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ABBREVIATIONS

AUGE	Universal Plan of Explicit Guarantees in Health (*Plan Acceso Universal con Garantías Explícitas en Salud)*
CONAMA	National Environmental Commission (*Comisión Nacional de Medio Ambiente*)
FONASA	National Health Fund (*Fondo Nacional de Salud*)
GDP	Gross Domestic Product
GIS	Geographic Information System
HDI	Human Development Index
IPCC	International Panel on Climate Change
ISAPRES	Institution for Provisional Health (*Institución de Salud Previsional*)
LRP	Local Regulatory Plan
Mideplan	Ministry of Cooperation and Planning (*Ministerio de Cooperación y Planificación*)
MINVU	Ministry of Housing and Urban Planning (*Ministerio de Vivienda y Urbanismo*)
MOP	Ministry of Public Works (*Ministerio de Obras Publicas*)
NGO	Non-Governmental Organization
PNUD	United Nations Development Programme (*Programa de las Naciones Unidas para el Desarrollo*)
SINIM	National Municipal Information System (*Sistema Nacional de Información Municipal*)
SISS	Supervision of Health Services (*Superintendencia de Servicios Sanitarios*)
UHIE	Urban Heat Island Effect

1 Introduction

1.1 Motivation and State of Research

Climate change impacts in the form of extreme weather events are occurring more and more often. Human settlements already have to deal with frequent floods, heat waves and droughts. Due to increasing emissions, environmental degradation and global warming, these phenomena are predicted to gain in frequency and intensity (Dodman 2009:10, Bartlett et al. 2009:6).

In this context, the role of cities becomes increasingly important. For centuries, society is in a process of adaptation to climatic conditions and climatic changes, facilitated by scientific cognitions and technological developments. For the urban architecture this process often resulted in a dominance of aesthetics over functionality at the price of high energy costs (on account of air conditioning and production, processing and use of new materials) (Sanchez-Rodriguez/ Solecki/ Fragkias 2008:4). As cities became the main producer of green house gases, research initially focused on the influence of cities on climate change. Today, it seems that climate change impacts are already unavoidable and focus shifts from mitigation to adaptation issues (Sherbinin/ Schiller/ Pulsipher 2009:130).

Since a few years, cities are increasingly recognised as particularly capable to respond to climate change. Essential features to adapt to climate change, like access to resources, population concentration as well as economic and institutional capacity, are increasingly becoming urban (Sanchez-Rodriguez/ Solecki/ Fragkias 2008:4; Martine 2008:6; Ricardo 2008:18).

However, until today only a few cities incorporated adaptation issues in their local development strategies (Heinrichs et al. 2009:2; Satterthwaite et al. 2009:30). While adaptation must be high on the urban agenda, it might not be clear how this should best be done. Cities are confronted with the task to utilise the potential and advantages in their concentration of population and economic capacity. The challenge is that properly managed urban areas can reduce the risks of extreme weather events for the population, but a poor management can as well increase such risks (Ricardo 2008:18, Dodman 2009.2).

Proper management needs to address the questions, what are exactly the risks, that accompany the hazards predicted for a specific region, who are the people affected by climate change, why are they affected and in which way. A useful approach is the concept of vulnerability. Vulnerability, composing the exposure to a hazard and the adaptive capacity to cope with a hazard, is an agreed concept to evaluate and discuss how people are subject to climate change impacts, as was among others shown by Adger (2006), Gallopín (2005), Heltberg/ Jorgensen/ Bennett Siegel (2008), Romero Lankao/ Tribbia (2009) and Smit/ Wandel (2006).

The poor and socially disadvantaged, while often barely responsible for global warming, have a disproportionate burden of climate change impacts. The IPCC report on climate change of 2001 pointed out the correlation of climate change adaptation and sustainable development and social equity (Smit/ Pilifosova 2001). It can be expected that low income, inadequate shelter, poor access and quality of services and infrastructure and weak social networks influence the degree of exposure and adaptive capacity and thus people's vulnerability. Vulnerabilities to the same hazard are thus distributed unevenly among population groups. The definition of sustainable adaptation strategies should take this into account. A set of studies puts a particular focus on the relationship of climate change impacts and poverty and social inequalities, as did for example ADB et al. (2003), Bicknell/ Dodman/ Satterthwaite (2009), Douglas et al. (2008), Kasperson/ Kasperson (2001), Richards (2003), Satterthwaite et al. (2009), Smit/ Pilifosova (2001), Yohe et al. (2006), and, specifically for Latin America, Hardoy/ Pandiella (2009) and Winchester/ Szalachman (2009). With the growing importance of cities, research also focused increasingly on the urban environment, for example Pelling (2003), Sherbinin/ Schiller/ Pulsipher (2007), or Srinivas (2007), and urban adaptation, as did Barton (2009), Heinrichs et al. (2009), Moser/ Satterthwaite (2008) or Ricardo (2008).

While the mentioned studies supply a broad basic knowledge and an assessment of general urban vulnerabilities to climate change, an identification of the specific local circumstances seems imperative to formulate appropriate risk management strategies: the local hazards and the vulnerability of the people. This was so far done by Roberts (2009) for Durban, South Africa, Mukheibir/ Ziervogel (2009) for Cape Town, South Africa and Revi (2009) for Indian cities. A lot of studies focus on single hazards: floods, sea-level rise, heat waves and droughts. For example, for flood risk, vulnerabilities and risk management, there are among others Faisal et al. (1999) in Dhaka city, Gordon/ Little

(2009) in New Orleans, Pelling (1997) in Georgetown and Szöllösi-Nagy/ Zevenbergen (2005) in London. The results of these studies show that each city has its own risk and vulnerability pattern.

Identifying these patterns seems vital to formulate locally optimized and sustainable risk management strategies that benefit the whole city and particularly those people most in need. Recognizing, via mapping, how vulnerability is distributed among urban locations appears to be necessary for setting priorities in policy formulation. There are a range of studies mapping different hazards in certain regions, as did Eriyagma/ Smakhtin/ Gamage (2008) for droughts on a global perspective, Ebert (2009) for floods in Santiago de Chile, Fernández/ Lutz (2010) for floods in an Argentinean province, Maantay/ Maroko (2009) for floods in New York, or Reid et al. (2009) for Heat Waves in the United States. These cover only a single hazard. Generally, cities are subject to more than one weather-related hazard. This thesis wants to assess all hazards that are expected to occur more intense and more frequently in one region.

1.2 Objective, Research Question and Methodology

The objective of this document is to contribute to the current debate by assessing and mapping vulnerabilities against the climate change impacts, floods, heat waves and droughts in Santiago de Chile.

Santiago de Chile was chosen as a case study for several reasons. While Chile in general and Santiago in particular can be described as one of Latin America's economically most advantaged regions, these regions show at the same time immense social inequalities (Dockemdorff/ Rodríguez/ Winchester 2000:171, Sabatini 2006a:7). It is very likely that Santiago will increasingly suffer from more frequent and more intense extreme weather events in the future because of its geographical and natural characteristics (CONAMA 2009). This raises the question how vulnerabilities are distributed under the conditions of its socially very diverse urban population.

As Santiago offers broad, accessible data on financial, social and territorial information on comuna level, the comuna is chosen as the unit of analysis. In addition, the comuna is the lowest responsible administrative unit for planning and implementation of risk management and adaptation measures. The research therefore intents a comparison of the 32 comunas of the province Santiago, regarding their population's vulnerability.

The investigation is guided by the following questions:

- What are particular impacts of climate change that are expected to occur in the region of Santiago de Chile?
- What are the vulnerabilities of the population and how can they be assessed?
- How are vulnerabilities distributed over the city?

The objected results are vulnerability maps for Santiago de Chile, which show which comunas of the city are the less and the most vulnerable and an illustration of specific vulnerabilities for each comuna.

To answer the questions above requires the following methodology:

The first question on impacts will be answered by looking at the pertinent scientific literature on climate change in Chile. The hazards are listed and investigated in detail: occurrence, impacts and potential risk management.

To address the second question, according to the literature, vulnerability is decomposed in exposure and adaptive capacity. Both are aggregates of indicators. The choice of indicators is derived from the previous analysis of the impacts. The actual values for the indicators will be taken from publicly available statistical data for Santiago de Chile. After standardizing the values to make them comparable, single indicators are summed up into aggregated exposure and adaptive capacity indices. In that way, vulnerability per comuna can be shown.

Based on the indicators developed previously, geographical vulnerability maps are sketched. Different colours indicate the degree of vulnerability. A specific chart per comuna offers a more detailed view and a comparison of comunas with the same degree of vulnerability.

The results of this work primarily address the urban administration and other local authorities. They play a critical role in the adaptation to climate change as many elements of risk management strategy and implementation lie within their assigned responsibility. They can serve as a bridge between the household and national policies (Satterthwaite 2007:3; Heltberg/ Jorgensen/ Bennett Siegel 2008:3). They are the closest administrative level to the household level and communicate and collaborate with regional and national levels. Still, what they need are appropriate political, regulative and financial frameworks. The national level is thus always indirectly addressed, too.

In a highly complex issue like climate change vulnerabilities, completeness cannot be claimed. The analysis presented in this document can be supplemented by more detailed models that require qualitatively assessed or more accurate information, such as GIS (geographical information system) based data. Still, the theoretical discussion and the used methodology can serve as a valuable contribution. The relations between the different indicators that are assumed here, as well as their weighting and the calculation of aggregated indicators is only one possible way and can easily be varied.

In that sense, the analysis and maps provided here should be seen as a first-stage analysis. Based on this work, a discussion of risk management strategies - with a focus on communal authorities - in Santiago de Chile can be initiated. At this place, no actual strategies or policies are reviewed. However, the basic principles and the results of this work can be used to define according policies.

1.3 Structure

Chapter two defines the relevant terms vulnerability, exposure and adaptive capacity and explains the relationship of risk, hazard and vulnerability. It furthermore relates it to poverty and social inequality.

Chapter three introduces the case study Santiago. The first part looks closer at urban and social characteristics and existing inequalities in Santiago's urban landscape with regard to the previous chapter. The second part summarizes national and international predictions for climate change impacts in Santiago. Finally, each of the hazards floods, heat waves, and droughts will be analysed in detail. This analysis is the foundation for the indicator derivation.

Chapter four covers the used methodology in detail. After informing about data sources for the indicators, it discusses and justifies the choice for each exposure and adaptive capacity indicator for each hazard in detail. Next, their weighting and display methodology, both for mapping and a refining analysis and comparison, are explained.

Chapter five subsequently lists the results and groups them into different maps. The maps allow an overview, which comunas of Santiago are the most vulnerable and why. After this broader overview, exposure and adaptive capacity for each hazard and each comuna are looked at in detail, which allows a comparison and the identification of distinctive features of individual comunas.

Chapter six closes with a brief summary and conclusions on the results. It also gives an outlook and a discussion of potential approaches for future work.

.

2 Terminology and Conceptualization

The difficulty with the terms is the absence of one single exact definition of the terms and their relation to each other. Instead, a range of similar notions with different emphasises is used in the pertinent literature on climate change impacts on ecological and social systems. The different approaches will not be discussed in detail at this place. An introduction to the different definitions and references can be found in Füssel`s background note to the World Development Report (2009).

The IPCC, the Intergovernmental Panel on climate change, is one of the most widely used references to climate change impacts in general and vulnerability in particular.[1]. It was established by the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO) and is the leading body for the assessment of climate change. It regularly publishes scientific assessment reports of the state of knowledge on climate change. The relevant terms will therefore be defined according to the IPCC Third Assessment Report of 2001.

2.1 Vulnerability, Exposure and Adaptive Capacity

Vulnerability is "the extent to which a natural or social system is susceptible to sustaining damage from climate change. Vulnerability is a function of the sensitivity of a system to changes in climate (...), adaptive capacity (...) and the degree of exposure of the system to climatic hazards" (Schneider/ Sarukhan 2001:89).

According to Adger (2006, quoted from Gallopín 2005:294), the term stems from natural and social sciences and refers to the condition of an individual, a group or a system of being susceptible to an external accident or stress. In general, it can be seen as "the capacity to be wounded" (Smit/ Pilifosova 2001:894). Chambers (1995:189) describes it as two-sided: an external side as exposure to shocks, stress and risks and an internal side as defencelessness and lack of resources to cope with damage and losses.

Sensitivity[2] is "the degree to which a system will respond to a given change in climate, including beneficial and harmful effects" (Schneider/ Sarukhan 2001:89). The change can

[1]See www.ipcc.ch [21.08.10]
[2]The term sensitivity is defined differently: For Smit/ Wandel (2006) sensitivity and exposure belong together and are dependent on adaptive capacity. Gallopín (2005) in contrast sees sensitivity as an inherent attribute of a system that exists prior to any risk exposure.

be direct or indirect and can affect the system positively or negatively. Sensitivity depends on various factors, such as the extent of change, the degree of exposure to the change and adaptive capacity (Gallopín 2005:300).

Exposure is not specifically defined by the IPCC, but a good definition can be found in Pelling (2003:48): “a product of physical location and the character of the surrounding built and natural environment.”

Sensitivity and Exposure will be summarized into one category ‘**Exposure’** in this thesis. In that sense, the term exposure refers not only to a physical condition, but also to a characteristic inducing high sensitivity, for instance high age as high exposure to heat-related risks.

Adaptive Capacity is “the degree to which adjustments in practices, processes, or structures can moderate or offset the potential for damage or take advantage of opportunities created by a given change in climate” (Schneider/ Sarukhan 2001:89). Adaptation both means to deal with consequences and to mitigate potential damages as well as to exploit opportunities that come up. It can be planned or spontaneous, in anticipation or in response to changes (Gallopín 2005:30).

Another concept that is often used in the context of climate change is **Resilience.** In general, resilience is “a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables“(ibid:298)[3]. The IPCC defines it as “the flip side of vulnerability – a resilient system or population is not sensitive to climate variability and change and has the capacity to adapt” (Schneider/ Sarukhan 2001:89). As this work concentrates on assessing and mapping vulnerabilities, this concept is not used in this thesis. It was nevertheless presented to complete the introduction of terms.

2.2 The Relationship of Risk, Hazard and Vulnerability

As mentioned in above, vulnerability is a function of exposure and adaptive capacity:

- The higher the exposure, the higher the vulnerability.
- The higher the adaptive capacity, the lower the vulnerability.

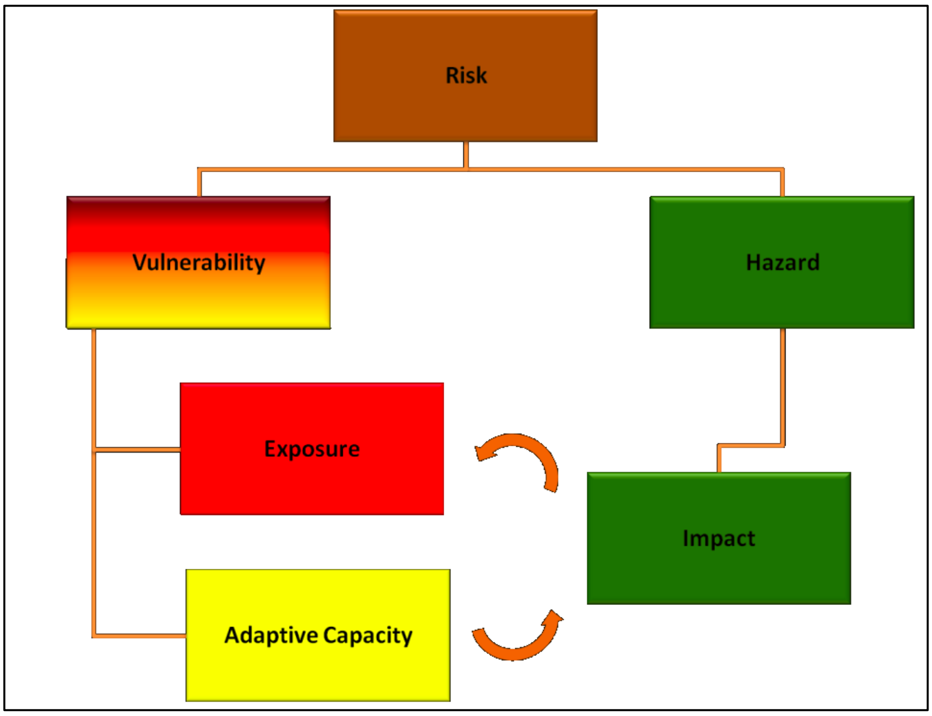
[3]Resilience is not to be confused with resistance. Both a resilient and a resistant system return to a stable condition. Still, a resistant system returns to its original condition and is therefore not changed by external influences, while a resilient system can end in a stable, but completely different condition (Smit/ Pilifosova 2001:894).

Vulnerability therefore is the ratio of exposure and adaptive capacity (Yohe et al. 2006; Fontaine/ Steinemann 2009):

$$\text{VULNERABILITY} = \frac{\text{EXPOSURE}}{\text{ADAPTIVE CAPACITY}};\ V = \frac{E}{AC}$$

Figure 1 illustrates the relationship of risk, hazard, vulnerability, exposure and adaptive capacity. A risk is composed of a hazard and vulnerability. A hazard can have physical or social impacts. Vulnerability in turn is composed of exposure and adaptive capacity. Exposure, adaptive capacity and impacts may reinforce or weaken each other. For example, a poor household with weak networks (low adaptive capacity) that settles near a floodplain (high exposure) could lose all its possessions in the event of flooding (hazard), including its home and may be forced to settle even further in the floodplain area. Consequently, the impact increases vulnerability by increasing exposure and lowering adaptive capacity, making the household even more vulnerable against future impacts.

Figure 1: The Relationship of Risk, Hazards and Vulnerability



Source: Own elaboration

2.3 The Relationship of Poverty and Vulnerability

Poverty is often confused with vulnerability. Clearly, there is a close connection. Most households exist in a vicious circle: their economical poverty amplifies their vulnerability. High vulnerability can mean high capital losses caused by external shocks. Such losses increase the economical poverty and the vulnerability against future shocks. "Loss of [these] assets through environmental factors (…) will cause the income earning capability of the household to fall and lower the range of entitlements to which household members can make claim, making the household and its members more vulnerable to any subsequent everyday or catastrophic stresses or shocks" (Pelling 2003:50).

Still, these two concepts cannot be used synonymously. Not all vulnerable groups are poor and poverty does not necessarily cause higher vulnerability (Moser 1998:3). However, poor population groups have often fewer options to minimize their risk: they have small resources for precautions, security, and recovery. They often cannot lower their exposure, for example by moving into a safer area, or increase their adaptive capacity, for example by using higher quality health care (Coy 2007:16). As Smit et al. (2991:895) outline: "Although poverty should not be considered as synonymous with vulnerability, it is a rough indicator of the ability to cope".

2.4 Vulnerability in the Context of Social Inequalities

Vulnerability is influenced by the various factors that influence exposure and adaptive capacity and is not a static, but a dynamic concept. Social groups can enhance or lower their vulnerability, for example by moving to a safer location, building social networks, investing in health care and the like. This depends on different physical and socio-economic characteristics. Satterthwaite et al. (2009:20) set urban vulnerability to climate change in the "development context". On the one hand, the ability to ease off current risks, to deal with changes and to avoid future risks, is dependent on individual resources like income and social capital as well as information and education. On the other hand, it depends on collective resources, such as social security, quality of infrastructure, services and warning and information systems as well as the ability and expertise of local authorities to drive adaptation measures. Using these resources is dependent on economic growth and above all access – two features that are increasingly becoming unequal (ibid.:20; Sanchez-Rodriguez/ Solecki/ Fragkias 2008:4).

Consequently, vulnerability does not only depend on the availability of resources, but also on the access to resources by decision makers and vulnerable subsectors of a population. If access to resources is distributed unequally, vulnerabilities are distributed unequally, too. In turn, lowering vulnerability via well planned risk management can contribute to equity considerations in urban sustainable development (Smit/ Pilifosova 2001:897, 899).

Nevertheless, adaptation measures often do not reduce the vulnerability of the groups most vulnerable, but of those who can best take advantage of these measures (Adger 2006:277). As Brown/ Damery (2002:423) put it: “Despite the increasing realization that management institutions need to adopt a more socially informed approach in order to develop more successful policies, the means by which this can be achieved is much more difficult to define”.

In that sense, a vulnerability assessment needs to take physical as well as socioeconomic aspects into account. The next chapter looks at social characteristics in the case study Santiago de Chile, which is characterized by remarkable social and spatial inequalities (De Mattos 2005a:28f; Sabatini 2006a:7; Rodríguez/ Winchester 2005:121).

3 Case Study Santiago de Chile

3.1 The 34 Comunas of Santiago de Chile: Urban and Social Characteristics

Chile is considered as a model country for neoliberal reforms (Borsdorf/ Dattwyler 2004:114). The neoliberal transformation under the Pinochet regime (1973 – 1989) stipulated a weakening of the state in favour of its subordination under strong economic players. The strong economy and the impressive growth lead to achievements in the reduction of poverty and unemployment, in the stimulation of demand and the stabilisation of the currency (ibid:122). Today, Chile is the success story of Latin America, based on its macroeconomic growth and its social indicators (Dockemdorff/ Rodríguez/ Winchester 2000:171).

Between 1990 and 1998, Chile achieved remarkable success in poverty reduction: poverty dropped from 38.6 % to 15.4%, indigence[4] dropped from 9.6% to 3.5%. Still, the country shows massive social inequalities. While this is characteristic for the whole Latin-American region, in Chile it's particularly strong and more distinctive as poverty (Sabatini 2006a:7). And while poverty indicators in the metropolitan region are the lowest in Chile, the same region shows highest income inequality (De Mattos 2005a:28f).

3.1.1 Urban Expansion and Administrative Division

Between 1970 and 2002, Santiago almost doubled its area. Population grew in the same time from 2.8 to 5.2 million, thus density did not change much but only decreased a little (Cavieres 2006:98). Nowadays, Chile is beyond the demographic transition[5] and population growth has stabilized on low levels (Riesco 2006:409). In Santiago, migration decreased and invasions[6] no longer exist. Still, the city area keeps expanding in the form of suburbanisation and peripherisation. This is due to the movements of the wealthy households to the suburbs and social housing policies (see below). Santiago is

[4] Poverty lines for the Metropolitan Region in 2006 were defined as 47.099 Chilean pesos (exchange rate November 2006) for poverty and 23.549 Chilean pesos for indigence. http://www.mideplan.cl/casen/publicaciones/2006/CASEN2006-Metropolitana.pdf [21.08.10]

[5] "Demographic transition is the change that countries go through when they progress from a population with short lives and large families (high mortality, high fertility) to one in which people tend to live longer lives and raise small families (low mortality, low fertility)". http://www.unescap.org/Stat/di6launch/session2.3-UNFPA-Regional-Office.pdf [19.06.10]

[6] Invasions are spontaneous land occupancies of informal settlements.

transforming from a traditional single-centre structure (model of concentric circles around the historic centre) to a multi-core structure (Cavieres 2006:99; Heinrichs/ Nuissl/ Rodriguez 2009:31; Riesco 2006:406; Galleguillos Schübelin 2007a).

Administratively, Chile is divided into 15 regions, which are divided into *provincias,* which are divided into *comunas*. “A comuna is a smaller territorial unit with direct forms of governance, which enables a more efficient local organization. Its highest authority is the local Mayor (Alcalde)” (Barriga/ Medina 2004:6).

Currently, Chile counts 54 provincias and 346 comunas. The metropolitan region (Región Metropolitana de Santiago) is divided into the provincias Chacabuco, Cordillera, Maipo, Melipilla, Santiago y Talagante; the regional capital is the city of Santiago de Chile. The metropolitan area Greater Santiago consists of 37 comunas, 32 in the provincia of Santiago, three in Cordillera (C), and one each in Maipo (M) and Talagante (T):

- Cerrillos
- Cerro Navia
- Conchalí
- El Bosque
- Estación Central
- Huechuraba
- Independencia
- La Cisterna
- La Granja
- La Florida
- La Pintana
- La Reina
- Las Condes
- Lo Barnechea
- Lo Espejo
- Lo Prado
- Macul
- Maipú
- Nuñoa
- Padre Hurtado (T)
- Pedro Aguirre Cerda
- Pirque (C)
- Peñalolén
- Providencia
- Pudahuel
- Puente Alto (C)
- Quilicura
- Quinta Normal
- Recoleta
- Renca
- San Bernardo (M)
- San Joaquín
- San José de Maipo (C)
- San Miguel
- San Ramón
- Santiago
- Vitacura

Map 1 gives an overview over the 37 comunas forming Greater Santiago (colours only serve to distinguish the comunas). There is no government authority that is responsible for Greater Santiago in total. "Although each comuna has an autonomous municipality, there is still direct intervention from central government institutions, and the fields and responsibilities of the different authorities are not clearly stated" (Dockemdorff/ Rodríguez/ Winchester 2000:172).

Map 1: The 37 Comunas of Greater Santiago

Source: http://www.newworldencyclopedia.org [16.3.10]

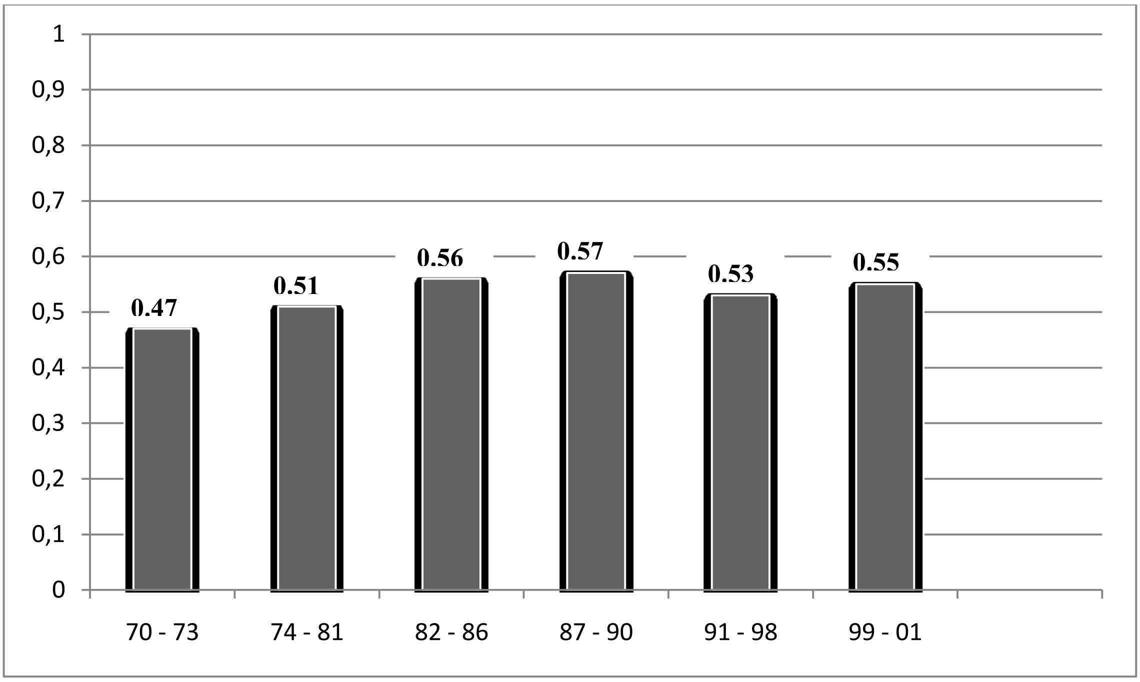
Therefore, the comunas have limited influence on sectoral policies crossing comunas boundaries; important decisions on infrastructure and social development are made by the central government (Dockemdorff/ Rodríguez/ Winchester 2000:172). This is an important fact when it comes to risk management strategies. Other factors that decide over the comuna's ability to manage risks are financial means and the quality of infrastructure and services. A distinctive characteristic of Santiago are the massive socio-economic differences that exist between the comunas. These will be described in more detail in the following.

3.1.2 Social Polarisation and Residential Segregation

Urban structures mirror the characteristics and peculiarities on which the labour market has been established and evolved. Therefore, also the segmentation and polarisation that characterise this market are reflected. The reforms of the military government in 1979 aimed at dismantling the existing institutional arrangements that were considered to be obstacles for accumulation and growth. Instead, major flexibility in the wage ratio should be reached (De Mattos 2005a:27). The period of 1985 – 98 listed elevated economic growth rates. Unemployment rate dropped by almost 50% and average income per inhabitant increased almost 3.5 times between 1986 and 1996. However, in spite of economic performance and intensified social policies, social polarization persisted as the labour market became increasingly precarious and showed a growing segmentation (ibid.). As mentioned before, income inequalities in Chile show their peak in the capital Santiago. Figure 2 displays the Gini Coefficient[7] for Greater Santiago. The index showed a steady increase until the 1990s, and after a short decline, raised again in the end of the 90s. This shows that in spite of the social policy in the democratic period starting in 1990, inequalities are still higher than they have been before the military regime (Riffo Perez 2005:180).

[7] The Gini Index lies between 1 and 100. A value of zero represents absolute equality; a value of 100 represents absolute inequality.

Figure 2: Gini Coefficient for Greater Santiago 1970 – 2001



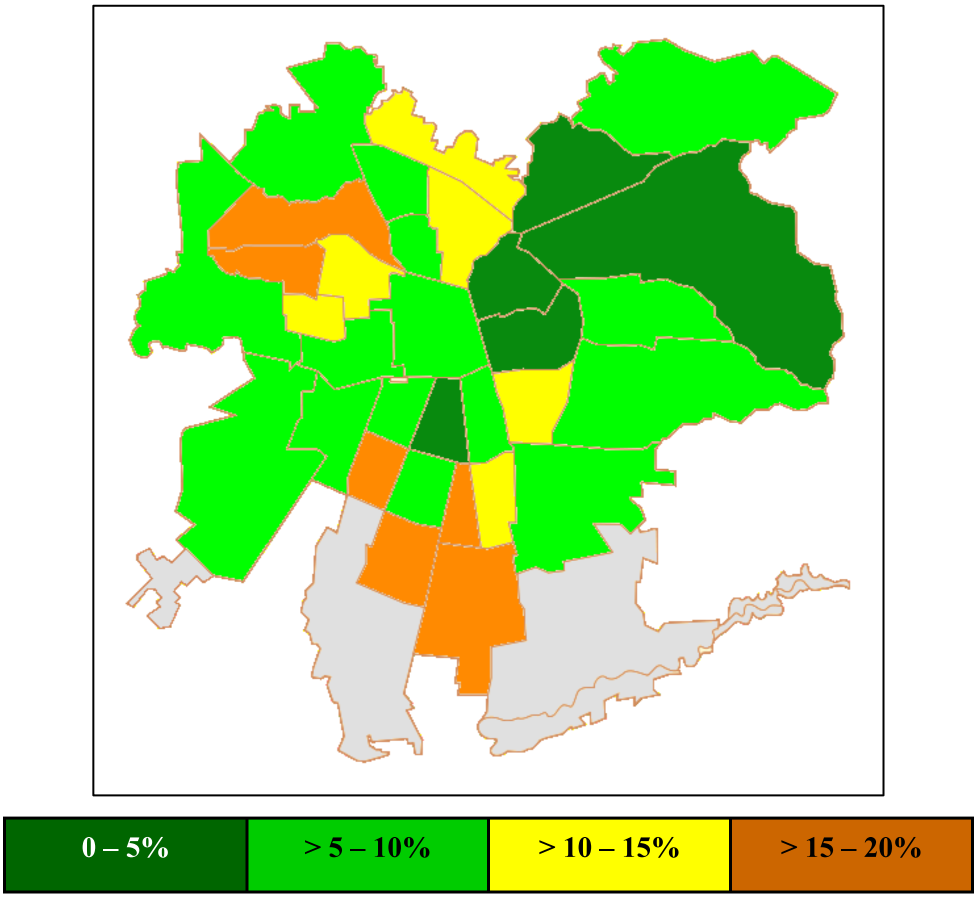
Source: Larrañaga 2001, taken over from Riffo Perez 2005:179

On the whole, spatial distribution of poverty did not change over the years (Rodríguez/ Winchester 2005:121). While the three richest comunas Providencia, Las Condes and Vitacura have poverty levels of around one percent, the three poorest comunas Huechuraba, Renca and Pedro Aguirre Cerda show levels between 32 and 38% (De Mattos 2005a:28). Between 1992 and 1997, income in the four poorest comunas increased by 21%, while it increased by 82% in the four richest comunas (Rodríguez/ Winchester 2005:123).

Map 2 shows the spatial distribution of poverty. In Chile "the current indicators used by the government to measure poverty bring an important weight to aspects such as access to basic services (water, electricity and sewerage) and housing conditions"[8] (Cavieres 2006:105). The areas with the highest poverty levels are characterized by low education levels, underemployment, weak networks and low self-esteem of the residents (Dockemdorff/ Rodríguez/ Winchester 2000:175).

[8] The poverty line is determined by the minimal income per person needed to cover twice the costs of a basket containing food and non-food needs. See http://www.unicef.cl/unicef/index.php/Pobreza [21.08.10]

Map 2: Poverty in Santiago in % according to CASEN [9]2008



Source: Own illustration based on SINIM's data on poverty per Comuna 2008, www.sinim.cl

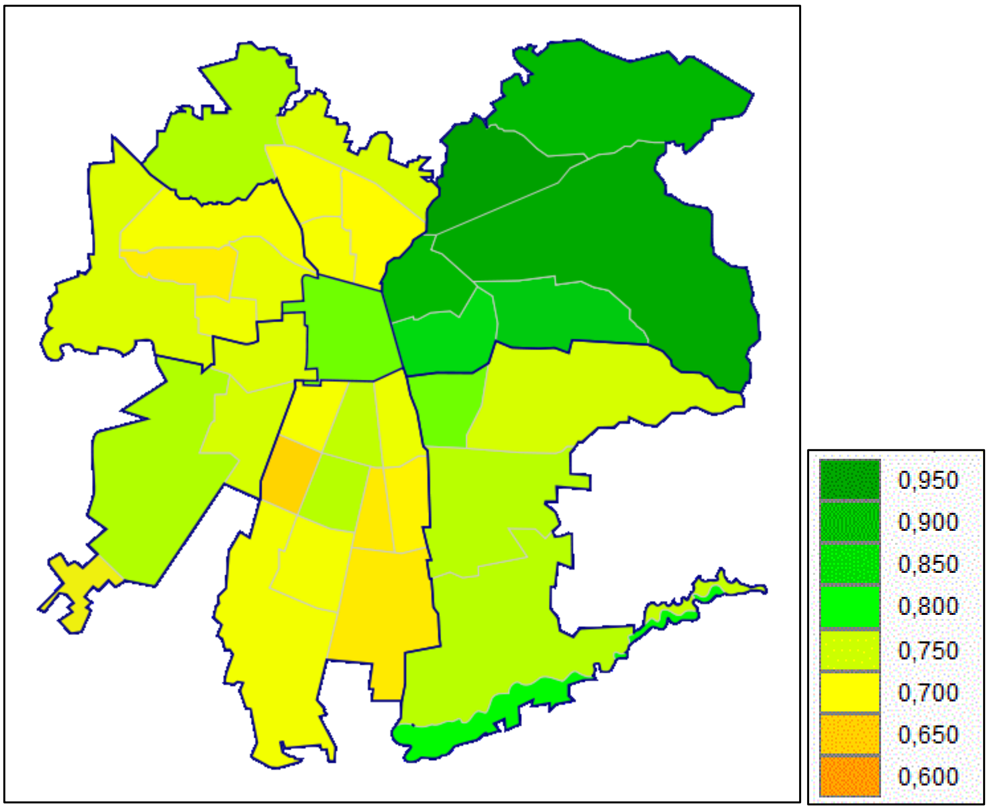
Social inequalities can be measured by the Human Development Index (HDI)[10]. HDIs reach values between 0 and 1. The higher the value, the more developed. The United Nation Development Program (UNDP) developed HDIs on comuna level in cooperation with the Ministry of Cooperation and Planning (Mideplan – *Ministerio de Cooperación y Planificación*)[11].

[9] CASEN is a national survey to assess socio-economic characterization of households in Chile and the impact of social policies and programs on these. See www.mideplan.cl/casen [21.08.10]

[10] The Human Development Index measures development by combining indicators of life expectancy, educational attainment and income. It was developed by the United Nations Development Program, see http://hdr.undp.org/ [21.08.10]

[11] www.mideplan.cl [22.09.10]

Map 3: Human Development Indices for the 34 Comunas of Greater Santiago 2003



Source: PNUD/ Mideplan (2006)

Map 3 outlines that the sectors with the highest HDI are located in a cone starting in the comuna of Santiago and opening towards the northeast. On the other hand, the comunas with the lowest HDIs are all concentrated westwards of the comuna of Santiago. Despite economic growth, poverty reduction and social reforms like the increase in minimum wages, a fiscal reform and higher social spending, inequalities persist. This leads to a perception of impoverishment in the poorer population and reduces capacities to overcome poverty (Rodríguez/ Winchester 2005:125).

3.1.3 Chilean Social Housing Policy

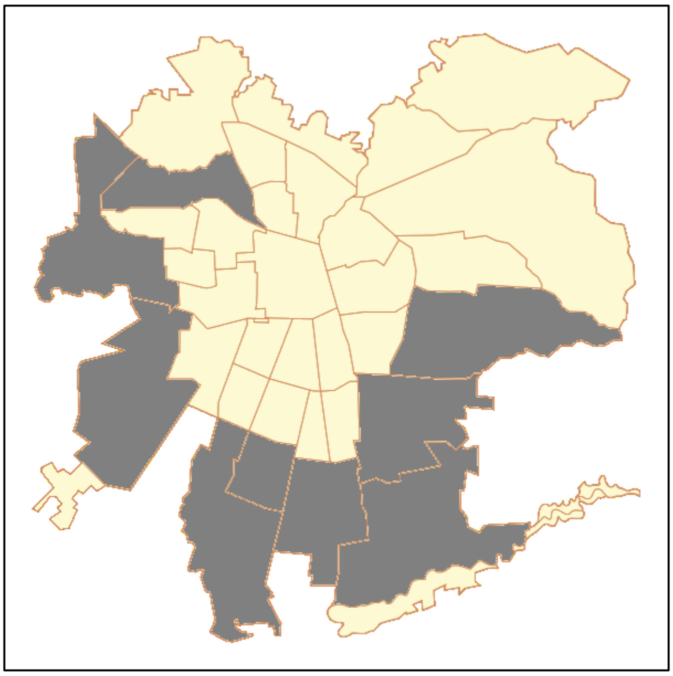
"Chilean housing policy is exemplary. It is meeting many of the goals set by all developing countries, such as bringing an end to the illegal occupation of land, providing housing solutions for all families that need them (including the poorest), and making basic services available to almost the entire population" (UN-HABITAT 2003:128). Despite this praising of the achievements of the Chilean housing policy, the other side of this policy is a reinforcement of segregation.

