Flood risk assessment in Santiago de Chile

(Working title)

Supervisors: Prof. Dr. Ulrike Weiland, Prof. Dr. Frido Reinstorf

Dipl.-Geogr. Annemarie Ebert, Helmholtz-Centre for Environmental Research – UFZ,

Department of Urban Ecology, Environmental Planning and Transport

Permoserstr. 15 D-04318 Leipzig; Phone: +49-341-235-1752; Email: annemarie.ebert@ufz.de

1 Introduction

Floods, as part of the natural water cycle, have already posed a threat to early urban settlements and put at risk people, their assets and the ecological environment. Regularly occurring floods do also have a history in Santiago de Chile, the capital of Chile with approx. six million inhabitants. Santiago has a dry Mediterranean climate with few but intense winter precipitation events. It is the political and economic centre of the country and is undergoing a rapid process of urbanization with changes in land use and urban morphology in a planned but also in an informal way. Former agriculturally used fields, crossed with an ample irrigation channel system as well as natural areas are transformed into areas with urban residential usage.

Respective land use/land cover (LULC) changes do amongst others lead to an increase of natural hazards, and do above that lead to an increasing amount of people and values that are exposed and potentially vulnerable to those hazards. The focus of this research lies on the analysis of flood risk in the east of Santiago de Chile (*Quebrada San Ramón*, Figure 1).

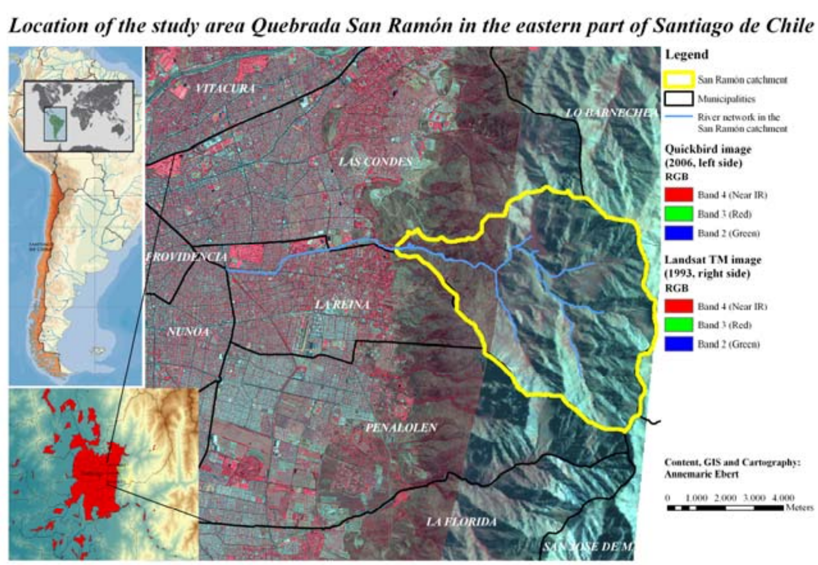

Figure 1: The location of the study area San Ramón catchment with the adjacent municipalities of La Reina and Peñalolén in the eastern part of Santiago de Chile.

The reduction of retention areas associated with urban expansion and a growing amount of sealed surface lead to a decline of the infiltration capacities of the soil. Thus, the surface runoff after precipitation events - and therewith the flood hazard - increases. At the same time, people, buildings and urban infrastructure are more and more exposed to floods and do not always have sufficient capacities to avert damage, i.e. they are vulnerable and finally face a certain risk. The location-specific flood risk that is being analyzed in the scope of this research depends on the hazard, the number of elements at risk and their vulnerability (do also see Chapter 3):

Flood risk = f (Flood hazard, Elements at risk, Vulnerability).

2 Research goal & key research questions

As the analysis of risk and its causes are crucial prerequisites for the development of prevention measures in the scope of disaster risk management, the goal of this research is to investigate the annual problem of floods in the eastern part of Santiago de Chile. It is aimed to point out those factors that lead to damage through floods and to show how these factors and alterations of those influence the flood risk. As a main interest lies on the influence of urban LULC changes, the interaction between flood risk and specific LULC types that amplify or minimize the risk will be a main research focus. The following specific key research questions have been formulated:

- What are the components influencing the flood risk in the study area on different levels?
- Where and for what reasons does the flood hazard become a risk?
- What is the influence of LULC types and their changes on flood risk in the study area?
- What measures concerning LULC could be taken to decrease flood risk?
- How is it or should the flood hazard and risk be incorporated in urban planning?

