

Disaster risk construction in the progressive consolidation of informal settlements: Iquique and Puerto Montt (Chile) case studies



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ABSTRACT

The relationship between informality and vulnerability, common in Latin American communities, is analyzed using data from two medium-sized cities in the Chilean urban system as case studies: Iquique, located in the northern desert zone of the country, and Puerto Montt, located in the rainy south. Informal settlements, or '*campamento*' (literally meaning campsites in Chile), within these cities were studied and analyzed. The results revealed that while these originally illegal *campamentos* have gradually been absorbed by urban sprawl and have reached internal consolidation, they continue to maintain their conditions of precariousness and social vulnerability.

The *campamento* settlements are frequently located in areas exposed to natural hazards. They have also been subject to institutional backwardness, or a lack of oversight, with little to no attention being paid to risk reduction. In Iquique, the *campamentos* located in the northern zone of the city are highly exposed to seismic threats and landslides. They are also close to the port and the tax free zone (ZOFRI). In the case of Puerto Montt, the most vulnerable areas of the *campamentos* are the coastline areas to the west and east of the city, which are subject to landslides and flooding.

The *campamento* settlements constitute real vulnerability *hotspots* for their residents, as they are high risk zones within the cities, characterized by high levels of precariousness. In general, they have not been considered in the urban improvement measures, even though they have been part of each city's main urban area for several decades now.

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1. Introduction

Informal urban settlements are particularly vulnerable to natural disasters [1,2]. Consequently, many studies have investigated the relationship between economic growth, poverty, informality, and urban vulnerability issues. However, few studies have addressed the link between informality and vulnerability in Latin America, one of the most urbanized regions of the world. One possible explanation for this is that the explosive growth in the cities and the formation of informal settlements, as a result of the rural-to-urban migrations, seems to be part of the past.

In countries like Chile, changes in urban patterns and processes produced by new demographic dynamics, constant economic growth and public policies, has helped hundreds of thousands of inhabitants leave their informal settlements and move to big social housing projects [3]. This has resulted in an institutional oblivion

regarding these informal settlements that have consolidated within the cities, preserving the unstable and precarious socio-residential conditions and the exposure to natural hazards, resulting in significant risk conditions that should be considered by researchers and decision-makers.

In this article, two Chilean medium-sized cities are analyzed, both of which have experienced significant demographic growth as a result of improvements in their economies. This growth has resulted in the generation and consolidation of informal settlements in disaster risk areas within their boundaries.

2. Urban growth, informal settlements and disaster risks

2.1. The debate between formality and informality in the urban context

Formality and informality have been addressed as opposite, dichotomous and mutually exclusive processes. Formality is strongly associated with the compliance of legal norms and is understood within social and cultural frameworks. Informality is

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the movement away from formality [4]. According to Gonzalez [5], informality is perceived as a consequence of poverty. However, it rarely reflects its relationship with development models, where processes, such as industrialization and neoliberalism, have radically influenced the urbanization process, encouraging movements of the population and changes in settlements that widely exceed the provision of housing and existing infrastructure, services, and markets.

The coexistence of formality and informality in the same territory, as described by Hernandez [6], reflects one of the most ancient paradigms: the existence of two cities within a city. These two cities are the formal and planned city and the informal, non-planned and (sometimes) illegal city. In the 'illegal' city, populations grow in the peripheral territories, without roads, public transport or basic utilities.

Fiori and Brandão [7] indicated that informality is not necessarily a problem, as it can be an opportunity. It is an alternative mode of the production of the urban space, where you can experience models of integrity, inclusion, and diversity. Hence, it is an opportunity to better understand the different ways to perceive and think about the city [8]. Unfortunately, as Romero et al. [9] argued, a different perception prevails, where informality becomes both a source of stigma that removes power to the informal neighborhoods and a systemic determinant characterized by a lack of access to assets and options to adapt and resist to the effects of stressors, such as climate variability, extreme climatic events and natural disasters.

Far from being static processes, formality and informality are dynamic states. As described by McFarlane [10], they are forms of practice that change over time. According to Roy [11], urban informality generates multiple challenges, due to the "unplannable" exceptions to the order of formal urbanization" [11]. Roy argues for the importance of acknowledging this unplannable exception and provides suggestions for how to work with it.

