SOCIO-ENVIRONMENTAL CHANGE AND FLOOD RISKS: THE CASE OF SANTIAGO DE CHILE

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With 3 figures and 1 table
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Summary: The extreme concentration of values, people, infrastructure and economic prosperity in megacities creates chances but also makes the population vulnerable to extreme events and natural catastrophes. There is a degree of consensus that, particularly in large agglomerations, hazardous events (e.g. storms, floods, landslides) are not solely the result of natural phenomena, but are rather the result of the interaction between (changing) natural and social/anthropogenic factors. Furthermore, risks resulting from this combination are distributed unevenly across the population: poorer urban households are more at risk to 'natural' hazards. This paper investigates these assumptions. It explores the social and environmental dimensions of land use changes and how they relate to flood risk. Its geographic focus is Santiago de Chile. This rapidly changing megacity with about 6 million inhabitants is located in the Maipo river basin between the central and the coastal Andean cordilleras. The study firstly examines flood risk by considering natural factors and anthropogenic land use change. Secondly, it explores processes of socio-spatial differentiation, aiming to evaluate their relevance for the attenuation of flood risk and its distribution across various socio-economic status groups. Thirdly, it provides a synthesis of the linkages between land use and socio-spatial differentiation processes leading to socio-environmental change and flood risks. The data used for the analysis is based on multi-temporal remote sensing data and statistical data from the Chilean National Census of Population and Housing. The results demonstrate that anthropogenic land use changes increase the exposure of residents to potentially hazardous events and aggravate flood hazards by increasing the surface water runoff after precipitation events. It shows that both poorer and better-off households are exposed to potentially hazardous events. This is due to a significant inflow of households from the latter strata that are attracted by the favourable location at the foothills of the Andean mountains. The study concludes with a set of lessons to be learned from the findings for land use planning and zoning.

Zusammenfassung: Megastädte sind Orte einer extremen Konzentration von Gütern, Menschen, Werten, Infrastruktur und wirtschaftlichen Aktivitäten. Sie bieten damit der Bevölkerung vielfältige Chancen für ökonomische und soziale Entwicklung. Gleichzeitig sind Menschen in Megastädten aber auch verwundbar gegenüber potenziellen Extremereignissen und Katastrophen. Dabei setzt sich die Erkenntnis durch, dass Naturgefahren wie Stürme, Hochwasser oder Hangrutschungen nicht allein die Folge natürlich ablaufender Prozesse sind. Vielmehr werden sie durch die Störung des Ökosystems durch den Menschen verstärkt oder gar verursacht. Hinzu kommt, dass die entstehenden Risiken ungleich auf die Bevölkerung verteilt und vor allem ärmere Bevölkerungsschichten gefährdet sind. Der vorliegende Beitrag knüpft an diese Erkenntnisse an. Er untersucht am Beispiel des Hochwasserrisikos in Santiago de Chile den Zusammenhang zwischen Landnutzungsänderungen, sozial-räumlichen Transformationsprozessen und den sozialen und physischen Risiken. Diese sehr dynamisch wachsende Stadt mit etwa 6 Millionen Einwohnern liegt im Tal des Flusseinzugsgebiets des Maipo-Flusses zwischen den Anden und der Küstenkordillere. Die Studie untersucht zunächst die Entstehung und Entwicklung von Hochwasserrisiken und den beeinflussenden natürlichen und anthropogenen Einflussfaktoren. Basierend auf einer Auswertung multitemporaler Satellitenbilder analysiert sie insbesondere Landnutzungsänderungen. Anschließend werden anhand von Daten des nationalen Zensus in Chile Prozesse sozialräumlicher Differenzierung näher untersucht. Abschließend werden aus dem Zusammenspiel von Landnutzungsänderungen und sozialräumlicher Differenzierung die sozial-ökologischen Veränderungen und Hochwasserrisiken abgeleitet. Die Ergebnisse der Studie zeigen, dass anthropogene Landnutzungsänderungen in Santiago zu einer erhöhten Exposition gegenüber potenziell gefährlichen Ereignissen führen. Entgegen der Ausgangsthese zeigt sich, dass im Untersuchungsgebiet sowohl arme als auch reiche Haushalte diesen Gefahren ausgesetzt sind, da vor allem reichere Haushalte in die attraktiven, aber hochwassergefährdeten unteren Hanggebiete der Anden ziehen. Der Beitrag leitet aus den Untersuchungsergebnissen schließlich eine Reihe von Schlussfolgerungen ab, welche besonders die Regulierung der Landnutzung betreffen.

Keywords: Santiago de Chile, environmental change, social change, flood hazards, risks, vulnerability

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1 Megacities as spaces of risk: the case of Santiago de Chile

Megacities are spaces of opportunities and risks. The concentration of values, people, infrastructure and economic prosperity creates chances, but makes megacities and their population likewise vulnerable to extreme events and natural catastrophes. This has prompted an interest in analysing damage potentials, assessing physical and economic losses and consequences and, more recently, analysing social vulnerability and capacity to cope with risks.

This paper relates to two particular aspects and hypotheses of this evolving debate. First, it acknowledges that hazardous events (e.g. storms, floods, landslides), particularly in large agglomerations, are not solely the result of natural phenomena, but are rather the result of the interaction between (changing) natural and social/anthropogenic factors (see e.g. Murray 2009; Wisner et al. 2004). Secondly, the risks resulting from this combination are unevenly distributed across the population: Poorer urban households are more at risk from 'natural' hazards. The arguments supporting this claim are: (i) low-income groups often concentrate in high-risk areas (see e.g. Hardoy et al. 2004) and (ii) local governments often fail to include the poorer groups living in 'risky locations' into risk management (Dodman and Satterthwaite 2008). An example is where local governments do not provide adequate storm water drainage to cope with floods or where these groups/locations do not appear in any disaster management/evacuation plans.