Segregation is an ancient phenomenon that was exacerbated during the military regime. In the 1960's and 1970's, land invasions (*tomas*) emerged and hence the city area grew faster than the population. Housing increasingly became a political instrument, each government tried to tackle the phenomenon invasion. The rightwing government Alessandri (1958 – 1964) directed the poor population segments to peripheral site-and-service areas. At the same time, large stocks of social housing were constructed, but these were addressed to middleclass and upper lower class households. Under the social-democratic government Frei (1964 – 1970), the Ministry of Housing and Urban Planning (MINVU – *Ministerio de Vivienda y Urbanismo*) was founded in 1965. It should supervise urban development and social housing, water and sewage infrastructure and the road system. The socialist government Allende (1970-1973) considered housing as a right and public provision as their duty. In this time and in spite of economical and socio-political difficulties, the construction of social housing reached peak values (Cavieres 2006:73).

The military government of Pinochet (1973 – 1990) followed a sound policy of socio-spatial homogeneity (*política de homogenización socio-espacial).* Informal settlements were dissolved and the residents were forced to relocate. The poor population was increasingly pushed to the outskirts of the city (Galleguillos Schübelin 2007a:261,267). This exacerbated already existing segregation and the Chilean cities became unique examples of social separation in Latin America. At the same time, the government started a process of municipal restructuring (*proceso de reformulación communal*), which founded new comunas, defined new comuna borders, and shifted a variety of government functions to the comunas (Galleguillos Schübelin 2007b:75). Invasions were rigorously suppressed and the phenomenon of the *allegados* emerged, "people who have to share a home, usually with their relatives, under overcrowded conditions" (Cavieres 2006:77). The social housing stock was expanded, however, in neoliberal tradition it was subject to market forces and it rather raised demand than supply (ibid.). Housing remained unaffordable for many families as the system excluded many households due to a lack of savings and the market did not allow for affordable loans (ibid:78). But, despite of the free market logic, Cavieres (2006:78) cited several authors saying that the Pinochet regime was not completely blind to the social impact of their policies and adjusted subsidies and living standards in a way so that low income families could access them, too.

Residential segregation was thus strategically exacerbated by public urban policy. Social housing was constructed on land with low real estate price, fostering socio-economic homogeneity (Galleguillos Schübelin 2007b:89). Therefore, social housing in Santiago is concentrated in the outskirts of the city, as can be seen in Map 4.

Map 4: Comunas in Santiago concentrating 90% of Social Housing built between 1982 and 2000



Source: Own illustration adapted from Cavieres 2006:96.

3.1.4 Inequalities in the Access to Basic Services

The fact that Santiago's territorial structure is clearly shaped by income, poverty and human development results in marked differences in offered services, infrastructure and housing between the comunas (Rodríguez/ Winchester 2005:121). Socio-economic differences between the comunas have an impact on the revenues of the comunas, which in turn decide on the quantity and quality of services, infrastructure and housing (Cavieres 2006:107).

In general, Santiago shows a good coverage of basic services and infrastructure. However, major deficiencies can be found in the quality of the services offered to the low-income groups (Rodríguez/ Winchester 2005:125). This is best observed in the schools system: municipalities offer free education, which is used by the low-income sectors. But due to a lack of resources, the offered quality is very low, thus not reducing but deepening inequalities. After a cut in public contributions to the municipal incomes, the majority of the municipal institutions suffered severe deterioration in their infrastructure and equipment in the 1990s (Rodríguez/ Winchester 2005:125).

Another observation can be made regarding housing: Due to the often overcrowded conditions per building in the peripheral quarters and the poor quality of the buildings, first residential blocks and subsequently the whole neighbourhood underwent rapid deterioration (Galleguillos Schübelin 2007b:77).

As will be discussed in chapter 3.4.5, the Chilean health care system is clearly dissected along income lines. Chapters 3.5.5 and 3.5.6 will analyze why universal access to water and electricity consumption still polarizes Santiago's population.

3.2 Climate Change Impacts on Chile and Santiago

3.2.1 Climate Change Awareness and Actions in Chile

In the field of climate change, Chile has so far signed and ratified the United Nations Framework Convention on climate change (1992) and the Kyoto Protocol (1997, ratified in 2002). Apart from that, it has become a member of the Inter-American Research Institute for Global Change (1996). In the course of the theoretical frameworks of the UN Convention, a national committee on climate change (*Comité Nacional de Cambio Climático)* was established in 1996. Its first activities were to list emissions and inform about vulnerabilities of the country, concluding that Chile was counting seven of the nine vulnerability conditions mentioned in the Framework Convention (Barton 2009:25). In 1998, the First National Communication on climate change was produced as a diagnostic tool to assess the status of the country (IACC 2006:18). In 2006, the national strategy on climate change that included an action plan was designed under the lead of the foreign ministry. It was presented at the climate conference in Poznan, Poland in 2008[12]. During this decade, the climate change focus lay on mitigation. This was only intermitted by the action plan, which formulated adaptation measures. However, the national information on climate change, published by the national environmental commission (CONAMA – Comisión Nacional de Medio Ambiente) predicts changes in temperature and precipitation, adaptation therefore is vital in Chile.

In the following, risks for Santiago are assessed out of international and national predictions.

3.2.2 International and National Predictions

3.2.2.1 Projected Climate Change Risks in Urban Areas

Implications of climate change cannot be predicted precisely. Apart from uncertainties in the actual change of the climate, there may be various indirect effects. Still, at least in the next few decades, the main impacts are likely to be increased levels of risk from existing hazards (Bartlett et al. 2009:6).

Table 1 gives possible changes and impacts on urban areas. This table gives a good overview, but nonetheless there are large differences between different urban locations in the severity of each impact and the interaction of different impacts.

[12] See http://unfccc.int/meetings/cop_14/items/4481.php [21.08.10]

Table 1: Possible Impacts of Climate Change on Urban Areas

CHANGE IN CLIMATE	POSSIBLE IMPACT ON URBAN AREA
Changes in means	
Temperature	▪ Increased energy demands for heating/ cooling ▪ Worsening of air quality ▪ High temperature impacts exaggerated by urban heat islands in cities
Precipitation	▪ Increased risk of flooding ▪ Increased risk of landslides ▪ Distress migration from rural areas ▪ Interruption of food supply networks
Changes in extremes	
Extreme rainfall/ Tropical cyclones	▪ More intense flooding ▪ Higher risks of landslides ▪ Disruption of livelihood and city economies ▪ Damage to homes, infrastructure and business
Drought	▪ Water shortages ▪ Higher food prices ▪ Disruption of hydro-electricity ▪ Distress migration from rural areas
Heat- or cold- waves	▪ Short-term increase in energy demands for heating/ cooling ▪ Health impacts for vulnerable populations
Abrupt climate change	▪ Possible significant impacts from rapid and extreme sea-level rise ▪ Possible significant impacts from rapid and extreme temperature change

Source: Adapted from Bartlett et al. 2009:6

3.2.2.2 International Findings: IPCC

The IPCC (Magrin/ Garcia 2007:586,588,606) predicts for the central region of Chile for this century a strong reduction in water availability and hydro-electric generation due to reductions in glaciers, as well as a possible severe land degradation and desertification. In addition to that, the *La Niña* phenomenon leads to severe restrictions for water supply and irrigation demands in central Chile. The possible intensification of *La Niña* will add further to water shortages. In the last 50 years, central Chile already showed a declining of 50% in precipitation.

3.2.2.3 National Findings: CONAMA

In Chile, there are three national studies to asset national vulnerability, launched by CONAMA. Two were realized in the first national communication on climate change. The arguments of these two studies were largely taken over from the IPCC in the third and fourth Assessment Report. They evaluated agricultural vulnerability in view of changes in climate, vulnerability of the different forest types considering water regimes and variation in superficial runoffs due to climate change effects. The atmospheric concentration of CO_2 projected for the year 2040 was used as a parameter. The impacts of sea level rise on the population of coastal areas and fish stock were also considered. Important outcomes for Santiago and the central zone are the following (CONAMA 2009):

- There will be restrictions in water availabilities and irrigation demands due to anomalies associated with the *El Niño* y *La Niña*[13] phenomenon.
- Temperatures can rise up to three degree Celsius in Chile's central zone.
- In annual precipitation intensity, changes up to 30% until 2040 can be expected in certain areas of the country. For the central zone, a clear decrease is projected, but with a strong increase in intensity. Thus, rainfall will occur less often but in great intensity, augmenting flood risks.

The third study was carried out by the faculty of physical sciences and mathematics at the University of Chile in 2007. It analyzed climate variability in Chile until the end of the 21st century. It showed that increases in temperature between two to four °C can be expected throughout the whole country. Annual rainfall will decrease for the pacific Andean region, especially in spring and summer.

It can be concluded that the main impacts of climate change for Santiago are changes in temperature and precipitation and the accompanying hazards:

[13] The *El Niño* and *La Niña* phenomena are oscillations of the ocean-atmosphere system in the tropical Pacific. *El Niño* is characterized by unusually warm water temperature in the Equatorial Pacific, *La Niña* by unusual cold temperatures. They both have important consequences for the weather worldwide. For more information see http://www.pmel.noaa.gov/tao/elnino/nino-home.html [19.06.10]

- Less frequent, but stronger rainfalls with consecutive floods and landslides.
- Heat waves and amplification of the Urban Heat Island Effect (UHIE).
- Droughts and water shortage.

So far, Chile's climate risk management is organized sectorally and puts strong emphasis on agriculture, forestry, minery, fishing, energy, biodiversity, health and water. Still, Barton (2009:25) shows that best practice in adaptation plans is an integrated *regional* and *not sectoral* approach. Additionally, focus should shift to urban settlements, as more than 80% of the national population are urban.

The following chapters will take a closer look at occurrence, impacts and risk management strategies of the hazards in general and in Santiago de Chile in particular. With this background, vulnerabilities for Santiago can later be assessed.

3.3 Floods

3.3.1 Risk and Occurrence

Urbanization is one of the processes that most significantly affect the natural conditions of watersheds and hydrological cycles. It alters the natural habitat by making the soil impermeable and compact and thereby alters the natural drainage channels and increases the pollution of water resources. Accelerated growth of purely urban areas has become a problem in cities that are not attentive to the interaction of urbanization and environmental changes (Fernandez/ Montt/ Rivera 2004:1).

Increased vulnerability to floods in cities is explained by different factors: systematic degradation of natural eco-systems increased urban migration, unplanned occupation as well as unsustainable planning and building practices. Douglas et al. (2008:187) describe this special interaction of weather-related and urban factors: "Increased storm frequency and intensity related to climate change are exacerbated by such local factors as the growing occupation of floodplains, increased runoff from hard surfaces, inadequate waste management and silted-up drainage".

To assess flood impacts requires looking at how climate change is likely to influence rainfall patterns and also to examine how urbanization alters flood streams. Increased storm and rainfall frequency and intensity may be related to climate change, but impacts are worsened by local factors such as increasing ground sealing, floodplain occupation and bad-quality drainages. As buildings and impervious cover like roads and parking lots replace trees and natural cover, urban areas face a loss of interception and depression storage, a decrease in potential infiltration and a redirection of flood paths (Douglas et al. 2008: 187f, Fernández/ Lutz 2010:92; Winchester/ Szalachman 2009:16).

Another example of the interaction of factors is: “The populations of towns and cities may be swollen by in-migration from rural areas in times of drought. That drought might be caused by climate change, but the local changes in the city stem from the activities of the migrants as they build homes, compacting the ground and altering the ways in which rainfall collects and flows towards streams and rivers” (Douglas et al. 2008:188).

In general, there are four types of floods that can be distinguished (ibid:187,190):

- Localized flooding due to inadequate drainage (this type of floods occurs in areas with few drains that additionally often get blocked with waste. Ground is highly compact and pathways between dwellings can become streams after heavy rain).
- Flooding from small streams within the built-up area.
- Flooding from major rivers.
- Coastal flooding.

3.3.2 Flood Impacts

Floods can have several impacts on cities depending on their type and intensity. Physical impacts occur in the form of structural damages to buildings and infrastructure as well as in the form of disruption of city life due to interruptions in transportation, power and communication systems. Large scale flooding may also disrupt water supply and sanitation and therefore result in disease epidemics (Parkinson 2003:115f). Health impacts are difficult to establish because of the complexities of disease transmission routes, but “there is considerable empirical evidence to indicate that flooding and poor drainage have a significant impact on the prevalence of illness (...)” (ibid:116).

3.3.3 Flood Risk Management

3.3.3.1 Prediction, Structural and Non-Structural Strategies

Historical data on floods can be useful for prevention and mitigation measures against floods. On the one hand, it gives a scale of magnitude for flood events and shows changes in flood patterns. On the other hand, emergency planning can be based on it, regarding the location of the most exposed areas and evaluating former emergency measures (Coeur/ Lang 2008:646). Prediction is harder to manage. According to Muller (2007:103), while there is a clear picture on global warming and its regional dynamics and scale, predictions of future seasonal rainfall are unclear: “(...) moving from temperature predictions to reliable predictions of seasonal rainfall and its distribution in time is already a big leap”. Also the effects of climate change on available water resources are difficult to foresee as they are influenced by different factors: water evaporating from plants due to higher temperature lessens water flows into rivers. Heavier precipitation instead increases water flows. Changes in plant cover (due to carbon dioxide concentrations, temperatures and rainfall) affect the behaviour of rainwater (ibid.). Still, what can be predicted is that “changes in temperature and rainfall will usually be amplified in the response of water resource systems, with relatively small (10-20 per cent) changes in rainfall leading to large (up to 75 per cent) changes in perennial stream flow” (ibid.:104).

Flood and storm water management measurements can be divided in structural and non-structural strategies. Structural strategies are physical interventions and investments in engineered infrastructure for improved drainage. Non-structural strategies are measures that aim at behavioural changes for preventive action (Parkinson 2003:120). Best risk management is achieved by a combination of structural and non-structural strategies (Douglas et al. 2008; Parkinson 2003; Fiselier/ Oosterberg 2004).

Non-structural measures include flood forecasting and warning systems, development of a flood evacuation system as well as land use regulation, including flood zoning (Gordon/ Little 2009:43). Faisal et al. (1999:149) underscore the importance of non-structural measures next to structural measures in a study on flood risk management in Dhaka: “(…) experience from previous floods (…) indicate that many factors that contributed to increasing the flood damage were related to non-structural aspects of flood management”. Douglas et al (2008:1999) were interviewing residents of five flood prone African capitals about imagined or desired adaptation measures, and came to similar conclusions. Next to the construction of well-designed drainage systems and proper waste disposal, the interviewees stated education, advocacy and sensitization of the community, enforcement of municipal laws on planning and urban design, construction of planned new houses and future development of infrastructures like access roads and bridges along the riverbank.

Structural flood risk management measures concentrate on flood barriers and adequate drainage systems. Fiselier/ Oosterberg (2004:6) investigated adaptive measures in nine

European countries[14], and discovered that technical measures still form the backbone of flood prevention, non-structural measures receive less attention. Næss et al. (2005:126) investigated flood risk management in Norway and see local power structures and limited social learning at the municipal level as a reason for the one-sided approach.

One major problem that frequently occurs in structural flood adaptation is the different responsibilities: “Public utilities or water companies may have the responsibility for sewerage, whereas road drainage is often the responsibility of the highways authority, and receiving waters may be the responsibility of the local authority or environmental agency. Responsibility for solid waste management is virtually always the responsibility of another department in the municipality (...) Also, hydrological systems are not constrained by administrative boundaries, and effective area drainage planning requires careful coordination between the relevant institutions responsible for urban drainage in different areas” (Parkinson 2003:125). As it is hard for municipalities to take coordinated action, the city government plays an important role as a coordinator (see Douglas 2008:202f).

In extreme cases, measures are taken at the national level. State level willingness to provide finance and support in emergency cases is per se a good thing. However, on the one hand it can lead to a misperception “that large-scale flood events are outside the responsibility of municipalities and that damages should be covered by the national government” (Næss et al. 2005:135). On the other hand, it can lead to a rapid implementation of unsustainable measures, resulting in “an ‘event-driven’ pattern of responses where consequences of the measures were not thoroughly assessed before implementation” (ibid.). This is confirmed by the New Orleans flood study by Gordon/ Little (2009:43). They mention that a possible dilemma can occur when areas are protected by publicly funded flood works. An expectation of total protection may arise and the illusion that individual risk has been minimized or eliminated may occur. In New Orleans, “(...) the federal flood protection program facilitates losses that would not otherwise occur and creates a climate of “moral hazard,” where people are less likely to purchase insurance or take other mitigating actions on the assumption that someone else will cover their losses” (ibid.).

[14] The selected countries were Austria, Belgium, England, France, Germany, Hungary, Italy, Poland and Sweden. Countries were selected because of flood experiences recent to the publication of the study.

3.3.3.2 Social Dimension of Flood Risk Management

Apart from the incorporation of environmental features into technical coping and adaptation strategies, integration must take a step further and take social aspects into account. For the example of the United Kingdom, Brown/ Damery (2002:3) criticize, that "traditional flood management strategies have either overlooked the important social dimensions of public hazard understanding and vulnerability, or incorporated these factors through inappropriate quantitative measures, such as cost-benefit analysis, when attempting to justify flood defence works or improvements in monitoring and prediction. Instead, there is a need to adopt long-term risk management strategies grounded in an understanding of exposure to the flood hazard, characteristics and patterns of vulnerability, and the relationships between different stakeholders in the perception of flood risk" (ibid.).

Flood maps can identify groups most at risk. These maps should include social vulnerability and resilience factors, because even inside a certain city area, risks are not divided evenly. "The socially and economically vulnerable, particularly if they have limited or no social support structure, may bear additional burdens than 'mainstream' or more affluent population when exposed to identical physical phenomena" (Maantay/ Maroko 2009:112). Some groups may be disproportionately exposed to hazards, not only because of their location in a high-risk zone or poor quality housing, but also because of a lack of social, financial or political support structures, which stipulates greater relative losses and a longer recovery time (ibid.).

In the following part, the flood risks in Santiago and its underlying urban factors as well as risk management strategies will be explained.

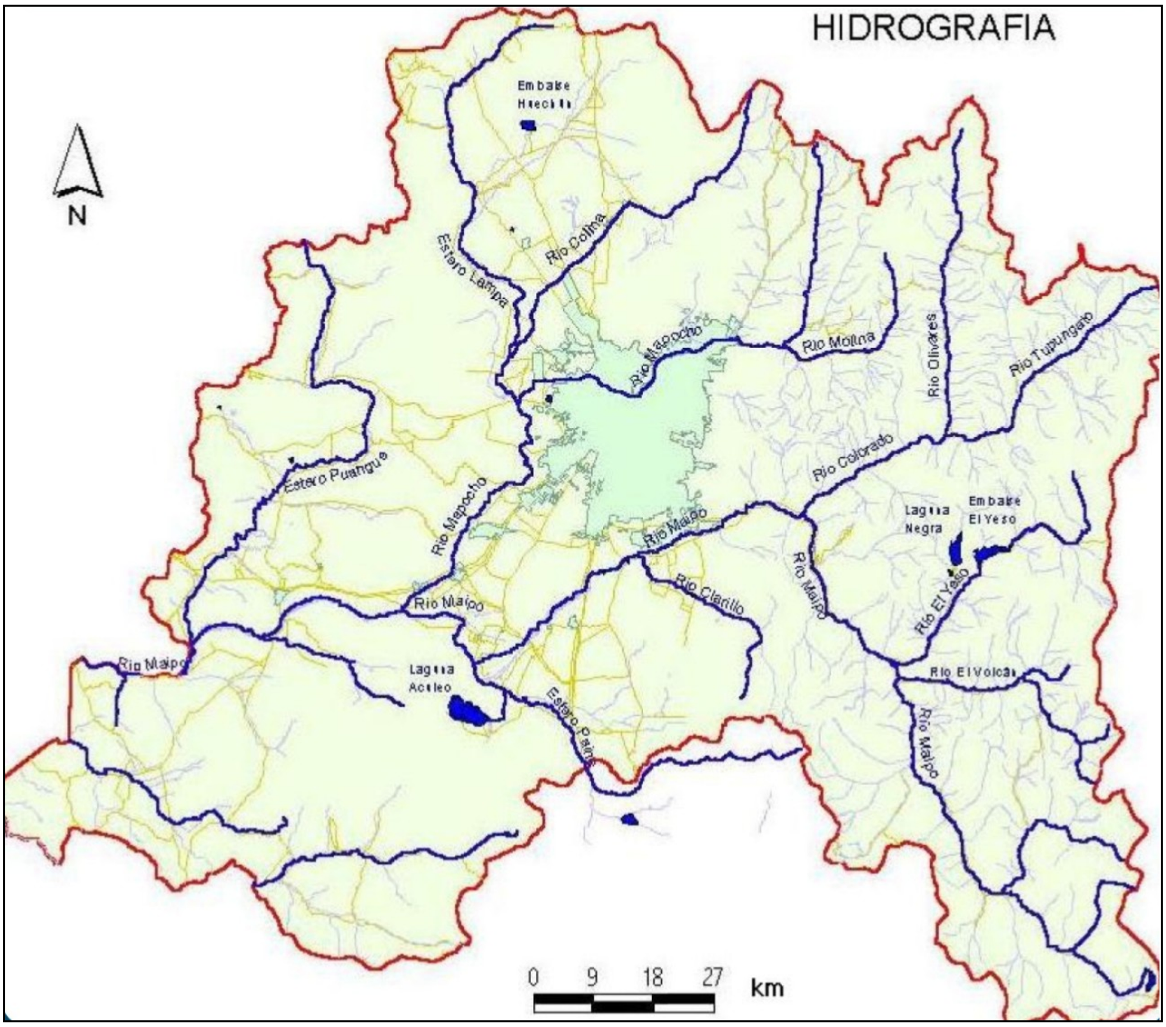
3.3.4 Urban Development and Expansion in Santiago

In Santiago de Chile, floods are occurring regularly, due to a combination of climate, geographical and urbanization factors. The Andean mountains in the east of Santiago function as headwater areas for the hydrological network. In the city there are two main rivers, the Río Maipo and the Río Mapocho, and several smaller creeks and rivers with high sediment fluxes. The city has a Mediterranean climate with warm dry summers and winter precipitation. In the areas above 1500 meters, 80% of annual precipitation falls as snow. The amount itself is influenced by *El Niño*. As the snowline is rising, and precipitation falls as rainfall instead of snow over a growing area, an increasing amount of total winter rainfall can be expected. If storm water infrastructure is not adapted to the increased runoff values due to higher precipitation, flood hazard increases (Ebert/ Banzhaf/ McPhee 2009:3).

As can be seen in Figure 3, the existing water network leads rain water to the main rivers through intermittent streams, thus avoiding the flooding of flat areas. Santiago stretches between the two main rivers and disrupts this network. Due to urbanization processes that did not take natural water networks into account, the rain water is not directed to the rivers, but causes floods in the south and the west of the city, where the poorer neighbourhoods are located (Reyes Paecke 2003:45). The Directorate of Hydraulic Works (*Dirección de Obras Hidráulicas*)[15] has identified 117 flood points in 33 of the metropolitan region's comunas. The most affected zones are situated in Maipú, Cerrillos, San Miguel, Pedro Aguirre Cerda, Lo Espejo, La Cisterna, San Bernardo, La Pintana, San Ramón, San Joaquín, La Florida y Puente Alto.

[15] www.doh.gov.cl [22.09.10]

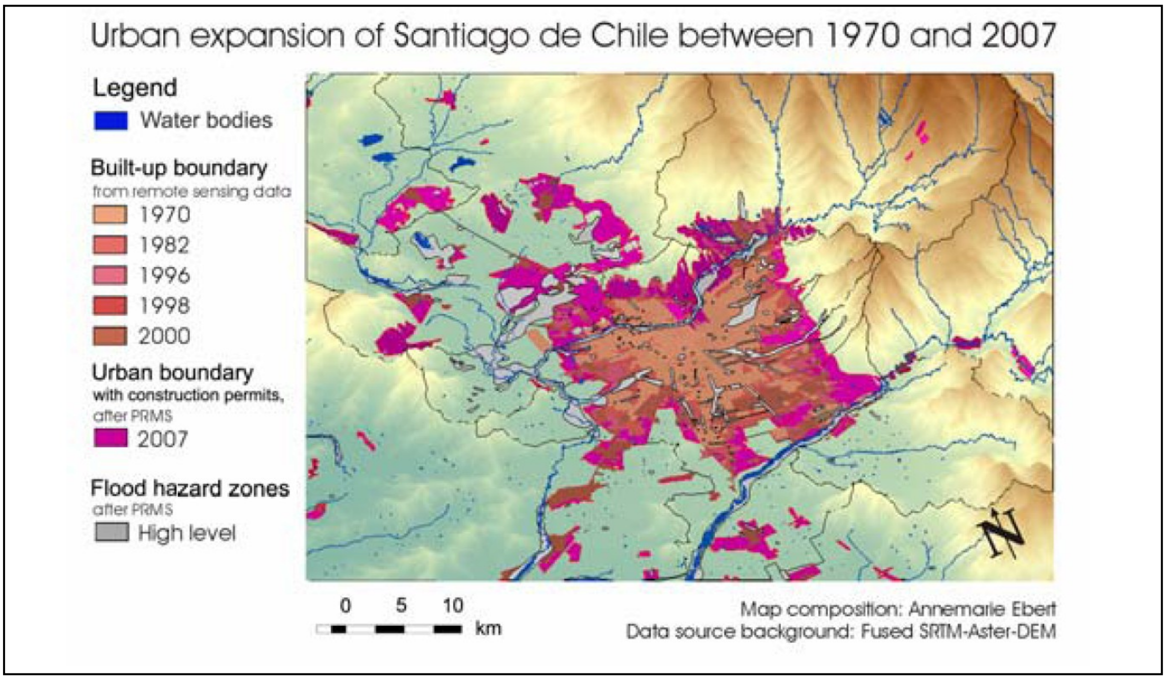
Figure 3: Hydrographical Basin Santiago



Source: Reyes Paecke 2003:49

The city is undergoing a rapid process of urbanization together with changes in land use and urban morphology, both in a planned and in an informal way. Figure 4 shows urban expansion since the 1970s. Between 1991 and 2000, urban built-up area increased by approx. 12.000 ha. Expansion spread in all directions, with residential areas in the eastern parts of the city and industrial areas or mixed use areas in the western and north-western parts. Only 0.2% of the urban growth involved the creation of green spaces accessible to the public (Ebert/ Banzhaf/ McPhee 2009:3).

Figure 4: Urban Expansion of Santiago de Chile between 1970 and 2007



Source: Ebert 2009

The process of expansion of Santiago has been a sum of private property initiatives, public social housing and spontaneous settlements. As different as these forms of urbanization may be, in the case of Santiago, they share a lack of awareness and a certain level of ignorance about the risks involved in the occupation of channels and streams (Ebert/ Banzhaf/ McPhee 2009:3). A possible reason for that could be that due to the dry climate, a lot of the smaller rivers coming from the mountains only carry water periodically during winter time or snow melt in spring (ibid.). Furthermore, former agricultural areas are transformed in urban residential areas, which leads to a reduction of retention areas and a growing amount of sealed surface (Ebert 2009:1f). Surface runoff after precipitation therefore increases and flood zones are developed and expanded in the metropolitan area (Reyes Paecke 2003:48). In recent decades even normal rainfall conditions can cause flood damage (Fernandez/ Montt/ Rivera 2004:1).

Additionally, there has been reluctance in creating new green spaces in recent years, which could infiltrate rainwater and hinder runoff. The three main reasons according to Ebert/ Banzhaf/McPhee (2009:4) are: "(i) not enough resources are foreseen for the maintenance of existing and construction of new green spaces, (ii) the existing green spaces that are open to the public can frequently be found in an undesirably poor conditions (garbage, destruction, etc.) and (iii) private resources from the users of the green spaces are requested for maintenance plus the public resources that are foreseen for the creation of green spaces are allocated to different institutions which do not always cooperate".

3.3.5 Flood Patterns and Flood-Damages in the Metropolitan Region

In June 2002, Santiago experienced massive rainfalls, which lead to the obstructions of major roads, including access roads to the city and some underground railway stations. Schools had to be closed for a week and the city as a whole had difficulties operating. 28 000 people were affected (Reyes Paecke 2003:89). Another example for severe flooding occurred in 2004. In a rainy storm in November 26-28, precipitation in 48 hours equalled that of a whole year. Consequences of the heavy rainfall were: flooding of streets, alleys and pathways as well as landslides leaving boulders on streets, often making them impassable.

Flood damages to houses occur mostly in the zones of Huechuraba, Peñalolén, San Joaquìn and Puente Alto. Associated costs are high, for example for the flood in August 2005, the municipalities of la Reina, Peñalolén and Barnechea had to spent five billion Chilean pesos to repair pavements, lighting and other damages (Carrasco Oviedo 2009:28f). Only the central sector of the city is equipped with rainwater collectors that transport rainwater towards the Mapocho River. Between 40 and 50% of the city are missing collectors (Reyes Paecke 2003:89), above all the sectors in the south and south west, and there particularly in Maipú and Pudahuel (Gutierrez Castellon 2003:46). Figure 5 gives an impression of flooded Santiago.

Figure 5: Flooded Santiago, 2006

Source: www.centroaguasurbanas.cl [21.08.10]

3.3.6 Current Flood Risk Management in Chile and Santiago

In Chile, no national flood prevention law exists. Only in extreme cases a state of emergency is called. Still, the Ministry of Public Works (MOP – *Ministerio de Obras Públicas*)[16] develops rainwater master plans for the different regions that organize the primary net of water evacuation and drainage systems. These plans define the drainage system, propose rainwater evacuation solutions for future situations in the respective area, estimate investments and prioritize networks projects.

The *Plan Maestro de Aguas Lluvias del Gran Santiago,* Santiago's master plan on rainwater management, is primarily concerned with structural measures, but gives complementary non-structural measures (Carrasco Oviedo 2009:95): land use control, regulation of natural and artificial channels, information and education, warning and emergency systems and design of adequate insurance schemes.

As for structural measures, rainwater drainage is considered a public good. Public goods are indivisible, which means that size or availability is not reduced during consumption. And they are inclusive, what means that no one can be excluded from their use. Guiterrez Castellon (2003:44) sees the principal problem that arises around public goods as the question of who finances the provision. Because public goods serve to several people or institutions, there is often a general reluctance to finance, as all parties wait for the others to start. In the case of drainage it is especially complicated as flood waters cross comuna borders and therefore drainage systems benefit to a broader area than just the comuna that installs the infrastructure.

In Chile, rainwater was traditionally treated as sewage water. Impervious surfaces direct water to the streets and through drains that feed the collectors. These collectors are similar to sewage collectors; they are located underneath street level and allow the use of surface land for other purposes (Fernández/ Montt/ Rivera 2004:1). Still, this solution rather treated symptoms than causes and collapsed with increasing urbanization. As a consequence, jurisdiction in the 1990s laid responsibilities for rainwater in the hands of MOP and MINVU. Storm water infrastructure is distinguished in mother collectors, that serve more than on region or comuna, and secondary localized collectors. The mother net is administered by the MOP, the secondary net by the MINVU and the corresponding

[16] www.mop.cl [22.09.10]

SERVIUs (*Servicio de Vivienda y Urbanizacion*)[17]. If new, undeveloped land is to be urbanized, the law says that the owner must provide rainwater infrastructure at his own expense (Carrasco Oviedo 2009: 82). MINVU (2005) published a guide on design and specifications of urban rainwater infrastructure. This guide is oriented at the jurisdiction of the 1990s and should be followed by all SERVIUs. It states specifically, that rainwater infrastructure management involves different parties and that all territorial plans, like the communal regulatory plans (see chapter 4.1.2.1), should be taken into account to reach a coherent solution in harmony with the whole urban landscape.

Methods that are based only on rainwater collection can sometimes exacerbate the problem downstream, as increasing flood flows are created (Fernandez/ Montt/ Rivera 2004:6). In that sense, adaptive measures that are directed at preventing flood water from entering main and business districts can cause water to spread into other areas that are even less prepared (Douglas et al. 2008:188): “More affluent communities often contribute to the flood problem by investing in drainage infrastructure which exacerbates flood problems elsewhere” (Parkinson 2003:118). MINVU’s guide takes this danger into account and states, that measures should be designed as to not accidentally direct rainwater up- or downstream and thereby just redirecting problems (MINVU 2005:2f).

After floods, the next important hazards for Santiago are heat waves.

3.4 Heat Waves, Warm Spells and the Urban Heat Island Effect

Heat related risks are higher in urban areas than in their rural surroundings. Urban areas typically experience higher temperatures based on their site density and ground sealing, the heat island effect. Apart from that, air pollution is typically higher in urban areas and often air pollution intensifies during periods of high temperatures (McMichael/ Githeko 2001:457). This shows the need to establish methods to adapt to continuously rising temperatures and to set up mechanisms for extreme situations. As McGregor et al. (2007:iv) put it: “(...) to date, heat as a natural hazard has been largely ignored”. Especially as there is “increasing evidence that climate change contributes to increased frequency, intensity and duration of heat waves and that climate change will affect the most disadvantaged populations, amplifying social disparities in health” (Bell et al. 2008:797).

[17] www.serviu.cl [22.09.10]

3.4.1 Impacts of Higher Urban Temperatures on Human Health

Several studies examined the impacts of the heat wave in Europe in 2003 on human settlements, economy and human wellbeing. The IPCC (Wilbanks/ Romero Lankao 2007:362) states that it created stress on health, on water supplies, on food storage and energy systems. "In France, electricity became scarce, construction productivity fell, and the cold storage systems of 25 – 30% of all food-related establishments were found to be inadequate (ibid.)."

Higher urban temperatures most severely impact on health. High urban warmth provides not only a preferential site for spread of vector-borne disease, but high temperatures induce heat-related illnesses like skin eruptions, heat fatigue, heat cramps or heat syncope, heat exhaustion and heat strokes (Voogt 2002:5; Schwarz/ Seppelt 2009:2). As an extreme consequence, mortality can increase: "In northern Mexico, heat waves have been correlated with increases in mortality rates, in Buenos Aires, 10 per cent of summer deaths are associated with heat stress; and records show increases in the incidence of diarrhoea in Peru" (Bartlett et al. 2009:17). Most vulnerable are elderly people, as they experience intrinsic changes in the regulatory system and/ or because of frequent medication that interferes with normal regulation (Schwarz/Seppelt 2009:2f).

Vulnerability to heat is influenced by individual biomedical factors, but also by other factors: levels of exposure, underlying medical or biological factors related to age, sex or disease status and/ or access to other amenities (like nutrition, water supply and health care) (Bell et al. 2008:797; Reid et al. 2008:1730). This indicates that vulnerability to high temperatures is divided unevenly in different segments of the population.

IPCC's third Assessment Report mentions some scientific studies that suggest a decrease in mortality rates in winter and argue that this decrease might be greater than increases in summer mortality. Still, it is difficult to assess health risks and mortality that are directly attributable to winter temperatures. "Limited evidence indicates that, in at least some temperate countries, reduced winter deaths would outnumber increased summer deaths. The net impact on mortality rates will vary between populations. The implication of climate change for nonfatal outcomes is not clear because there is very little literature relating cold weather to health outcomes" (McMichael/ Githeko 2001:458).

3.4.2 The Interacting Factor Urban Heat Island Effect

In addition to global warming, urban areas experience another heat-related phenomenon: a higher urban temperature or heat content, called the Urban Heat Island Effect (UHIE). The UHIE is "the characteristic warmth of urban areas compared to their (non-urbanized) surroundings" (Voogt 2002:1). That is mainly caused "due to the anthropogenic heat released from vehicles, power plants, air conditioners and other heat sources, and due to the heat stored and re-radiated by massive and complex urban structures" (Rizwan/ Dennis/ Liu 2007:120). Urban areas often show a lack of vegetation and a high roughness structure that reduce convective heat removal (ibid.)

The UHIE can be a beneficial or a non-beneficial phenomenon, depending on the climate of the urban area. As a positive impact, in temperate and cold climates, the UHIE may reduce heating loads and length of snow cover and may prolong the growing season (Voogt 2002:1,5). Negative impacts of the UHIE, particularly felt in hot climates, are the deterioration of the living environment, an increase in energy consumption for cooling, elevation in ground-level ozone and an increase in mortality rates (Rizwan/ Dennis/ Liu 2007:120).

To mitigate impacts, Rizwan/ Dennis/ Liu (2007:124) conclude that planting and vegetation are the most widely applied measures, "which could achieve huge energy savings through temperature reduction of the area, […] parks could help control temperatures through an evaporation of more than 300% as compared to its surrounding" (ibid). As an alternative option, optimized office building can reduce cooling demand.

UHIEs are not a cause or outcome of global warming (Voogt 2002:1, Shaw et al. 2007:18). However, Voogt (2002:1) sees global warming and the changing climate as "an additional thermal burden to urban areas, accentuating UHI impacts" because "higher urban temperatures can increase the formation of urban smog because both emissions of precursor pollutants and the atmospheric photochemical reaction rates, which produce smog, are enhanced" (ibid.:5). The substantial, UHIE related warming that cities have undergone over the past 100 years shows similarities to expected future climate change. Cities therefore provide important laboratories for assessing impacts and adaptation strategies (ibid.:6).

3.4.3 Heat-related Risk Management

Reid et al. (2008:1730) state that heat-related deaths are preventable. Several cities have implemented heat emergency response plans, and subsequently, mortality has decreased during heat waves. As heat waves will increase with climate change and urban centres often show highest vulnerabilities, municipalities should incorporate heat wave monitoring and warning systems into their emergency planning (ibid.:1736).

A problem that occurs is that elderly people often do not perceive heat waves as a threat. Wolf et al. (2009:46) state that "primary respondents articulated either that they liked and enjoyed hot weather or reported feeling listless and staying out of the sun to avoid sun burn and other effects of UV. (...) the effects of heat on health were not well understood because of confusion about the effects of UV radiation versus the effects of heat". Therefore, not only information on how to adapt should be disseminated, but awareness of warm spells and heat waves as a health risk must be raised. While other cases of adaptation may be more related to natural resource management and policies, "the case of adapting to heat wave risks is related to how health and social welfare institutions are managing and indeed preparing for these risks" (ibid.:50).

Consequently, to understand heat-related risks in Santiago, a closer look has to be taken on urban temperatures and on the health system.

3.4.4 Urban Structure and Temperatures in Santiago de Chile

As mentioned in chapter 3.3.5, during approximately three decades, Santiago experienced a massive expansion of its urban area. The increase in built area and the decrease in green spaces caused a series of environmental impacts for Santiago, particularly on the urban climate and also the creation of the urban heat island effect.

The inner city forms an urban mosaic that is dominated by high density uses. This use is characterized by a high coverage with impermeable surfaces and a low coverage with vegetation; natural coverage is almost exclusively limited to the Andean foothills (Romero/ Molina 2009:3,5). Green spaces and impermeable surfaces influence urban temperature. The loss of natural vegetation produces a negative impact on atmospheric temperature regulation, increasing urban temperatures. These impacts will be even more pronounced as the city continues to expand in a way that does not consider environmental aspects (ibid.:7). The highest temperatures occur in the central business district of

Santiago and extend south of downtown to San Miguel, La Cisterna and Pedro Aguirre Cerda, and in the north extend to the comunas of La Independencia and Recoleta (Romero/ Molina 2009:4).

As heat waves most severely affect health, health care in Santiago will be closer looked at.