3 Methodology

The analysis and assessment of flood risk in the study area is based on the application of a multi-scale (individual, household, municipal level) set of flood risk-related indicators (Chapter 4.2, Table 1). These indicators are grouped into hazard and vulnerability indicators as well as indicators referring to the elements at risk. Using methods of remote sensing, GIS, hydrologic and hydraulic modelling as well as a range of statistical methods, values are generated for all of these indicators (Figure 2).

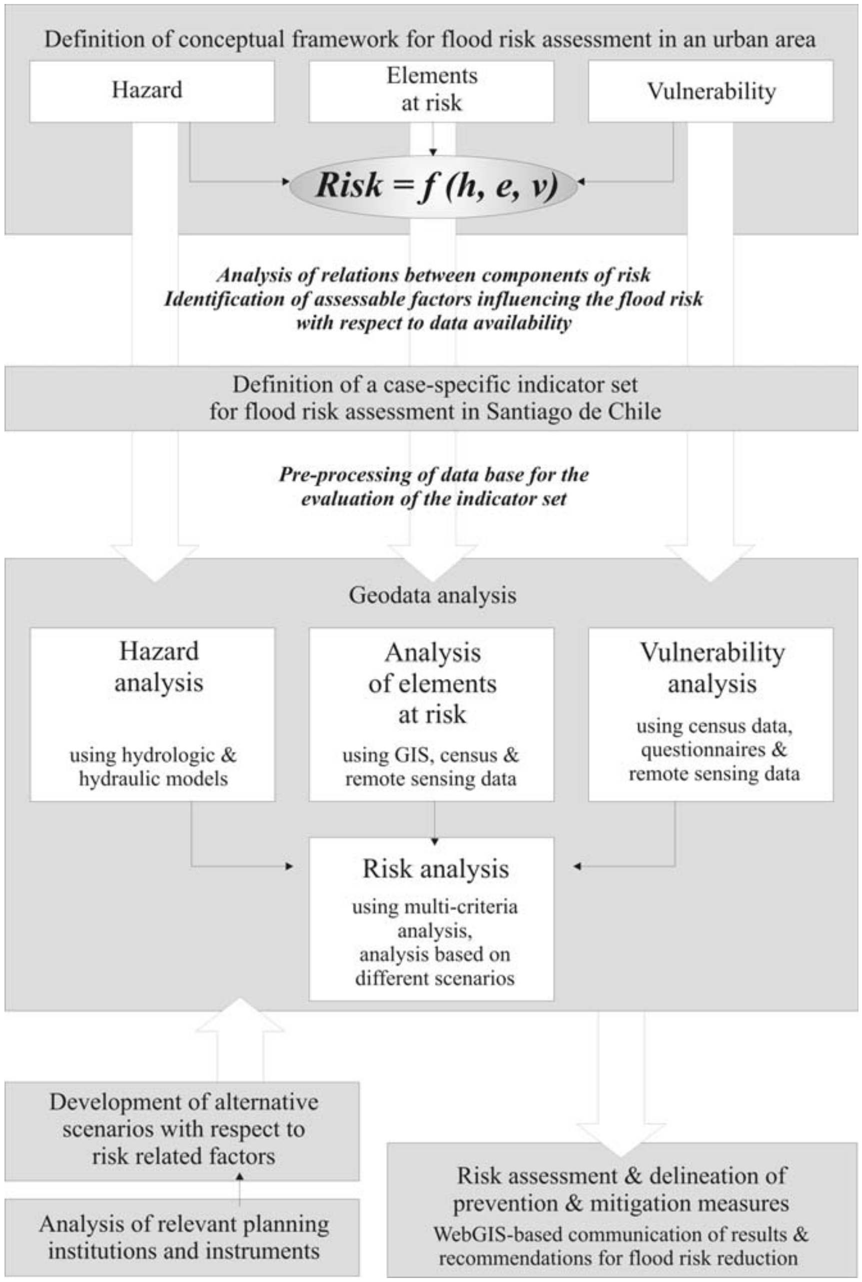

Figure 2: Flow chart showing the working scheme with the main steps in the PhD project.