In this context, the paper explores the physical and social dimensions of land use change and how they relate to flood risk in Santiago de Chile, a rapidly changing megacity. In particular, the paper

- uncovers (some of) the physical consequences of land use change and their environmental effects on flood hazard,
- highlights the social forces (socio-demographic trends) that both drive land use change and shape exposure to the hazard, and
- analyses how the resulting flood risks are distributed across various socio-economic groups.

The subject of the case study, the Megacity of Santiago de Chile, is located in the Maipo river basin between the central and the coastal Andean cordilleras and is subject to a subtropical dry climate. Most of the precipitation occurs between May and August (mean total rainfall per month 57–85 mm, WMO), mainly in the form of intense rainfall. The topographical location of Santiago de Chile forms natural conditions for its susceptibility to natural hazards such as floods, landslides and earthquakes.

As the national capital and Chile's economic centre, Santiago de Chile currently has about six million inhabitants. According to projections, the population will exceed eight million people by 2030 (MINVU 2008). Population growth and the demand for urban land use are associated with spatial and functional changes in land use, in particular intensive land conversion from non-urban (e.g. agricultural, natural forests or wetlands) to urban uses (housing, industry and services).

These ongoing changes in land use and land cover are leading to the loss of environmental services such as storm water infiltration, heat mitigation and biodiversity conservation in certain areas of the city (e.g., in the Andean piedmont). These trends are likely to amplify the intensity of potentially hazardous events. This interrelation between natural hazards and anthropogenic amplification becomes especially evident in the case of flood events. The occurrence of floods in Santiago de Chile is induced by periodical intensive rainfall in winter and is part of the natural water cycle. The intensification of flood events and their potential effects on people, values and goods are directly influenced by land use changes in general and the increase of sealed surfaces in particular. Sealing of soils reduces the amount of retention area and the infiltration capacity of the affected soils. It is widely acknowledged that especially green and open spaces best fulfil the function as retention areas due to infiltration, interception through vegetation, and storage of rainwater (Gill et al. 2007). Their reduction increases the surface water runoff after precipitation events and leads to an aggravation of the flood hazard (Romero et al. 2009).

There is evidence that flood events in Santiago de Chile have been increasing in frequency over the last two decades, with recent floods in 1993, 1997, 2000, 2005, 2008 and 2009 (AC INGENIEROS 2008). At the same time, the increase in population and economic values in Santiago de Chile has increased exposure to flood events. However, as elsewhere, exposure in Santiago differs across location and socio-economic status groups.

In the attempt to uncover the interlinkages between land use changes, socio-spatial differences and flood risks, the study focuses on a particular case – the municipality of Peñalolén.

The paper is organised as follows: section 2 outlines the risk concept and its elements as applied in this study, as well as methodological considerations (data used, analyses performed and spatial and temporal extent). Section 3 presents the results of the analysis of socio-environmental changes. Firstly, it examines flood risk by considering natural factors and anthropogenic land use changes. Secondly, it explores processes of socio-spatial differentiation, aiming to evaluate their relevance for the attenuation of flood risk and its distribution across various socio-economic status groups. Thirdly, it provides a synthesis on the linkages between land use and socio-spatial differentiation processes leading to socio-environmental change and flood risks. Section 4 discusses the findings of the analysis. A concluding section reflects on the significance of the results for the general debate on risk and vulnerability in an urban context.

2 Risk concept and methods

2.1 The underlying risk concept

There are many definitions of risk and a broad range of risk concepts in the literature (Brooks 2003; Wisner et al. 2004; Birkmann and Wisner 2006; Hansjürgens et al. 2008). In order to address socio-environmental change, i.e., the interplay of physical conditions and human conditions as decisive factors determining the degree and severity of risk, in this article we refer to a distinct concept of risk that can be characterized by the components of *hazard* and *vulnerability*, whereby the latter is comprised of *exposure* and *coping-capacity*.

When analysing risk very often the degree and severity of the *hazard*, here understood as the probability of a potentially damaging event to occur, is at the focus of attention. According to this view, it is the hazard that creates risk and determines its degree and severity. Following the classical work by Frank Knight (1921), the definition of risk is based on two factors: (i) the expected damage a hazard can cause, and (ii) the probability of the occurrence of the damage. In this view, risk in megacities is associated primarily with increasing hazards emerging from changes of the physical environment, e.g., through global and/or climate change such as increasing occurrences of storms or floods.

However, hazards do not affect all members of the society equally. Instead, various individuals, societal groups, sectors of the economy, or inner-urban regions are affected differently. A decisive factor determining the degree to which a person, a societal group, an economic sector, or a region is affected is its *vulnerability*. Therefore, concepts of vulnerability have become widespread in the scientific community as an analytical approach to explain the occurrence of disasters and crises. Despite its diverse interpretation (Weichselgartner 2001), some key parameters are considered important in the definition of vulnerability: The exposure to perturbation or external stresses and the capacity to adapt to and/or cope with perturbation and external stresses (Adger 2006).