3.4.5 Excursus: Chile's Health System

Chile's health system experienced a major change during the Pinochet dictatorship (1979-1990). The health care sector underwent privatization and provision in the public sector shifted towards a market-orientated system. These developments were part of a greater reform that transformed the Welfare State, *Estado de Beneficiencia,* into a Subsidiary State, *Estado Subsidaria* (Dannreuther/Gideon 2008:851f). Important implications were: "it signified a shift from citizens as bearers of social rights to primarily consumers of health care services. At the same time entitlements were dependent on individual earnings rather than on redistributive mechanisms based on collective earnings" (Dannreuther/Gideon 2008:852).

In 1979 the national Health Fund (FONASA – *Fondo Nacional de Salud*)[18] and in 1981, private insurance providers (ISAPRES)[19] were created (Unger et al. 2008:0542). "Two parallel systems of financing and provision now existed with the result that the health care system was deeply segmented with clear differences in quality of care and access to services across different income groups. This dual system created marked inequalities within the health system" (Dannreuther/ Gideon 2008:852). Clients were clearly distributed along income lines: "the mean income of ISAPRES members in 2003 was more than four times higher than FONASA members" (Unger et al. 2008:0542). Subsequently, health indicator improved more rapidly amongst high-income groups and contagious diseases spread in lower-income groups. There was a lack of coherence in state policy and the system did not take into account demographic changes (Dannreuther/ Gideon 2008:855).

Since then, a mixed health system exists in Chile. In 2005, 88% of the population were covered by health care, around 69% by FONASA, around 17% by ISAPRES and around 2.5% by the health care of armed services. ISAPRES memberships declined over the

[18] www.fonasa.cl [22.09.10]
[19] www.isapre.cl [22.09.10]

years due to improved performance by the public sector, unemployment, new health plans (see next paragraph) and the steadily rising costs of private health plans (Unger et al. 2008:0544). This system did not manage to cover an important segment of the population in informal occupations. Special regulations, introduced at 2005, aimed at closing that gap. Legislation was changed in favour of temporary workers, unemployed, indigent groups, dependent family members, and pregnant women (Urriola 2006:277). Still, Urriola (2006:278f) states that the most pressing health problems in Chile today still show marked inequalities, which affect the poor, the less educated and the elderly.

Chile's public health care system guarantees formal universal access to health care. Registered people should not face any exclusion due to age, income, sex or the like. As Unger et al. (2008:0544) put it: "access to care is somewhat equitable, but quality of care is not". Practically, exclusions exist and are manifested in waiting times, quality and pre-required financing (Urriola 2006:279). Under the presidency of socialist Ricardo Lagos (2000 - 2006) a broad health sector reform was started. The Plan AUGE (*Plan Acceso Universal con Garantías Explícitas en Salud* – Universal Plan of Explicit Guarantees in Health*)* intended to introduce a solidarity element into the health system: "The Aim of the Plan AUGE was to remove inequalities in provision and ensure equity in access to health care services, regardless of the type of provider used by people or their income level" (Dannreuther/ Gideon 2008:856f). In 2005, explicit guarantees in health, *Garantías Explícitas en Salud*, were put into practice, meaning that 25 health conditions were to be made available to the people regardless of their affiliation to FONASA, ISAPRES or other. Subsequently, other health conditions were added (ibid.:857).

Dannreuther/ Gideon (2008:858) criticize the Plan AUGE for different reasons. Firstly, as many health conditions are not covered by the Plan AUGE, inequalities between the private and public systems remain unchanged. Secondly, information on rights under the Plan AUGE is distributed unevenly. The Health Superintendence found out, that only 40% of FONASA members are informed about their entering into the system and know about their enforceable guarantees, whereas in contrast, 98% of AUGE patients in ISAPRES were aware of these facts. Dannreuther/ Gideon (2009) and Urriola (2006:280) conclude that while the success of the Plan AUGE remains to be seen, apart from the mentioned flaws, it is an important step in the right direction. "Whilst it is still too early to evaluate the success of the Plan AUGE, it does represent a significant shift in social policy within the region, as many reformers search for an effective way of providing universal social protection. Although transforming social exclusion in the region requires more than just a progressive health programme, the Plan AUGE does offer an important starting point for discussion for promoting more inclusive forms of right" (Dannreuther/ Gideon 2009).

This shows that socio-economic inequities in the Chilean society, as described in chapter 3.1.2 and 3.1.4, are mirrored in the health system. Although access is equal to a broad part of society, treatment and consumption of health services is not, but is divided along income and information. This in turn produces unequal vulnerabilities against heat waves as health care as an adaptive capacity can't be used equally by all. The argument of Bell et al. (2008) and Reid et al. (2009) that the elderly are at greatest risk from heat-related hazards becomes even more valid in Chile, as "clear differences by socioeconomic status were observed for the indigent population aged ≥65 years who under-utilized primary health care services" (Vargas/ Wasem 2006:463ff).

The last important hazards for Santiago are droughts.

3.5 Droughts

"Compared with other natural disasters like hurricanes and floods, drought impacts are the most costly, affect a larger area and are more frequent" (Singh 2006:ii).

3.5.1 Risk and Occurrence

Droughts belong to the hazards that directly affect most people. They differ from other natural hazards in the sense that they are a slow-onset hazard whose beginning often can't be determined (Hayes/ Wilhelmi/ Knutson 2004:107). There is no universally accepted definition of a drought, but "in the simplest terms, drought is a period of less than normal levels of precipitation. By this definition, virtually every place on the planet experiences drought at some time [...] Droughts can pose very serious risks when their severity exceeds expected levels, or when they strike in areas which are not used to coping with them" (Engle 2009).

In general, droughts can be divided into four different disciplinary perspectives (NDMC 2006:2):

- **Meteorological drought**, defined usually on the basis of the degree of dryness.
- **Agricultural drought**, linking drought characteristics to agricultural impacts.
- **Hydrological drought**, the effects of periods of precipitation shortfalls on surface or subsurface water supply.
- **Socio-economic drought**, associating to the supply and demand of some economic good with elements of meteorological, hydrological and agricultural drought.

The latter category refers to socio-economic vulnerability: "Socioeconomic droughts occur when the demand for an economic good exceeds supply as a result of weather-related shortfall in water supply" (NDMC 2006). An example is the Uruguayan drought in 1988/89 that resulted in significantly reduced hydroelectric power generation and forced the government to convert to more expensive imported petroleum and stringent conservation measures (ibid.).

A special peril of droughts is that the hydrological drought is in most cases out of phase with the occurrence of meteorological and agricultural droughts. Furthermore, as hydrological systems interconnect different regions, the impact of the drought might extend well beyond the precipitation-deficient area (NDMC 2006). Although climate is the primary contributor to hydrological droughts, changes in land use like deforestation and land degradation also affect hydrological characteristics.

3.5.2 Drought Impacts

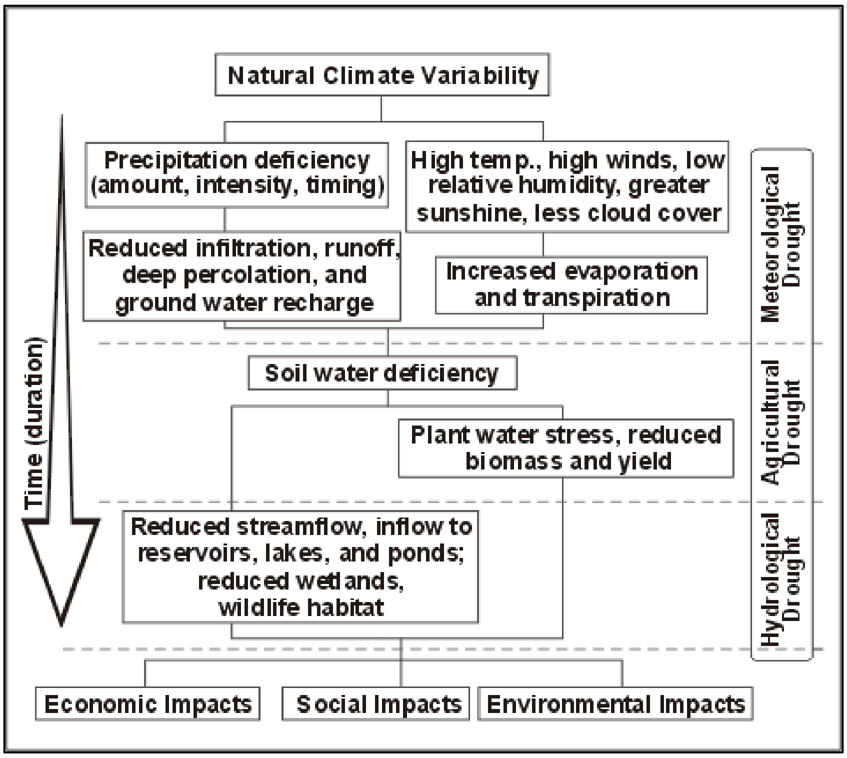
The most common physical drought effects are on soil and sediments in the form of erosion as well as wildfire that causes further erosion and makes soil impermeable. Effects on surface and ground levels are a drop of water levels and an increase of salinity and turbidity. Dropping pressure in primary and secondary water systems can create potentials for cross-connection contamination and potential illness. The higher risk of wildfires is exacerbated by low community water pressures. Air can become warm, dry and dusty which can cause a further desiccating of soil, increasing evaporations from water bodies and an increase in respiratory ailments. Another important effect is the possible disruption of hydro-electricity (Knutson/ Hayes/ Phillips 2004:20; Bartlett et al. 2009:6).

Important economic impacts for urban areas can be on industry, tourism and recreation, energy and transportation. The severest environmental impact in urban areas is a change in water quality (Knutson/ Hayes/ Phillips 2004:3). All these effects can cause severe social impacts as the following (NDMC 2006):

- **Health risks,** such as mental and physical stress, heat-related low-flow problems, reductions in nutrition, loss of human life, public safety from fires and increased respiratory ailments.
- **Increased conflicts**, such as water user conflicts, political conflicts, management conflicts and other social conflicts.
- **Reduced quality of life**, changes in lifestyle: increased poverty in general, population migrations, loss of aesthetic values and reduction or modification of recreational activities.

Figure 6 summarizes the different drought perspectives and their impacts.

Figure 6: Drought Occurrence and Impacts



Source: http://drought.unl.edu/whatis/concept.htm [21.08.10]

3.5.3 Drought Risk Management

According to the World Bank, reactions on droughts so far have been purely reactive, mostly ineffective and often untimely (Wilhite 2006:1). Therefore, they argue for a functioning monitoring and early warning system: "Drought early warning systems must have the capacity to detect the first signs of an emerging rainfall deficiency, the best indicator of meteorological drought, but other key drought indicators (water reservoir levels, groundwater levels, stream flows) are also important"(ibid). They also state that there are critical economic and social indicators, such as food price development and purchasing power (ibid). The following are the advices on municipal level to adapt to occurring and future droughts (ibid.:4):

- To provide guidance to water supply providers.
- To encourage water conservation programs.
- To provide water efficiency education for industries and business (which should include households).

The United States Western Drought Coordination Council (WDCC)[20] (Knutson/ Hayes/ Phillips 1998) focuses on identifying underlying vulnerabilities to reduce drought risks sustainably. With this approach, no ex post drought reaction but an ex ante drought mitigation should be aspired.

3.5.4 Drought Management in Central Chile

An example for drought management is central Chile in 2008: In the summer of 2008 and as a consequence of the La Niña phenomenon, the semi-arid centre of Chile experienced one of its lowest levels in precipitation in half a century (Martinez 2008). The severe drought caused "an agricultural emergency in 50 rural districts in the centre of the country" (Vargas 2008) and raised concerns about possible electricity rationing[21]. The central government provided forage and water tanks for the affected farmers and settlements. Measures taken by the central government to address the possible electricity shortage were a reduction of voltage from 220 to 210 volts, an extension of daylight saving time, more flexible agreements for water usage to fully exploit power generation capacity and education campaigns on reducing electricity consumption (ibid.). Efforts

[20] http://www.drought.unl.edu/wdcc [22.09.10]

[21] These concerns were intensified by the fact that one of the largest hydroelectric power stations, the Nehuenco power plant, was out of service due to a fire. When this plant turned out in 1999, the president that time, Eduardo Frei, decreed electricity rationing in eight of the countries then 13 regions (Vargas 2008).

were made to avoid electricity rationing, as this would have serious consequences for the country's industry and investments. Still it might be a necessary option during a longer and more severe drought.

A closer look at the water and electricity sector will help to understand how water and electricity shortages might affect the urban region Santiago de Chile.

3.5.5 Water Supply and Consumption in Santiago de Chile

In the last three decades, Santiago managed to create universal access to water and sanitation in the context of neoliberal privatisation. Traditionally, the urban water sector was managed by different public actors and water management in Santiago was incapable to follow the urbanization process (Figueroa 2004:243). In the late 70s, the military government reformed the whole sector and it underwent a period of modernization. Water and electricity supply were broadened in the course of new housing policies[22] and extension of services went together with urban expansion (ibid.). Duran (2008:3) sees the reason for the attempt to improve access to public utilities in creating an efficient supply of the economically important companies. Pflieger/ Matthieussent (2008:1911) state that "improving the sanitary conditions of housing and access to basic utilities was a major argument advanced by the military regime to justify the destruction of certain slums, in an attempt to cover up the purely authoritarian and segregationist character of such interventions".

The 1981 Water Code[23] converted existing water rights (which are entitlements to use a certain flow of water under specified conditions) into private property, that is regulated through economic and market mechanisms (Budds 2009:420). The Water Code was part of a broad range of neoliberal reforms undertaken by a group of monetarist economists. Water was considered a commodity like any other. Until 2005, when greater regulatory power was assigned to it, the role of the National Water Directorate (DGA)[24] was purely administrative. Only in emergency conditions of droughts, DGA could assume authority over private water use (ibid.:421). Art. 314 of the water Code from 1981 states, that in a period of extreme drought (with the extreme drought previously defined by the General

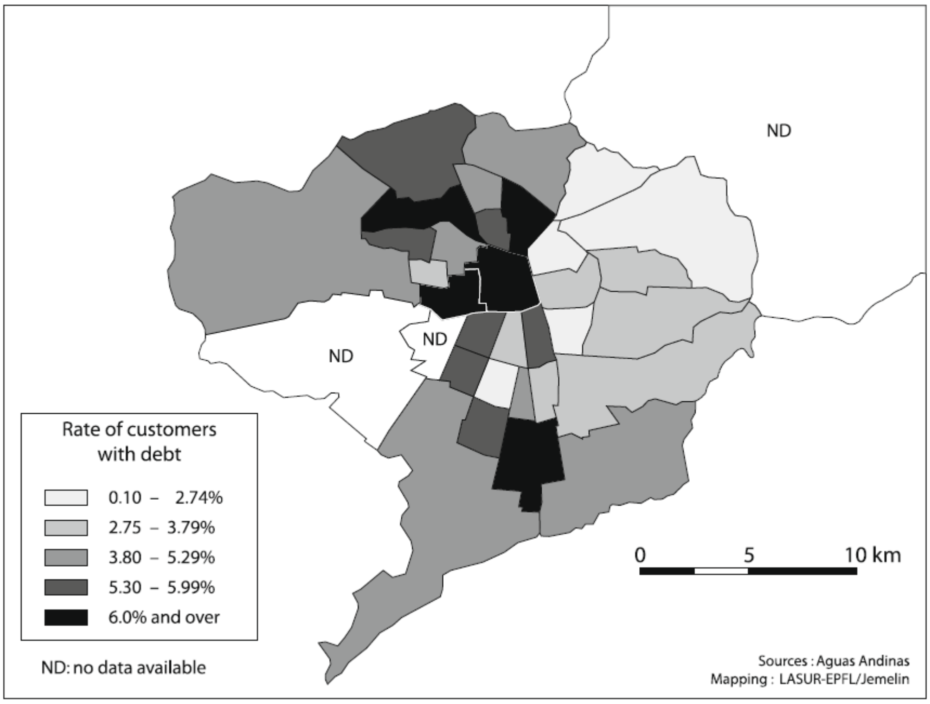
[22] These were targeted at the sometimes violent eradication of slums and a social homogenization within the municipalities. These policies markedly increased socio-economic disparities (in living standards, economic development and tax income) between the municipalities (Pflieger/ Matthieussentt 2008:1911).
[23] See Budds 2009 for a more detailed explanation.
[24] www.dga.cl. [22.09.10]

Water Directorate), the president of the republic Chile may declare shortage areas for a period of up to six month. In these declared shortage areas, water use may be rationed and redistributed by the Water Directorate without license to minimise drought damages.

In 1989, another major reform of the sector generated the separation of the public operative and regulatory functions. The *Superintendencia de Servicios Sanitarios* (SISS) was created as an independent authority, separated from any intervention by the state shareholder. It functioned as an economic regulator for urban areas. The rate structure was overhauled and the average water price increased by 50% between1989 and 1990 and had almost doubled by the end of 1998 (Pflieger/ Matthieussent 2008:1915).

Thus, Chile does not have a problem of coverage, but of pricing and over all of quality (Pflieger/ Matthieussent 2008; Rodríguez/ Winchester 2005). Pflieger/ Matthieussent (2008:1918) discovered that “the geography of water cuts reflects social inequalities”, as is shown in Figure 7 - payment lags in the poor communities and hardly is a problem in the wealthy comunas in the northeast. If payment for water bills lags for a period over three month, the operator is authorized to cut the supply. Often, payment agreements are made between customer and operator, but these rather tend to increase the dept amount instead of clearing it: “in June 2003, no municipality had debts going back over 20 months. In 2004, 11 out of 34 did” (ibid).

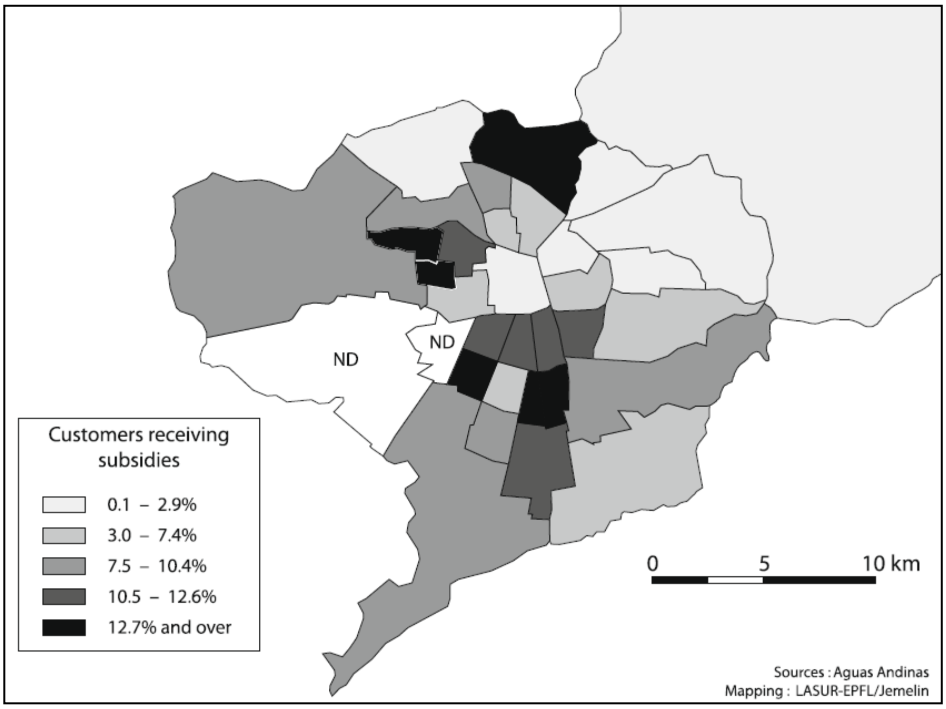
Figure 7: Rate of Debt Dating Back Three Months or More in Greater Santiago Municipalities, June 2003



Source: Pflieger/ Matthieussent 2008:1918)

Subsidies for the poorest households exist to limit the social cost of higher prices. They are "output-based aids: they are granted and their amount is fixed according to the household's social status" (Pflieger/ Matthieussent 2008:1918). Subsidies are distributed among the comunas according to average population income. Mideplan (Ministerio de Planificación y Cooperación, Ministry of Planning) gives the subsidy to the water operators which then deduct bills from clients chosen by the respective comuna (ibid.). Households wishing a subsidy have to apply in their comuna; they are subject to a maximum monthly consumption and are not allowed to lag in their previous water bill payments. In that way, the subsidy system shows a strong limitation and "one can observe a spiralling process of reduced access, a vicious circle of debt leading to the suppression of subsidies leading to debt resulting in payment agreements and growing debt, resulting in definitive insolvency"(ibid.).

Figure 8: Rate of Customers Benefiting from Subsidized Water Consumption, June 2003



Source: Pflieger/ Matthieussent (2008:1919)

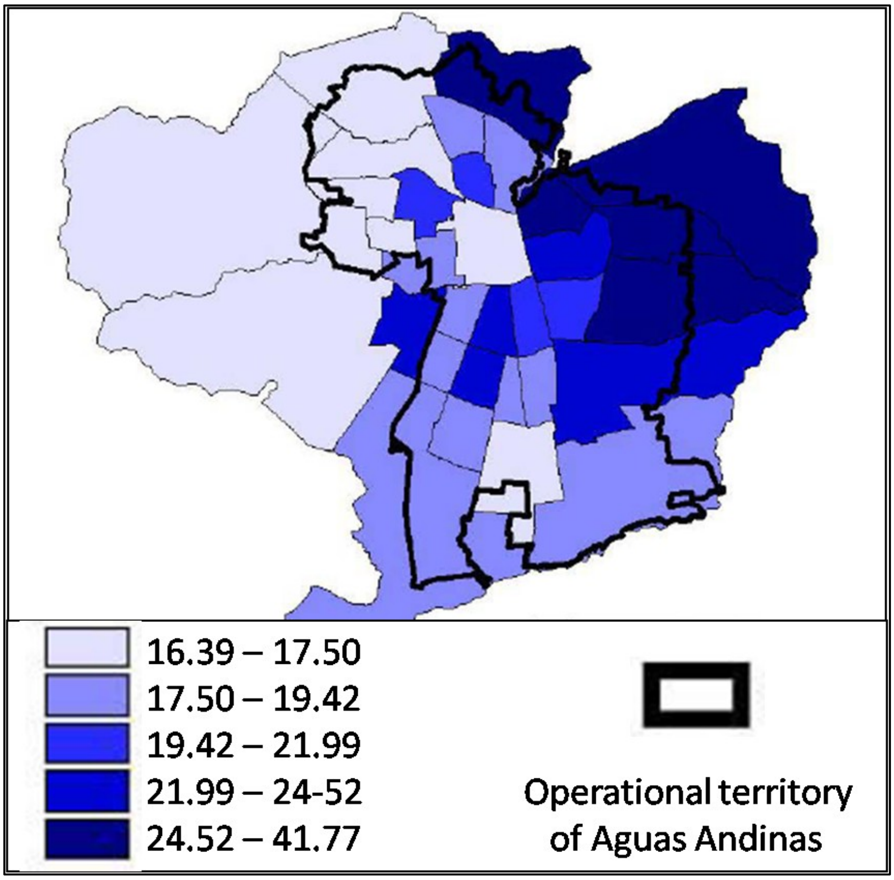
Finally, actual water consumption on comuna level will be regarded.

Duran (2008) elaborated average monthly water consumption for the comunas served by. Aguas Andinas serves the bulk of Greater Santiago's comunas. Unfortunately Vitacura and Lo Barnechea are missing in the map. Data on their monthly consumption was not available. Still, some cognition about consumption patterns can be drawn out of a SISS (2008) study on water consumption by company for the year 2007/2008. SISS defined, according to the UN, 60 litres per day and person as the minimal amount to serve basic needs (SISS 2008:4). As can be learned on the SISS homepage[25], the comunas Vitacura and Lo Barnechea are served by Aguas Cordillera SA. SISS (2008:6) criticizes the high water consumption in the households served by this operator: average daily consumption of clients of Aguas Cordilleras is 405 litres. They trace the irresponsible high water consumption back to the fact that clients basically belong to the socio-economic groups ABC1 and own large gardens and swimming pools that demand higher water usage. In comparison, Aguas Andinas clients use an average of only 150 litres. Figure 9 gives an overview over the different average monthly water consumption patterns per comuna served by Aguas Andinas. The map shows a clear distribution of high and low

[25] http://www.siss.cl/article-4864.html [21.08.10]

consumption according to income and socio-economic group of the respective comunas: high consumption in the wealthy cone in the northeast of the city, low consumption in the south-western and north-western comunas.

Figure 9: Average monthly Water Consumption in m^3 the Comunas served by Aguas Andinas, February 2009

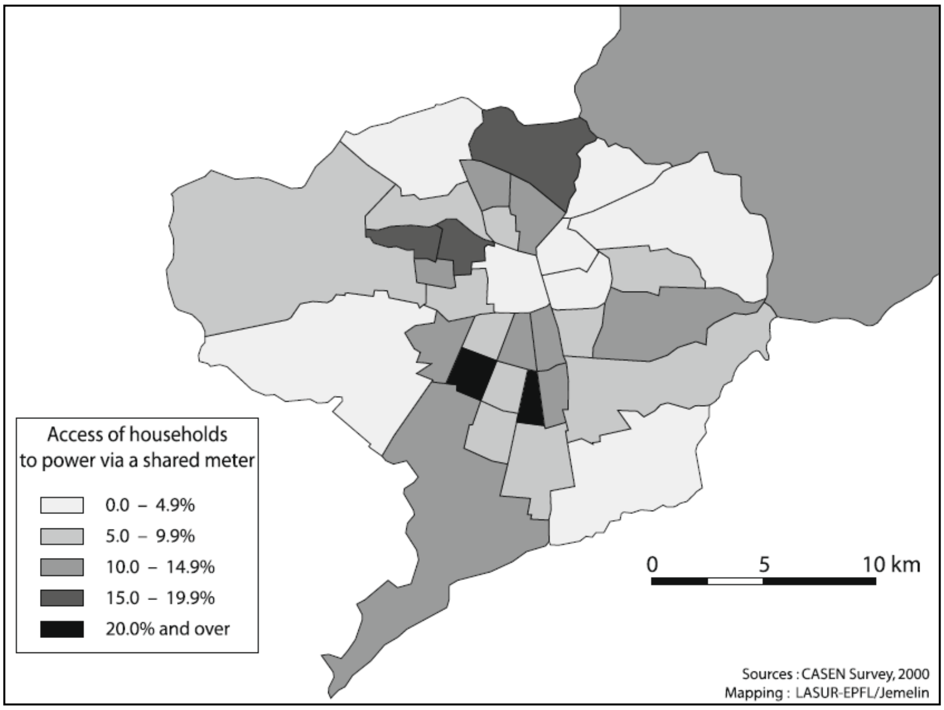


Source: Duran 2009: 11

3.5.6 The Electricity Sector in Santiago de Chile

The electricity sector underwent privatization in the second privatization wave between 1985 and 1989. Pflieger/ Matthieussent (2008:1915) call it "'popular capitalism': the government offered shares to employees, to pension companies, to the general public and to other traditional investors with the aim of diluting company ownership". This should improve quality and reduce the fiscal deficit (ibid.). The electricity sector became fully subject to free market rules and utilities just provided services without any geographical or social subsidization. 50% of the bill of small consumers (100kWh) is made up of fixed charges on every supply agreement (ibid.:1916). There is no direct subsidy as in the water sector and the common municipal fund doesn't provide compensation to poorer municipalities either (ibid.:1915f). There is no data on electricity debts available, but what can be observed is a correlation of comunas with low medium household income and the use of share electricity meters, as can be seen in Figure 10. "To be connected to the service via a shared meter means that several households are provided with electricity through one meter and jointly pay the bill" (ibid.:1916). This practice cuts down costs, but also shows severe disadvantages: "Not being official customers they cannot demand better service from the operator, notably when there are problems with supply" (ibid.). Although this practice has diminished since 1987 it is still common in municipalities with low average income.

Figure 10: Rate of Access to Power via a shared Meter 2000



Source: Pflieger/ Matthieussent 2008:1917

The practice of the shared meter originated in times when power supply was run by the state and supplied through a collective meter. Therefore, the municipalities in the centre, which are the urbanized the longest, show the highest rates (ibid.:1916).

In contrast to other large cities in Latin America, Santiago does not have a problem with physical coverage of potable water and electricity. Instead, the problem lays in other aspects of service performance: corporate governance, the tariff system, capacity and status of distribution networks as well as the actual consumption levels, which are problematic (Duran 2008:7). These factors affect urban development, because they determine in part the trends of physical growth and social differentiation of urban space. In cases of drought, water and electricity supply may be limited. As both sectors are subject to free market mechanisms, shortage of these goods likely leads to price increases. In periods of severe droughts, this might be cushioned if the national government steps in, like is stated in the Water Code. If not, price increases can imply disproportional high social costs for the households of poor comunas, which already struggle with bill payments.

4 Methodology

The objective of this document is to measure and display vulnerability of each comuna for each of the three hazards floods, heat waves and droughts. According to the explanation of vulnerability in chapter 2.2, vulnerability is measured as the ratio of exposure and adaptive capacity. Consequently, indicators for exposure as well as adaptive capacity will be defined.

Chapters 4.1, 4.2 and 4.3 discuss the choice of indicators. Chapter 4.4 explains the methodology, how the indicators are used to compare and map Santiago's vulnerabilities.

Indicators are derived from the findings in the pertinent scientific literature and the situation in Santiago. All values are listed in the annex. If not stated otherwise, data sources for the respective indicators are:

- SINIM – *Sistema Nacional de Información Municipal*. This is an information system of the Ministry of the Interior with nationwide coverage that makes a set of variables and indicators available to the public. Currently, information is available from 2001 to 2009 in the areas of Administration and Finance, Health, Development and Territorial Management, Social Aspects and Community as well as Gender and Communal Characterization. www.sinim.gov.cl [21.08.10]
- MINVU OU – *Observatorio Urbano*. The urban observatory is a portal of MINVU that gives public information about the development of the Chilean cities 1990 – 2009 (different indicators available for different years). www.observatoriourbano.cl [21.08.10]
- PNUD (Programa de las Naciones Unidas para el Desarrollo)/ Mideplan: They jointly published the calculations of the HDIs on comuna level for 1994 and 2003 (see PNUD/ Mideplan 2006).

4.1 Indicators for Flood Exposure and Adaptive Capacity

4.1.1 Exposure to Floods

Decisive for an area to be flooded is first of all its location - near water bodies, part of flood plains, and the like. Localizing risks in form of hazard maps "is a basic prerequisite for the development of long-term flood management strategies and has an important role in identifying areas that might benefit from detailed assessments of social vulnerability"

(Brown/ Damery 2002:415).

Ebert (2009) undertook an elaborated study to define flood risks and vulnerability in the east of Santiago. She analyzed collected geographical data, satellite data, GIS (geographical information system) data as well as census data, questionnaires and field surveys. She defined hazard related indicators like amount of precipitation per event, runoff, capacity of the water course, water height in flooded area, land use/ land cover and local topography to measure flood risk according to location (Ebert 2009:7). This data was not available for this research; neither could indicators be derived out of an existing flood map. Therefore it should be kept in mind that an important next step is to supplement exposure indicators with this missing data.

4.1.1.1 Urban Green Spaces

As explained in detail in chapter 3.3.1, vegetation cover and distribution as permeable soil function as a natural drainage, influence the local water balance. Hence, they play a significant role in flood risk reduction by (Ebert/ Banzhaf/ McPhee 2009:4):

- The infiltration of rainwater.
- The interception of rainwater.
- The effect of shading.
- The evaporative cooling.
- And the storage of rainwater.

The more water is absorbed and stored in the ground, the less water will flow rapidly into surface streams. Vegetation cover in urban areas is mainly irrigated grasslands (parks), deciduous woodland and private gardens.

The **Flood Exposure Index *Green Spaces*** was calculated by adding SINIMs data of 2008 on:

- Agricultural area (as opposed to urban and industrial areas) in %.
- Area covered by bush and grassland in %.
- Area covered by woods in %.

Values varied in the individual comunas, from a minimum of 0% share of green spaces to a maximum of 81.49%, with a mean share of 24%.

A shortcoming of this index is that some green spaces in the form of public parks do not belong to the comuna in which they are located, but belong to and are maintained by the cities authority, for example the Cerro San Cristobal in Providencia. As these special cases often stretch over more than one comuna, they could not be considered in the calculation.

4.1.1.2 Housing Condition

The second exposure indicator refers to housing conditions. Pelling (1997) undertook a study of flood risks in Georgetown, Guyana and defined vulnerability as "determined by a household's resource characteristics (economic, political, social, demographic, psychological and environmental) and, in this case, their appropriateness in reducing the likelihood of living space being flooded and the scale and distribution of impacts should flooding occur" (ibid:203). Secure housing reduces risk of injuries and loss of personal belongings (Mantaay/ Maroko 2009:112; Pelling 1999:250; Moser/Satterthwaite 2008:8; Bartlett et al. 2009:4).

MINVUs urban observatory gives different indicators on housing quality: 'housing in good condition', 'irrecoverable housing' and 'precarious housing'. The first indicator is defined as the percentage of households whose material, sanitation and type, are acceptable. The second indicator refers to housing that requires improvements in materials and/ or basic services to achieve an acceptable standard. As a clear definition of the term 'acceptable' could not be found, but precarious housing obviously suffer great flood risk, precarious housing was chosen as the second exposure indicator. Precarious housing is defined by MINVU as conventillos[26], shacks, huts, sheds and the like, that exist in the comuna.

The **Flood Exposure Index *Precarious Housing*** was calculated out of MINVU's urban observatory data of 2002 on:

- Number of precarious dwellings per comuna.
- Total number of dwellings per comuna.

The values lay between 0.1% and 11%.

[26] Conventillo is a form of urban housing in South America, where each room of a housing unit is rented to a family or a single person. Community rooms like kitchen and dining room but also bathrooms are usually shared by all tenants.

4.1.2 Adaptive Capacity to Floods

Adaptive Capacity can be divided in several levels: national, regional, municipal and individual adaptation measures. As Douglas (2008:202f) puts it: "Where the problems are essentially internal to a specific community, then that community should manage them. Where they lay totally within the boundaries of a single local authority, then the local authority should manage them. Where they cut across many administrations, then national governments, or even international consortia, should manage them". Is local flooding owed to inadequate drainage, the local community should act; for example in form of local voluntary groups, assisted by national or international NGOs (non-governmental organizations) and with support from local governments and national disaster reduction organizations. Flooding from small streams inside the build-up area of a comuna should be the respective comuna`s task. Accordingly, where flood occurs from major rivers, flood protection and adaptation measures refer to the whole river bank and therefore are a citywide task.

Climate-related hazards put new demands on existing institutions as current flood risks are reinforced or new floods occur and "the *ability* (economically, politically and logistically) of a local community to carry out measures to reduce the risk of negative effects from future similar climatic-induce events may be closely related to the *capacity* and *ability* to prepare for climate change in future" (Næss et al. 2005:126). Local ability is always influenced by the degree of centralization and decision-making processes. Decision-making can incorporate conflicts of interest and unequal power relations can lead to the shaping of preferences and conceptions by local elites (Næss et al. 2005:128). Structural adaptation measures in Santiago are planned in the master plan and are SERVIUs task. However, comunas could deal with the non-structural measures.

4.1.2.1 The Local Regulatory Plan

Adaptation measures require institutional planning and cooperation on municipal and city level, as parts of the whole city are affected. Structural measures like drainage construction or improvement lay in the hands of SERVIU and not of the comunas. Still, municipalities in Santiago are assigned by law the responsibility for managing municipal and national property for public use and the cleanliness of national public goods in the community. They are allowed to sanction waste disposal in the channels and are obliged to clear debris. Furthermore, municipalities are authorized to land acquisition in order to eradicate populations in flood risk zones as designated by the communal regulatory plan. This plan should furthermore contain a feasibility study on construction of storm water drainage (Carrasco Oviedo 2009:118). According to the General Law of Urban Planning and Construction, communal urban planning should promote the harmonious development of the communal territory, especially its settlements, in line with the regional goals for economic and social development. The local regulatory plan is an instrument of territorial planning that consists of a set of rules on appropriate conditions to design buildings and urban spaces, according to the functional relationship between residential areas, labour, equipment and leisure[27]. It has to establish provisions for land use or zoning and density and intensity of land use (ibid.:127). Through the local regulatory plan (LRP), comunas can influence SERVIUs work, as SERVIU is obliged to take these plans into account. The local regulatory plan therefore serves as an instrument to plan and implement structural as well as non-structural measures.

Still, some comunas in Santiago do not have a regulatory plan at all or it has not been updated in recent years. On the other hand, in 2008, the comuna La Pintana supplemented their LRP by the required feasibility study on rainwater evacuation – which is most exemplary for the LRPs importance in flood risk management and concurring adaptation measures. As a regular update or reconsideration of local development strategies is a prerequisite for sustainable adaptation, actuality of the local regulatory plan is serving as an indicator for adaptive capacity.

The **Flood Adaptive Capacity Indicator *Update LRP*** was taken over from SINIM's data of 2008.

The last update of the different plans occurred between 1983 and 2008. Accordingly, values lay between 25 and zero years. Special cases are the comunas that do not have a LRP at all (Cerrillos, Estación Central, Independencia, Pudahuel, San Ramon). As no comuna tool exists to fix adaptation measures, the value of the worst performing comuna (25 years) is assigned to these comunas to include them in the map. Data was missing for Cerro Navia, Las Condes and Quilicura.

[27] Paraphrased from http://www.minvu.cl; http://www.cartografia.cl [21.08.10]

4.1.2.2 Municipal Spending per Capita

As learned in chapter 2.4, adaptation measures depend son collective resources such as quality of infrastructure, services and warning systems. The structural and the non-structural measures, like education and awareness raising, warning and evacuation systems or resettlements consider great effort of municipal authorities, both technical and financially. Furthermore, Expenses vary according to measures, therefore municipal spending is used as a general indicator for adaptive capacity on comuna level.

The **Flood Adaptive Capacity Index *Municipal Spending*** was calculated out of SINIM's 2008 data on:

- Total municipal spending in the financial year in Chilean pesos.
- Population per comuna.

Values varied between 33.000 and 496.000 Chilean pesos.

4.1.2.3 Individual Adaptation Measures

Often adaptation measures through local coping practices are disregarded in flood risk management strategies. These measures include (Brown/ Damery 2002:420; Douglas et al. 2008; Faisal 1999:152):

- Social and family support networks.
- Moving valuables to elevated places and helping each other in doing so.
- Moving temporarily in with friends or family in a safer location.
- Undertaking of collective efforts to clear up drains.
- Small adjustments in the houses such as construction of barriers against water entry at doorsteps or outlets at the rear so that entering water can flow out quickly.
- Bailing water out of houses.

Apart from that, according to Næss et al. (2005:129), the question is not only what experiences, knowledge and strategies are available at local level, but "to what degree this knowledge can be successfully transferred to the institution, that is, to what degree the society as a whole can 'learn' from the experience of its individuals" (ibid).

