cities. In this context, the general Latin American megacity can serve as a striking example. The findings from the MAS will serve to test to what extent social-environmental fragmentation is a precondition for urban vulnerability, before testing transferability to other Latin American megacities. It will be important to test if the selected indicators are also relevant and applicable in other cities.

Both, the concepts of urban vulnerability (three dimensions: exposure, susceptibility, and coping capacities) and socio-environmental fragmentation (two dimensions: morphological-environmental and socio-economic) still have the potential to evolve further. Developing them further and establishing additional linkages between them represents an exciting research challenge, especially regarding the selection of feasible indicators in the context of the MAS. Finally, the assessment and mapping of these indicators is an important basis for developing adaptation measures. Discussing the strengths and weaknesses of such a combined research strategy not only with local actors but also among scientists and finding a common language for linking the discussed concepts is a challenging task, which is helpful for validating the theoretical approach and can lead to strategies for dealing with future climate change in these and other regions worldwide.

The CLAVE approach ideally will support and provide guidance for any party wanting to set up a similar process regarding climate change management by reflecting on current practices and visions from Latin American actors. Climate change action management is a very complex and complicated endeavor. Legal aspects, technical requirements, political demands as well as environmental, economic and spatial planning aspects must be considered. For this reason, the methodology and information generated by the CLAVE project is of great use to policy makers on both a regional and municipal scale, when it comes to determining relevant urban areas for intervention, and deciding on appropriate actions to take.

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