2.2. Urban growth patterns in Latin America

In Latin America, the process of rapid urbanization has been studied by Bähr and Mertins [12], Janoschka [13], and Borsdorf [14], among others. These studies have developed urban growth models that illustrate the presence of rapid growth, not only in large cities, but also in medium-sized and small cities as well. In regard to this, Bähr and Mertins [12] proposed a new structural model of the functional and social differentiation of the city that is expressed in three patterns: circular, sector-based and cellular patterns. Cellular patterns correspond to discontinuous settlements primarily located in the periphery. These cellular patterns are characteristic of rapid unregulated growth and are referred to as informal settlements. Many of these settlements are "regularized" afterwards through a legal formalization process.

In a recent contribution, Abramo [15] postulated the term, "com-fused city", which represents a city experiencing 'compaction' and 'diffusion.' The Latin American cities of today can be considered com-fused cities. The formal and informal real estate markets in these cities leads to the construction of "compact" cities, as a result of the concentration and consolidation processes. It also leads to "diffused" cities, due to the dispersed migrations to areas of the urban periphery.

Besides the great interdependence between the two, there is a tendency, in diffused cities, towards consolidation or "compaction". More specifically, the market not only responds to the demand for plots and construction that comes from the formal and informal sectors, it also guides the definition of the policy that will determine local urban development and land use.

Local governments are seen as being limited in their competence and responsibility. For that reason, they are often alienated

by those who dominate the land market and construction sector. It is within this context that the traditional informal settlements of the 1960s and 1970s are undergoing consolidation within the urban areas, far from the interest and attention of the real estate and public sectors, particularly in the Chilean case.¹

2.3. Informal settlements: establishment, consolidation and definition problems

Mertins [16] defines an irregular or informal settlement as "an area or settlement where development (spatial expansion) and occupancy are not conforming to the legal, urban and environmental standards set by the public authorities". Consequently, Mertins estimated that nearly 70% of the urban areas in Latin America were initiated as informal occupations of land.

In Latin American, there is clear evidence of the existing governance structures' priorities regarding land tenure, the plot and the real estate market, interactions between the State and the private sector, and the role of local politicians in committing to investments in the urban infrastructure in exchange for votes. "In informal quarters, the non-adherence to norms of urban planning and building laws or to labor-legal standards are examples of a common habit to tolerate or ignore certain (informal) processes, which have characterized Latin metropolitan areas for decades" [16].

The link between poverty, informality and urban settings has been developed by authors like Gonzalez et al. [17]. They talk about the so-called 'new poverty', characterized by being more structural, more segmented and more exclusive than before. This significantly reduces the opportunities for social mobility among the urban poor. Far from considering this process as something that is isolated and local, Ziccardi [18] indicated the direct relationship between the imposition of neo-liberal economic policies to developing countries and the acute processes of poverty's urbanization, where the local governments play a critical role in the implementation of the social and inclusion policies within the cities.

While this trajectory, observed in Latin American urban settings, is useful in better understanding the distinction between the formal and the informal, it also leaves some questions open, especially regarding disaster risks. Compliance with legal rules, in and of itself, does not indicate much about living conditions, vulnerabilities, and risks. In fact, as observed in the study area in this investigation, it is the progressive consolidation process of informal settlements, including their formalization, which seems to amplify the existing risks and create new risks, as a result of the socio-political "oblivion" discussed previously.

In a recent contribution, Nuissl and Heinrichs [19] reviewed the progress made in the discussion about what they call "the slum phenomenon", stating that: "(1) *Slums are too complex to be defined by a single parameter*, (2) *Slums are too multifaceted for a slum definition based on a set of criteria that can be universally applied*, (3) *Slums are too changeable for a permanent slum definition*, (4) *Slums frequently have blurred boundaries; their limits, for example, depend on the shape of the administrative units*".

Under the premise of informal settlements, or *slums*, are "relational concepts" [19]. The UN-Habitat proposed: "...any specific place, whether a whole city or a neighborhood, as a slum area if half or more of all households lack [i] improved water, [ii] improved sanitation, [iii] sufficient living area, [iv] durable housing, [v] secure tenure, or combinations thereof. An area or neighborhood deprived of

¹ There are countries where informal settlements do play an important role in urban planning and public policy. One example is Brazil, with its Favela Bairro Program. In Chile, there is a program called "I love my neighborhood", which does not reference the socio- and natural risks and issues.

improved sanitation alone may experience a lesser degree of deprivation than an area that lacks any adequate services at all, but both are considered slums in this definition" [20]; numbering ['i' ... 'v' added by the authors].