So it is clear that individual adaptation measures on local level play an important role in flood risk management. In order to consider all relevant adaptive measures, an assessment of local practices to identify coping strategies on individual or household level, must be undertaken. On the one hand, assessing these individual measures went beyond the scope of this study. On the other hand, as a comparison of the different comunas due to their specific characteristics is objected, these measures are not taken into account here and are not indicated.

Personal income as GDP (gross domestic product) per capita was not counted as an indicator. First, it will be calculated as an adaptive capacity index for heat related risks, if values are of interest, they can be taken over from chapter 4.2.2.3. Second, the relation between income and flood risk cannot always be clearly established, as mentions Pelling (1999:253) in the case of Guyana: “Whilst high income was associated with greater security (home ownership, dwelling security, less household density) it was also linked to higher incidences of flood losses (…). However, in absolute terms it is likely that higher income households were more able to absorb such losses than lower-income households” (ibid.). Still, high income households often can transfer risks from health to economic investment and loss (ibid.:256). Hence, personal income as GDP per capita can be kept in mind as a possible indicator for adaptive capacity, but won’t be shown related to floods.

4.2 Indicators for Heat Wave Exposure and Adaptive Capacity

There are several studies about heat-related vulnerabilities that define different indicators. Reid et al. (2008:1731) identified the following factors as constitutive for heat-related vulnerability in the United States: The demographic and socioeconomic variables age, poverty, education, living alone and race/ethnicity as demographic and socioeconomic variables; land coverage measured as the existence of green spaces; pre-existing health conditions like diabetes prevalence or pulmonary conditions and air conditioning.

Different schools of thought investigated the relation between social capital (for example in the form of social trust, participation in social associations and civic engagement) and health and showed a strong positive link between the two. For example “involvement in formal and informal networks, having friends to rely on when ill, having control over one`s own life, and trust are indicators of social capital which contribute to better self-rated health” (Wolf et al. 2009:45). Accordant to that, Reid et al. identified ‘living alone’ (as opposed to having social contacts) as a relevant factor for heat-related vulnerability. Still, the study of Wolf et al. (2009) on heat wave vulnerability of the elderly in the United Kingdom found out that social capital does not necessarily decrease vulnerability but may as well exacerbate it. This is due to the fact that the respondents did not perceive their self as being at risk or vulnerable to heat and the social networks did not challenge but rather supported that view. As the relation between vulnerability and social contacts respectively social capital is unclear and besides, no data on 'living alone' or 'social networks' was available, this factor was not considered in the analysis.

4.2.1 Exposure to Heat Waves

When thinking about exposure to heat-waves, one of the first things that come in mind is air conditioning. Reid et al. (2008) cite different sources that see air conditioning as a factor explaining differences in heat-mortality associations by subgroup in the United States. Unfortunately, data on air conditioning in the different comunas was not available. Nonetheless, based on Bell et al. (2008:801), air conditioning is not seen as playing a large role in temperate Latin American cities. Air conditioning will therefore not serve as an indicator. Still, it is to be kept in mind, that air conditioning can reduce heat exposure and if data were available, should be included. Especially as air conditioning not only comes with initial costs, but raises electricity consumption, which in Santiago is a factor mirroring social and spatial inequality, as was discussed in chapter 3.5.6.

As urban heat island effect in Santiago is closely linked to vegetation cover and built-up area (see Romero/ Molina 2009) and no data on comuna level was available, the UHIE will not be a single indicator.

4.2.1.1 Urban Green Spaces

As mentioned above, urban green spaces greatly influence urban temperature, therefore, the share of green spaces per comuna was chosen as the second exposure index. The indicator was calculated the same way like for floods in chapter 4.1.1.1.

The **Heat Wave Exposure Index *Green Spaces*** was calculated the same way as for floods in chapter 4.1.1.1.

4.2.1.2 Population over 60

In accordance with the health risks through heat waves, Reid et al. (2008) and Schwarz/ Seppelt (2009) defined age as a constitutive factor for heat-related vulnerability. A crossover case study carried out by Bell et al. (2008) for the cities of Santiago, Chile, Sao Paulo, Brazil and Mexico City, Mexico affirms age as the common factor to indicate higher risk of heat-related mortality for older populations. And as described above, as the indigent population aged over 65 years is under-utilizing primary health care services, they are more sensitive to heat stress and more exposed to heat-related risks.

The **Heat Wave Exposure Index *Population over 60*** is calculated out of MINVU's urban observatory data, stating the share of people over 60 years out of the total population in the comuna in 2002. Shares varied between 4.2% and 21.5%.

4.2.2 Adaptive Capacity to Heat Waves

Schwarz/ Seppelt (2009) differentiated adaptive capacity into adaptive capacity of the urban system and of the population. Adaptive capacity of the urban system means providing more health-related infrastructure or re-structuring urban green spaces. The corresponding indicator was city expenditures. Population's adaptive capacity refers to the ability of the population to adapt to heat waves, for example by being able to afford air-conditioning. GDP per capita was used as the corresponding index.

Accordingly and in reference to the discussion of risk management strategies in chapter 3.4.3, health, municipal spending per capita and GDP per capita were chosen as indicators

4.2.2.1 Health

In accordance with Schwarz/ Seppelt (2009); Reid at al. (2008) and Wolf et al. (2009), the health system is a constitutive factor for heat-related risks. Data on hospital beds per 1000 inhabitants was only available for a few comunas on the urban observatory. In SINIM's database, different data on spending per comuna for specific health related issues could be found, but no overall spending on health. Furthermore, Urriola (2006:280) questions the positive correlation of health spending and health outcome, measured as life expectancy. Chile and the United States both reach a national life expectancy of 77 years, still Chile only spends 5.9% of GDP on health, while the US spend 15%.

Another interesting indicator would have been the share of the population not inscribed into any health plan at all. Data of the urban observatory only indicates how the inscribed persons divide into private, public or other types of health care. Still, access to health care is good, but inequalities are found between people in the same system, due to pre-financing, waiting times or unequal information. There is no quantified data for these factors and therefore, inscription to health care alone is not satisfying. Given this situation, the most appropriate health indicator available on comuna bases seemed to be the Health Indicator which comprises the HDI. This refers to life expectancy at birth.

The **Heat Wave Adaptive Capacity Index *Health*** is calculated by the UNDP and Mideplan, as a mean of the rates of the potentially lost years of life per 1000 inhabitants for the years 1999-2003 (*Años de vida potencial perdidos per mil habitants)* (UNDP/Mideplan 2006:147). Sub indices for the HDI calculation appear on a scale from 0 to 1. Values varied between 0.627 and 0.914.

4.2.2.2 Municipal Spending per Capita

Schwarz/ Seppelt (2009) see adaptive capacity of the urban system as the provision of more health-related infrastructure or re-structuring urban green spaces. As a corresponding indicator, they used city expenditures.

Consequently, municipal spending per capita is used as the next indicator, also to complement the health care argument. In the course of decentralization, responsibility for primary health care facilities was laid in the hands of the municipalities; almost all municipalities had these responsibilities by 1998. "Decentralization of financing in Chile involved the allocation of intergovernmental transfers specifically assigned to primary health care and directly allocated to the municipalities based on a per capita formula adjusted for rurality and municipal poverty level" (Bossert et al. 2003:2). Differences between the municipalities should be adjusted by the Municipal Common Fund, which reallocates resources from wealthier to poorer municipalities. But, in addition municipalities can assign their own local revenues from municipal budget to health services (ibid.). This may give advantages to the population of wealthier municipalities. Bossert et al. (2003:3) found out that "municipalities with higher per capita total municipal expenditure rates also had higher per capita rates of utilization". On the other hand, Arteaga/ Darras (2003) commented on the same study and state that "municipalities allocating the highest per capita funds are not the ones with the greatest health care needs".

However, municipal spending is not only important for health care. Restructuring or expanding of urban green spaces is dependent on the comunas finances. Also the establishment of monitoring and warning systems or education campaigns to inform about heat-related risks requires municipal spending. If these measures are solely carried out inside a comuna, comuna finances will decide over scope and quality. Municipal spending per capita was therefore chosen as the second adaptive capacity indicator.

The **Heat Wave Adaptive Capacity Index *Municipal Spending*** is calculated like the Flood Adaptive Capacity Indicator FAC_{MS} in chapter 4.1.2.2.

4.2.2.3 GDP per Capita

Satterthwaite (2009:20) states that adaptive capacity is dependent on individual resources like income (compare chapter 2.4). This is confirmed by Schwarz/ Seppelt (2009), they divided adaptive capacity in municipal capacities and personal capacities. As heat-related vulnerability is strongly dependent on personal factors such as health correlated with age, individual lowering of exposure by air conditioning and nutrition during heat waves and to round off the health care argument, GDP per capita was used as the corresponding index to personal adaptive capacity.

For the **Heat Wave Adaptive Capacity Index *GDP per Capita***, the UNDP/ Mideplan HDI income component was used.

This component is derived out of adjusted medium income per household respectively medium income per household corrected by poverty (UNDP/ Mideplan 2006:147). Sub indices for the HDI calculation appear on a scale from 0 to 1. GDP per capita and comuna varied between 0.575 and 1.

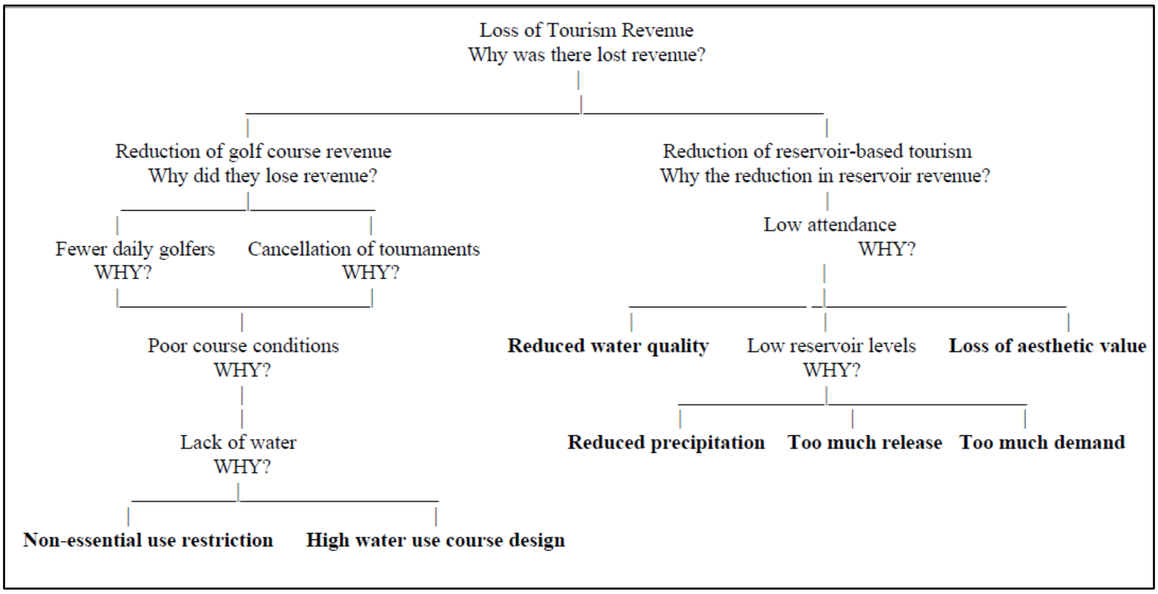
4.3 Indicators for Drought Exposure and Adaptive Capacity

There are several internationally used indicators for droughts, that "assimilate thousands of bits of data on rainfall, snowpack, stream flow and other water supply indicators into a comprehensible big picture" (Hayes 2002:1). Hayes (2002) gives an overview and pro and contras. Still, these indices only measure probability of droughts whereas "drought risk is based on a combination of the frequency, severity, and spatial extent of drought (the physical nature of drought) and the degree to which a population or activity is vulnerable to the effects of drought" (NDMC 2006). Studies to assess impacts and vulnerabilities so far have been undertaken mostly in the United States, Australia and the African continent (Singh 2006, NDMC 2006, Hayes/ Wilhelmi/ Knutson 2004). They concentrated rather on the hazard in form of precipitation measurements than investigating vulnerability causes. Additionally, they focused mainly on agricultural and fishery impacts or on rural living conditions.

While there are many approaches to research and map disaster risks, water scarcity, climate change and related subjects on a global scale[28], "there has been little, if any, attempt to date to comprehensively describe and map various aspects and impacts of a drought as an individual natural disaster and as a global multifaceted phenomen" (Eriyagama/ Smakhtin/ Gamage 2008:3). This is in fact a difficult task as social factors such as population, technology level, policy, land use patterns and economic development influence a population's vulnerability (Singh 2006:15).

A promising approach is developed by the Western Drought Coordination Council of the University of Nebraska-Lincoln, who seeks to address underlying social factors. In its Drought Risk Reduction Guide (Knutson/ Hayes/ Phillips 1998), a special group of relevant stakeholders develops a drought impact assessment by identifying direct consequences of the drought. Subsequently, secondary consequences (which often are social effects like household assets, dislocation or stress) are detected. Each identified impact should then be questioned, why it might have occurred. Based on that, adequate actions should be identified. Figure 11 gives an example of a tree diagram generated to identify vulnerabilities and impacts in an urban area.

Figure 11: Simplified Urban Drought Impact Tree Diagram



Source: Knutson/ Hayes/ Phillips 1998:7

[28] Such as the Global Water System Project or the Natural Disaster Hotspots project of the World Bank, UNDP's Individual Disaster Risk Index. Eriyagama/ Smakhtin/ Gamage (2008:2) give a short description of these and other drought and disaster related indices.

It is not easy to identify these aspects on a local scale, especially on comuna level. Fontaine/ Steinemann (2009) conducted a study on drought vulnerabilities in the state of Washington. They did not define indicators and a threshold beforehand and measured their occurrence but instead conducted telephone interviews with key persons in the region. They qualitatively interpreted this data and ranked it from 1 (very low exposure/ sensitivity/ adaptive capacity) to 5 (very high), based on the people's views and experiences with former droughts. Timeframe and experience of this work did not allow such a complex assessment and in Chile, so far there is no wide data on drought proneness or literature on drought impacts in urban areas. Most probable impacts of droughts in the surrounding areas of Santiago are on agricultural production, water availability and electricity usage. These problems might affect Santiago as well.

4.3.1 Exposure to Droughts

Vulnerability assessment therefore concentrates on the two factors that proved probable to effect urban areas: water and electricity supply. As seen in chapter 3.5.5 and 3.5.6, water and electricity coverage in the metropolitan area is universal. Still, consumption, unpaid bills and disconnections show marked inequalities and therefore, comunas are affected differently by supply cuts or restrictions.

4.3.1.1 Water Consumption

Households water consumption patterns differ on a great scale. As the SISS study suggests, households of the socioeconomic group ABC1 live in neighbourhoods with large gardens and swimming pools, therefore water consumption is higher. Households receiving a water consumption subsidy are only allowed to use a certain amount of water, which is significantly smaller than that of other households. A correlation between income and water consumption can be seen, which is affirmed by the occurrence of outstanding payments. Households with less income can only afford lower water consumption. Although this does not necessary mean that these households only use water in a responsible way, it suggests that water will primarily be used for basic necessities. In a case of drought, if water use must be cut down due to shortages and/ or higher tariffs, these households might be more vulnerable than households using a great share of their water use to water gardens. Water consumption is therefore chosen as a first drought exposure index.

The **Drought Exposure Index *Water Consumption*** was taken over from the calculation of Duran (2009:11). He measured average monthly consumption per comuna (in m^3) (compare **Figure 9**). Consumption ranged from 16.93 to 41.77 $m^{3.}$

4.3.1.2 Household Income

Unfortunately, no data on electricity consumption per household and comuna was available. To incorporate the possibility of higher electricity tariffs and to support the argument of the correlation of household income and drought vulnerability, GDP per capita serves as a second drought exposure indicator.

The **Drought Exposure Index *GDP per capita*** is calculated like the Heat Wave Adaptive Capacity Index in chapter 4.2.2.3.

4.3.2 Adaptive Capacity to Droughts

Knutson/ Hayes/ Phillips (1998) published a Checklist of potential, historical and current drought impacts. When the impacts are identified, each one should be investigated carefully to identify underlying vulnerability. "For example, the direct impact of a lack of precipitation may be reduced crop yields. The underlying cause of this vulnerability, however, may be that the farmers did not use drought resistant seeds, either because they did not believe in their usefulness, the costs were too high, or because of some commitment to cultural beliefs" (ibid:5). Out of the direct impacts and the underlying impacts, specific strategies for adaptation can be derived and drought plans can be developed.

As mentioned earlier, a severe difference of droughts is that the beginning can't really be assessed. Therefore, monitoring, information and preparation of the population is a vital measures. Drought plans are an important instrument to lessen the effect of drought. In the US, only seven states did not have a formal drought plan in 2006. The NDMC (2006) homepage gives a detailed 10-step instruction how to process one. As historical data on drought occurrence and impacts in Chile could not be found, it is difficult to assess future impacts and vulnerability in detail and formulate adaptation measures and corresponding indicators.

Muller (2007:102) stresses that water management to address vulnerability is not restricted to infrastructural means, but equally important are institutional mechanisms that regulate supply and risks. In that sense, "organized drought restrictions should not be seen as supply failures but, rather, as institutional mechanisms to manage variability by prioritizing different water uses during times of supply stress" (ibid). Beyond the direct water management, there are other instruments that can reduce vulnerability, for example land use planning or water-related infrastructure (Muller 2007:102).

These tasks seem to lay on national level or at least in the hand of Santiago`s authorities and not in the comuna's responsibility. The National Plan of Action intends the development of a package of adaptation measures to protect human health, hydrologic resources, food production, urban and coastal infrastructure and energy supply (CONAMA 2009:27). Still, it might be useful for the comunas to identify underlying vulnerabilities, which could be identified by developing a tree diagram, as proposed by Knutson/ Hayes/ Phillips (1998). Comunas could carry out measures to raise awareness and educate about considerate water consumption. This is even more valid when bearing in mind, that some of the comunas are consuming water in an irresponsible manner that requires profound changes (SISS 2008:1).

However, at this time and due to the non-available data, no adaptive capacity indicators could be defined that would serve a comparison on comuna level.

Having defined all indicators, the next part explains, how indicators are used to assess and map vulnerability in Santiago de Chile.

4.4 Displaying the Indicators

As mentioned above, the indicators serve to assess and display vulnerability. In a first step, exposure and adaptive capacity indicators are aggregated to sketch vulnerability maps of Santiago.

In a second step and to get a refined analysis, for each comuna and each hazard, a radar chart is displayed. This allows pointing out special characteristics of a single comuna and allows a comparison of the comunas.

While the approach here tries to cover different foci, it is just one way of using the indicators. The collected indicators can be complemented by other indicators or can be used in different methods.

4.4.1 Standardization and Thresholds

As the indicators have different units, they first need to be standardized to be aggregated and to be compared to each other in the radar charts.

The Z-transformation will be used to standardize all distributions to one in which the mean is always zero and the standard deviation becomes one (Streck 2004:40, 79). The formula is:

$$\mathrm{Z-SCORE} = \frac{\mathrm{SCORE} - \mathrm{MEAN}}{\mathrm{STANDARDDEVIATION}}$$

$$\mathrm{Z} = \frac{\mathrm{Xi} - \mu}{\delta}$$

Source: adapted from Streck (2004)

All the indicator scores can be found in the annex. The respective z-scores will be calculated with Microsoft Excel using the corresponding built-in function.

To assess the degree of exposure or adaptive capacity according to the indicators, threshold values need to be defined. This is done based on Schwarz/ Seppelt (2009:6): “For this purpose, either fixed values can be used, e.g. a certain number of hospital beds per 1,000 inhabitants necessary to cope with a heat wave, or a statistical threshold can be defined. As no sufficient information could be obtained in the literature on the first approach, the second was chosen for this study.” Consequently, the indicator scores of all comunas are compared and the mean value of all scores for one indicator is chosen as the threshold. Because of the use of the z-transformation this is zero.

This approach takes the objective of this study into account: a comparison of the vulnerability of Greater Santiago’s comunas. Thus, indicators don’t serve for a comparison on city or regional level but just give comparable information on comuna level.

4.4.2 Point Diagrams and Vulnerability Maps

The intention is to display the vulnerability of each comuna on one map per hazard. Vulnerability can be calculated as the ratio of exposure and adaptive capacity (compare chapter 2.1):

$$VULNERABILITY = \frac{EXPOSURE}{ADAPTIVE\ CAPACITY}$$

$$V = \frac{E}{AC}$$

Unfortunately, adaptive capacity for droughts could not be indicated in this analysis (compare chapter 4.3.2). Therefore, the following only refers to the hazards flood and heat wave.

It is not defined in the literature how the sets of exposure indicators or adaptive capacity indicators are weighted to produce the quantities E and AC. It is also not agreed, what is the weighting factor for their ratio. The different exposure and/ or adaptive capacity indicators in reality might influence each other, in the sense that one might reinforce or extenuate another indicator in a non-obvious fashion.

In the absence of a clear definition of the interrelation among the individual exposure and adaptive capacity indicators, this work places a simplifying assumption:

It is assumed that all indicators have the same influence in the result.

Still, for other purposes or if the relation is clear, weights can be easily varied. Thus, indicators are added up to get an aggregated exposure and an aggregated adaptive capacity Indicator.

Combining these two aggregated indices into one quotient left too much of a speculation margin. For instance, it is not obvious if *Municipal Spending* as an indicator for adaptive capacity has the same weight as *Health* as an indicator for exposure and if adaptive capacity can therefore compensate exposure. The generalization of the indicators to terms like municipal spending or *GDP per Capita* or abstract indicators like *Update of Local Regulatory Plan* leaves open what exact measure might be undertaken in the respective comuna.

An improvement in the Adaptive Capacity might certainly compensate the exposure, but given the limited data for Santiago, it is not evident if this relation is simply additive or linear. The examination of the nature of this correlation is certainly an important field of future research.

To keep it simple, this thesis uses another approach than their (weighted) ratio to illustrate exposure and adaptive capacity. The aggregated exposure and adaptive capacity indicators appear as coordinates in an orthogonal diagram. It shows the exposure on the abscissa and the adaptive capacity on the ordinate. Aggregation in this case is just the addition of the Z-scores of the indicator values.

Not all indicators are based on the argument 'the higher the value the better for the comuna'. The indicators *Green Spaces*, *Municipal Spending per capita* and *GDP per capita*, *Health* and *Water Consumption* follow the principle 'the higher, the better'. However, this is not the case for the indicators *Share of Precarious Housing*, *Update of Local Regulatory Plan* and *Share of Population over 60*. They follow the opposite principle 'the higher the value, the worse'. Therefore, the latter three indicators will be multiplied by -1.0.

Special attention needs to be paid to the x-axis that displays the exposure of the comunas. As the principle 'the higher, the better' is now established in all indicators, the aggregated exposure indicator also follows this principle. Therefore, *the higher the aggregated exposure index*, the better performs the comuna, what means *the lower is the exposure* of the comuna.

Four quadrants exist in the point diagram. The upper right quadrant holds low to medium exposure with medium to high adaptive capacity. According to definition, this indicates low vulnerability. The diagonally opposite lower left quadrant holds medium to high exposure with low to medium adaptive capacity. According to definition, this indicates high vulnerability. Based on similar arguments, the other two quadrants indicate moderate vulnerability. This classification is helpful to derive priorities for actions.

Vulnerability maps are derived out of these diagrams, using the colours assigned to the vulnerability specification as shown in Figure 12.

4.4.3 Special Case Droughts: Exposure Point Diagram and Exposure Map

For droughts, no adaptive capacity indicators could be defined (compare chapter 4.3.2) but only two exposure indicators, *Water Consumption* and *GDP per capita*. Thus it is not possible to draw the vulnerability point chart and the vulnerability map the same way as for floods and heat waves.

Instead of that, a point chart with the two indicators forming the two axes will be sketched. This will inform about the combined exposure of each comuna. Based on the diagram, an exposure map for the province Santiago can be sketched. This follows the same logic according to quadrants as do the vulnerability point charts for floods and heat waves as can be seen in Figure 13.

4.4.4 Detailed Analysis: Radar Charts

The flood and drought vulnerability maps classify comunas into four categories (high, moderate, moderate, low). The comunas inside one category can still show significant differences in their different indicators. The point chart only gives information on aggregated exposure and adaptive capacity values. The next methodological step takes the finer differences between the comunas into account. For each comuna, a radar chart will be displayed, showing each indicator. In addition, the radar charts are overlaid to allow a better comparison.

Radar charts also follow the principle ‘the higher the value, the better’. Therefore, for the indicators *Precarious Housing, Local Regulatory Plan* and share of *Population Over 60*, the reversed Z-scores will be used to achieve a consistent presentation in the radar chart.

Figure 12: Vulnerability According to the Different Combinations of Exposure and Adaptive Capacity

EXPOSURE	*ADAPTIVE CAPACITY*	*VULNERABILITY*
High	Low	High
Low	Low	Moderate
High	High	Moderate
Low	High	Low

Source: Own elaboration

Figure 13: Drought Exposure According to the Different Combinations of GDP per Capita and Average Water Consumption

GDP PER CAPITA	*AVERAGE WATER CONSUMPTION*	*EXPOSURE*
Low	Low	High
High	Low	Medium
Low	High	Medium
High	High	Low

Source: Own elaboration

5 Results

Chapter 4 described how to illustrate the vulnerability to flood and heat wave hazards into a two-dimensional point diagram with the exposure and adaptive capacity on the axes. The diagram decomposes into four quadrants of low, moderate, and high vulnerability level. Each level then represents a colour on two geographical comuna map, the flood and heat wave vulnerability Map 5 and Map 6. For presentation and comparison of individual comunas, a radar chart for each comuna displays the exposure and adaptive capacity indicator values, see Figure 15 - Figure 32.

As the hazard drought only consists of exposure indicators and no adaptive capacity indicators, the point diagram uses the two exposure indicators as axes. This point diagram also decomposes into four quadrants of low, moderate, and high exposure level. Each level then represents a colour on the geographical drought exposure map, as can be seen in Map 8.

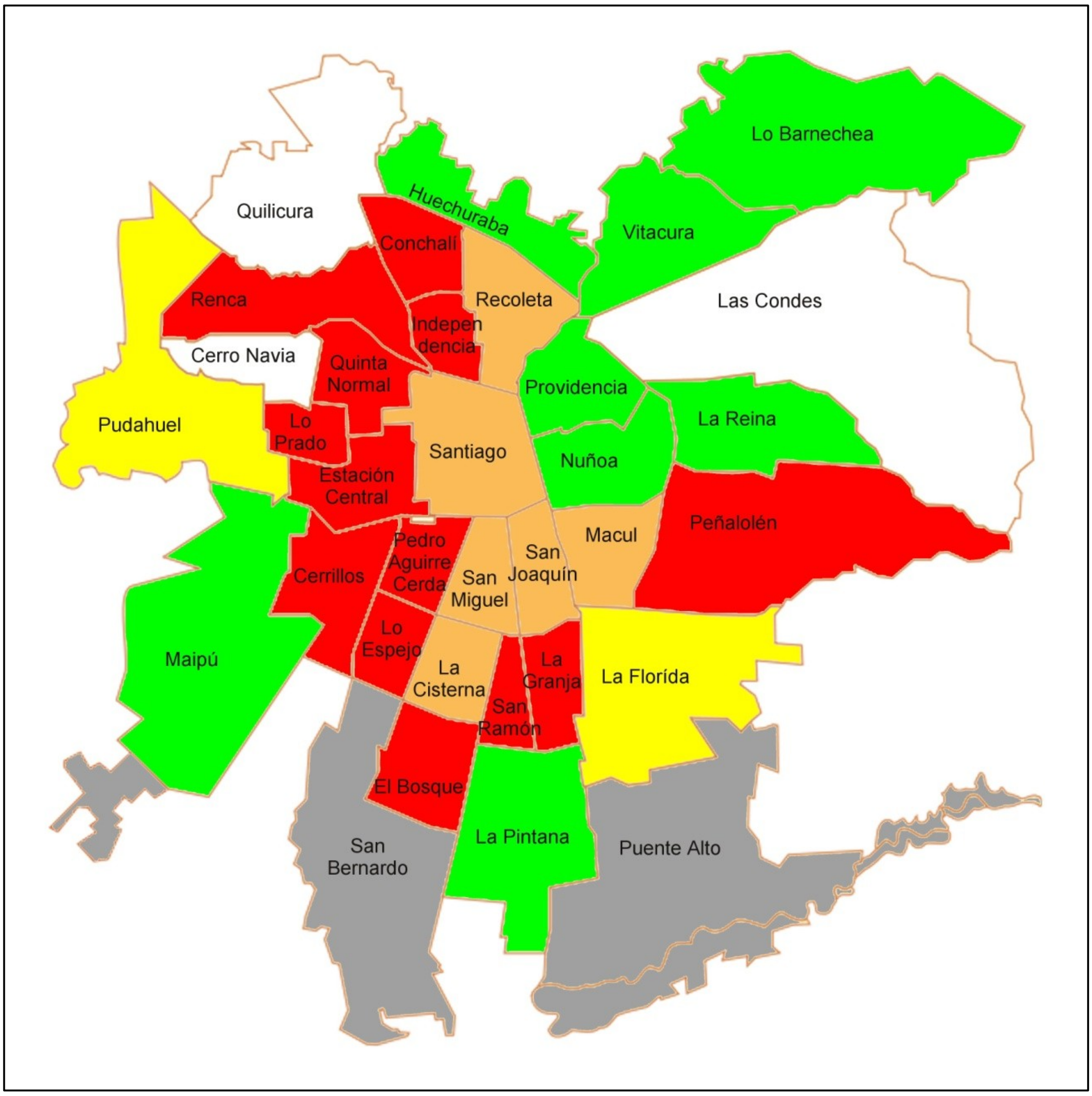
All indicators according to hazard type are listed with data source, value, Z-score and aggregated Z-score in Annex 1-3.

5.1 Analysis of Vulnerability to Floods

5.1.1 Flood Vulnerability Map and Point Charts

Chapter 4.1 defined *Housing Quality* and *Green Spaces* as exposure indices as well as *Update LRP* and *Municipal Spending* as adaptive capacity indices. Map 5 shows vulnerability to floods according to the aggregated exposure and adaptive capacity indicators of each comuna.

Map 5: Vulnerability Map for the Province Santiago for Floods



HIGH VULNERABILITY (High Exposure Low Adaptive Capacity)	MODERATE VULNERABILITY (High Exposure High Adaptive Capacity)	MODERATE VULNERABILITY (Low Exposure Low Adaptive Capacity)	LOW VULNERABILITY (Low Exposure High Adaptive Capacity)

NO DATA	NOT ANALYZED

Source: Own elaboration

The largest group of comunas is highly vulnerable, that means characterized by high exposure and low adaptive capacity. These are the 13 comunas Peñalolén, La Granja, San Ramón, El Bosque, Lo Espejo, Pedro Aguirre Cerda, Cerrillos, Estación Central, Lo Prado, Quinta Normal, Renca, Independencia and Conchalí. Except for Peñalolén, which is located in the eastern outskirt of the city, they run from the north westwards to the south around the central comuna Santiago.

These highly vulnerable comunas require high priority in the planning of risk management strategies and the implementation of appropriate actions. The high exposure results from either a lack of green spaces, from a high share of precarious housing or from a combination of both (a more detailed discussion will follow in chapter 5.2.2). Green spaces could be restructured and new parks, grasslands etc. could be created to serve as natural drainage and lowering flood exposure. Improvements in the housing conditions and constructions of protections against water entering the houses could help to prevent damages and losses. The low adaptive capacity requires a closer look at the comunas finances and a regular update of the LRPs laying down risk management strategies.

As the highly vulnerable comunas are located close to each other, combined actions might be an option. For instance, if exposure shall be lowered, infrastructural measures (housing improvements, drainage clearing) and non-structural measures (like establishments of warning systems) could be planned and implemented collectively for more than one comuna. In that way, local authorities could support and learn from each other and certainly cut down on implementation cost.

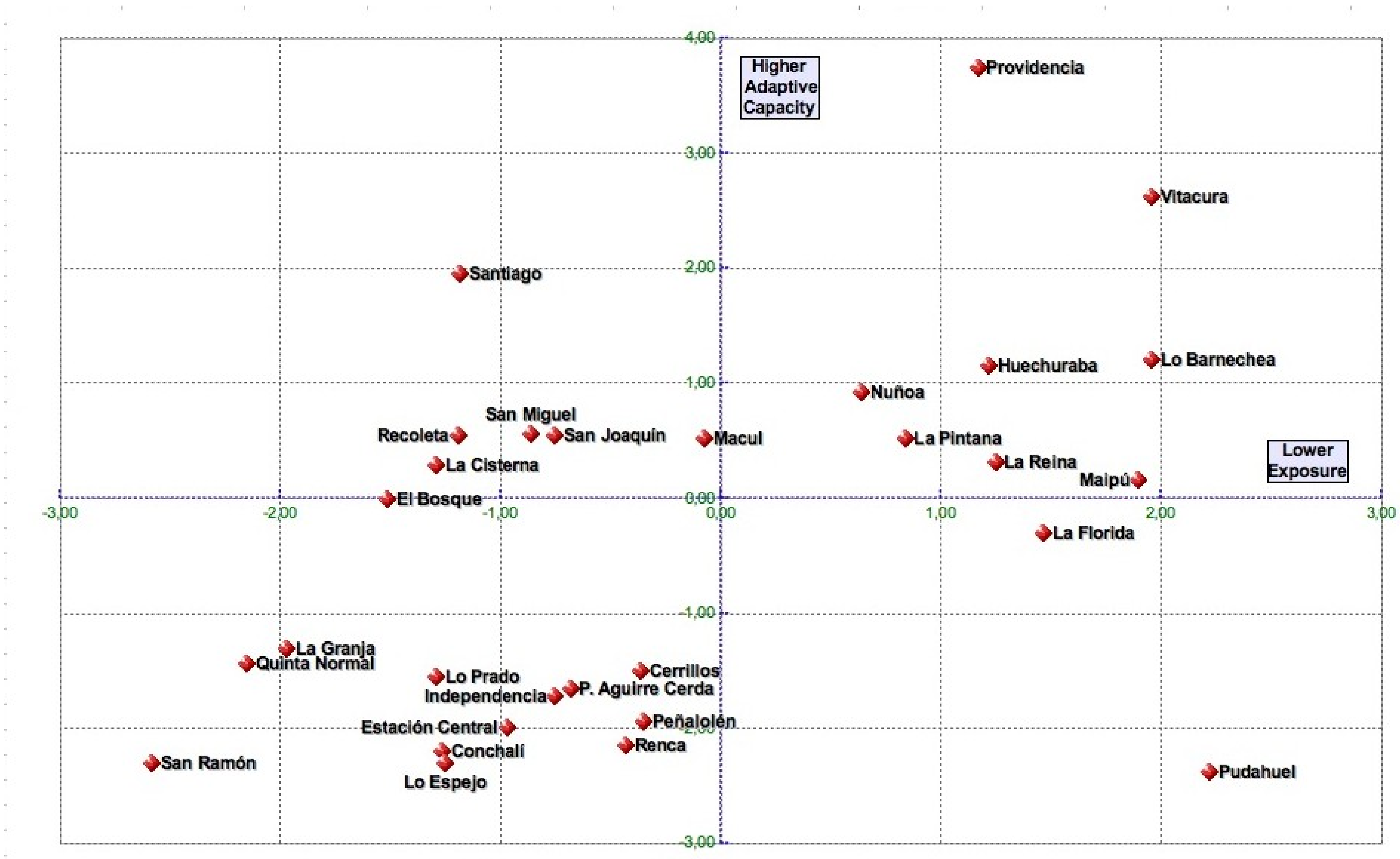
The second largest group of comunas is characterized by low vulnerability due to low exposure and high adaptive capacity: Huechuraba, Vitacura, Lo Barnechea, Providencia, Nuñoa, La Reina, La Pintana and Maipú. Chapter 5.1.2 will take a closer look at the single indicators.

The comunas characterized by moderate vulnerability due to high exposure and high adaptive capacity are grouped in the city centre: Recoleta, Santiago, San Miguel, San Joaquín, Macul and La Cisterna. Their exposure could be lowered by expanding urban green spaces and improving the quality of the precarious housing stock.

Only the two comunas Pudahuel and Peñalolén are characterized by moderate vulnerability due to low exposure and low adaptive capacity. Their adaptive capacity could be increased by reviewing municipal spending and/ or regular revisions of the LRP.

Figure 14 shows the point diagram that served as a basis for the vulnerability map.

Figure 14: Point Diagram for Flood Vulnerability



Source: Own elaboration

Cerro Navia, Las Condes and Quilicura are missing in the point chart and in the map as there was no data available for the *Update LRP* indicator. Chapter will nevertheless analyse their other indicators in more detail.

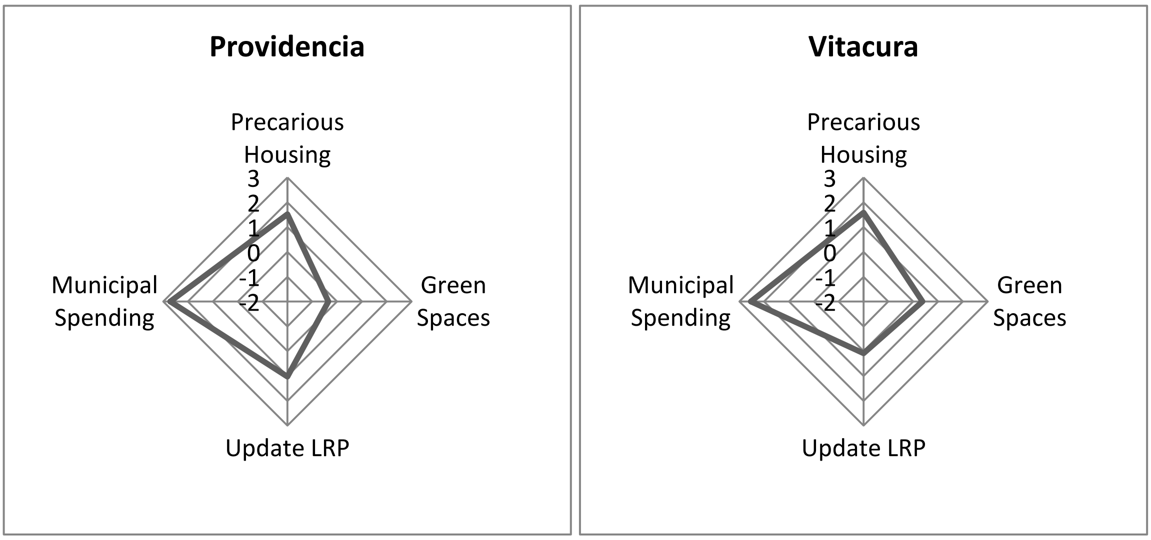
The following chapter looks at the vulnerabilities of the single comunas more closely. For instance, all the comunas mapped as highly vulnerable (i.e. with high exposure and low adaptive capacity), still show significant differences in the individual indicators that aggregate to the exposure and adaptive capacity values. To derive policies and activities it also appears important to understand in detail how indicators determine high or low vulnerability.