Thus, a comprehensive flood risk assessment is done for the catchment of *Quebrada San Ramón* based on present but also on potential future LULC patterns. As the intention is also to minimize future damage, basic scenario techniques will be applied in order to show what impact possible development directions could have on flood risk. The dynamics of flood risk are modelled and mapped. The hydrological precipitation-runoff model HEC-HMS (Hydrologic Engineering Center – Hydrologic Modelling System) will be applied to balance the runoff in the upper part of the catchment area where forestation is planned, and in the lower part of the study area (municipality of *La Reina*) - an area with residential usage of different densities. The hydraulic model HEC-RAS (Hydrologic Engineering Center - River Analysis System) will be employed in the part of *La Reina* to simulate the flow patterns of water during precipitation events. Very high resolution (VHR) satellite data (Quickbird, geometric resolution 2.4 m and 0.6 m) are used in combination with GIS and census data to delineate the elements at risk (e.g. buildings, infrastructure, people). These same data are then analysed to obtain information about the vulnerability of those elements located in the hazard zones. One methodological focus is to investigate the potential use of VHR satellite data for physical and social vulnerability analysis by comparing them with socio-economic census data and results from field surveys.

The results from this part of the study are risk maps for the study area considering precipitation events of different probabilities, different LULC patterns and different vulnerabilities by using data of the present situation as well as the scenario storylines.

The analysis of relevant planning institutions and instruments will allow finding out how flood prevention can possibly be done by changing LULC. Findings will be reflected in the scenarios. A WebGIS-based interface will be used to make the results accessible to the local stakeholders and to raise awareness for the complexity of the problem and possible solutions.

4 First results

4.1 Selection of concepts of flood risk-related terms

Based on literature review and the context analysis, suitable concepts of risk, hazard, vulnerability and elements at risk have been chosen.

4.1.1 Risk

The risk of a flood to occur and to cause damage depends on the existence of a hazard and of people and objects that are located in the hazard zone and that do not have sufficient capacities to avert the damage – i.e. elements at risk with a certain level of vulnerability. If one of the components is missing there is no risk (see Figure 3). The relation between the three components is expressed as a function and not as an equation (see Chapter 1), as quantitative values cannot be established for all components and thus relative measures are used.

4.1.2 Hazard

Natural hazard: the probability of occurrence of a potentially damaging natural phenomenon, within a specific period of time in a given area (CARDONA 2003).

4.1.3 Elements at risk

Since this study is done for an urban agglomeration, a part of a megacity, and a strong focus of the analysis is laid on the population and constructed urban environment, people and urban infrastructure as a third contributing factor 'elements at risk' (CARDONA 2003, ALEXANDER 2000) cannot be left out. Most important is the fact, that the risk of a disaster to happen is higher in areas with higher concentrations of people and values. If the number of people potentially affected remains part of the vulnerability framework (e.g. under the term exposure) it will not become clear, where exactly the vulnerability values comes from: either from a high number of people and values potentially affected with comparatively high coping capacities or from a low number of people and values potentially affected with comparatively low coping capacities (see Figure 3). This is especially important to know if prevention and mitigation measures are planned.

The elements at risk are defined as all populations, communities, the built environment, the natural environment, economic activities and services (ALEXANDER 2000) that are situated in a hazard zone.

4.1.4 Vulnerability

While the concepts of hazard and elements at risk are relatively straightforward, the concept of vulnerability is a frequently debated issue. First, a variety of types of vulnerability exist: social, physical, ecological, economic, individual and urban vulnerability, amongst others. WISNER et al. (2005, WISNER et al. 2005) emphasize the diversity of relevant scales for vulnerability research. Besides physical and social exposure on an individual or household level, institutional, economic and systemic conditions that influence the vulnerability are included in their "Pressure-and-Release-Model" (PAR-Model) (WISNER et al. 2005). WISNER et al. (2005:11) define vulnerability as: "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard"

The basic structure of this approach can also be found in the holistic approach of CARDONA (2003), which is for this research context considered to be the best suited concept of vulnerability. Same as BIRKMANN (2005a), CARDONA (2003) defines vulnerability as the internal risk factor – in contrast to hazard which is defined as the external risk factor, a concept also carried by the PAR-Model.