The *exposure* to external stresses or hazards refers to all "elements" that are exposed to a hazard: humans, social groups, economic sectors, regions within the city or within a country (e.g., coastal zone areas), buildings, the urban infrastructure, etc. While humans and physical assets play a pivotal role in mega-urban agglomerations (because cities are mainly characterised by populated built-up environments), the natural environment (natural capital) may also have a "value"; however, this value is often neglected in the urban context.

A further factor that is critically important for the degree of vulnerability within a megacity is the *coping-capacity* of affected "elements at risk". In understanding this "capacity", the definition of vulnerability developed by Wisner et al. (2004, 11) is helpful. According to their definition, vulnerability is "the characteristics of a person or a group and their situation that influence their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard". Instead of emphasising solely characteristics of the natural or technological hazard itself or the exposure (of a structure, building etc.) to the hazard, this interpretation focuses on the question of how communities and social groups are able to deal with the impact of a natural hazard.

To conclude, in a general sense, vulnerability emphasizes that risks are never the simple result of natural processes but rather are a mixture of physical conditions and social circumstances (O'Keefe et al. 1976). As White (1945, 2) stated already some sixty years ago: "Floods are 'acts of God', but flood losses are largely acts of man". In this sense, the subsequent sections address the impacts of environmental and socio-demographic changes on risk, as exemplified for the case of flood risk in one municipality of Santiago de Chile.

The analysis of flood risk presented here does not consider all the variables presented in this section to the same degree. It thus does not present a complete risk analysis. It focuses on the hazard (based on information obtained from existing data and maps covering locations prone to flood risk) and the factors that amplify it (land use changes and changes in socio-spatial differentiation). Furthermore, it assesses vulnerability with respect to exposure of the population.

2.2 Data and methods

The data analysis in this paper consists of four steps. The first step (presented in section 3.1) is an analysis of land use and land cover (LULC) changes in the case municipality of Peñalolén, uncovering (some of) the physical consequences of land use change and their environmental effects on flood hazard. The analysis is based on the interpretation of multi-temporal remote sensing data from 1993/95 (fusion of Landsat-4 and SPOT), 2002 and 2009 (ASTER). The time period was chosen such as to facilitate the interpretation and combination with statistical data from the Chilean National Census of Population and Housing (1992 and 2002). Data from 2009 was analysed in order to provide an impression of the most recent situation. Obtaining information about the type and pattern of LULC from satellite data requires the analysis of the spectral properties contained in the image. Using a pixel-based classification approach (Richards and Jia 1999) and additional GIS data, 16 urban LULC types were initially derived from the satellite images at a geometric resolution of 15m, and then aggregated into four LULC classes: Green spaces, open spaces, agriculturally used areas and residential areas. A cell-by-cell change detection permitted a quantification of LULC changes over the research period. The analysis focused on detecting the changes from green and open spaces to residential uses.

In a second step, the study overlays the above with information about flood hazard originating from a study comprising hydraulic modelling and capacity calculations for each stream in the study area, carried out by a private consulting company (AC INGENIEROS 2008), as a contributing 'layer' for the risk analysis (Section 3.1). The data set comprises zones along water ways that are prone to flooding (blue lines) and points of overflow with red lines indicating the angles of inundated areas where the creeks continue as roads (Fig. 2 and 3). This information is used to visually relate land use and land cover changes with the location of hazard prone areas and the spatial distribution of socio-economic groups.

A third step (presented in section 3.2) consists of the analysis of demographic trends based on statistical data from the Chilean National Census of Population and Housing of 1992 and 2002 in order to make the social forces (socio-demographic trends) that both drive land use change (or are the result of land use changes) and shape exposure to the hazard explicit. The census dataset provides information not only about the demographic and housing situation of the population, but also about residential mobility (migration). For this purpose, it contains a specific question that requires respondents to provide information about their place of residence over a period of five years preceding the interview. This information was used to describe the migration-based changes of households from various socio-economic groups and the resulting social-spatial composition in the study area. This differentiation of households and aggregation into several socio-economic groups is based on the availability of a range of household goods and the educational level of the head of household. This calculation follows commonly applied standards in Chile (e.g. ASOCIACIÓN CHILENA DE EMPRESAS DE INVESTIGACIÓN DE MERCADO (AIM) 2008) that differentiates five socio-economic status groups: very high (ABC1), high (C2), middle (C3), low (D) and very low (E) socio-economic status. This classification serves as a suitable proxy indicator for household income and income disparities (for which the census does not provide data).

A fourth and final analytical step combines the results of changes in both land use and land cover with socio-economic composition and flood hazards in order to identify how the flood hazard is distributed across the various socio-economic groups (section 3.3). Due to limited information contained in the flood hazard maps (only points of overflow and no complete flood prone areas are available), a deeper statistical analysis and correlation of the census data with the hazardous areas cannot be provided. Therefore, the data is overlaid in a digital map to visually relate the location of flood hazard areas with recent changes in both land use/land cover and the socio-economic pattern of the residents. Afterwards the overlaid results are analysed qualitatively.

3 Results: land use changes, social changes and flood risk

Peñalolén, the subject of the case study, is one of the 52 municipalities of the Metropolitan Region of Santiago de Chile and is situated in the eastern part of the city, bounded by the Andean cordillera. The intensive land use changes, as well as changes in the amount and composition of population, which this municipality has experienced during recent decades are the subjects of the following sections. Particular attention is paid to the effects of these changes on flood risk, which has traditionally been a problem in the study area (Romero et al. 2009; Naranjo and Varela 1996).