5.1.2 Detailed Analysis: Comunas' Radar Chart for Floods

To systematize this, comunas will be grouped and considered according to their vulnerability quadrant. A radar chart for each comuna shows the Z-scores for all the involved exposure and adaptive capacity indicators. Note that the Z-scores of the indicators *Precarious Housing* and *Update LRP* have been multiplied by -1.0 to reverse them to the common principle: 'the higher, the better' and to achieve a consistent presentation in the radar charts.

5.1.2.1 Comunas with Lowest Vulnerability to Floods

Figure 15: Radar Charts for Providencia and Vitacura

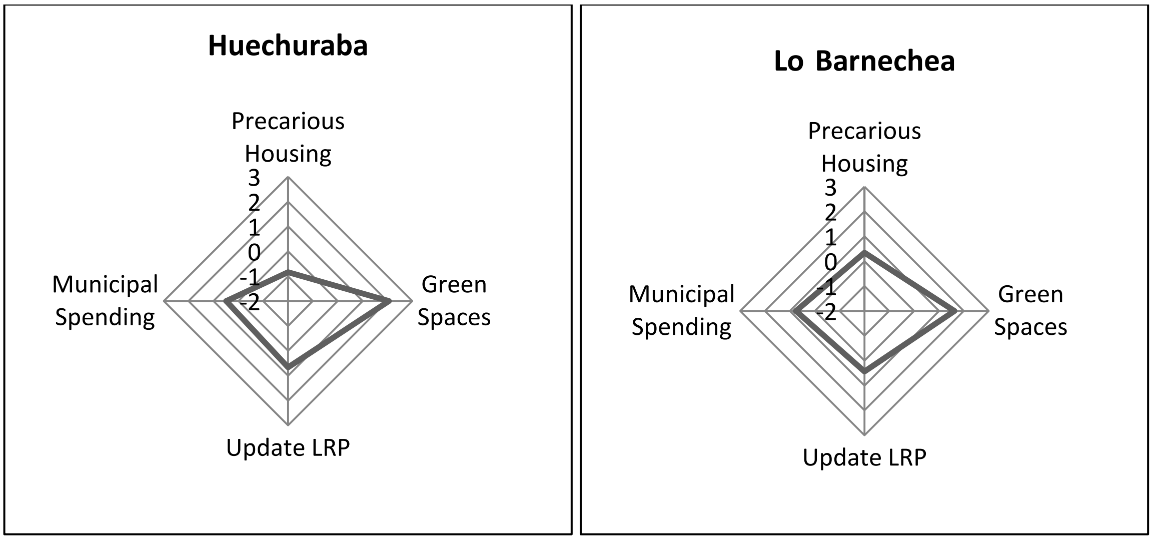


Source: Own elaboration

Providencia shows best values in adaptive capacity. This is due to the high value in *Municipal Spending*, after Santiago the second highest value of all 32 comunas. It also shows the second highest (after La Pintana) value in the *Update LRP* indicator. While it's performing fine in the *Precarious Housing* indicator, the value for *Green Spaces* is low.

Vitacura in comparison shows a higher value in the *Green Spaces* indicator. Along with its good values (low share) in *Precarious Housing* it is one of the three comunas with lowest exposure. Its adaptive capacity is lower than Providencia's, as the LRP update was not as recent as Providencia's.

Figure 16: Radar Charts for Huechuraba and Lo Barnechea

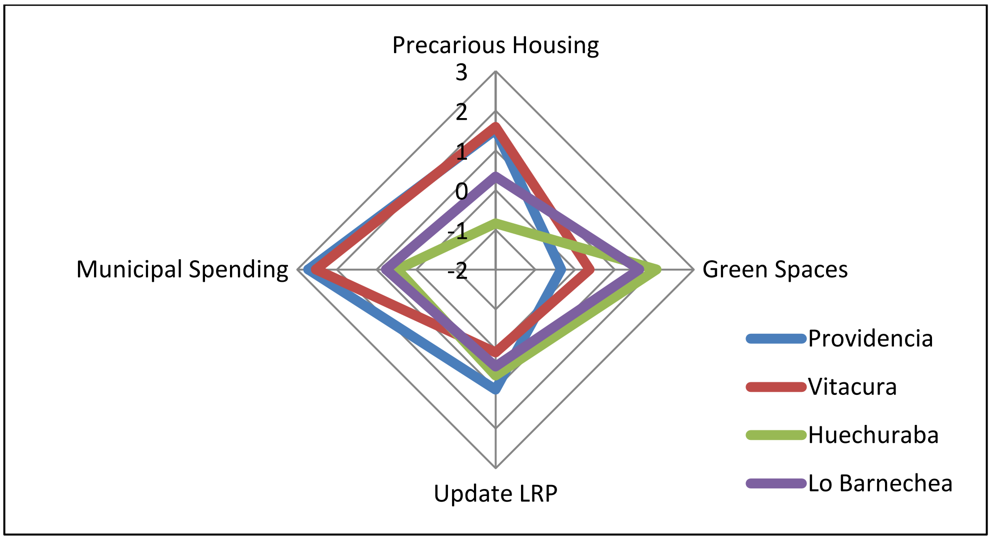


Source: Own elaboration

Huechuraba and Lo Barnechea perform similarly in adaptive capacity. Lo Barnechea has a higher share in the Precarious Housing indicator, which can't be compensated by Huechuraba's slightly higher value in *Green Spaces*. Therefore Lo Barnechea has a higher aggregated exposure.

The following chart overlays the individual comuna charts for direct comparison. It shows immediately how the comunas behave in terms of indicator values. This can be helpful when discussing which improvements could be applied to level the differences between one comuna in relation to others.

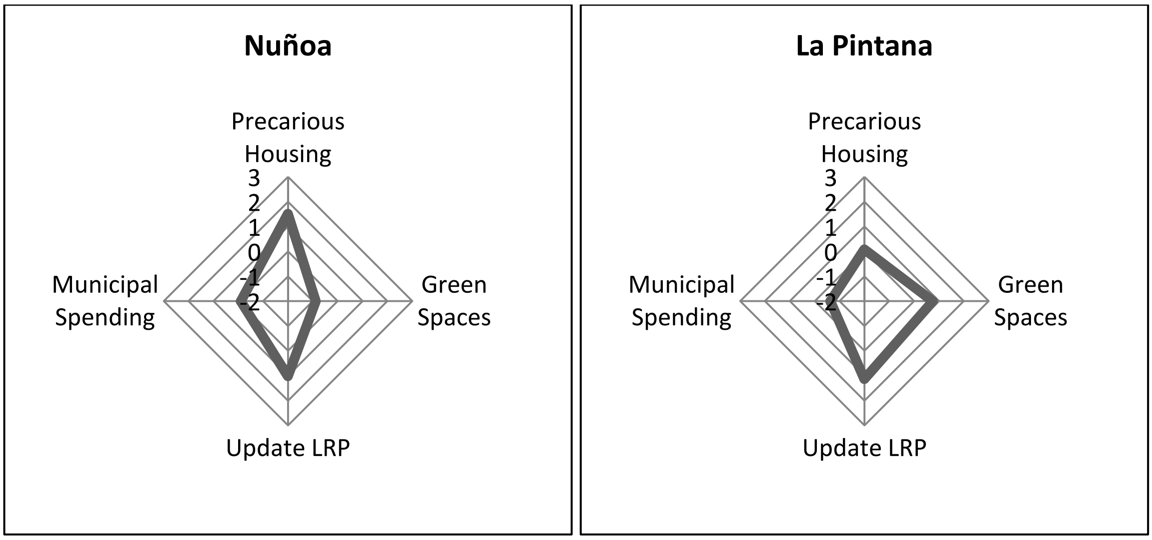
Figure 17: Overlaid Radar Charts for Providencia, Vitacura, Huechuraba and Lo Barnechea



Source: Own elaboration

Next are Nuñoa, La Pintana, La Reina and Maipú

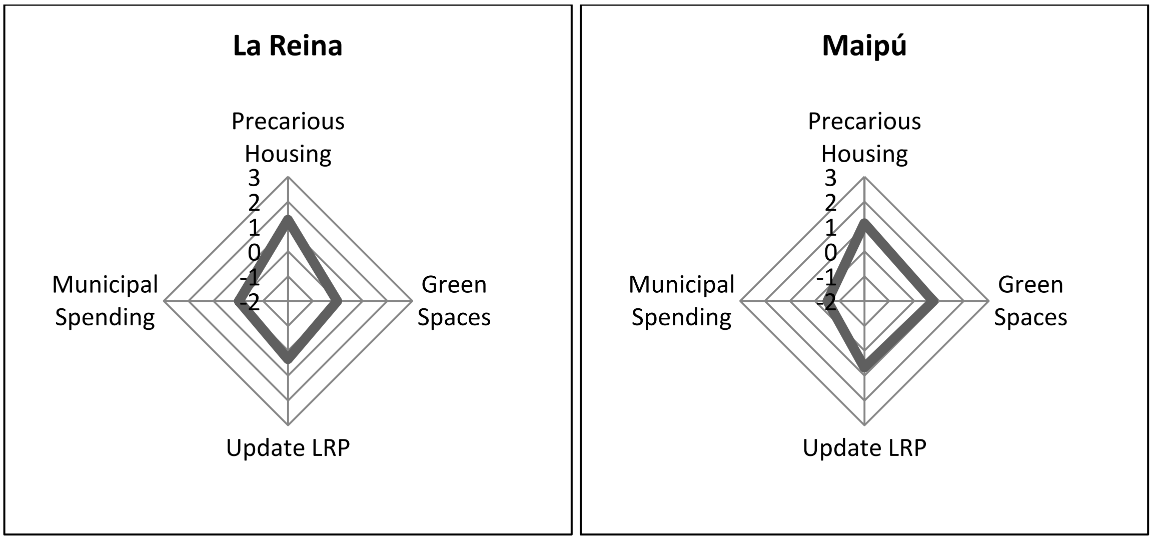
Figure 18: Radar Charts for Nuñoa, La Pintana, La Reina and Maipú



Source: Own elaboration

Nuñoa and La Pintana perform similarly in exposure. Nuñoa shows a high value in *Precarious Housing* and a low value in *Green Spaces*, La Pintana shows the opposite. Both show low values in the *Municipal Spending* indicator but high values in the *Update LRP* indicator.

Figure 19: Radar Charts for La Reina and Maipú

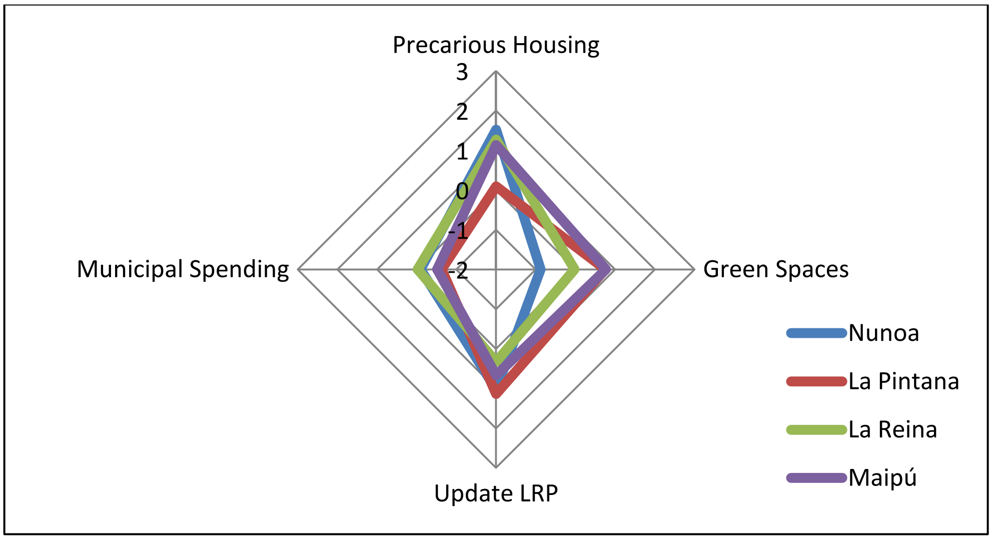


Source: Own elaboration

La Reina and Maipú show low exposure but their aggregated adaptive capacity value brings them close to the fourth quadrant (characterized by low exposure and low adaptive capacity). This is due to the values in the *Municipal Spending* indicator, which are low in comparison to the other comunas in this quadrant.

The following chart overlays the individual comuna charts for direct comparison.

Figure 20: Overlaid Radar Charts for Nuñoa, La Pintana, La Reina and Maipú

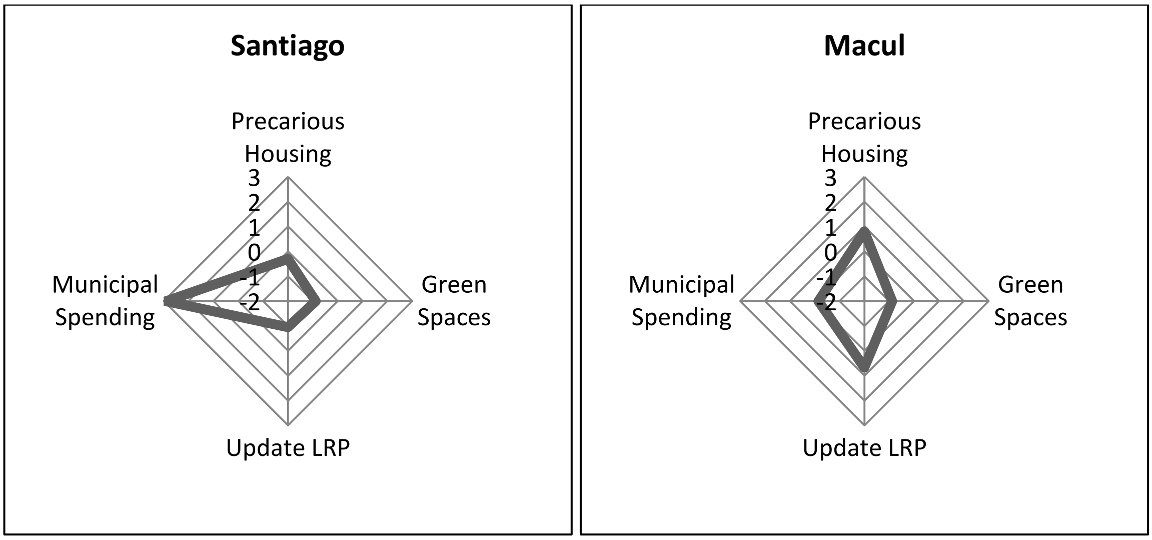


Source: Own elaboration

5.1.2.2 Comunas with Moderate Vulnerability (High Exposure/ High Adaptive Capacity) to Floods

This quadrant holds six comunas. The analysis splits them in two groups: Santiago and Macul as well as Recoleta, La Cisterna, San Miguel, San Joaquín.

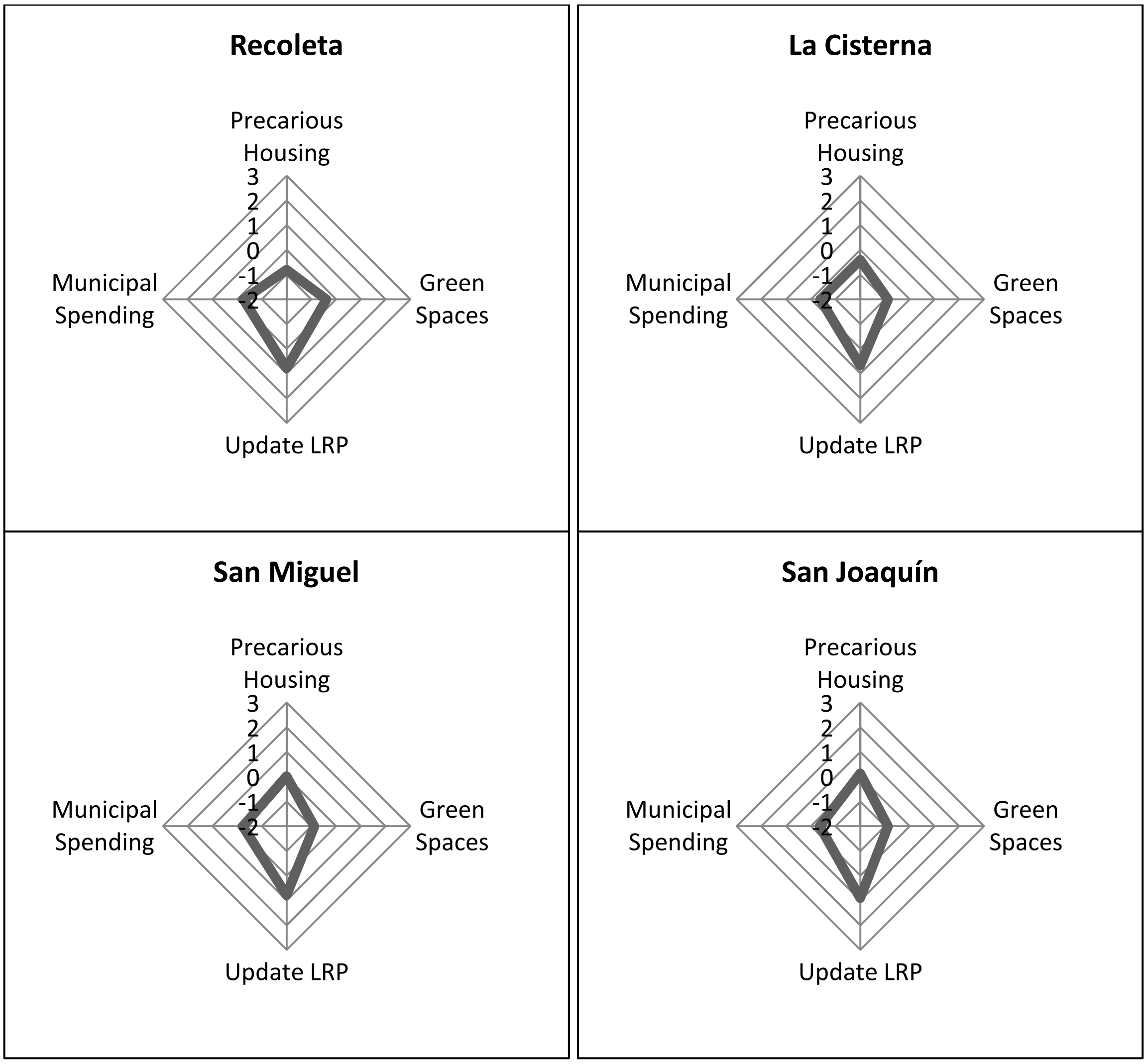
Figure 21: Radar Charts for Santiago and Macul



Source: Own elaboration

Santiago has the highest adaptive capacity in this quadrant and is among the top three of all 32 comunas. This results from an extraordinary value in *Municipal Spending*, the highest value of all 32 comunas. Still, its adaptive capacity is decreased by a low value in *Update LRP*. Exposure is high due to low values in both *Precarious Housing* and *Green Spaces*. This is probably because Santiago contains the innermost and oldest parts of the city. Macul shares Santiago's low value in *Green Spaces* but has average exposure among all comunas. Its over-average adaptive capacity is driven by the *Update LRP*.

Figure 22: Radar Charts of Recoleta, La Cisterna, San Miguel and San Joaquín

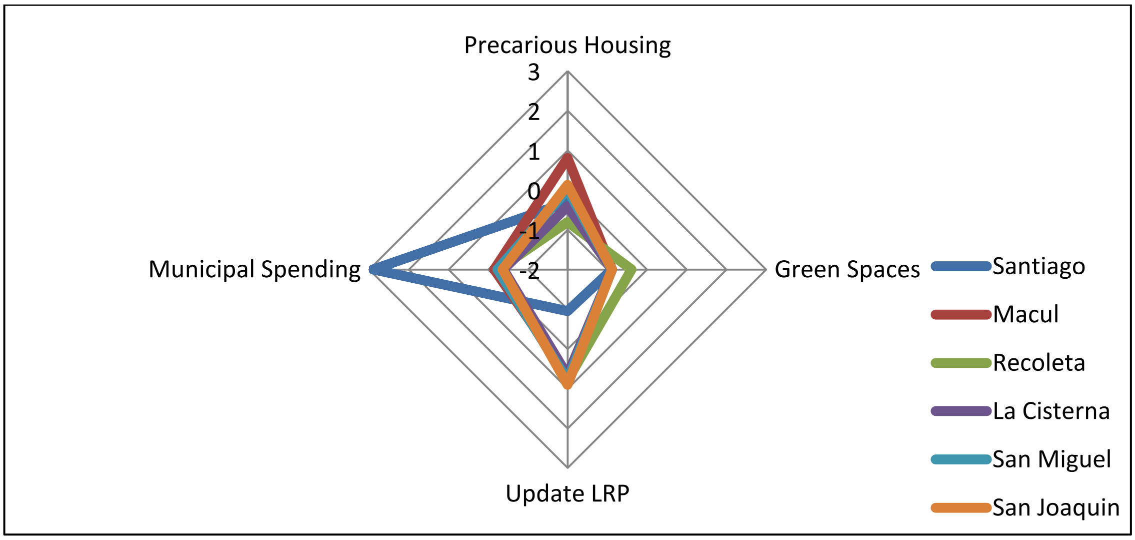


Source: Own elaboration

All four comunas show a very similar shape in their radar chart. They all show minimum values in *Green Spaces*. The values in *Precarious Housing* are near or below average. Their *Update LRP* values are among the top five of all comunas, but the values of their *Municipal Spending* are in the lowest quarter of all comunas.

The following chart overlays the individual comuna charts for direct comparison.

Figure 23: Overlaid Radar Chart for Santiago, Macul, Recoleta, La Cisterna, San Miguel, San Joaquín

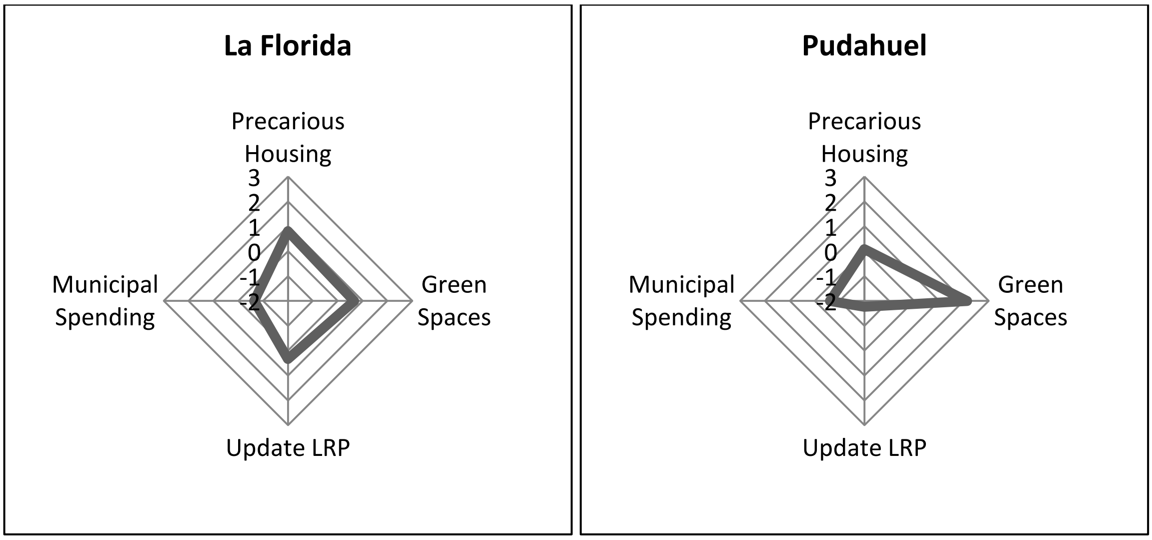


Source: Own elaboration

5.1.2.3 Comunas with Moderate Vulnerability (Low Exposure/ Low Adaptive Capacity) to Floods

There are only two comunas in the moderate (low exposure and low adaptive capacity) quadrant: La Florída and Pudahuel.

Figure 24: Radar Charts for La Florída and Pudahuel

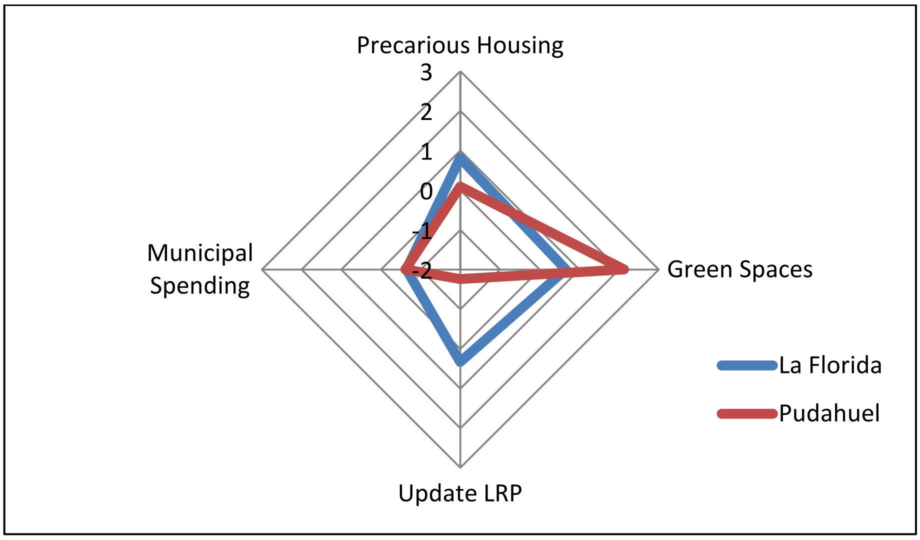


Source: Own elaboration

Pudahuel escaped the high vulnerability quadrant because of its high share of green spaces and the moderate value in *Precarious Housing*. Pudahuel is an extreme case in both aspects: while exposure is lowest of all the 32 comunas (Pudahuel has the highest share in green spaces), aggregated adaptive capacity is also lowest of all comunas (Pudahuel has no LRP and *Municipal Spending* is near the minimum of all comunas).

La Florída's exposure is in the top quarter due to good values in both housing quality and green spaces. However, its adaptive capacity is rather poor because its value for *Municipal Spending* is closed to the minimum of all comunas.

Figure 25: Overlaid Radar Chart for La Florída and Pudahuel

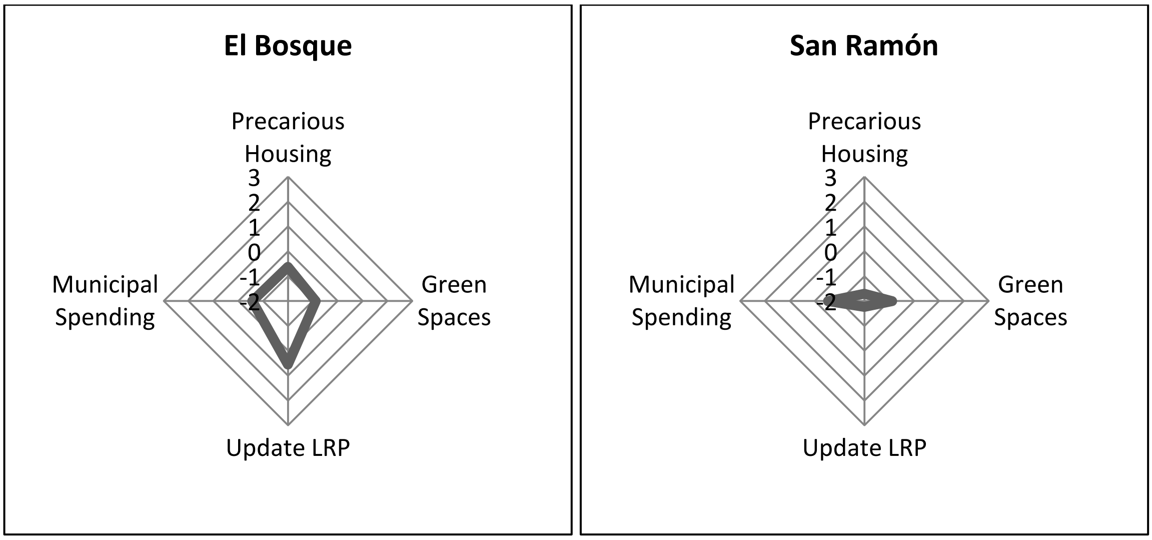


Source: Own elaboration

5.1.2.4 Comunas with High Vulnerability to Floods

This quadrant contains 13 comunas: El Bosque, La Granja, Quinta Normal, San Ramón, Lo Prado, Estación Central, Conchalí, Lo Espejo, Cerrillos, Pedro Aguirre Cerda, Independencia, Peñalolén and Renca. With the exceptions Cerrillos, Lo Espejo, Pedro Aguirre Cerda, Peñalolén and Renca, they share the minimum value in the *Green Space* indicator. Also the Precarious Housing indicator is generally clearly below average. In the adaptive capacity, their municipal spending is generally close to the minimum value of all comunas. Within this quadrant are four of the five comunas without a LRP. With the exception El Bosque, all the other comunas in this quadrant show significantly low values in the *Update LRP* indicator. It is obvious that attention to the revisions of LRP could improve adaptive capacity.

Figure 26: Radar Charts for El Bosque and San Ramón

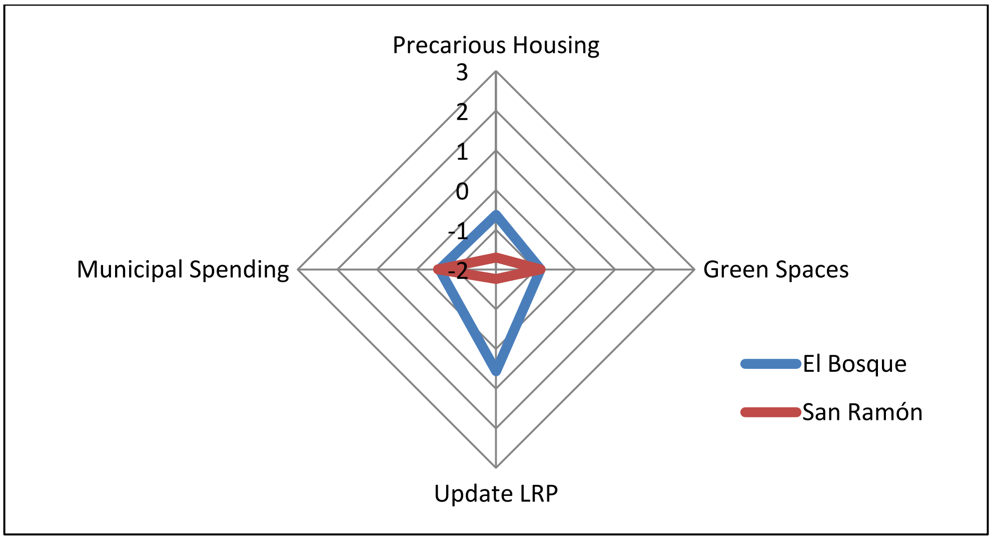


Source: Own elaboration

As the shape of the radar chart shows, El Bosque and San Ramón mark two extreme points in this quadrant. San Ramón's indicator values are practically the lowest ones of all the comunas. While El Bosque's value for Green Spaces and Municipal Spending are also close to the minimum, its better position is driven by its high value in *Update LRP*. It is the highest one in this quadrant, putting it almost from high vulnerability (high exposure/ low adaptive capacity) to moderate vulnerability (high exposure/ high adaptive capacity).

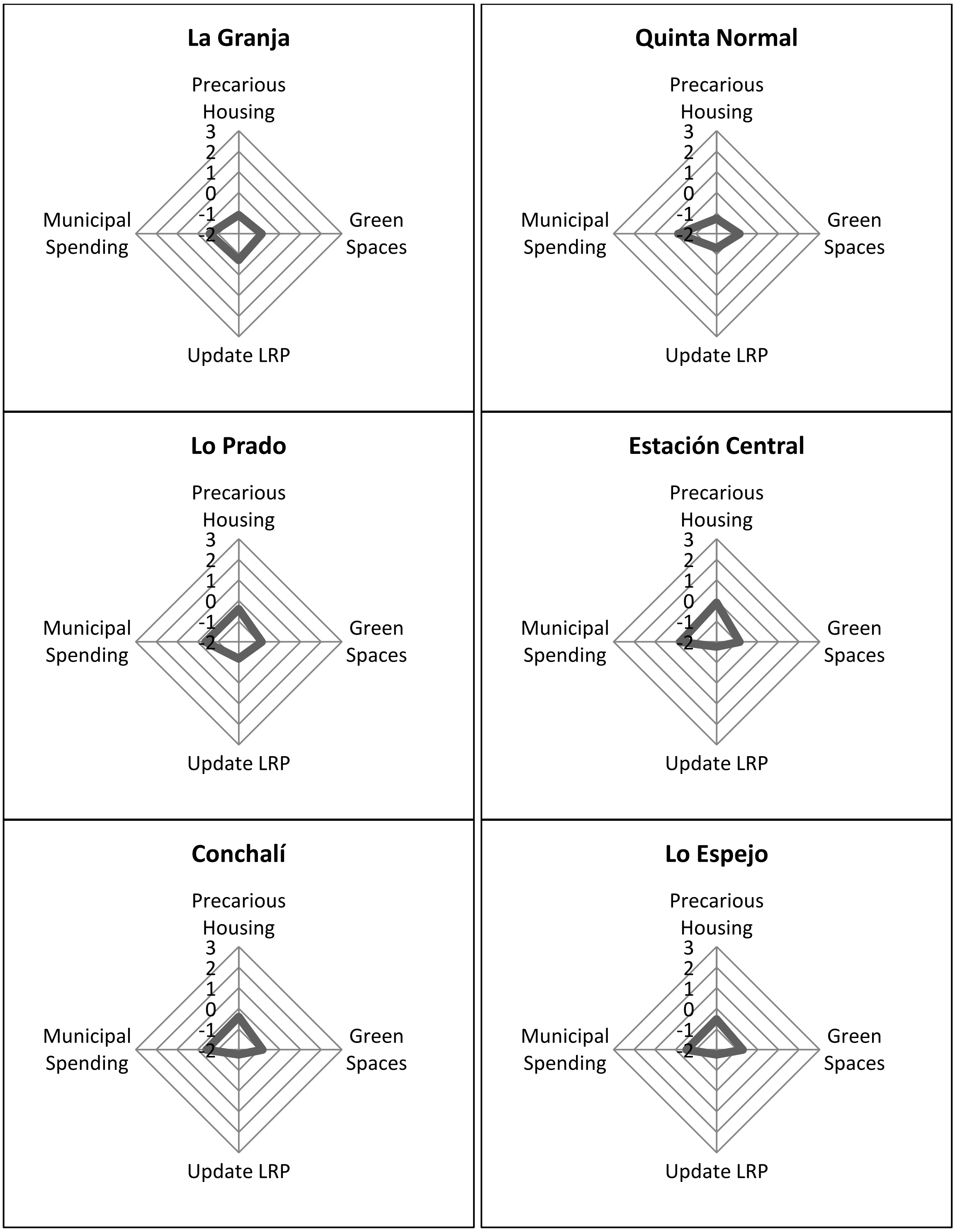
The following chart overlays the individual comuna charts for direct comparison.

Figure 27: Overlaid Radar Chart for El Bosque and San Ramón



Source: Own elaboration

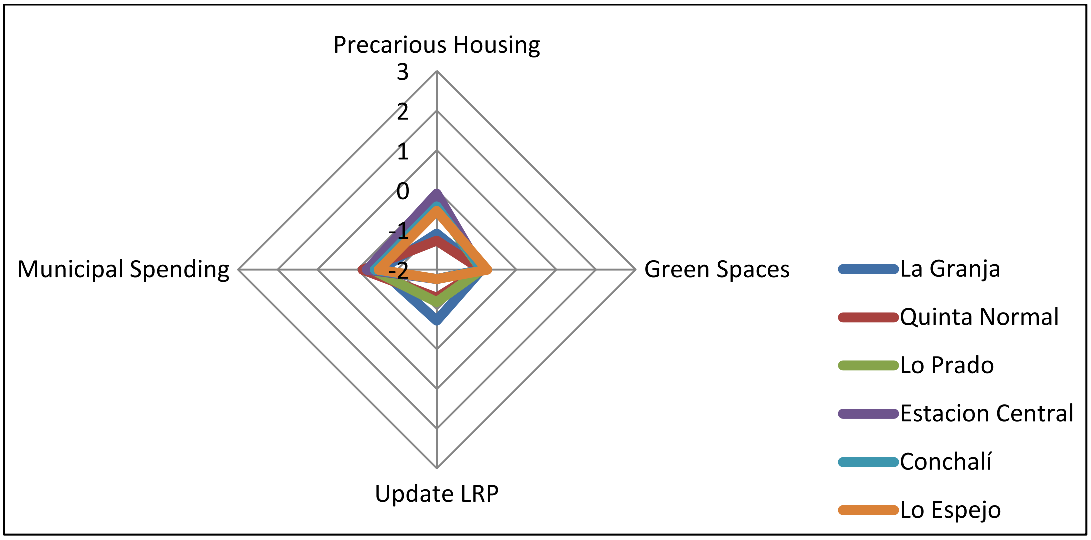
Figure 28: Radar Chart for La Granja, Quinta Normal, Lo Prado, Estación Central, Conchalí, Lo Espejo



Source: Own elaboration

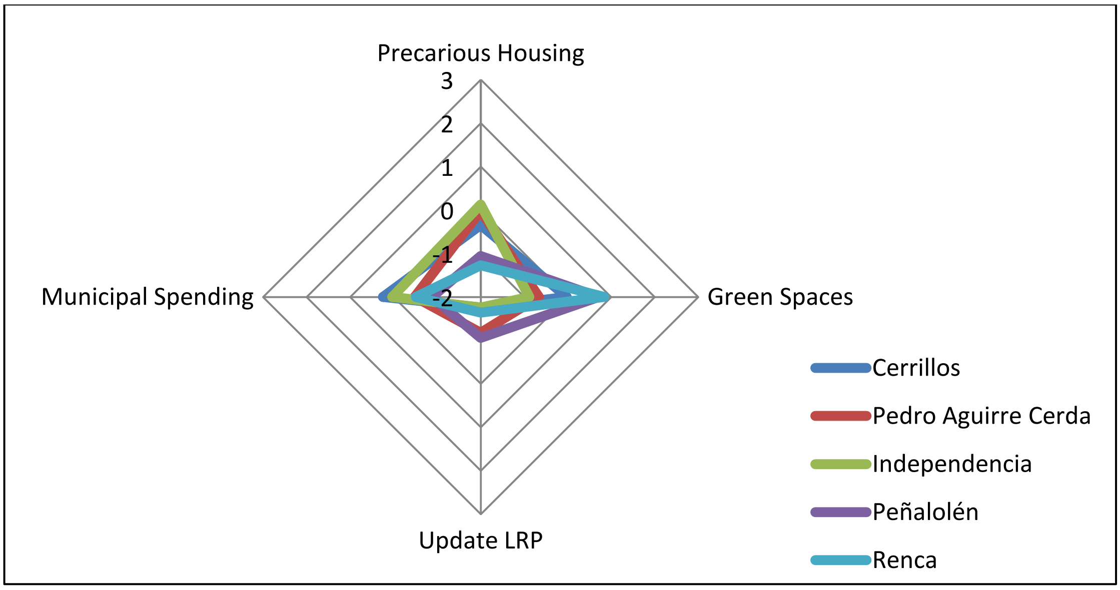
As can be seen in Figure 28, the other comunas in this quadrant have the same low adaptive capacity; they differ basically in their exposure. With the exception of Peñalolén, they have the same lack of green spaces, thus their exposure is driven by the precarious housing quality. As their values are very similar, they will not be analysed one by one. Instead, they are grouped in two according to their exposure (Group 1: La Granja, Quinta Normal, Lo Prado, Estación Central, Conchalí and Lo Espejo; Group 2: Cerrillos, P.A. Cerda, Independencia, Peñalolén and Renca) and only the charts will be displayed. The two overlaid radar charts will be displayed in Figure 29 and Figure 30, followed by the single radar charts for the second group in Figure 31.