For Cardona vulnerability originates as a consequence of three factors (CARDONA 2003):

- "Physical fragility or exposure, linked to the susceptibility of human settlements to be affected by natural or social phenomena due to its location in a hazard-prone area;

- Socio-economic fragility, linked with the predisposition to suffer harm due to marginalization, social segregation in human settlements, and due to poverty and similar factors; and
- Lack of resilience, related to the limitations of access and mobilization of resources, and incapacity to respond when it comes to absorbing the impact of a disaster. It can be linked with under-development and the lack of risk-management strategies."

Besides the selection of components that are needed for risk assessment, the relation between these factors has to be clarified. In general, risk in form of a mathematical equation either equals the sum or the product of the two or three influencing factors (BROOKS 2003, COBURN et al. 1994). Alternatively, for qualitative risk assessment, risk is treated as a function of the contributing components (BIRKMANN & WISNER 2006, BRIGUGLIO 2003). As normalized numbers can neither be provided for the factor hazard nor for vulnerability, risk is treated as a function of hazard, vulnerability and elements at risk.

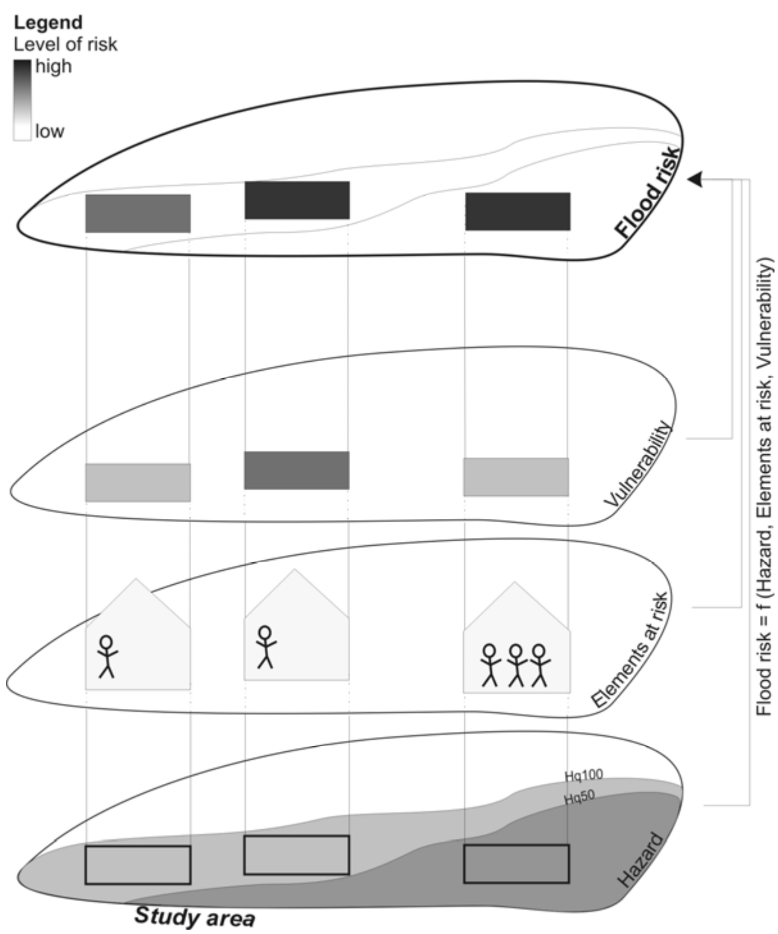

Figure 3: The components of risk exemplified for the case of floods: hazard, vulnerability, elements at risk.

4.2 Compilation of a case-specific set of indicators

A case-specific set of flood risk indicators delineated from a variety of definitions and previous studies are compiled to cover the relevant and influencing points with respect to data availability. Table 1 gives an overview. The main intention in the scope of this thesis with respect to indicators is to show the complexity of the processes associated with flood risk, to communicate interdependencies, to give orientation concerning threshold values and to show how the flood risk as a whole changes if single indicators, such as land use/land cover, number of elements at risk, flood protection measures, e.g. are altered. BIRKMANN (2005b) states that the employment of indicators requires an overall goal and guiding vision, which is in this case the reduction of flood risk.

The set of indicators can be used by authorities on the one hand to show the complexity of this problem and to communicate it to relevant parties and involved people. On the other hand it can be used to define and control development directions and to identify problematic areas, for example areas with a high number of people exposed or areas with unfavourable usage. By bringing the indicators into relation it can be demonstrated – at least in a qualitative or directional way – how different processes interact and influence the flood risk. The development of indicators and target values can already be seen as a tool for vulnerability reduction (BIRKMANN 2005b:6).