3.1 Environmental change and flood risk

The analysis of land use changes using high resolution remote sensing data (see section 2) shows that the proportion of green spaces, including all public green spaces and parks, private green spaces and agriculturally used areas in Peñalolén, substantially decreased from 53.9% to 49.9% between 1993 and 2002 (Fig. 1) and to 48.1% between the years 2002 and 2009 – resulting in a total loss of green spaces of approximately 5.8% or 767 km². The built-up areas, with various building densities and streets, in turn increased from 31.1% in 1993 to 38.9% in 2002 and 42.3% in 2009. The amount of built-up area in the entire city was 32.9% in 1993, 37.6% in 2002 and 38.6% in 2009 (own calculations based on the analysis of remote sensing data). That shows that the increase in construction activities in Peñalolén was above average during the last decade. The decreasing amount of urban barren land, from 3.2% in 2002 to 2.2% in 2009 (loss of 114 km²), shows that not only green space but also open land was substituted by newly constructed built-up areas.

The main LULC changes have taken place in the central areas of Peñalolén where former vineyards were located (Fig. 1, yellow parts in the middle). These areas are covered by a large number of medium-density housing areas today, especially as standardized single-family homes. Commercially used areas (shopping centres) have been constructed in the western part of the municipality, resulting in an almost complete sealing of the previously agriculturally used areas.

According to the definition of risk, a pure increase of the flood hazard does not necessarily lead to an increasing level of risk. Risk is only generated if vulnerable elements are exposed to the hazard, a fact that is considered further in section 3.3. Section 3.2 highlights the socio-demographic development in the study area as a second decisive factor for flood risk generation.

3.2 Social change

The history of the municipality of Peñalolén dates back to the 1940s, when the first new residents arrived and settled on informal plots of land. During the 1960s, the first plots were parcelled, an act that formally created the settlements of Peñalolén. In subsequent decades, the municipality experienced a continuous population increase. To

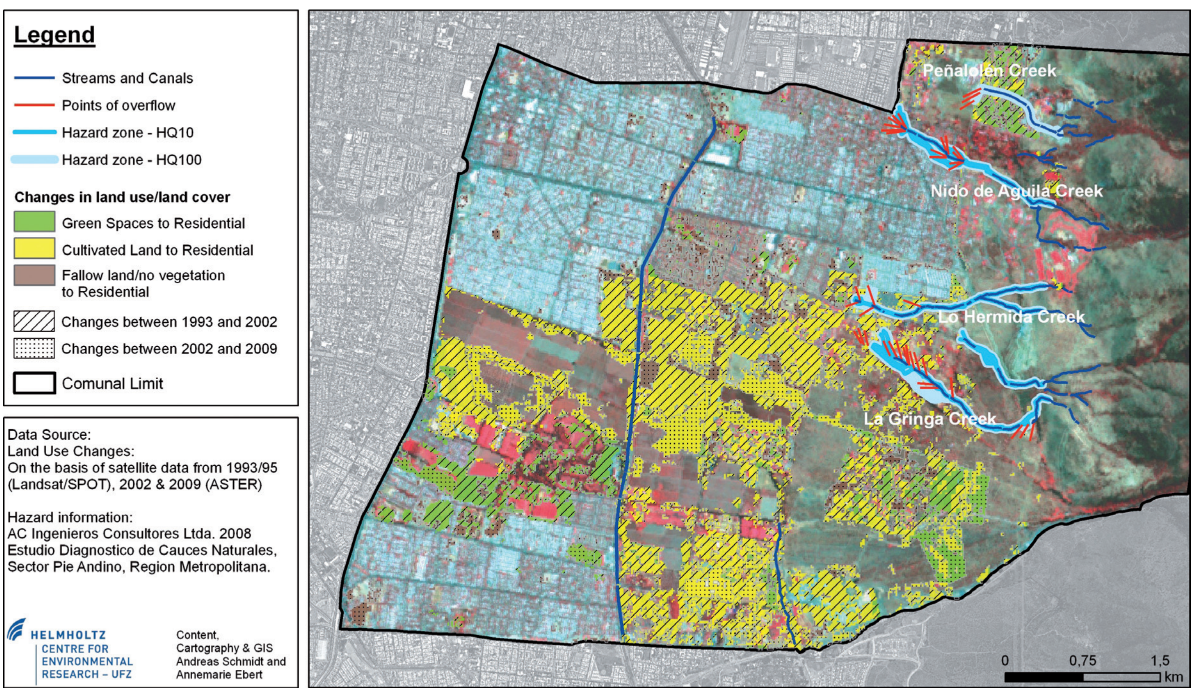

Fig. 1: Land use and land cover (LULC) changes in Peñalolén between 1993/95, 2002 and 2009

illustrate this trend, more than 50,000 persons migrated to Peñalolén between the early 1950s and the 1970s (MUNICIPALIDAD DE PEÑALOLÉN 2006). Between the census periods of 1970 and 1982, the total population further increased by 129%. From the beginning of the 1980s, the Chilean Government started a process of adjustment and structural changes in the social housing policies, aiming at combating the housing deficit of the poorest social groups. Social housing was offered principally at the periphery of the capital in locations such as Peñalolén where land prices were low. Consequently, the communal population kept on growing: From 137,298 inhabitants in 1982 to 179,781 inhabitants in 1992 (CEPAL 2005). As a recipient community of large-scale social housing, Peñalolén was characterized by a high concentration of poverty at that time and was classified as one of the poorest municipalities of the Metropolitan Region according to the CASEN survey of the Ministry of Development and Planning (MIDEPLAN) in 1992 (Galleguillos Araya-Schübelin 2007).