Figure 29: Overlaid Radar Chart for La Granja, Quinta Normal, Lo Prado, Estación Central, Conchalí, Lo Espejo



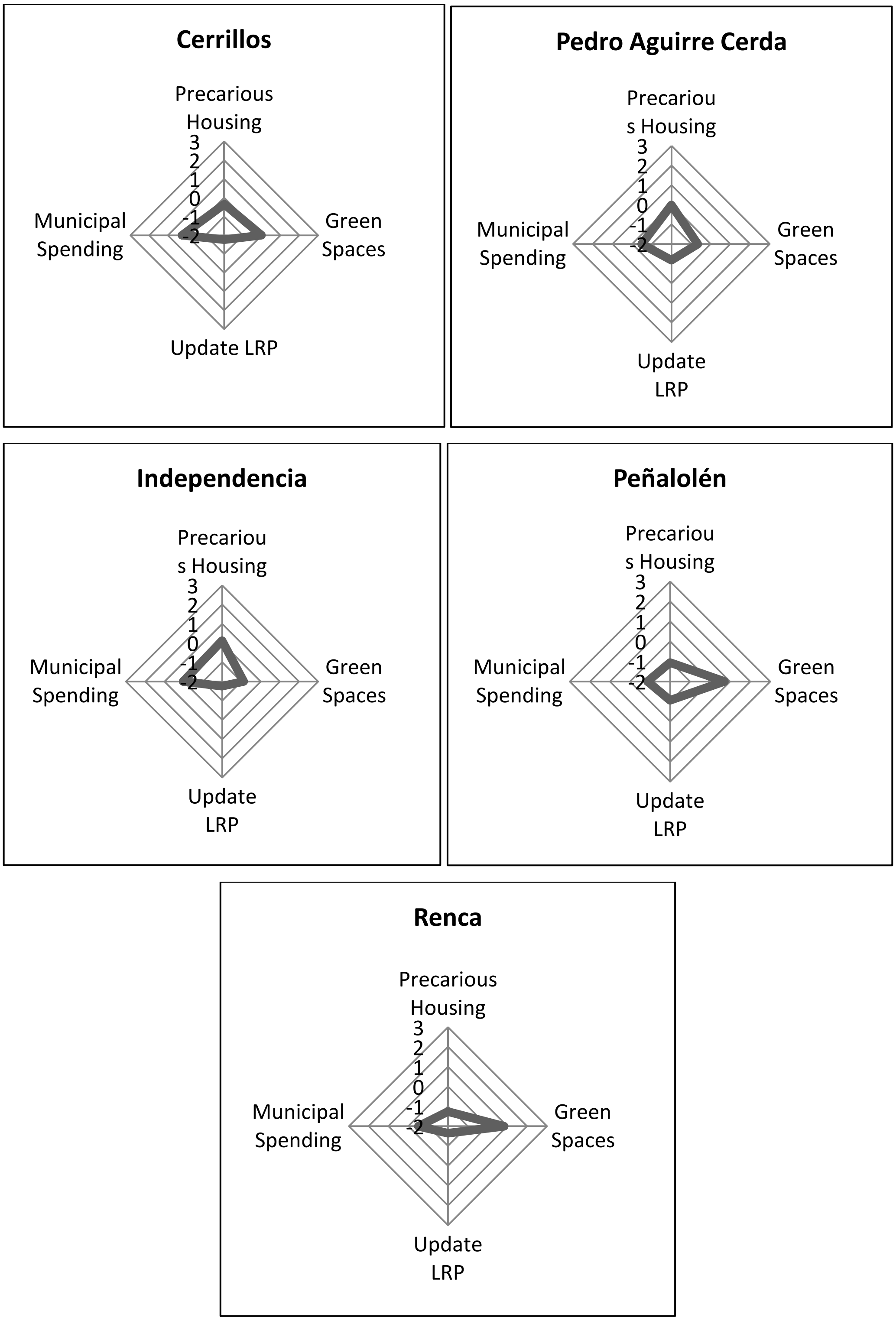
Source: Own elaboration

Figure 30: Overlaid Radar Chart for Cerrillos, Pedro Aguirre Cerda, Independencia, Peñalolén, Renca



Source: Own elaboration

Figure 31: Radar Charts for Cerrillos, Pedro Aguirre Cerda, Independencia, Peñalolén and Renca



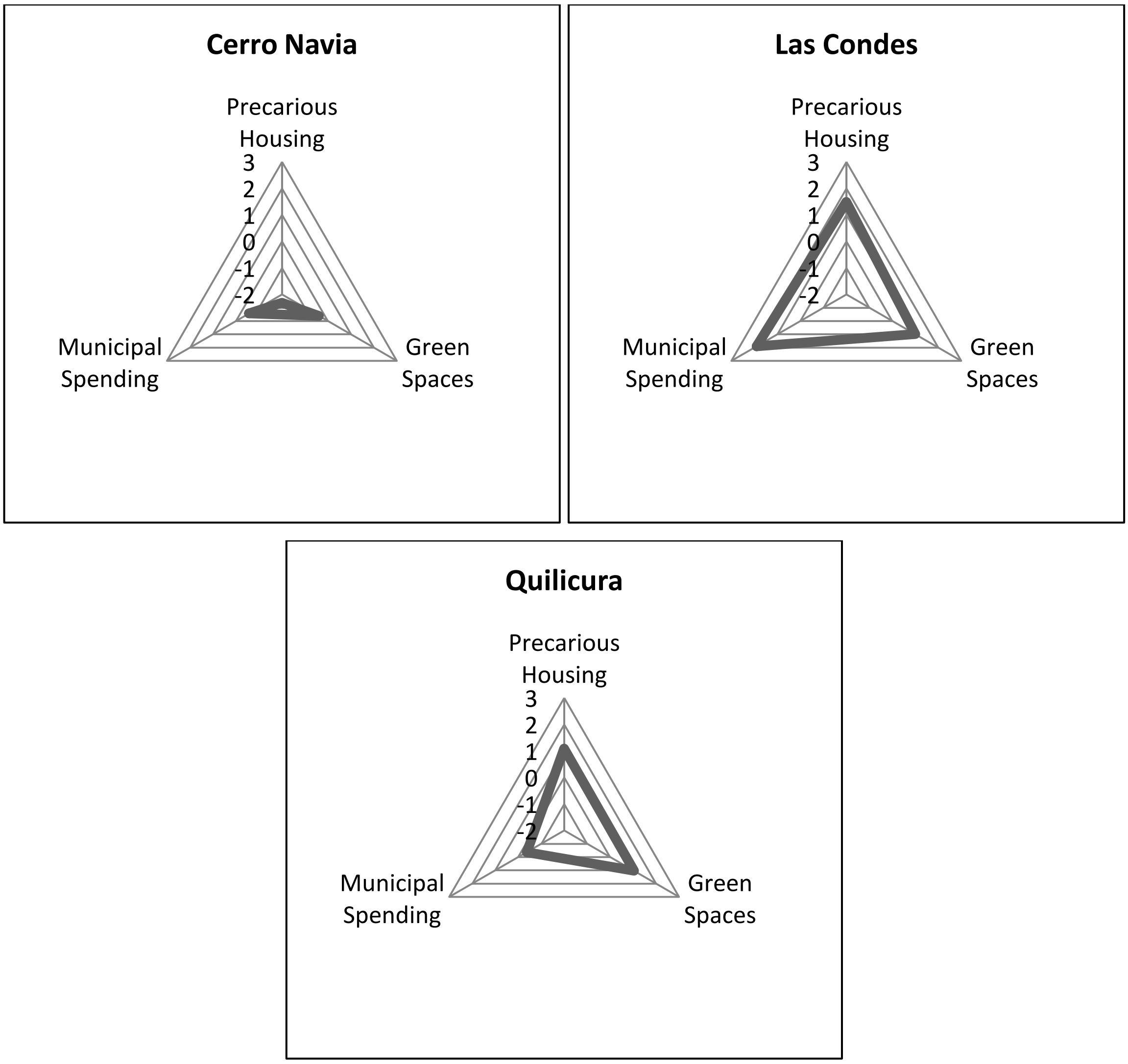
Source: Own elaboration

To complete the analysis of all 32 comunas, the next paragraph will attend to the comunas missing in the point diagram and the vulnerability map due to missing data.

5.1.2.5 Comunas with Missing Data on the LRP

For the comunas Cerro Navia, Las Condes and Quilicura, no data on the *Update LRP* indicator was available. Nevertheless, this paragraph will look closer at the available indicators.

Figure 32: Radar Charts for Cerro Navia, Las Condes and Quilicura



Source: Own elaboration

There is a marked difference between Cerro Navia and Las Condes. Cerro Navia is highly exposed due to a low value in Green Spaces and the lowest value (highest share) of all comunas in the *Precarious Housing* Indicator. Its *Municipal Spending* indicator shows one of the lowest values of all comunas; even with a good value in the *Update LRP* indicator it would have a sub-average adaptive capacity. Together with its high exposure, Cerro Navia would be highly vulnerable.

Las Condes on the contrary shows high values in all indicators. Its exposure is low due to its high value (low share) in the *Precarious Housing* indicator (among the top five of all comunas) and a good value in *Green Spaces*. After Santiago, Vitacura and Providencia it has the highest municipal spending. Even with no LRP or the worst value, it would still show a positive aggregated value in adaptive capacity and therefore it would be located in the low vulnerability quadrant.

Quilicura shows low exposure with high values in both the *Precarious Housing* and the *Green Spaces* indicator. In the *Municipal Spending* indicator is performs rather poorly. If its *LRP Update* value were high, adaptive capacity would be moderate to high and thus its vulnerability low. If the *LRP Update* indicator value were low, adaptive capacity would be low to medium and its vulnerability moderate (low exposure/ low adaptive capacity).

5.2 Analysis of Vulnerability to Heat Waves

Chapter 4.2 defined *Green Spaces* and *Population over 60* as exposure indicators as well as *Health*, *Municipal Spending* and *GDP per Capita* as adaptive capacity indicators. The heat wave vulnerability map, the point chart and the analysis follow the same structure as for floods.

5.2.1 Heat Wave Vulnerability Maps and Point Charts

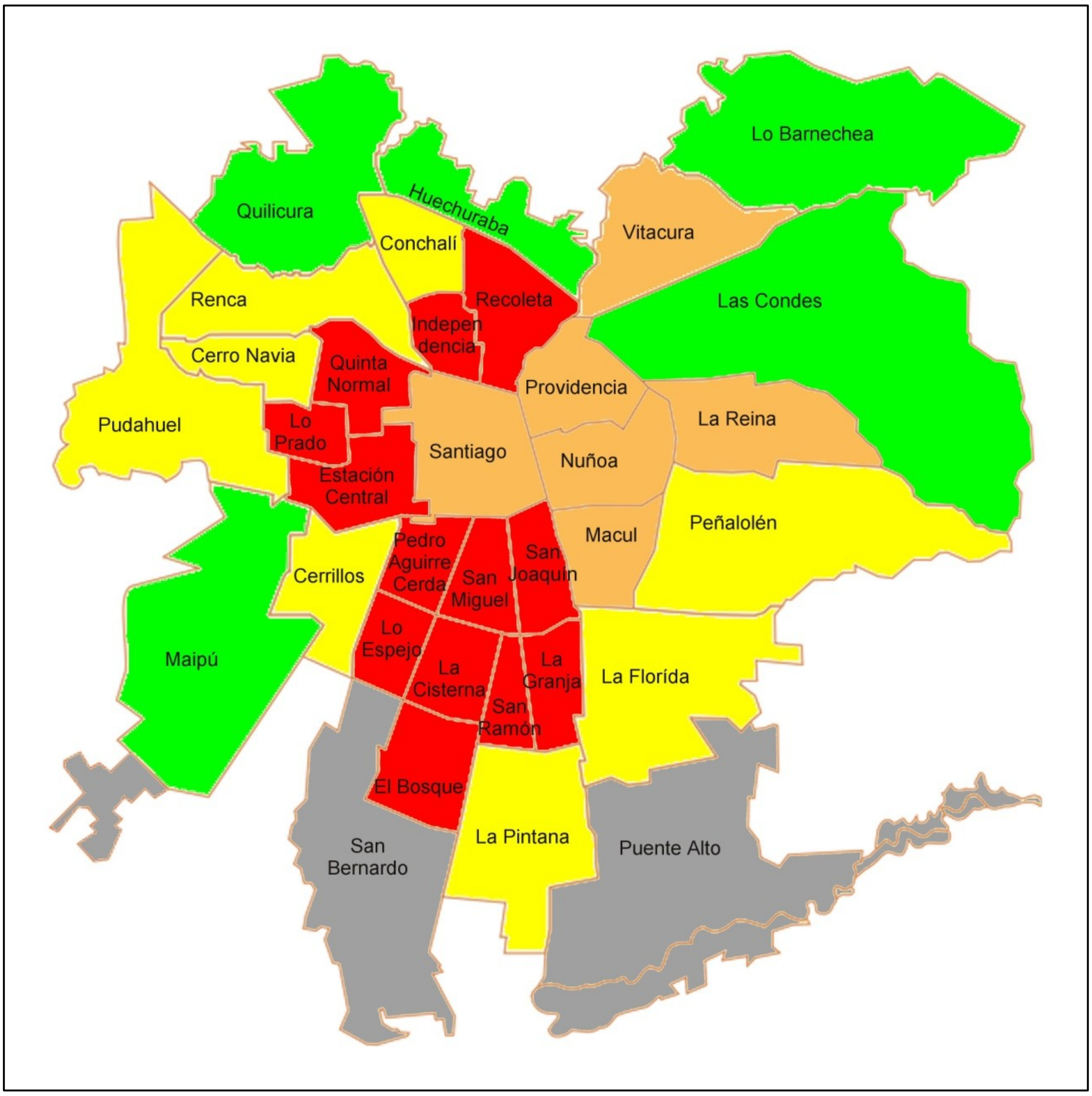
Map 6 shows vulnerability to heat waves, according to the aggregated exposure and adaptive capacity indicators of each comuna.

The comunas with high vulnerability appear in three groups. One group shows up to the south of the central comuna of Santiago: San Joaquín, La Granja, San Ramón, La Cisterna, San Miguel, Pedro Aguirre Cerda and Lo Espejo. The other two appear to the west and north of Santiago comuna: Estación Central, Lo Prado, Quinta Normal, Independencia and Recoleta. The highly vulnerable comunas almost form a semicircle around the comuna Santiago; this is only interrupted by the comuna Cerrillos which is characterized by moderate vulnerability, due to low exposure and low adaptive capacity.

As with floods, the highly vulnerable comunas most certainly need immediate attention and the development of risk management strategies. Their common high exposure results from either a lack of green spaces, from a high share of the population over 60 years or from a combination of these two (a more detailed discussion follows in 5.2.2). As mentioned above, green spaces could be restructured to lower exposure. Acknowledged measures to mitigate exposure particularly of the elderly people are careful information about heat-related health-risks and possible individual and local coping strategies. The low adaptive capacity requires a closer look at the comunas finances as well as quality of and access to health services.

Again, highly vulnerable comunas are located close to each other, which encourages combined actions for more than one comuna.

Map 6: Vulnerability Map for the Province Santiago for Heat Waves



HIGH VULNERABILITY (High Exposure Low Adaptive Capacity)	MODERATE VULNERABILITY (High Exposure High Adaptive Capacity)	MODERATE VULNERABILITY (Low Exposure Low Adaptive Capacity)	LOW VULNERABILITY (Low Exposure High Adaptive Capacity)

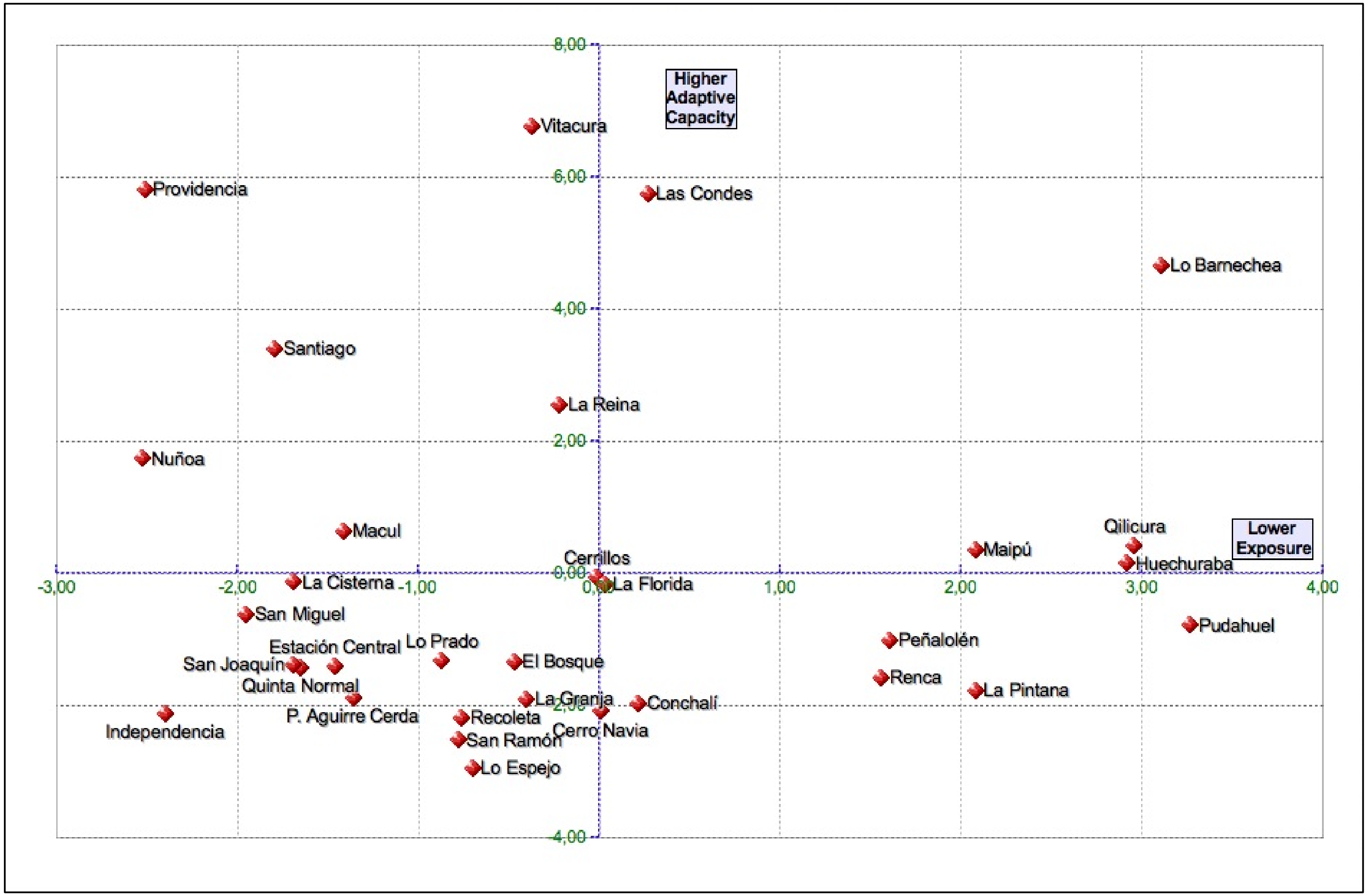
Source: Own elaboration

Grouped in the centre and stretching eastwards are the comunas characterized by moderate vulnerability with high adaptive capacity but also with high exposure: Santiago, Providencia, Nuñoa, Macúl, La Reina and Vitacura. As adaptive capacity is already high, these comunas should concentrate on lowering their exposure, which like above demands the creation of additional green spaces and the raising of awareness to heat-related health risks, especially addressing elderly people.

The other group of comunas with moderate vulnerability to heat waves is characterized by low exposure, but also by low adaptive capacity. This category is distributed all over the province of Santiago and includes the comunas Peñalolén, La Florida, La Pintana, Cerrillos, Pudahuel, Cerro Navia, Renca and Conchalí. They perform well in exposure, but their adaptive capacity should be increased.

Finally, there are five comunas characterized by low vulnerability to heat waves, resulting from low exposure and high adaptive capacity: Lo Barnechea, Las Condes, San Bernardo, Quilicura and Huechuraba. All of them are located in the outskirts of the city. In Santiago, in such locations, the share of green spaces is usually higher and the share of elderly people is usually lower because of the distance to the city centre. Both these facts are lowering exposure. Adaptive capacity is high due to a combination of medium to high municipal spending per capita, GDP per capita and a good health system.

Figure 33: Point Diagram for Heat Wave Vulnerability



Source: Own elaboration

The heat wave vulnerability point chart served as basis to sketch the heat wave vulnerability Map 6. Remarkably, the group of comunas with high risk is the biggest and the group of comunas with low risk the smallest.

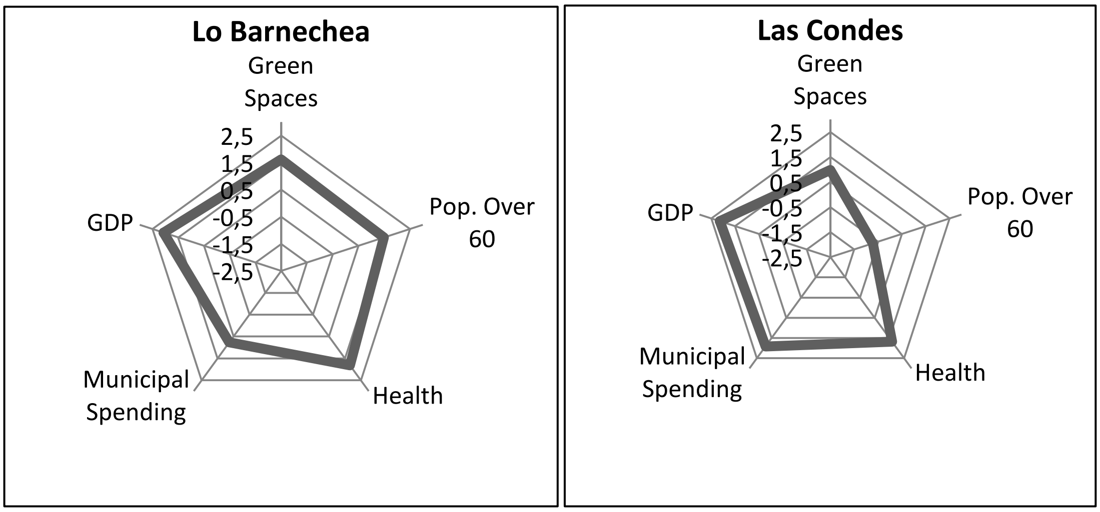
The following chapter looks at the vulnerabilities of the single comunas more closely.

5.2.2 Detailed Analysis: Comuna's Radar Charts for Heat Waves

Comunas will again be grouped and considered according to their vulnerability quadrant. A radar chart for each comuna shows the z-scores for all the involved exposure and adaptive capacity indicators. It is to be noted that the Z-scores of the indicator *Population over 60* has been multiplied by -1.0 to reverse it to the common principle: 'the higher, the better' and to achieve a consistent presentation in the radar charts.

5.2.2.1 Comunas with the Lowest Vulnerability to Heat Waves

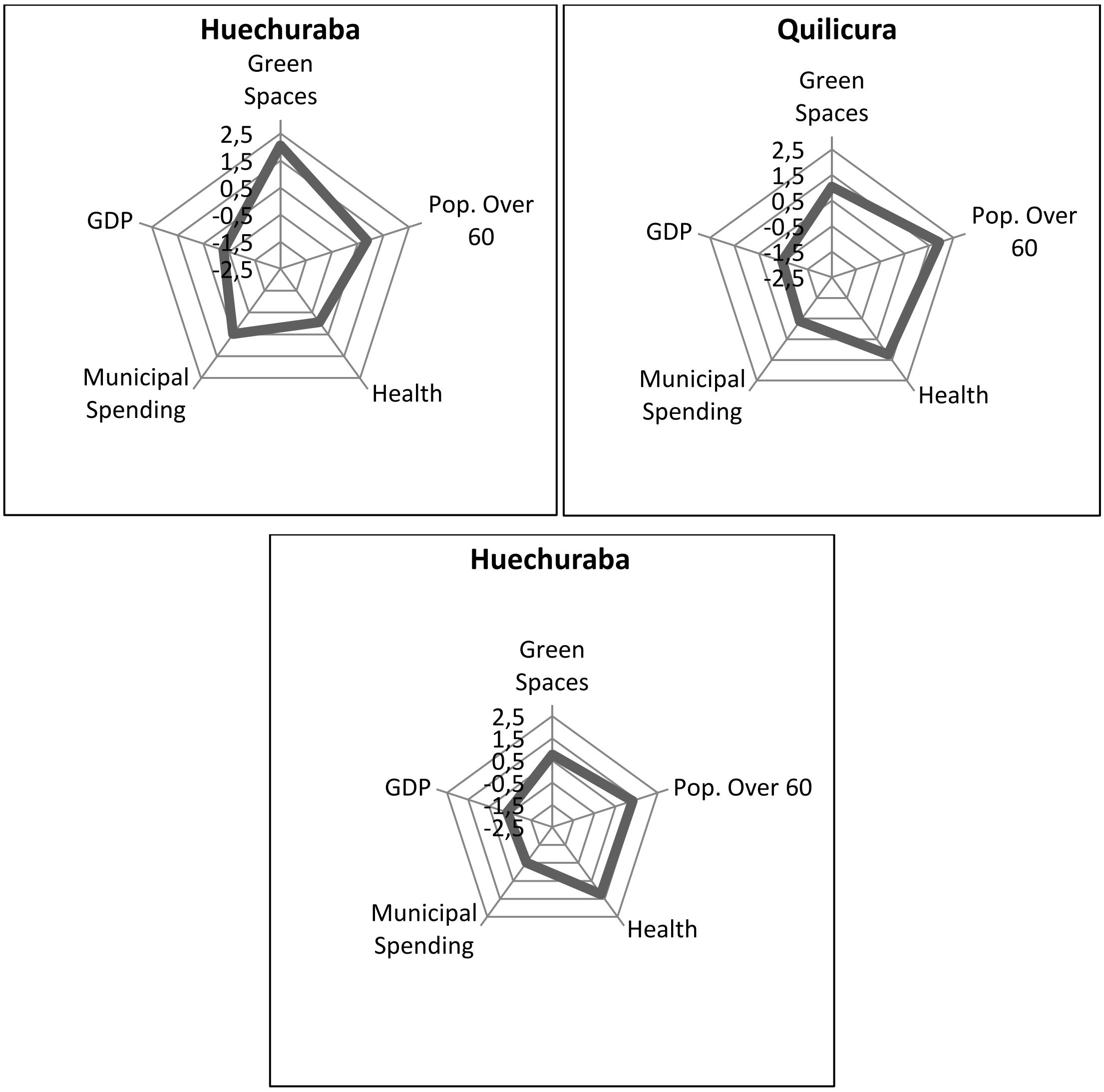
Figure 34: Radar Charts for Lo Barnechea and Las Condes



Source: Own elaboration

As already shown in the point-diagram, Lo Barnechea shows the lowest vulnerability, followed by Las Condes. While they perform similarly in the *GDP* and in the *Health* indicator, Lo Barnechea shows a lower percentage in the *Population Over 60* years (better value) and has a higher share of *Green Spaces*, and Las Condes has the higher *Municipal Spending*.

Figure 35: Radar Charts for Huechuraba, Quilicura and Maipú



Source: Own elaboration

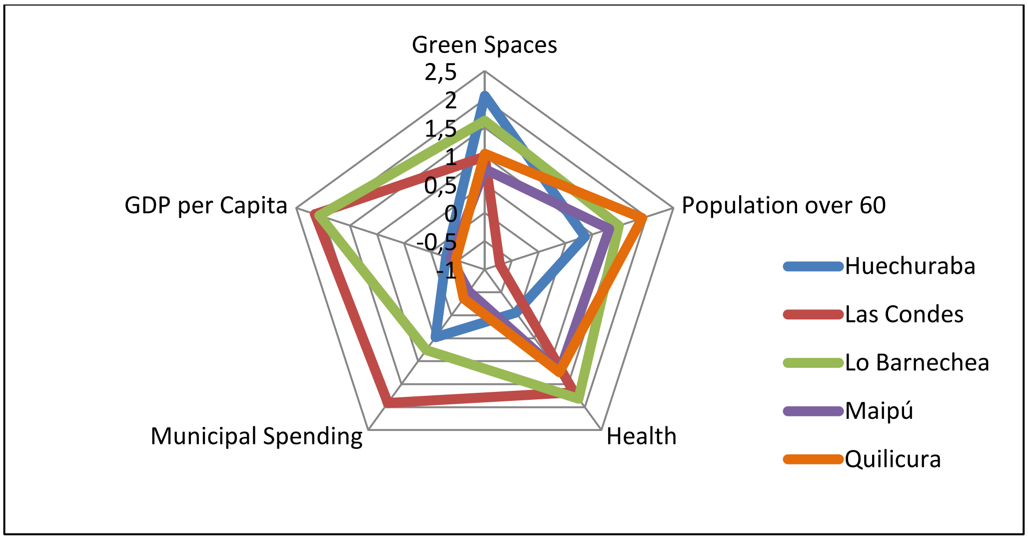
Similar to Lo Barnechea, Huechuraba has a low exposure, but its adaptive capacity shows room for improvement. Additionally, in its adaptive capacity, Huechuraba is performing poorly compared to Lo Barnechea and Las Condes.

Quilicura shows a similar pattern like Huechuraba but is performing well in the *Health* indicator. The other two adaptive capacity indicators, however, could be improved to further lower vulnerability.

Maipú and Quilicura show fairly similar values, although they are not located close to each other in the province Santiago. Both might consider combining their activities or exchanging the lessons learned, in experience with impacts as well as in risk management strategies.

The following chart overlays the individual comuna charts for direct comparison.

Figure 36: Overlaid Radar Chart for Huechuraba, Las Condes, Lo Barnechea, Maipú and Quilicura

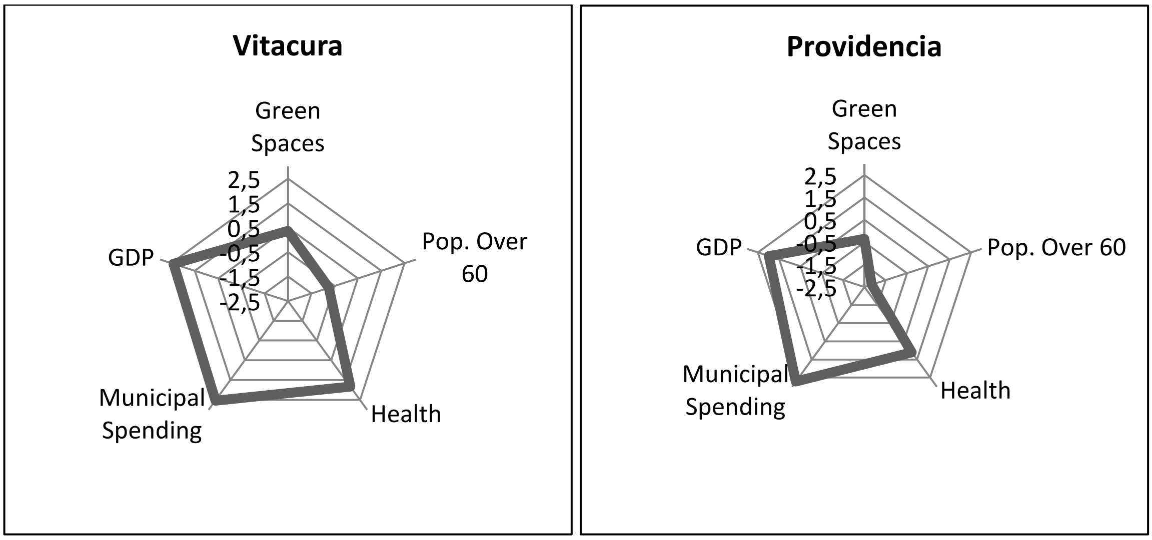


Source: Own elaboration

5.2.2.2 Comunas with Moderate Vulnerability (High Exposure/ High Adaptive Capacity) to Heat Waves

In this quadrant, six comunas are located and are characterized by high exposure and high adaptive capacity.

Figure 37: Radar Chart for Vitacura and Providencia

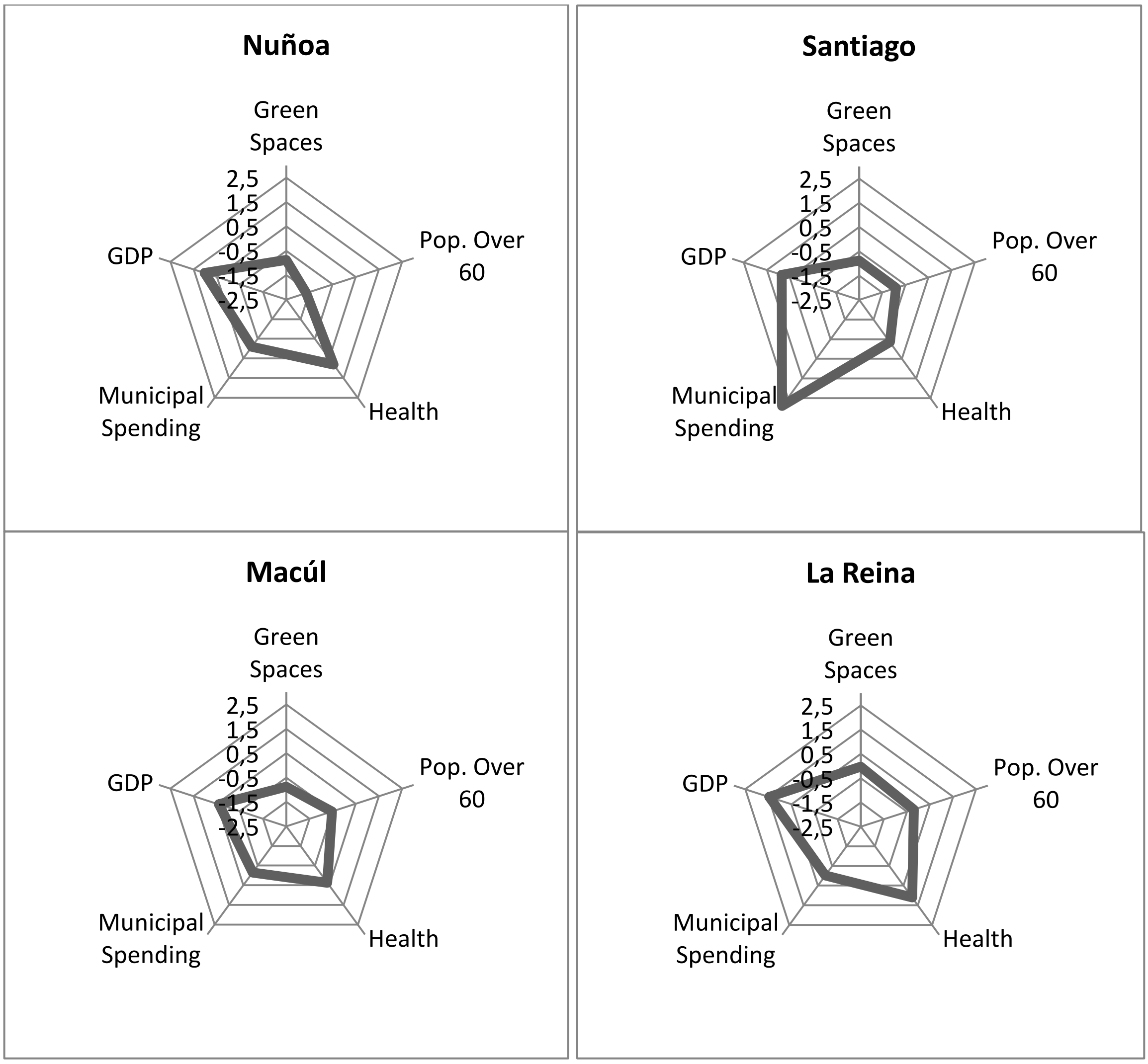


Source: Own elaboration

The comuna Vitacura is best performing in this quadrant. As the quadrant is characterized by high exposure, Vitacura is no exception from that and shows a low value in *Green Spaces* and a high share of *Population Over 60* (the latter indicated by a low value in the corresponding indicator). However, its adaptive capacity indicators appear exceptionally well with *Health* and *GDP* values ranking at the top and *Municipal Spending* within the top 3 positions of all 32 comunas.

Providencia performs similarly well in adaptive capacity, but its exposure is significantly higher. Providencia has the lowest value in the *Population Over 60* indicator which means that it has the highest share of elderly population of all the 32 comunas. Additionally, it lacks green spaces. Even with its fine adaptive capacity, Providencia could try to lower its exposure.

Figure 38: Radar Charts for Nuñoa, Santiago, Macúl and La Reina



Source: Own elaboration

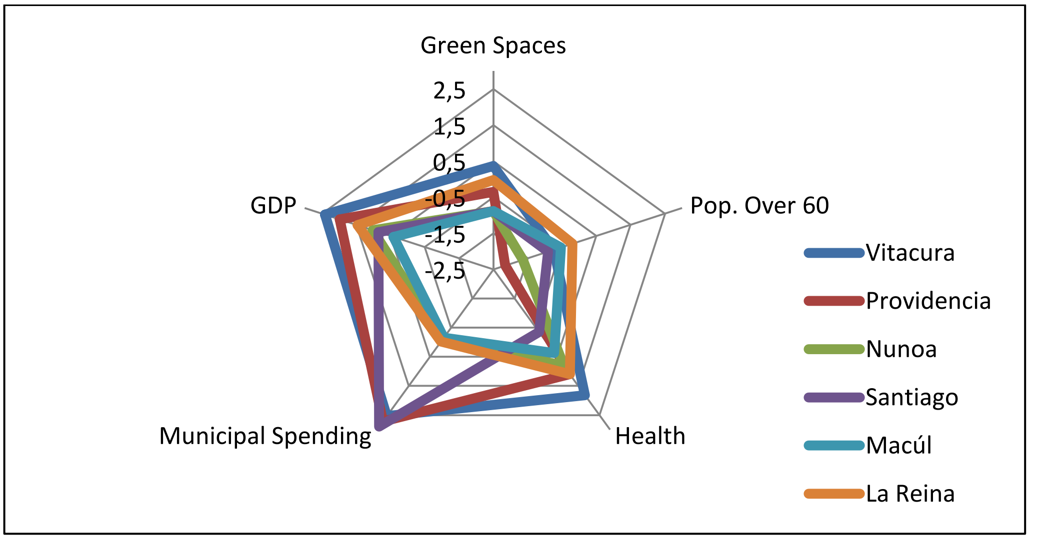
Similar to Providencia, Nuñoa shows highest exposure (i.e. least indicator values aggregate sum) of all 32 comunas. Options applying for Providencia to mitigate exposure therefore appear also valid for Nuñoa. Nuñoa's adaptive capacity is lower than Providencia's due to a lower *GDP* and a much lower *Municipal Spending*.