Table 1: Set of indicators used for the flood risk analysis and consecutive risk assessment.

Indicator	**Data source**	**Type of scale**
Hazard related indicators		
Amount of precipitation per event	Measured data	Ratio scale
Runoff	Measured data	Ratio scale
Capacity of the water course	Measured data	Ratio scale
Water height in flooded area	Model result	Ratio scale
Land use/land cover	Satellite data	Nominal scale
Local topography	GIS data	Ratio scale
Vulnerability indicators		
Position of building in relation to street	GIS	Nominal scale
Main construction material of wall, floor & roof	Census data	Nominal scale
Location of household within the building	Questionnaire	Nominal scale
Knowledge about private protection measures	Questionnaire	Ordinal scale
Availability of flood protection on buildings	Field survey	Nominal scale
Age	Census data	Ratio scale
Gender	Census data	Nominal scale

Social status	Census data, Satellite data	Nominal scale
Settlement density	Census data, GIS	Ratio scale
Urban structure type	Satellite data, GIS	Nominal scale
Proportion of green spaces	Satellite data, GIS	Ratio scale
Number of lifelines	GIS data	Ratio scale
Household (HH) size	Census data	Ratio scale
Level of education	Census data	Ordinal scale
Employment status	Census data, Questionnaire	Nominal scale
Knowledge about flood hazard	Questionnaire	Ordinal scale
Experience with floods	Questionnaire	Nominal scale
Indicators referring to the elements at risk		
Number of people in hazard zone	Census data	Ratio scale
Number of critical infrastructure in hazard zone	GIS	Ratio scale
Developments of new settlements in hazard zones	Satellite data	Nominal scale

4.3 Scenario creation

Three exploratory scenarios showing possible development directions of factors relevant for flood risk in the study area are being created. The relevant driving factors and key words have been selected. The storylines will be written after the risk assessment based on the current conditions has been done.

4.4 Data collection, pre-processing & first processing results

Available satellite and GIS data, census data and hydro-meteorological data (precipitation, runoff) have been compiled. Field surveys were used to gather data about settlement types, the canal system and critical inundation points. Expert interviews were conducted with decision makers in the field of municipal and regional planning and with employees of the ministry for construction (hydrologic engineering). All available data are pre-processed and are being analyzed at present. That comprises a variety of satellite data from different years, GIS data, census data from 2002 and measured hydro-meteorological data. Results from a field survey focused on vulnerability against floods in the study area are derived in the scope of a Masters thesis. Land use/land cover classifications have been performed for the catchment area of *Quebrada San Ramón* for the years 1993, 2002 and 2008 using a pixel-based method.

Hydrological soil groups have been delineated. The hydro-meteorological data are pre-processed and brought in an adequate format to be used for the model.

5 Perspectives/outlook

The next steps will be the analysis of the census data base and other relevant socio-economic data sets to compare those data with the data acquired during field work (both data collected in the scope of the Masters thesis and own field data about settlement types). The VHR remote sensing data will be analysed in combination with GIS and census data using an object-oriented approach. Their potential for flood risk studies will be investigated. The hydrological and hydraulic model will be applied for the mentioned areas.

Based on these steps, values for all indicators will be generated, weighted and evaluated. A GIS-based multi-criteria analysis will be performed to bring all indicators together and to analyse and assess the flood risk in the study area. Storylines with respect to certain scenarios will be written based on the conducted interviews, official statistic predictions, the analysis of previous LULC developments and own ideas in terms of risk reduction measures. Additional risk analyses will be performed based on the scenario conditions. An analysis of the planning institutions will in that scope be involved to show what potential measures can be taken from institutional perspectives. All results will be implemented in an existing WebGIS to be able to communicate the findings in a transparent manner.

6 Open questions

- How can all indicators be best brought together using multi-criteria analysis?
- What is the best method to rank and weight the indicators and their variables?
- Which value do the (point) results from the field survey in the scope of the Master thesis have? As how representative can the interviews be regarded?
- How should the risk be scaled and evaluated?
- How interactive and transparent has the method to be in order to be accepted by the stakeholders? And what is the best method to present the results?

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