At the beginning of the 1990s, the location attracted the interest of the real estate market in the form of new investments that focused particularly on the development of gated communities, with households almost exclusively from the middle to high socio-economic status groups. As a consequence, particularly wealthy families (high and very high socio-economic status) started to move to Peñalolén, a trend that was confirmed by the 2002 Census (Tab. 1). Most of the gated communities to accommodate the new residents were constructed on agrarian land (especially vineyards) (section 3.1), although in a few cases poor families were forced to leave their houses and plots of lands (Galleguillos Araya-Schübelin 2007). In contrast to the inflow of better-off households, the net migration balance was lower for middle, low and lower socio-economic groups in 1992 and even negative in the most recent census period, 2002 (Tab. 1).

Associated with these migration trends, a change in the socio-economic composition within the municipality took place, which becomes evident when looking at the change in average socio-economic status of households at the scale of statistical blocks. Figure 2 highlights two contrary trends. In several statistical blocks, the average socio-economic status changed in an upward direction (shown in green in Fig. 2), in some cases by more than one bracket (shown in dark green in Fig. 2). This trend is particularly pronounced for areas at the upper eastern end of the municipality. In contrast, the opposite trend occurred in other statistical blocks where the average socio-economic status changed in a downward direction (shown in orange in Fig. 2).

The increasing presence of better-off socio-economic groups (indicated by a rise in the average socio-economic status) is particularly visible in areas that have been characterized by changes in the land use patterns from previously cultivated or fallow land to urbanized land (see section 3.1). More specifically, these groups settled predominantly in the eastern part of the municipality along the slopes of the Andean piedmont. The western and northern part of the municipality show less clear and more divergent changes in the socio-economic pattern. Since these areas did not experience major changes in the land use patterns, the social changes seem to be attributable to either residential mobility (migration) or social mobility (households moving up or down in socio-economic status). Here a more detailed analysis would be necessary in order to deliver more robust results.

The subsequent section 3.3 examines how the resulting flood risks are distributed across the various socio-economic groups and how land use / land cover changes are related to flood risk (hazard, elements at risk, vulnerability (exposure)) across the municipality. Rather than performing a full risk assessment that would require detailed analysis of cop-

Tab. 1: Net migration of the municipality of Peñalolén in 1992 and 2002 differentiated by socio-economic groups. (Source: own calculations based on INE 1992, 2002)

Socio-economic groups	1992			2002		
	N° of Households	Net Migration	Net Migration / 1,000 Households	N° of Households	Net Migration	Net Migration / 1,000 Households
Very High (ABC1)	1611	1113	691	5477	4912	897
High (C2)	5577	1171	210	8310	950	114
Middle (C3)	9635	618	64	11930	-2204	-185
Low (D)	20139	846	42	23534	-2847	-121
Very Low (E)	7558	266	35	7487	-293	-39

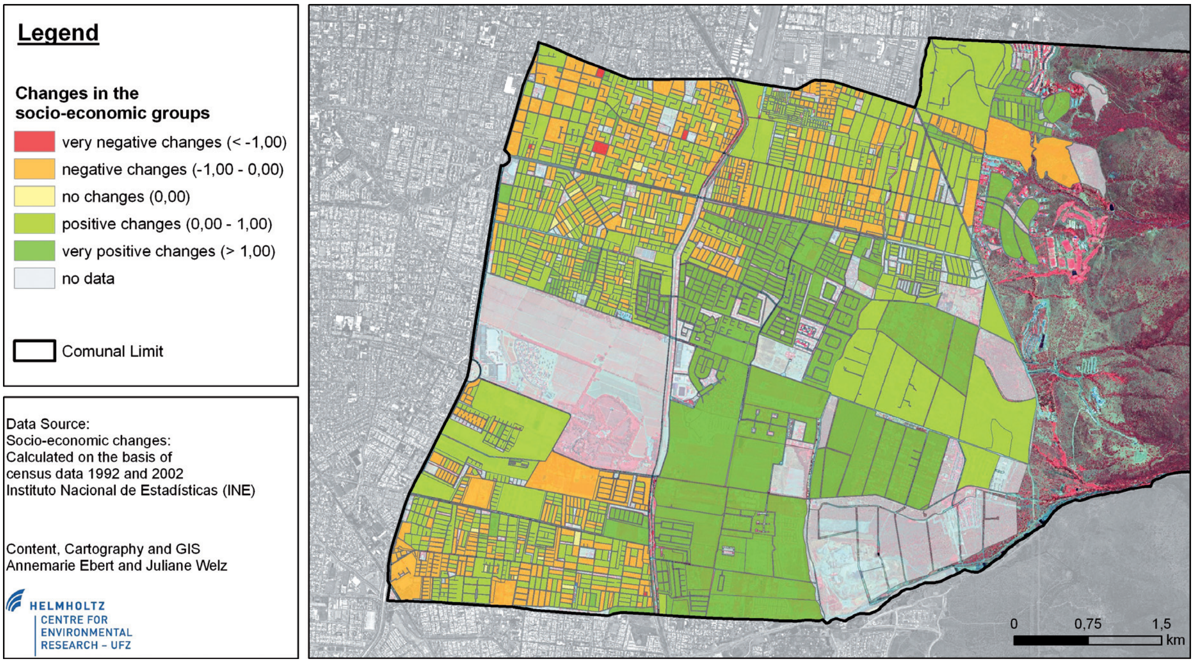

Fig. 2: Changes in the average composition of socio-economic status of households at the level of statistical blocks in Peñalolén between 1992 and 2002. (Source: own calculation based on census data INE 1992, 2002)

ing capacities, this study demonstrates in qualitative terms how land use/land cover changes increase the exposure and in consequence the risk of people with different socio-economic capabilities located in hazard prone areas to suffer various types of damage.