The comuna Santiago shows a clear outlier: exceptional *Municipal Spending*, top among all comunas. Compared to its eastern neighbours Providencia and Vitacura, its adaptive capacity indicators are low. Apart from a lack of green spaces common to intercity comunas, it performs worst among comunas in this quadrant in the *Health* indicator. This can be a problem in combination with the high share of *Population Over 60*. Macúl, in comparison to the other comunas in this quadrant, suffers from low (although average over all comunas) adaptive capacity and clearly high (above average over all comunas) exposure.

La Reina has the highest value of the *Population Over 60* indicator (lowest share) and the second best in *Green Spaces,* which makes it the least exposed comuna in this quadrant. In its adaptive capacity it only scores a medium range due to the low value in *Municipal Spending*.

Like above, the following chart overlays the individual comuna charts for direct comparison.

Figure 39: Overlaid Radar Chart for Vitacura, Providencia, Nuñoa, Santiago, Macúl and La Reina

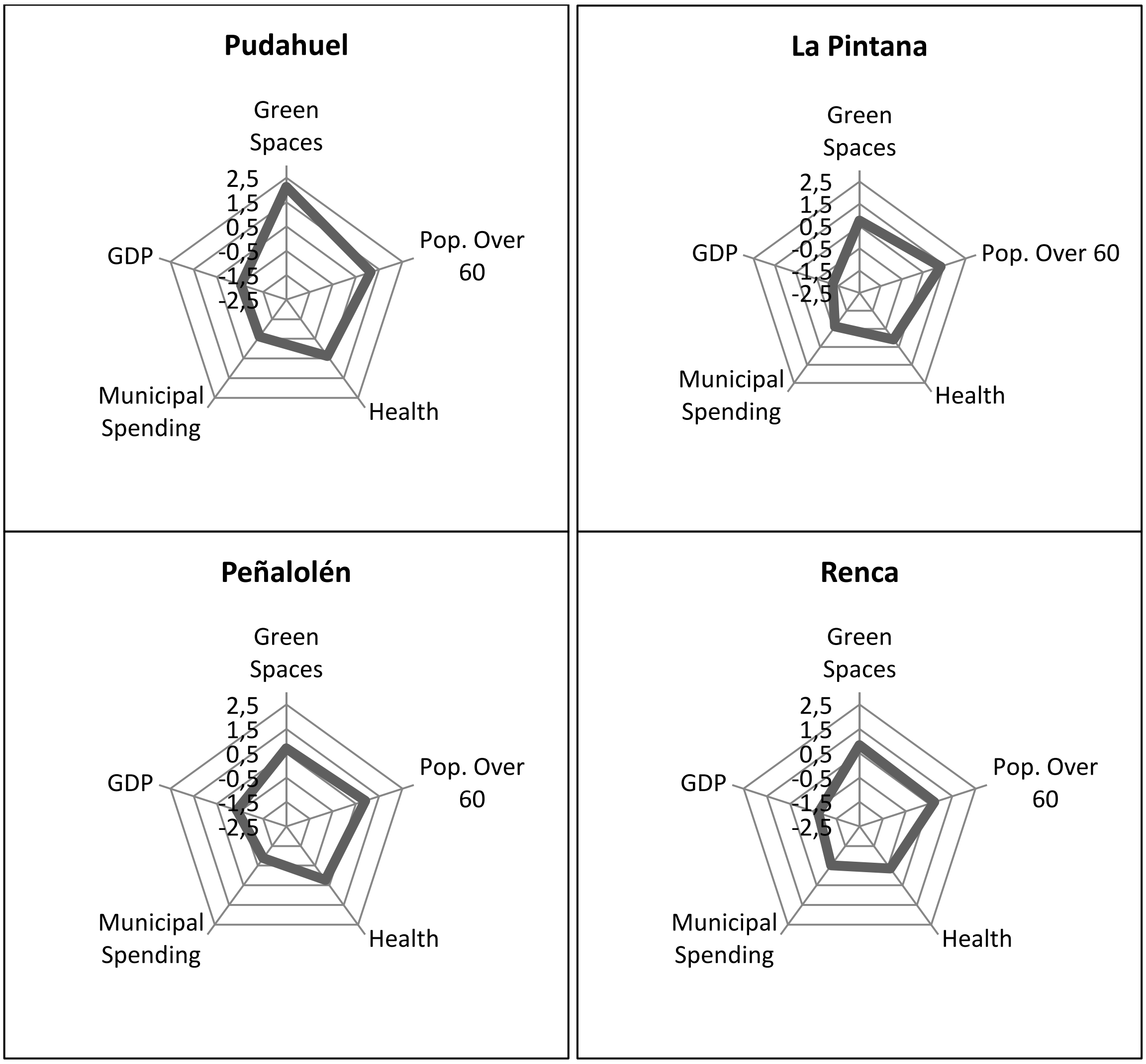


Source: Own elaboration

5.2.2.3 Comunas with Moderate Vulnerability (Low Exposure / Low Adaptive Capacity) to Heat Waves

There are eight comunas in this quadrant characterized by low exposure but also by low adaptive capacity. These are grouped in two sets of four by their horizontal coordinate.

Figure 40: Radar Charts for Pudahuel, La Pintana, Peñalolén and Renca



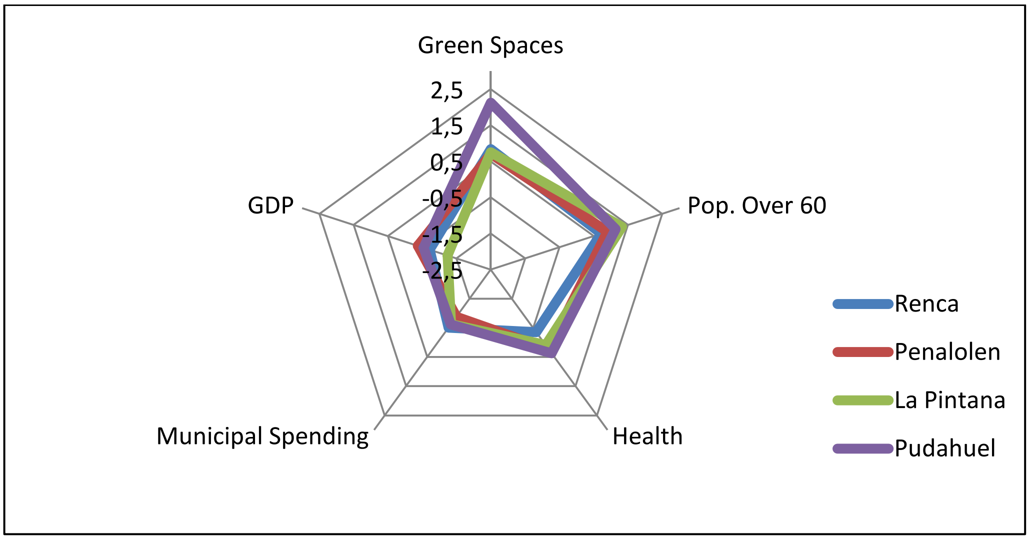
Source: Own elaboration

Pudahuel is the comuna with the lowest exposure (highest indicator value). This is a consequence of the high value in *Green Spaces*, the highest value of all 32 comunas, and a high value in the *Population Over 60* indicator. Pudahuel is one of the five comunas with highest values for this indicator. Its adaptive capacity shows low values in all indicators.

The trio of La Pintana, Peñalolén, and Renca is very similar with almost the same low exposure and almost the same low adaptive capacity. The latter is mainly caused by limited ability to invest due to a low value in *GDP* and *Municipal Spending*.

Like above, the following chart overlays the individual comuna charts for direct comparison.

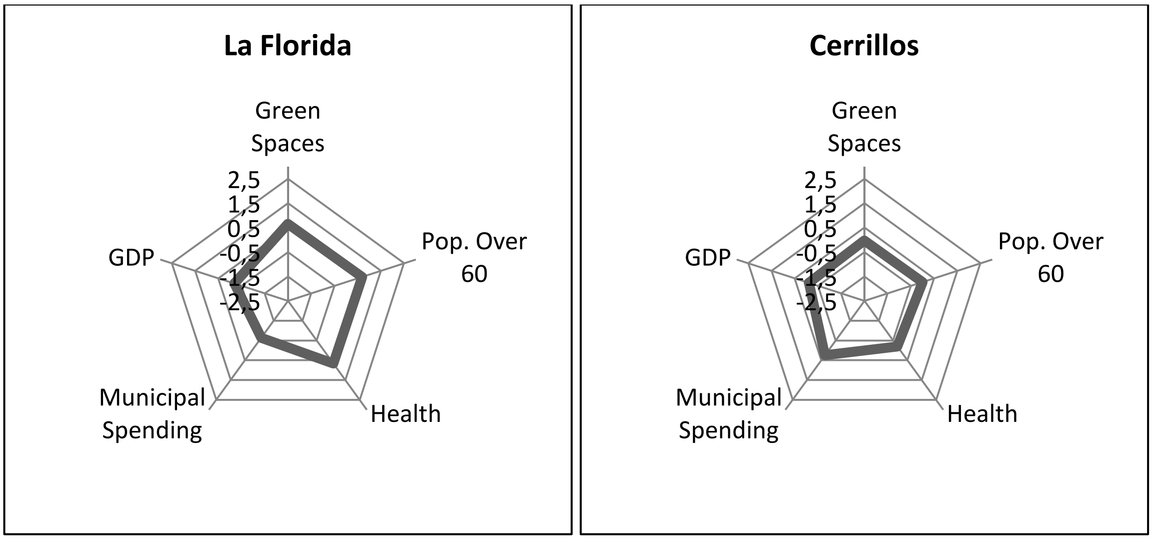
Figure 41: Overlaid Radar Chart for Renca, Peñalolén, La Pintana and Pudahuel



Source: Own elaboration

Next are the comunas La Florida, Cerrillos, Conchalí and Cerro Navia.

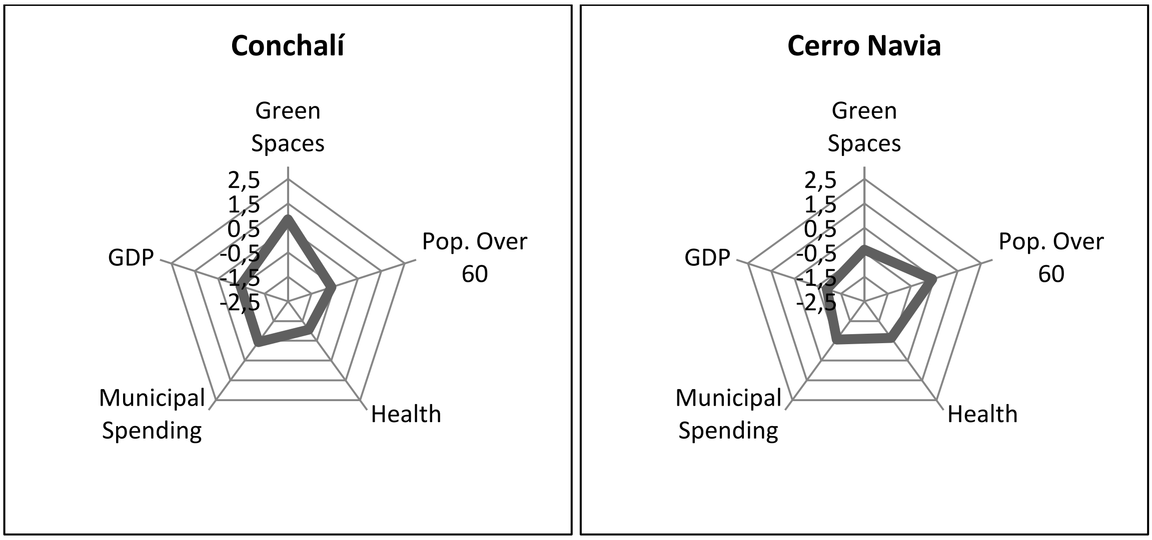
Figure 42: Radar Charts for La Florida and Cerrillos



Source: Own elaboration

La Florida and Cerrillos are almost at the chart origin and thus have most average exposure and average adaptive capacity among all comunas. However, La Florida has the second lowest municipal spending of all comunas.

Figure 43: Radar Charts for Conchalí and Cerro Navia

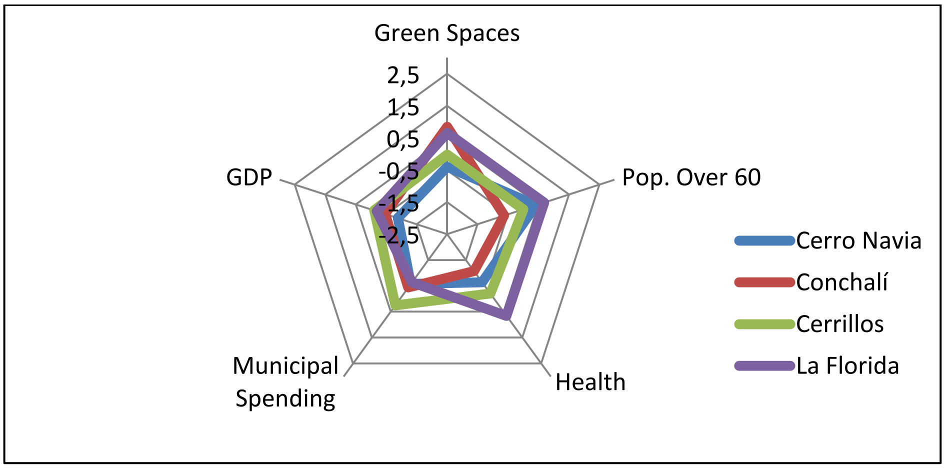


Source: Own elaboration

Conchalí and Cerro Navia are located close to each other in the point chart. Conchalí shows a higher value in *Green Spaces*, Cerro Navia a higher value (lower share) in the *Population Over 60* indicator. Conchalí furthermore has a lower value in *Health*, therefore its adaptive capacity is slightly lower.

Like above, the following chart overlays the individual comuna charts for direct comparison.

Figure 44: Overlaid Radar Chart for Cerro Navia, Conchalí, Cerrillos and La Florída

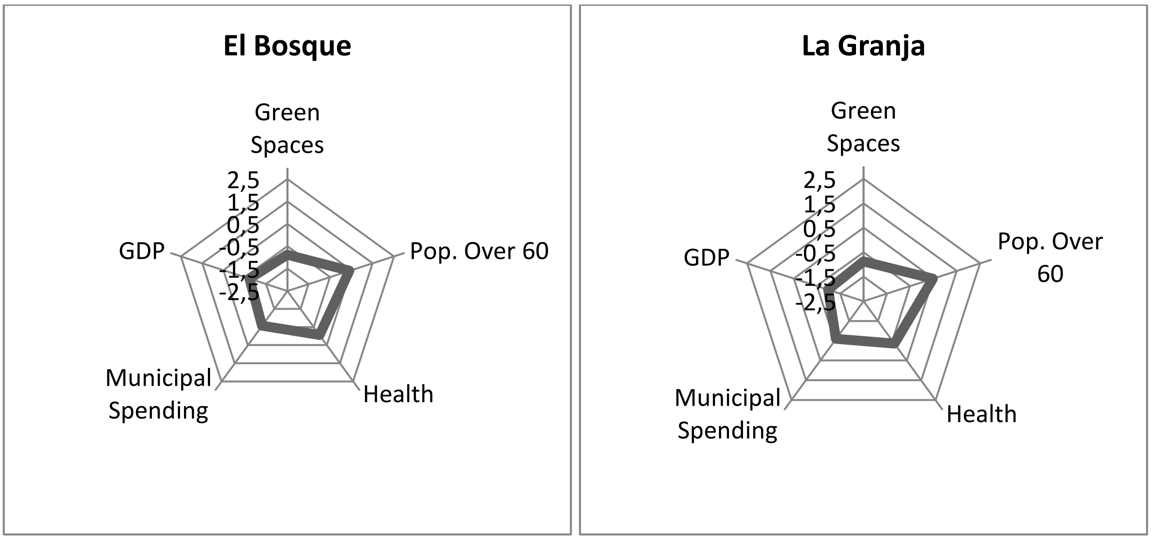


Source: Own elaboration

5.2.2.4 *Comunas with High Vulnerability to Heat Waves*

There are 13 (about 40%) of the 32 comunas in this quadrant. Due to this quantity and to keep the analysis transparent, the comunas will be grouped according to their horizontal location in the quadrant going from higher to lower exposure (from right to left on the x-axis).

Figure 45: Radar Charts for El Bosque and La Granja

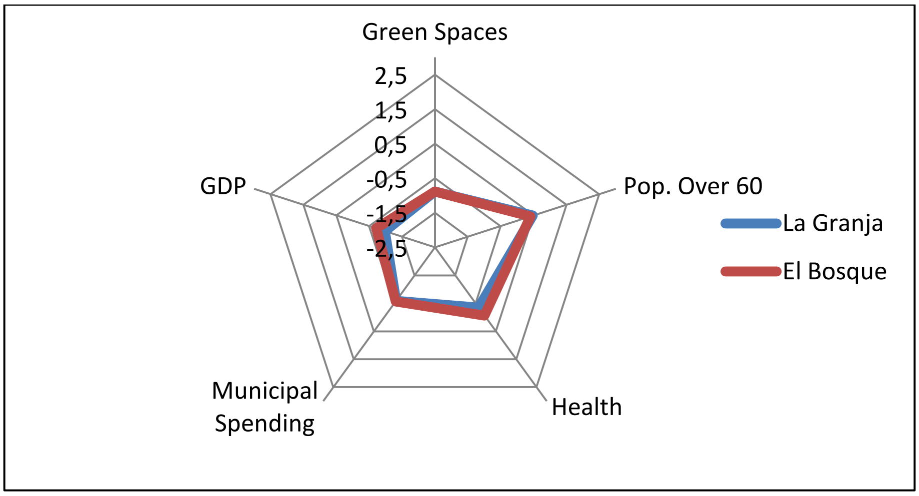


Source: Own elaboration

El Bosque and La Granja show lowest exposure in the high vulnerability quadrant. They have similar values in *Green Spaces* and *Population Over 60*. In the adaptive capacity indicators, the two comunas also have similar values in *Municipal Spending*. El Bosque performs better in *GDP* and *Health* and therefore shows a higher aggregated value.

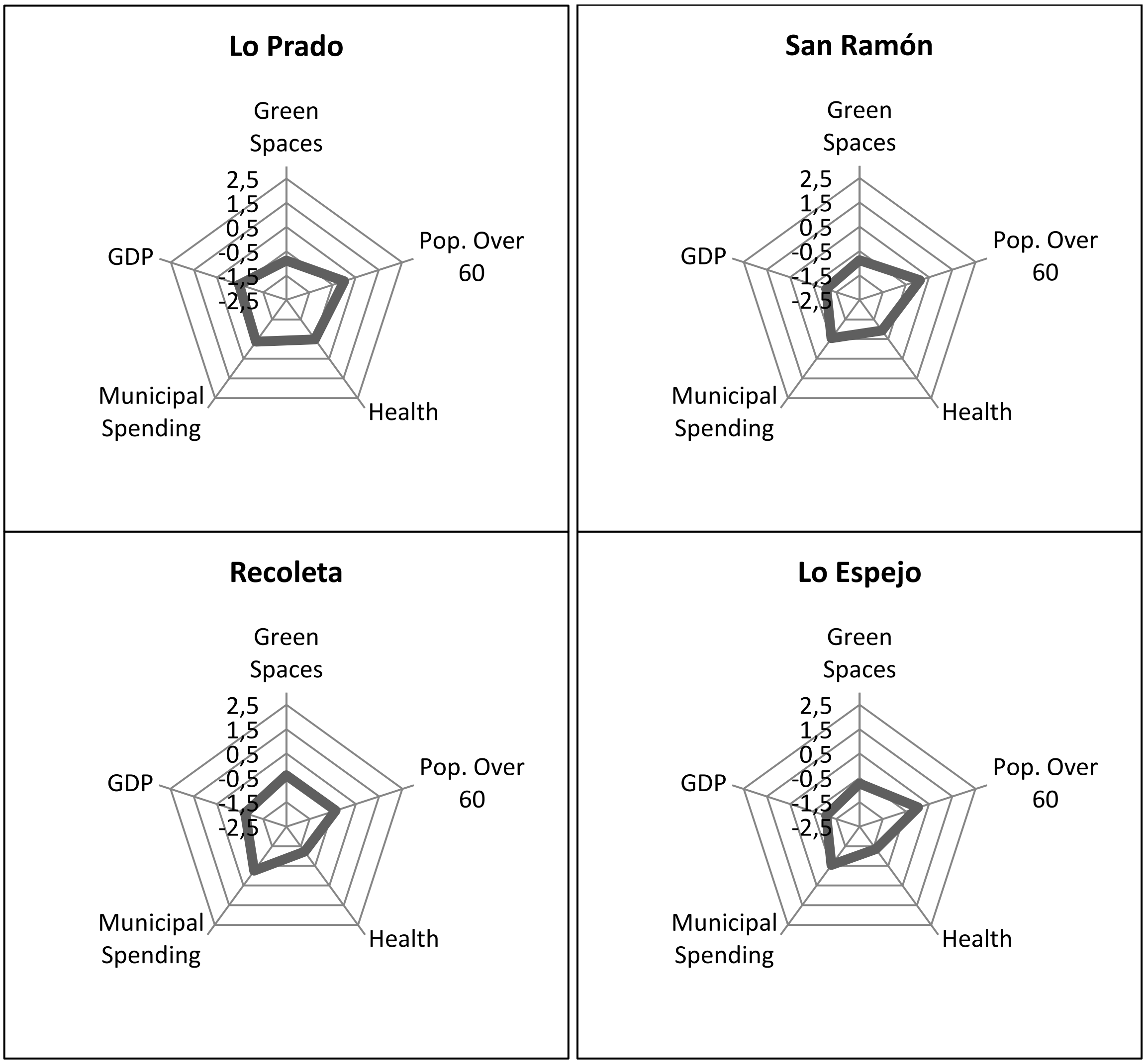
Figure 46 overlays the individual comuna charts for direct comparison. This is followed by Figure 47, the radar charts for the four comunas Lo Prado, San Ramón, Recoleta and Lo Espejo.

Figure 46: Overlaid Radar Chart for El Bosque and La Granja



Source: Own elaboration

Figure 47: Radar Charts for Lo Prado, San Ramón, Recoleta and Lo Espejo

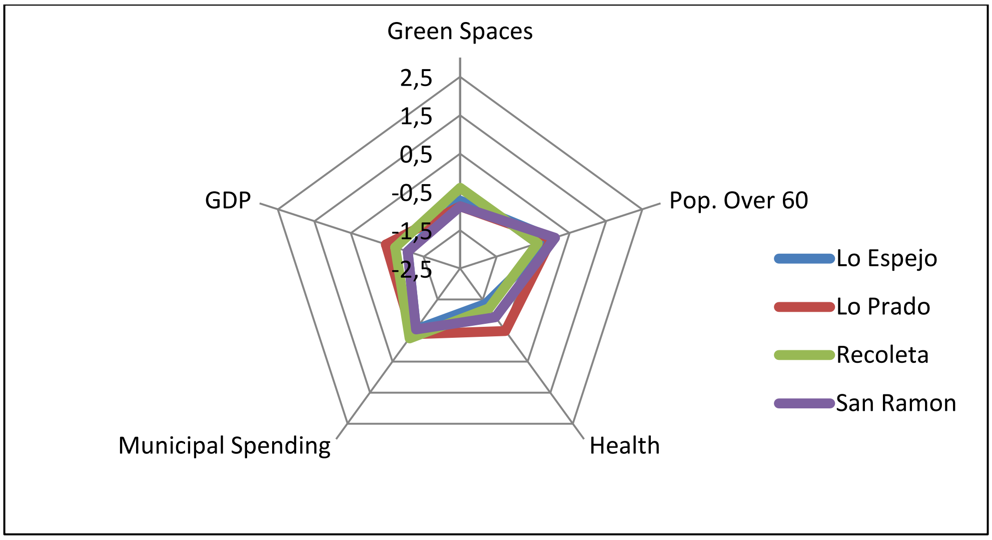


Source: Own elaboration

The five comunas Lo Prado, San Ramón, Recoleta, Lo Espejo and Lo Prado show a similar shape on their individual charts. Having the same below average value for exposure, they show visible differences in their adaptive capacity. These result basically from the *GDP* and the *Health* indicators. Lo Espejo, San Ramón, and Recoleta have the three lowest overall values in the adaptive capacity.

As above, the following chart overlays the individual comuna charts for direct comparison.

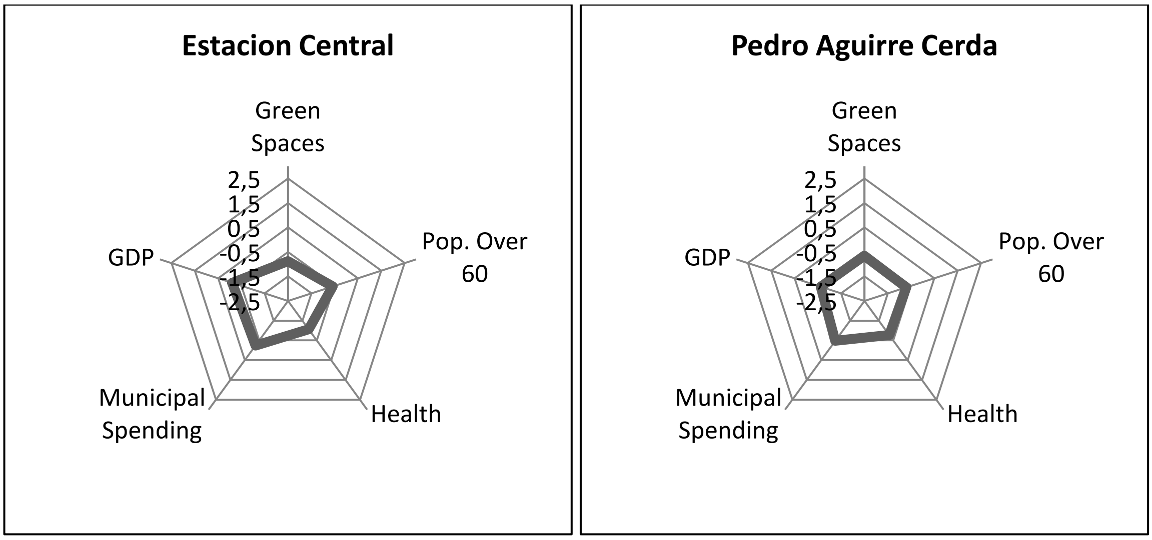
Figure 48: Overlaid Radar Chart for Lo Espejo, Lo Prado, Recoleta and San Ramon



Source: Own elaboration

Next are the comunas Estación Central and Pedro Aguirre Cerda.

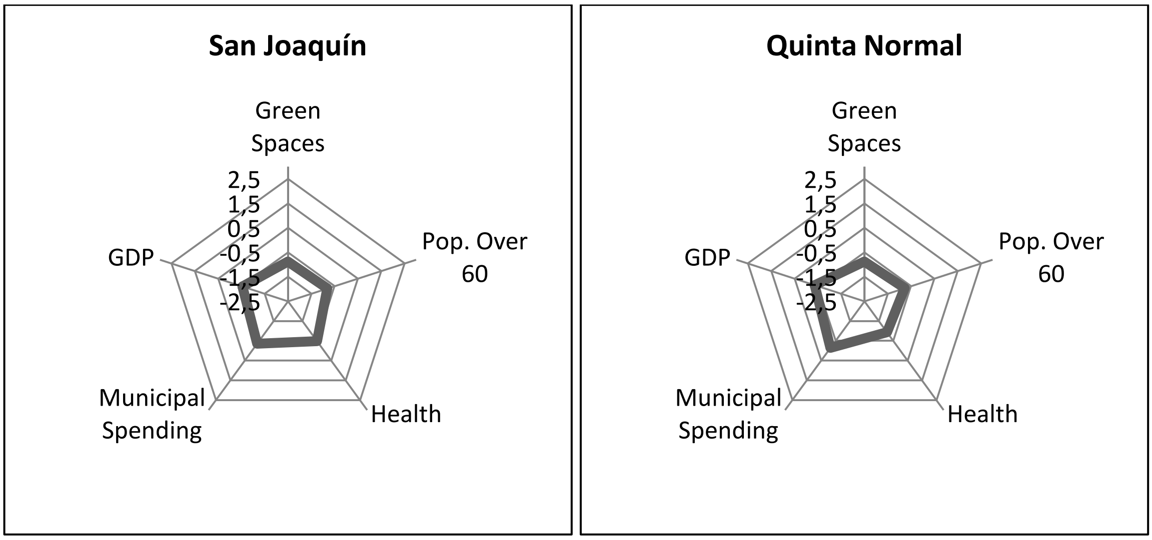
Figure 49: Radar Chart for Estación Central and Pedro Aguirre Cerda



Source: Own elaboration

Similar arguments as for the 4 comunas above apply to the pair Pedro Aguirre Cerda and Estación Central. Their exposure is comparable; different is in their adaptive capacity, driven by low values for *Health* and low *GDP* together with low *Municipal Spending*.

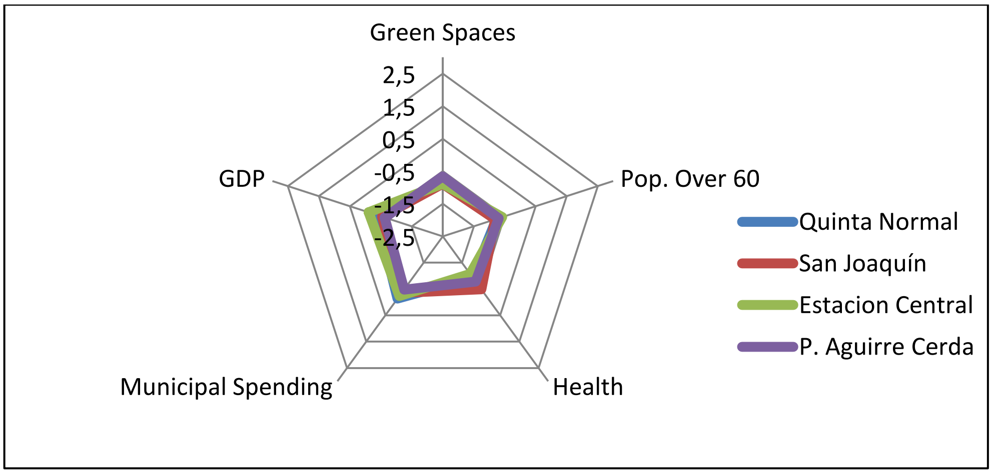
Figure 50: Radar Charts for San Joaquín and Quinta Normal



Source: Own elaboration

San Joaquin and Quinta Normal occupy almost the same location in the point-diagram. Their exposure indicators have almost identical values with the *Green Space* values being the lowest of all comunas. The adaptive capacity indicators also sum up to the same value by mutually compensating small differences. The following chart overlays the individual comuna charts for direct comparison.

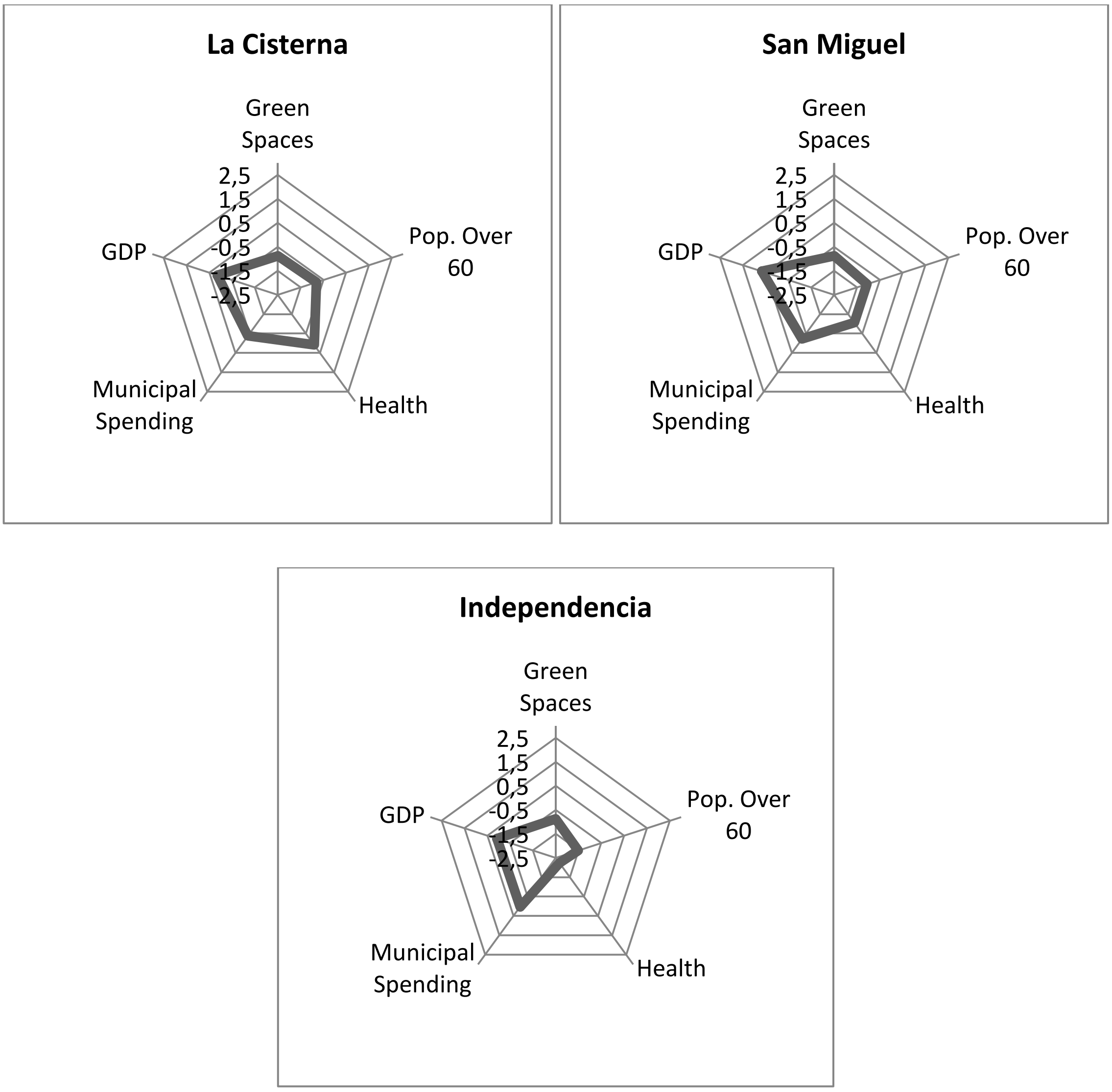
Figure 51: Overlaid Radar Chart for Estación Central, Pedro Aguirre Cerda, San Joaquín and Quinta Normal



Source: Own elaboration

Last are La Cisterna, San Miguel and Independencia.

Figure 52: Radar Charts for La Cisterna, San Miguel and Independencia



Source: Own elaboration

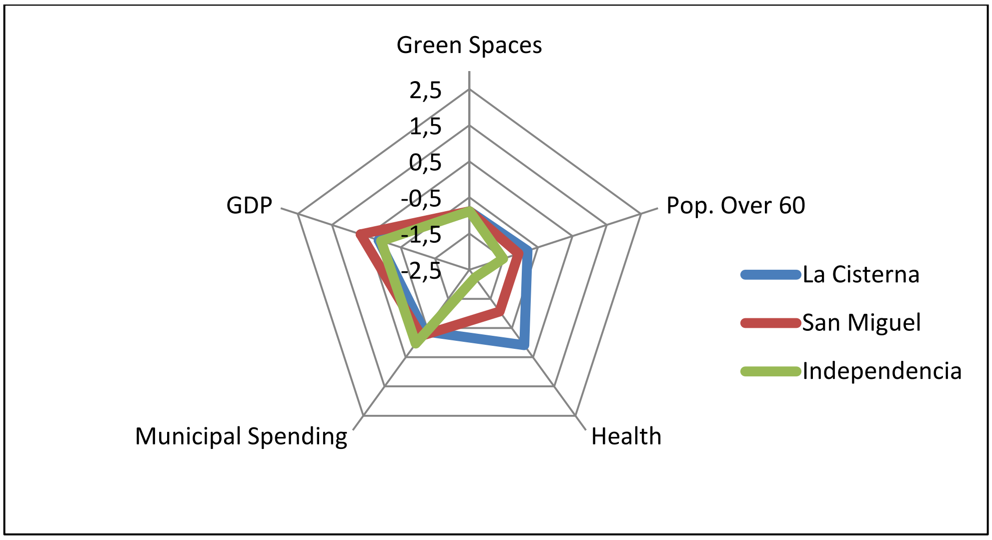
La Cisterna has average adaptive capacity and could have been discussed in the quadrant with high exposure and high adaptive capacity, too. The average adaptive capacity is driven by the best *Health* indicator and second best *Municipal Spending* value in this quadrant.

San Miguel, with second best adaptive capacity in this quadrant, has the best *GDP* value in this quadrant, but suffers from a low *Health* value. Its exposure is second worst in the quadrant with indicator values among the bottom five of all comunas.

Independencia has the lowest value (highest share) in the *Population Over 60* indicator in this quadrant. Together with the low value in *Green Space* that is typical for this quadrant, this sums up to a high exposure. The value for *Health* is the minimum value of all comunas and lowers the adaptive capacity to a level that even the best *Municipal Spending* of all comunas in this quadrant cannot compensate.

The following chart overlays the individual comuna charts for direct comparison.