3.3 Socio-environmental changes and flood risk

As stated in section 2, the impact of a hazardous event – in this case a flood – varies spatially. Figure 1 shows that new construction primarily occurred in those areas that are located closed to small creeks. Individuals are affected unequally depending on their vulnerability. They experience damage if they are physically exposed and/or if they have insufficient coping capacities to deal with the adverse impacts of a flood. In terms of exposure, the identified flood hazard areas potentially affect not only households and buildings from lower social strata (older settlements) but likewise well-off households (new settlements) (Fig. 3). This exposure includes areas where the average socio-economic status has increased between 1992 and 2002. The areas along Lo Hermida and La Gringa creek as two examples are newly constructed medium-high class settlements that are located directly below a point of overflow. The example of Nido de Aguila creek shows that positive as well as negative changes of the socio-economic level (increasing and decreasing average socio-economic status of a neighbourhood) occur along the water ways.

As commonly pointed out, the effects in the case of an actual flood event may have different forms or intensities for different socio-economic groups. In the case of Peñalolén, related field work (Reiter 2009) shows that both poorer and richer households are negatively affected by floods. While the lower status groups mostly experience physical damage such as destruction of their goods, moisture remaining in buildings or dysfunctional public transport services, the higher status households living in closed neighbourhoods might be locked in their buildings during floods when existing water gates are kept closed to protect the community. All groups are more or less equally affected by blocked roads and water accumulation on streets, and might also suffer psychological damage such as extreme fear during future flood events.

4 Discussion

Structural and demographic changes in the case municipality of Peñalolén have led to a spatial and social fragmentation of the municipality that is also reflected in the residential socio-economic pattern of the various areas. Since the 1990s, residential segre-

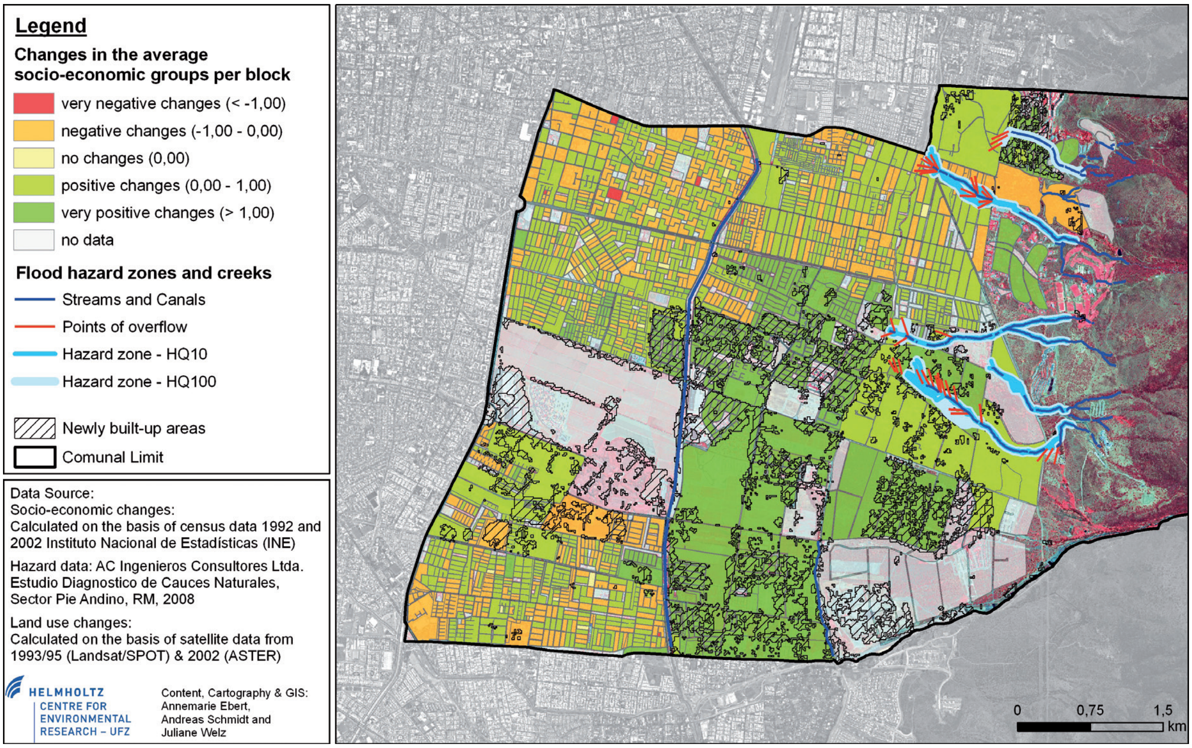

Fig. 3: Changes in the distribution of the socio-economic groups (very negative to very positive changes as further described in section 3.2) and changes in LULC (newly built-up areas) in Peñalolén between 1992 and 2002

gation has been a marked trend in the municipality of Peñalolén due to the differences between the long-established population (mostly with few resources) and the new inhabitants (well-off households) (MUNICIPALIDAD DE PEÑALOLÉN 2006). As a consequence, Peñalolén is one of the municipalities that are characterized by a wide range of different socio-economic status groups living in spatial proximity to each other. Against this background it is important to discuss how different socio-economic groups are affected by floods.

Given the fact that the flood hazard in urban areas is most influenced by urban expansion and associated changes in LULC, reinforced by a periodical increase in intense rainfall due to global and subsequently regional climate change, the ongoing transformations in the case study predict an increase in flood hazard as the infiltration and the retention capacities of the soil decrease. The result is an increasing amount of surface runoff and subsequent accumulation of water in local depressions, with floods after precipitation events.

These "acts of man" do indeed lead to an acceleration of urban floods in the municipality of Peñalolén. Especially the areas along the smaller creeks Lo Hermida, Nido de Aguilas, La Gringa and Peñalolén (Fig. 1), which all come from the Andean foothills, are prone to flooding, as latest projections prove (AC INGENIEROS 2008). While some of the vineyards that still exist in the western part of the municipality will be maintained, it can already be observed that the remaining open spaces are being built-up: For example, the new settlements evolving at the westernmost point of overflow of the Lo Hermida creek (Fig. 1) where the creek is first channelled and then continues underground. These newly evolving settlements are located directly in a flood-prone area. Even though a smaller channel that is capable of directing a certain amount of storm water around the new settlements has been constructed above that area, the loss of retention areas resulting from the ongoing construction work will amplify the amount of surface runoff reaching the lower western parts of the municipality.

Another trend occurring in the study area is that main roads have been constructed in areas of former river beds (e.g., Avenida Antupiren). These roads regularly turn into waterways during precipitation events and become impassable. Since there is no official data to show which streets and areas are most affected, a detailed exposure analysis is not possible. The trend, however, of constructing new buildings for residential and commercial use at the Andean foothills is continuing because of profitable land prices. As a result, the zoning of land as construction sites yields more financial benefit than its use as agricultural land, public green spaces or ecologically protected areas. An increasing demand for personally-owned real estate through inner-urban migration (compare with section 3.2), preferably into gated communities or into newly constructed high-rise buildings equipped with private amenities such as swimming pools and gymnasiums, additionally fosters construction activities. However, new social housing areas also evolved in various parts of the municipality.

While the positive economic consequences of urban expansion are evident and appreciated, the negative environmental consequences are often neglected, especially at the scale of the entire municipality or city. This deficit becomes evident when consulting existing flood hazard maps used in the regional development plan: The official hazard zoning has not been updated since 1986, although catchment characteristics have changed significantly with respect to land use. Even though flood hazard studies have been carried out in parts of Santiago de Chile and also for the municipality of Peñalolén (e.g. AC INGENIEROS 2008), the results obtained are hardly ever transferred into practice – not only for financial reasons but also as a result of poor communication among stakeholders and decision makers. One example is provided by the previously mentioned new settlements along the Lo Hermida creek. The latest information on flood hazards is therefore not considered in decision-making with respect to urban development, resulting in a continuation of construction in flood-prone regions and a loss of retention areas.

5 Conclusion

This paper explores the physical and social dimensions of land use change and how they relate to flood risk in Santiago. It aligns the analysis to two hypotheses of the contemporary debate in the context of hazards and risks.

The first hypothesis argues that hazardous events (e.g. storms, floods, landslides), particularly in large agglomerations, are not solely the result of natural phenomena, but rather the result of the interaction between (changing) natural and social/anthropogenic factors. The evidence presented for the case municipality of Peñalolén in Santiago confirms this hypothesis. It demonstrates that anthropogenic land use changes increase the exposure of residents to potentially hazardous events and aggravate the flood hazard by increasing the surface water runoff after precipitation events.

The second hypothesis states that the resulting risks are distributed unevenly across population: poorer urban households are more at risk to 'natural' hazards. The study cannot confirm this assumption. At least in the case municipality, both poorer and better-off households are exposed to potentially hazardous events. This is connected to a significant inflow of households from the latter strata that are attracted by the favourable location at the foothills of the Andean mountains.

Beyond these immediate conclusions, potentially adverse impacts of urban growth in Peñalolén towards the Andean foothills and the densification of the existing settlement areas in the lower-lying areas provide at least three lessons for urban spatial planning and flood risk management. Firstly, it becomes evident that the problem of flood risk is the result of an 'aggregate' impact of land use changes permitted by the local land use plan. What may seem unproblematic with respect to an individual project accumulates to create risks when all conversions are considered together. This suggests that a more strategic assessment of the local land use plan is required with respect to environmental consequences in general and flood risk in particular. Secondly, land use planning needs to incorporate knowledge about the 'changing hazard'. Official hazard zoning has not been updated since 1986, even though catchment characteristics have changed significantly with respect to land use. Thirdly, land use planning and zoning must face the challenge of adequately building risk mitigation into their specifications with respect to the types of permitted uses. To illustrate this point, it is evident that urban green spaces have a positive mitigating effect on hazard factors. In addition, they provide several other important environmental and social services such as local climate effects and recreation. However, the amount of green space in Peñalolén has diminished drastically. A change in priority and increased attention to the value of this type of land use could make a substantial contribution to flood risk mitigation.