Figure 53: Overlaid Radar Chart for La Cisterna, San Miguel and Independencia

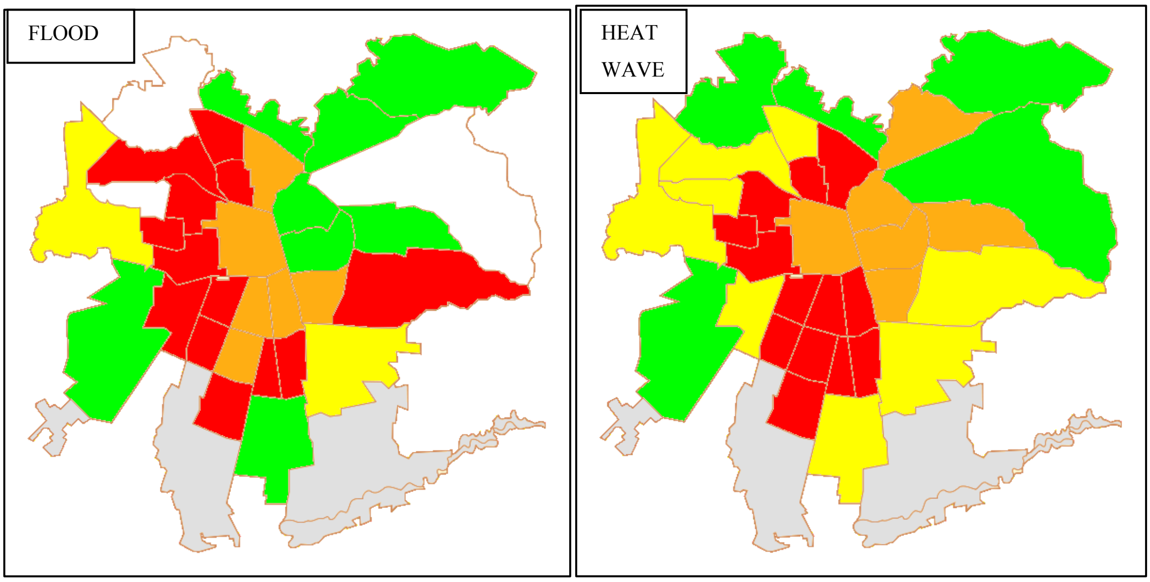


Source: Own elaboration

The next chapter compares the maps for flood and heat wave vulnerability.

5.3 Comparison of Flood and Heat Wave Vulnerability

Map 7: Comparison of Vulnerability Maps for Floods and Heat Waves



HIGH VULNERABILITY (High Exposure Low Adaptive Capacity)	MODERATE VULNERABILITY (High Exposure High Adaptive Capacity)	MODERATE VULNERABILITY (Low Exposure Low Adaptive Capacity)	LOW VULNERABILITY (Low Exposure High Adaptive Capacity)
	NO DATA	NOT ANALYZED	

Source: Own elaboration

A comparison of maps shows noteworthy aspects. The comunas with the same degree of vulnerability are located close to each other in the city and are not randomly scattered.

This is also a consequence of geographical factors that change steadily throughout the city rather than being randomly distributed. For example, comunas in the outskirts usually have a higher share of green spaces than the heavily built-up comunas near or in the centre. More green spaces reduce the exposure against floods as well as against heat waves.

On the other hand, it seems that the established distribution of population groups is not purely random but has grown over time. Thus for example, the share of elderly people usually does not change abruptly among adjacent comunas.

The two maps show that comunas at the outskirts of the city and particularly in its north-eastern area have predominately low to moderate vulnerability. This follows under the assumption, that the comuna Vitacura would have low vulnerability, Quilicura most likely would have low or moderate vulnerability, and the comuna Cerro Navia would have high vulnerability (as stated in chapter 5.1.2.5).

The comunas at an arc swinging from the north westwards around the centre of the city to the south show high vulnerability against one or the other hazard, most of them against both. This includes more than 50% of all the comunas.

The area to the south-east of the city centre and the central comuna Santiago itself have moderate vulnerability against both hazards. Their high exposure is compensated by a high adaptive capacity which is partly caused by their ability to invest more extensive into countermeasures to or recovery from hazards by an over-average GDP and municipal spending.

Finally, Santiago's exposure to drought will be analyzed.

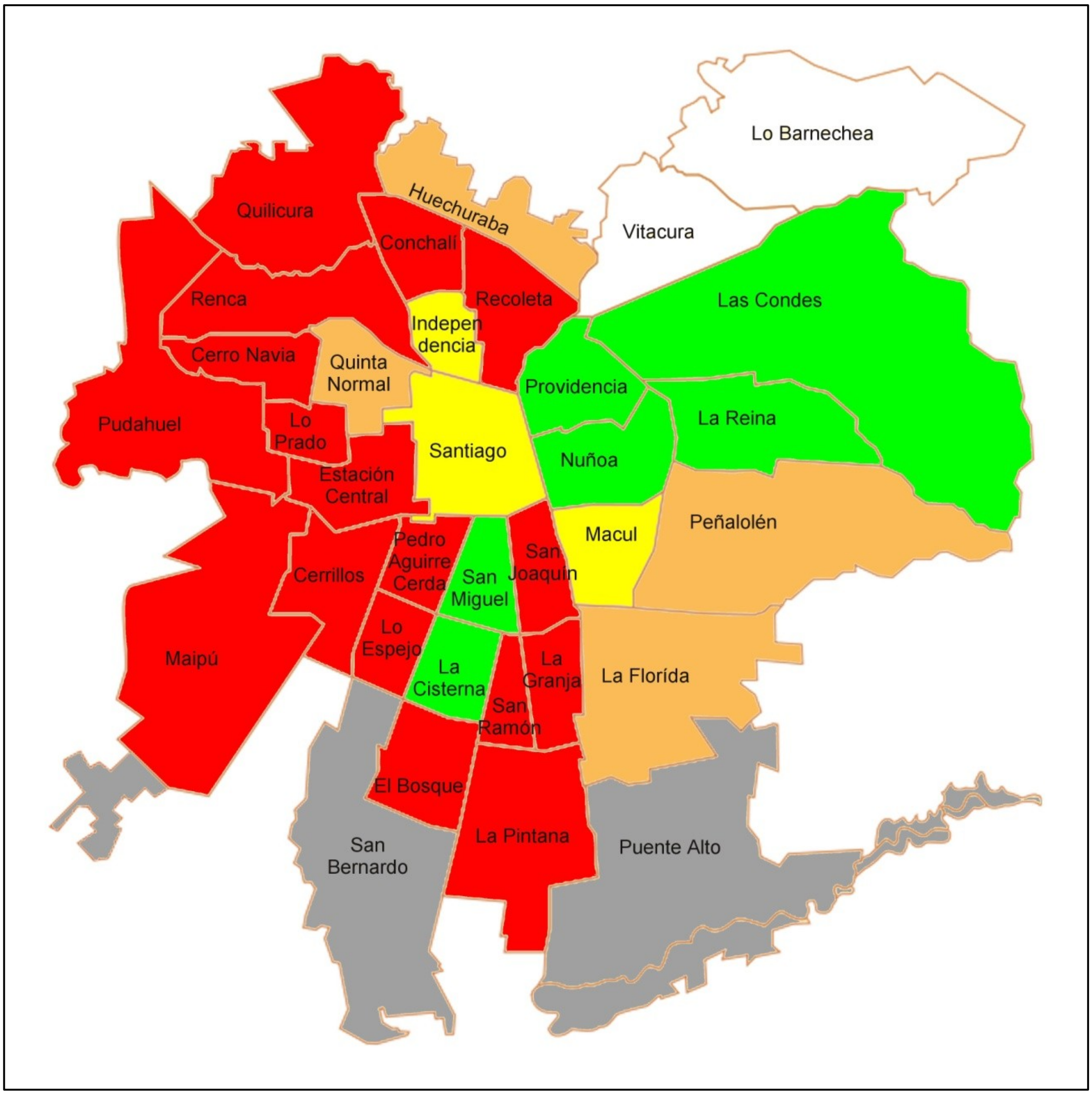
5.4 Analysis of Exposure to Droughts

As explained in chapter 4.3.2., no adaptive capacity indicators for droughts were defined. Thus, sketching a vulnerability point diagram and a vulnerability map is not possible.

The two exposure indicators defined for the hazard droughts are *Medium Water Consumption* and *GDP per Capita*. Out of these two indicators, an exposure point diagram will be sketched. The indicator GDP serves as the x-axis, Medium Water Consumption as the y-axis. Out of the four quadrants, an exposure map for the province Santiago will be sketched with four colours.

Map 8 shows exposure to droughts for the 32 comunas of the province Santiago.

Map 8: Droughts Exposure Map for the Province of Santiago

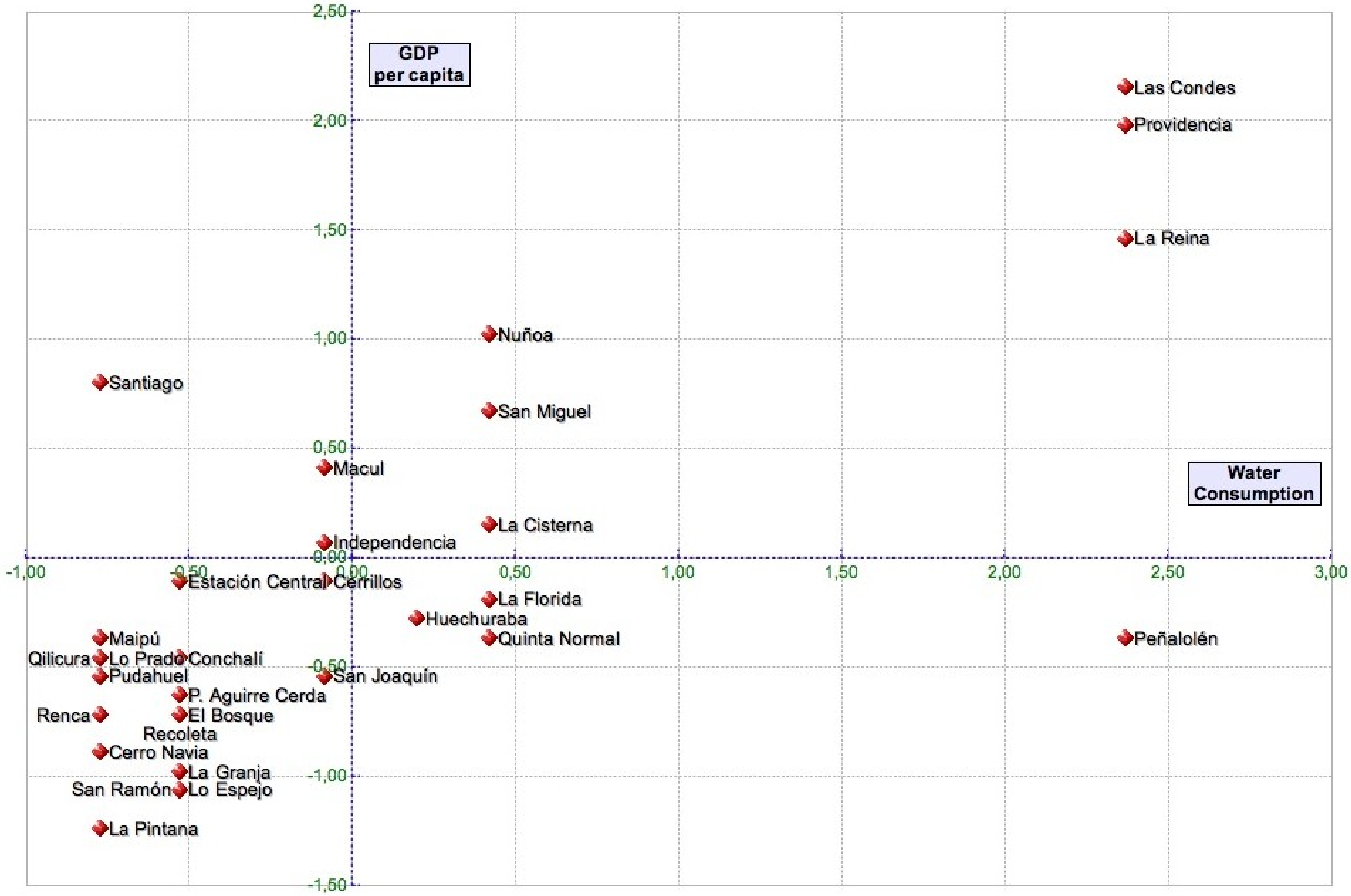


HIGH EXPOSURE (Low GDP Low Water Consumption)	MODERATE EXPOSURE (Low GDP High Water Consumption)	MODERATE EXPOSURE (High GDP Low Water Consumption)	LOW EXPOSURE (High GDP High Water Consumption)
	NO DATA	NOT ANALYZED	

Source: Own elaboration

The following figure shows the exposure point-diagram for droughts that served as a basis for the exposure map.

Figure 54: Point Diagram for Drought Exposure



Source: Own elaboration

More than 50% of the comunas are highly exposed to droughts: Quilicura, Conchalí, Recoleta, Renca, Cerro Navia, Pudahuel, Lo Prado, Estación Central, Cerrillos, Maipú, Pedro Aguirre Cerda, Lo Espejo, El Bosque, San Joaquín, San Ramón, La Granja and La Pintana. They have low GDP per capita and low average water consumption. Chapter 3.5.5 argued that in households with low water consumption, water will primarily be used for basic necessities. In the case of severe drought, with water supply restrictions these comunas might receive a water quantity below the level of their basic necessities. That makes them more exposed than comunas with high water consumption that consume considerable amounts, for example to water their gardens or swimming pools.

Low GDP exposes them even more. In the case of severe droughts water and electricity supply will decrease and most certainly be only available at higher prices, see chapter 3.5.6. The highly exposed comunas are located in one large group that covers almost the entire western half of the city, only with the exception of Huechuraba, Quinta Normal, Independencia, Santiago, San Miguel and La Cisterna.

The comunas with moderate or low exposure are almost equally large. The six comunas with low exposure characterized by high GDP and high water consumption include Las Condes, Providencia, Nuñoa, La Reina, San Miguel and La Cisterna. They are located to the north-east and south of the Santiago comuna in the city centre.

For the north-eastern comunas, Lo Barnechea and Vitacura, comparable data on average monthly water consumption is not available. However, due to a SISS (2008) study with data on their water supply company Aguas Cordillera SA, it is highly probable that these two comunas have very high water consumption (compare chapter 3.5.5). Given their high GDP, they would certainly show up the low exposure quadrant.

Four comunas show moderate exposure due to low GDP and high water consumption: Huechuraba. Quinta Normal, La Florída, Peñalolén. With the exception of Quinta Normal, they are located in the outskirts of the city. They show a high share of green spaces and might therefore have higher water consumption.

Three comunas show moderate vulnerability, due to high GDP and low water consumption: Santiago, Independencia, and Macul. Santiago is among the comunas with the lowest water consumption. Macul and Independencia show average water consumption and a slight over-average GDP and are close to the low exposure quadrant.

6 Conclusion

6.1 Summary

This paper addressed the determination, comparison and presentation of the population's vulnerabilities towards climate change impacts in the comunas of Santiago de Chile.

The scientific literature predicts that the climate change impacts floods, heat waves and droughts will occur more and more often in the region around Santiago. These hazards are often related with high physical, economical and social damages. They can destroy the natural and built environment, cause high financial losses, threaten human health and interrupt the vital urban infrastructures for energy, transport, communication, food supply and waste removal.

A set of indicators was developed to determine the exposure and adaptive capacity against these hazards. The indicators are composed of physical and socio-economic factors. The combination of both, exposure and adaptive capacity, then allowed to estimate the respective vulnerability.

Investigating the hazards more closely made apparent that flood exposure depends on the growth of built-up areas or, equivalently, on the decrease or absence of urban green spaces. It also depends on the housing quality. Flood adaptive capacity depends essentially on up-to-date local regulatory frameworks as well as on the capabilities to invest as indicated by municipal spending.

The exposure to heat waves also depends on urban green spaces, and, as elderly people have more difficulties to cope with heat wave impacts, on their share in the total comuna population. Adaptation to heat waves depends on a capable public health system and on the financial capacities on the household and municipal levels.

The case of droughts was more complicated, as a drought is always affecting a wider geographical area and its impacts cannot be reliably predicted. Vulnerabilities are complex because urban lifestyles depend on rural production which itself might be severely affected. Drought impacts thus require additional analysis in the context of the drought vulnerability of a larger geographical region. As it is very likely that water supply will be among the first services most certainly rationed, households with water consumption well beyond average will suffer less than households with water consumption close to their personal needs.

The measurement of the vulnerabilities of the population of Santiago de Chile against the climate change hazards floods, heat waves, and droughts was then possible via these indicators. They were assigned values from standardised statistical data that was available for the comunas. Summing up the respective indicators for exposure and adaptive capacity allowed assigning each comuna its individual level. The vulnerability for a comuna was defined as one of the four possible combinations of low or high exposure with low or high adaptive capacity. Low exposure and high adaptive capacity constituted low vulnerability, whereas high exposure and low adaptive capacity constituted high vulnerability, and the remaining combinations moderate vulnerability.

Drawing the vulnerability level into a map of Santiago allowed a direct comparison of the comunas and an overview of the situation of the entire city. This overview showed some remarkable aspects. With respect to vulnerability there is a clearly visible distinction between the city centre, the area around the centre and the city outskirts.

The comunas in the north-eastern part and the outskirt comunas have low vulnerability to floods and heat waves, predominantly as a consequence of their higher amount of green space or high municipal spending. The area to the south-east of the city centre and the central comuna Santiago itself have moderate vulnerability against both hazards. Their high exposure due to a lack of green spaces and/ or a high share of population over 60 is partially compensated by their high adaptive capacity due to their over-average financial abilities and well-rated health systems.

More than 50% of all the comunas are highly vulnerable against floods and heat waves. They are located in the form of an arc swinging from the north westwards around the city centre. They predominantly performed badly in all indicators.

For droughts, only the exposure could be assessed and mapped. Low exposure is again visible in the north-eastern parts of the city. Some central comunas and the south-eastern part of the city show moderate exposure. Most apparent is the group of highly exposed comunas located north and west of the centre.

The identification of these vulnerability patterns built a foundation to discuss and develop specific adaption measures to meet the climate change impacts. Local authorities within comunas can use this as a starting point for individual action or joint activities involving multiple comunas.

As risk management generally involves multiple comunas (for example for the rainwater drainage), private suppliers (for the electricity system), and regional and national regulations, most combined actions require also a coordinating instance with appropriate competence and authority. The local authorities still seem to be the most important player, as they act as a bridge between the household and the regional or national level. In formulating risk management strategies, the household level must be addressed, too. While they usually cannot alter their vulnerability by themselves due to a lack of assets, they can contribute by local actions like clearing the rainwater infrastructure or in helping to raise awareness.

In accordance with Satterthwaite (2007:15), there are two conclusions that can be drawn and can help to raise awareness and willingness to develop risk management strategies among all actors:

- There is a very large overlap between adaptation measures and local development (like the improvement of housing and infrastructure, equal access to public services, particularly of health care, and balance of municipal spending).
- There is also a large overlap of adaption to climate change and adjustment to other disasters not related to climate change. In Chile, this is particularly important as the country is frequently hit by earthquakes.

6.2 Outlook

The investigation of population's vulnerabilities in Santiago de Chile returned first answers, which can serve as a foundation to discuss and even develop risk management strategies. However, the study showed that several issues will remain open, essentially because of lack of appropriate data or because their investigation required effort beyond the capacity available.

The first open issue is the relationship of the indicators that determine the exposure and the adaptive capacity. Aggregated indicators were calculated under the assumption that their relationship is linear, that each indicator has the same weight and is independent from the others. An investigation of the mutual dependency and interaction of the indicators therefore seems a worthwhile topic for future investigation.

The second open issue is the consideration of additional indicators to describe more precisely the exposure and adaptive capacity. The methodology in this work was limited by the available data sets for Santiago and can be completed by various other exposure and adaptive capacity indicators. For floods, physical flood risk maps could be considered to determine flood exposure more accurately. These are often based on GIS derived data to determine and evaluate the extent of flooding in a certain area. They incorporate variables like precipitation intensity, flow peak discharges, distance to discharge channels, heights, slopes, depth to groundwater level and a more extensive analysis of impervious and pervious cover (Fernández/ Luz 2010:92;97).

Similarly, heat wave exposure can be determined more accurately by evaluating temperature developments and urban heat island effects in the different comunas. While there might not be great differences in the inner comunas (the comuna Santiago and the comunas forming a ring around it), temperatures can vary between these comunas and the outskirt comunas, particularly when considering green spaces and built-up areas.

The case for droughts is more difficult. As drought impacts on urban areas cannot be generalized, a better, but also a more demanding way would be the creation of a vulnerability tree diagram as mentioned previously. Every drought analysis should look at a broader area and incorporate rural specifics and an investigation of rural impacts on urban lifestyles.

What was not captured by this work is a study of historical data, documenting previous risk management and actions performed. Analyzing previous impacts could improve exposure assessments, looking at previous coping strategies could help to decide which and how risk management strategies should be applied now.

A third open issue is that some important data to supplement vulnerability analyses can only be assessed qualitatively, like for instance household assets. Assessing assets can help to define the weighting and the interactions of the different indicators (Maantay/ Maroko 2009:112, Moser/ Satterthwaite 2008:5). For example, households with a high financial asset base can manage risks by transferring vulnerability of flood impacts from health impacts to economic investment or financial losses (Moser/ Satterthwaite 2008:5).

Introducing household assets into risk assessment is a highly complex issue: the coping strategies that the households will apply are hard to predict, but generalizations could be drawn from qualitative analyses, as tried by Pelling (1998).

All these open issues appear worthwhile topics of future research, to get an even clearer picture of Santiago's vulnerability to climate change impacts. Santiago is certainly vulnerable and needs to continue to incorporate risk management strategies in local plans to achieve a sustainable, more socially and geographically balanced development and to alleviate its vulnerability.

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8 Annex

8.1 Indicator Values for Droughts, Floods and Heat Waves

Drought: Values and Z-Scores

Comuna	**Medium Water Consumption (in m3)** ***Duran 2009***	**Z-Transformed**	**GDP pC HDI** ***PNUD/ Mideplan 2003***	**Z-Transformed**
Cerrillos	20.71	0.04	0.71	-0.11
Cerro Navia	17.22	-0.53	0.62	-0.89
Conchalí	18.46	-0.33	0.67	-0.46
El Bosque	18.46	-0.33	0.64	-0.72
Estación Central	18.46	-0.33	0.71	-0.11
Huechuraba	22.15	0.27	0.69	-0.28
Independencia	20.71	0.04	0.73	0.07
La Cisterna	23.26	0.45	0.74	0.15
La Florida	23.26	0.45	0.70	-0.19
La Granja	18.46	-0.33	0.61	-0.98
La Pintana	17.22	-0.53	0.58	-1.24
La Reina	33.15	2.04	0.89	1.46
Las Condes	33.15	2.04	0.97	2.15
Lo Barnechea	ND	ND	0.96	2.07
Lo Espejo	18.46	-0.33	0.60	-1.06
Lo Prado	17.22	-0.53	0.67	-0.46
Macul	20.71	0.04	0.77	0.41
Maipú	17.22	-0.53	0.68	-0.37
Nuñoa	23.26	0.45	0.84	1.02
P. Aguirre Cerda	18.46	-0.33	0.65	-0.63
Peñalolén	33.15	2.04	0.68	-0.37
Providencia	33.15	2.04	0.95	1.98
Pudahuel	17.22	-0.53	0.66	-0.54
Qilicura	17.22	-0.53	0.67	-0.46
Quinta Normal	23.26	0.45	0.68	-0.37
Recoleta	18.46	-0.33	0.64	-0.72
Renca	17.22	-0.53	0.64	-0.72
San Joaquín	20.71	0.04	0.66	-0.54
San Miguel	23.26	0.45	0.80	0.67
San Ramón	18.46	-0.33	0.60	-1.06
Santiago	17.22	-0.53	0.82	0.85
Vitacura	ND	ND	1.00	2.41
Mean / Min.	20.49	-0.53	0.72	-1.24
S.deviation / Max.	6.20	2.04	0.12	2.41

Floods: Values, Z-Scores and Aggregated Z-Scores

	FLOOD EXPOSURE					***FLOOD ADAPTIVE CAPACITY***				
Comuna	**Precarious Housing (%)** ***UO 2002***	**Z-Transformed**	**Green Spaces (%)** ***SINIM 2008***	**Z-Transformed**	**Aggregated Exposure Z-Score**	**Last Update of CRP (years)** ***SINIM 2008***	**Z-Transformed**	**Municipal Spending pC (1000 CLP)** ***SINIM 2008***	**Z-Transformed**	**Aggregated Adaptive Capacity Z-Score**
Cerrillos	5.50	0.34	23.22	-0.02	-0.36	no plan	no plan	171.00	0.25	-1.51*
Cerro Navia	11.00	2.31	12.91	-0.40	-2.71	no data	no data	71.00	-0.57	not available
Conchalí	5.70	0.41	0.92	-0.85	-1.26	25.00	1.76	87.00	-0.44	-2.20
El Bosque	6.30	0.63	0.07	-0.88	-1.51	5.00	-0.56	71.00	-0.57	-0,01
Estación Central	4.80	0.09	0.00	-0.88	-0.97	no plan	no plan	111.00	-0.24	-2.00*
Huechuraba	6.90	0.84	79.57	2.06	1.22	4.00	-0.67	200.00	0.48	1.15
Independencia	4.20	-0.13	0.00	-0.88	-0.75	no plan	no plan	144.00	0.03	-1.73*
La Cisterna	5.70	0.41	0.00	-0.88	-1.29	4.00	-0.67	94.00	-0.38	0.29
La Florida	2.30	-0.81	41.79	0.66	1.47	7.00	-0.33	62.00	-0.64	-0.31
La Granja	7.60	1.09	0.00	-0.88	-1.97	16.00	0.72	68.00	-0.59	-1.31
La Pintana	4.30	-0.09	44.02	0.75	0.84	0.00	-1.14	63.00	-0.63	0.51
La Reina	1.00	-1.27	23.37	-0.02	1.25	7.00	-0.33	138.00	-0.02	0.31
Las Condes	0.40	-1.49	50.67	0.99	2.48	no data	no data	374.00	1.91	not available
Lo Barnechea	3.60	-0.34	67.70	1.62	1.96	6.00	-0.44	234.00	0.76	1.20
Lo Espejo	6.00	0.52	4.16	-0.73	-1.25	25.00	1.76	75.00	-0.54	-2.30
Lo Prado	5.70	0.41	0.00	-0.88	-1.29	20.00	1.18	94.00	-0.38	-1.56
Macul	2.30	-0.81	0.00	-0.88	-0.07	4.00	-0.67	122.00	-0.15	0.52
Maipú	1.40	-1.13	44.76	0.77	1.9	4.00	-0.67	77.00	-0.52	0.15
Nuñoa	0.30	-1.52	0.00	-0.88	0.64	1.00	-1.02	128.00	-0.10	0.92
P. Aguirre Cerda	4.60	0.02	5.82	-0.66	-0.68	20.00	1.18	82.00	-0.48	-1.66
Peñalolén	7.50	1.06	42.91	0.71	-0.35	19.00	1.06	33.00	-0.88	-1.94
Providencia	0.30	-1.52	14.31	-0.35	1.17	1.00	-1.02	473.00	2.72	3.74
Pudahuel	4.30	-0.09	81.49	2.13	2.22	no plan	no plan	65.00	-0.62	-2.38*
Qilicura	1.50	-1.09	51.88	1.04	2.13	no data	no data	95.00	-0.37	not available
Quinta Normal	8.10	1.27	0.00	-0.88	-2.15	21.00	1.30	123.00	-0.14	-1.44
Recoleta	6.80	0.80	13.29	-0.39	-1.19	3.00	-0.79	110.00	-0.25	0.54
Renca	8.10	1.27	46.63	0.84	-0.43	24.00	1.64	78.00	-0.51	-2.15
San Joaquín	4.20	-0.13	0.00	-0.88	-0.75	2.00	-0.90	97.00	-0.36	0.54
San Miguel	4.50	-0.02	0.00	-0.88	-0.86	3.00	-0.79	113.00	-0.23	0.56
San Ramón	9.30	1.70	0.00	-0.88	-2.58	no plan	no plan	74.00	-0.54	-2.30*
Santiago	5.40	0.30	0.00	-0.88	-1.18	18.00	0.95	496.00	2.90	1.95
Vitacura	0.10	-1.59	33.84	0.37	1.96	9.00	-0.09	450.00	2.53	2.62
Mean/ Min.	4.55	-1.59	23.80	-0.88		9.81	-1.14	140.65	-0.88	
S.deviation / Max	2.79	2.31	27.05	2.13		8.63	1.76	122.38	2.90	

Comunas with no plan were treated like comunas with oldest LRP (= worst value) to calculate the aggregated adaptive capacity indicator

Heat Waves: Values, Z-Scores and Aggregated Z-Scores

	HEAT EXPOSURE					***HEAT ADAPTIVE CAPACITY***						
Comuna	**Green Spaces (%) *SINIM 2008***	**Z-Score**	**Population over 60 (%) *UO 2002***	**Z-Score**	**Aggregated Exposure Z-Score**	**Health HDI *PNUD/ Mideplan 2003***	**Z-Score**	**Municipal Spending pC (1000 pesos) *SINIM 2008***	**Z-Score**	**GDP pC HDI *PNUD/ Mideplan 2003***	**Z-Score**	**Aggregated Adaptive Capacity Z-Score**
Cerrillos	23.22	-0.02	12.30	-0.01	-0.01	0.77	-0.20	171.00	0.25	0.71	-0.11	-0.06
Cerro Navia	12.91	-0.40	10.60	-0.41	0.01	0.74	-0.64	71.00	-0.57	0.62	-0.89	-2.1
Conchalí	0.92	-0.85	15.00	0.63	0.22	0.71	-1.07	87.00	-0.44	0.67	-0.46	-1.97
El Bosque	0.07	-0.88	10.60	-0.41	-0.47	0.78	-0.06	71.00	-0.57	0.64	-0.72	-1.35
Estación Central	0.00	-0.88	14.80	0.58	-1.46	0.71	-1.07	111.00	-0.24	0.71	-0.11	-1.42
Huechuraba	79.57	2.06	8.70	-0.86	2.92	0.78	-0.06	200.00	0.48	0.69	-0.28	0.14
Independencia	0.00	-0.88	18.80	1.52	-2.4	0.63	-2.23	144.00	0.03	0.73	0.07	-2.13
La Cisterna	0.00	-0.88	15.80	0.81	-1.69	0.79	0.09	94.00	-0.38	0.74	0.15	-0.14
La Florida	41.79	0.66	9.40	-0.69	0.03	0.83	0.66	62.00	-0.64	0.70	-0.19	-0.17
La Granja	0.00	-0.88	10.30	-0.48	-0.4	0.76	-0.35	68.00	-0.59	0.61	-0.98	-1.92
La Pintana	44.02	0.75	6.70	-1.33	2.08	0.79	0.09	63.00	-0.63	0.58	-1.24	-1.78
La Reina	23.37	-0.02	13.20	0.20	-0.22	0.86	1.10	138.00	-0.02	0.89	1.46	2.54
Las Condes	50.67	0.99	15.40	0.72	0.27	0.90	1.68	374.00	1.91	0.97	2.15	5.74
Lo Barnechea	67.70	1.62	6.00	-1.49	3.11	0.91	1.82	234.00	0.76	0.96	2.07	4.65
Lo Espejo	4.16	-0.73	12.20	-0.03	-0.7	0.69	-1.36	75.00	-0.54	0.60	-1.06	-2.96
Lo Prado	0.00	-0.88	12.30	-0.01	-0.87	0.75	-0.49	94.00	-0.38	0.67	-0.46	-1.33
Macul	0.00	-0.88	14.60	0.53	-1.41	0.81	0.37	122.00	-0.15	0.77	0.41	0.63
Maipú	44.76	0.77	6.80	-1.31	2.08	0.87	1.24	77.00	-0.52	0.68	-0.37	0.35
Nuñoa	0.00	-0.88	19.30	1.64	-2.52	0.84	0.81	128.00	-0.10	0.84	1.02	1.73
P. Aguirre Cerda	5.82	-0.66	15.30	0.70	-1.36	0.73	-0.78	82.00	-0.48	0.65	-0.63	-1.89
Peñalolén	42.91	0.71	8.50	-0.90	1.61	0.80	0.23	33.00	-0.88	0.68	-0.37	-1.02
Providencia	14.31	-0.35	21.50	2.16	-2.51	0.86	1.10	473.00	2.72	0.95	1.98	5.8
Pudahuel	81.49	2.13	7.50	-1.14	3.27	0.81	0.37	65.00	-0.62	0.66	-0.54	-0.79
Qilicura	51.88	1.04	4.20	-1.92	2.96	0.87	1.24	95.00	-0.37	0.67	-0.46	0.41
Quinta Normal	0.00	-0.88	15.60	0.77	-1.65	0.72	-0.93	123.00	-0.14	0.68	-0.37	-1.44
Recoleta	13.29	-0.39	13.90	0.37	-0.76	0.70	-1.22	110.00	-0.25	0.64	-0.72	-2.19
Renca	46.63	0.84	9.30	-0.72	1.56	0.76	-0.35	78.00	-0.51	0.64	-0.72	-1.58
San Joaquín	0.00	-0.88	15.80	0.81	-1.69	0.75	-0.49	97.00	-0.36	0.66	-0.54	-1.39
San Miguel	0.00	-0.88	16.90	1.07	-1.95	0.71	-1.07	113.00	-0.23	0.80	0.67	-0.63
San Ramón	0.00	-0.88	11.90	-0.10	-0.78	0.72	-0.93	74.00	-0.54	0.60	-1.06	-2.53
Santiago	0.00	-0.88	16.20	0.91	-1.79	0.76	-0.35	496.00	2.90	0.82	0.85	3.4
Vitacura	33.84	0.37	15.50	0.74	-0.37	0.91	1.82	450.00	2.53	1.00	2.41	6.76
Mean / Min.	23.80	-0.88	12.34	-1.92		0.78	-2.23	140.65	-0.88	0.72	-1.24	
S.deviation / Max.	27.05	2.13	4.24	2.16		0.07	1.82	122.38	2.90	0.12	2.41	

8.2 Abstract

Cities are already affected by the negative impacts of climate change in the form of extreme weather events. The scientific literature predicts that these phenomena will increase in intensity and frequency. The integration of adaptation strategies into local development plans is therefore vital. Vulnerability is an agreed concept to discuss and evaluate the risks of the population and possible countermeasures. Vulnerability is defined as the ratio of exposure to a hazard and the adaptive capacity to the hazard’s impact.

The object of this paper is an assessment and a comparison of the vulnerability of the comunas of Santiago de Chile towards the risks floods, heat waves and droughts. Consequently, this work derives indicators out of an analysis of the pertinent scientific literature to measure and map the degree of exposure and adaptive capacity. These indicators describe different factors of urban development and planning, such as housing quality, share of urban green spaces or local regulatory planning. Additionally, they cover social and economic factors, such as demographical structure, income, municipal spending, quality of health care and water consumption per household.

The analysis of the indicators shows an uneven distribution of vulnerabilities across the city. The distribution varies per indicator, but it can be summarized that the comunas in the northeast of the center and the outskirt comunas show rather low vulnerability. The comunas in the southeast and the central comuna Santiago in general show moderate vulnerability. The comunas that form an arc running westwards around the comuna Santiago show predominantly critically vulnerable.

The presented analysis demonstrates a possible way to use the concept vulnerability to identify the most vulnerable urban areas. Based on the results, primary political guidelines and administrative strategies of action can be worked out. Including further indicators and/ or adapted weighting allows to adjust the results to new cognitions.

8.3 Deutsche Zusammenfassung

Städte sind heute bereits von negativen Auswirkungen des Klimawandels, in Form extremer Wetterereignisse, betroffen. Die Wissenschaft prognostiziert, dass diese Phänomene in Frequenz und Intensität zunehmen werden. Daher ist es ratsam, Adaptionsstrategien in lokale Entwicklungspläne einzubeziehen. Vulnerabilität ist ein akzeptiertes Konzept, um die verbundenen Risiken der Bevölkerung und umsetzbare Gegenmaßnahmen zu evaluieren und zu diskutieren. Vulnerabilität ist das Verhältnis aus Exposition gegenüber einem Risiko und der Anpassungsfähigkeit an die Auswirkungen des Risikos.

Der Gegenstand dieser Arbeit ist eine Erhebung und ein Vergleich der Vulnerabilität der einzelnen Comunas von Santiago de Chile gegenüber den Risiken Überschwemmungen, Hitzewellen und Dürren. Dazu werden als Folge einer Literaturanalyse spezifische Indikatoren bestimmt, um den Grad an Exposition und Anpassungsfähigkeit der einzelnen Comunas zu bestimmen und zu kartieren. Diese Indikatoren beschreiben städtebauliche und –planerische Faktoren, wie Wohnbauqualität, Anteil an Grünflächen oder kommunale Planung. Ferner umfassen sie soziale und ökonomische Faktoren, wie demographische Struktur, Einkommen, kommunale Ausgaben, Qualität des Gesundheitssystems und Wasserverbrauch pro Haushalt.

Die Auswertung der Indikatoren zeigt eine starke Ungleichverteilung der Vulnerabilitäten im Stadtraum. Obwohl diese je nach Risikofaktoren variieren, lässt sich zusammenfassend sagen, dass die Comunas nordöstlich des Zentrums und am Stadtrand durch eher niedrige Vulnerabilität gekennzeichnet sind. Die Comunas im Südosten und die zentrale Comuna Santiago haben meist moderate Vulnerabilität. Die Comunas, die einen Ring westlich um die Comuna Santiago bilden, weisen überwiegend eine kritische Vulnerabilität auf.

Die hier dargestellte Analyse und Auswertung zeigen einen möglichen Weg, das Konzept Vulnerabilität zur Identifizierung der verletzlichsten Stadtteile zu verwenden. Auf Basis der Ergebnisse können prioritäre politische Leitlinien und administrative Handlungsstrategien erarbeitet werden. Durch Einbeziehung weiterer Indikatoren und/ oder einer geeigneten Gewichtung der Indikatoren lassen sich die Ergebnisse an neue Erkenntnisse anpassen.

8.4 Lebenslauf

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Geboren am 10.10.1982 in Starnberg

AUSBILDUNG

02/2010 – 05/2010	Forschungsaufenthalt für die Diplomarbeit in Santiago de Chile
10/2007 – 06/2008	Teilnahme am Projekt 3 Uganda von TU Wien und Horizont 3000 (Interdisziplinäres Studentenprojekt zu integrierter Regionalentwicklung in Uganda)
09/2006 – 02/2007	Erasmussemester an der Università l'Orientale, Napoli, Italien
Seit 04/2004	Individuelles Diplomstudium \`Internationale Entwicklung´ an der Universität Wien
10/2003-03/2004	Diplomstudium \`Soziologie´ an der Ludwig-Maximilians-Universität München
06/2002	Abitur Willi-Graf-Gymnasium München

PRAKTIKA UND STUDIENBEGLEITENDE TÄTIGKEITEN

04/2009 – 10/2009	Deutsche Gesellschaft für technische Zusammenarbeit (GTZ) GmbH, Eschborn: Praktikum
08/2008 – 01/2009	Wiener Institut für Internationalen Dialog und Zusammenarbeit (VIDC), Wien: Verfassen einer Studie zum dezentralisierten, gendergerechten Budget in zwei Distrikten Ugandas
12/2007 – 01/2008	Entwurf eines Beitrags für das *Projekt Mercado_53-19*: \`der öffentliche Raum als Arbeitsplatz´ und Veröffentlichung in der Zeitschrift Trialog
08/2007 – 09/2007	Fundación Yanapuma, Quito, Ecuador: Praktikum
06/2007	Kurier, Wien: Verfassen eines Artikels für die entwicklungspolitische Beilage
03/2007 – 06/2007	Koordinierungsstelle der Österreichischen Bischofs-konferenz für internationale Entwicklung und Mission (KOO), Wien: Praktikum