The findings of this research – that exposure is neither necessarily unequally distributed across households from different socio-economic status groups nor are the poor more negatively affected by floods – are relevant for the general debate on risk and vulnerability in a methodological and conceptual sense. The implication with respect to methodology is that research on urban risk has to clearly differentiate the types of potential damage because different groups tend to incur different damages. While the poor mainly suffer material damage as their houses, for example, might be fragile, the well-off suffer immaterial damage as they are 'captives' in their walled communities. This implies that the analysis and assessment of risk needs to capture a higher degree of complexity and systemic perspective as the hazardous event not only affects buildings or human health that exposure and coping capacity may change at different spatial or temporal scales. Likewise damages can not only be measured by a single variable of economic loss. This challenge leads to the second implication of this study which is related to the conceptualization of the term vulnerability. The study shows that vulnerability and its two sides – exposure and coping capacity are complex components of risk that require a methodologically comprehensive assessment.

References

AC INGENIEROS (2008): Diagnóstico de Cauces Naturales, Sector Pie Andino. Región Metropolitana. Santiago de Chile.

ASOCIACIÓN CHILENA DE EMPRESAS DE INVESTIGACIÓN DE MERCADO (AIM) (2008): Grupos socio-económicos 2008. Santiago de Chile. http://www.aimchile.cl/Grupos_Socioeconomicos_AIM2008.pdf (Date 2010/03/05)

ADGER, N. W. (2006): Vulnerability. In: Global Environmental Change 16, 268–281. DOI: 10.1016/j.gloenvcha.2006.02.006

BIRKMANN, J. and WISNER, B. (2006): Measuring the unmeasurable. The challenge of vulnerability. UNU-EHS Source 5. Bonn.

BROOKS, N. (2003): Vulnerability, risk and adaption: a conceptual framework. Tyndall Centre Working Paper 38, Centre for Social and Economic Research on the Global Environment (CSERGE), University of East Anglia, 01/06 2003. Norwich.

CEPAL (COMISIÓN ECONÓMICA PARA AMÉRICA LATINA Y EL CARIBE) (2005): Latin America: urbanization and urban population trends 1950–2000. Demographic Bulletin 75. Santiago de Chile.

DODMAN, D. and SATTERTHWAITE, D. (2008): Institutional capacity, climate change adaptation and the urban poor. In: IDS Bulletin 39, 67–74.

GALLEGUILLOS ARAYA-SCHÜBELIN, M. X. (2007): Möglichkeiten zum Abbau von Segregation in Armenvierteln. Die Frage nach der sozialen und ökonomischen Nachhaltigkeit urbaner Ballungsräume am Beispiel Santiago de Chile. Kieler Geographische Schriften 115. Kiel.

GILL, S.; HANDLEY, J.; ENNOS, A. and PAULEIT, S. (2007): Adapting cities for climate change: the role of the green infrastructure. In: Built Environment 33, 115-133. DOI: 10.2148/benv.33.1.115

HANSJÜRGENS, B.; HEINRICHS, D. and KUHLICKE, C. (2008): Mega-urbanization and social vulnerability. In: BOHLE, H.-G. and WARNER, K. (eds.): Megacities. Resilience and social vulnerability. UNU-EHS Source 10. Bonn, 20–28.

HARDOY, J.; MITLIN, D. and SATTERTHWAITE, D. (2004): Environmental problems in an urbanizing world. London, Sterling.

INE (INSTITUTO NACIONAL DE ESTADÍSTICAS) (1992): Censo de Población y Vivienda 1992. Santiago de Chile.

– (2002): Censo de Población y Vivienda 2002. Santiago de Chile.

KNIGHT, F. (1921): Risk, uncertainty, and profit. New York.

MINVU (MINISTERIO DE VIVIENDA Y URBANISMO) (2008): Propuesta de Modificación del Plan Regulador Metropolitano de Santiago. Santiago de Chile.

MUNICIPALIDAD DE PEÑALOLÉN (2006): Estudio Actualización PLADECO de Peñalolén. Informe Final. Tomo 1: Diagnóstico Global, Diagnóstico Sectorial. Santiago de Chile.

MURRAY, M. (2009): Fire and ice: unnatural disasters and the disposable urban poor in post-apartheit Johannesburg. In: International Journal of Urban and Regional Research 33, 165–192. DOI: 10.1111/j.1468-2427.2009.00835.x

NARANJO, J. and VARELA, J. (1996): Flujos de detritos y barro que afectaron al sector oriente de Santiago el 3 de mayo de 1993. Servicio Nacional de Geología y Minería, Chile. Boletin 47.

O'KEEFE, P.; WESTGATE, K. and WISNER, B. (1976): Taking the naturalness out of natural disasters. In: Nature 260, 566–567. DOI: 10.1038/260566a0

REITER, J. (2009): Vulnerabilität gegenüber Überflutungen in ausgewählten Stadtteilen von Santiago de Chile. Diploma thesis. Berlin.

RICHARDS, J. and JIA, X. (1999): Remote sensing digital image analysis: an introduction. Berlin, Heidelberg.

ROMERO, H.; MOSCOSO, C. and SMITH, P. (2009): Lecciones y conclusiones sobre la falta de sustentabilidad ambiental del crecimiento espacial de las ciudades chilenas. In: HIDALGO, R.; DE MATTOS, C. and ARENAS, F. (eds.): Chile del país urbano al país metropolitano. SERIE GEOlibros 12, Colección EURE-Libros. Santiago, Chile, 89–110.

Weichselgartner, J. (2001): Disaster mitigation: the concept of vulnerability revisited. In: Disaster Prevention and Management 10, 85–94. DOI: 10.1108/09653560110388609

White, G. F. (1945): Human adjustment to floods: a geographical approach to the flood problem in the United States. Chicago.

Wisner, B.; Blaikie, P.; Cannon, T. and Davies, I. (2004): At risk: natural hazards, people's vulnerability, and disaster. London, New York.

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