In this UN-HABITAT definition of a slum, a concept that is often times used as a synonym for an informal settlement, property rights and secure tenure, among others, are the other criteria considered. This is due to the complexity of conducting vulnerability and risk analyses of the "forgotten settlements" ("forgotten places" [21]), it is important to recognize both aspects: the socio-residential conditions (e.g. access to services, multifamily households, construction quality) and the legal property rights.

The official Chilean definition for informal settlements embraces several of these topics in an integrated manner. The Ministerio de Vivienda y Urbanismo (Ministry of Housing and Urban Planning, MINVU) [22] defines *campamentos*, or settlements, as mainly urban areas, constituted by more than eight families, inhabiting land in an irregular possession, lacking coverage of at least one of the three basic utilities (i.e. electricity, running tap water, or a sewage system), whose housings are grouped and contiguous. This definition is useful and complex. Nevertheless, it does not consider informally consolidated settlements that have become regularized without having changed their fragile socio-residential characteristics in a fundamental way.

2.4. Disaster risks

There has been a significant change in the way that the study of risks has been approached since the 1990s. The evolution of thought regarding risk analysis has evolved from a focus on natural hazards to vulnerability assessments, making implicit the exposure to those hazards, while centering attention on the capacity of societies to respond to the effects of extreme events [23].

This approach, to the issue of risks, has allowed for greater academic influence on the respective policies [24] fostered within the International Decade for the Reduction of the Disasters framework. More emphasis has recently been placed on social vulnerability as a relevant risk component, alongside hazards and exposure, resulting in a change from the objectives geared towards disaster management to ones that favor disaster risk management. As a result, multiple approaches to vulnerability have been developed, going from a complex and robust set of indicators developed by Cutter [25] and Cutter et al. [26], to the Vincent's index of Social Vulnerability [27], or the more recent developments (e.g. the CapHaz-Net project [28]), which confirmed the challenges of achieving a consensus on the influencing factors and assessment methodologies [29, 30].

For the purposes of this study, we will use what we call 'socio-residential' vulnerability, a highly specific application of the concept of vulnerability. This will be particularly useful when the subject of the analysis is focused on housing/settlement quality and is highly dependent on a limited dataset; more detail on this process will be discussed in the method's section of this article.

Socio-residential vulnerability represents the prevalent social condition. It is the essential habitat of human beings. The housing location, design, construction and materials of the buildings influence the susceptibility of the community to experience damages and losses due to extreme events (e.g. earthquakes, flooding, hurricanes), compromising their capacity to respond and recover, as well as generating a long-term impact on their quality of life.

2.5. Growth, informal settlements and urban planning in Chile

In Chile, informal settlements began to appear in the 1950s, when some families coming from rural areas engaged in

spontaneous land occupations. These land occupations became the 'callampas' settlements (shanty towns), alluding to their spontaneous growth. During the 1960s, these settlements were called *tomas de terreno* (land occupations) and followed more structured and organized actions by settlers, with a clear objective of the long-term occupation of the land. Since the 1970s, the so-called *campamentos* have evolved into organized communities, despite the fact that the residents were relocated and the old settlements were destroyed as a result of the radical eradication plans during the military dictatorship.

The 1970s *campamentos* have since reappeared, the communities living there have transformed themselves into complex entities, with interests beyond the sole necessity of housing, as they have become political actors [22]. This tendency occurred within an environment characterized by a significant loss of governance and regulation [31]. Simultaneously, as different actors and forces intervened, trying to lead, according to diverse priorities and governance structures [16], the informal settlements came to be less regulated and more informal; as such, they have technically become illegal.

Abramo [15] stated that during the 1980s, Chile was able to separate itself from the dominant tendency of the growth slums described in Latin America through a housing policy initiated during Augusto Pinochet's dictatorship. This housing policy was used to address the housing deficiency and regulate housing that was in an informal state. The *campamentos*, in particular, were considered loci of resistance to the regime, so a policy was adopted to eradicate many of them. At the same time, a housing policy was designed based on the demand for subsidies. This was a policy that continued on in the subsequent governments after the dictatorship.

New population movements, especially in the intra-urban area, have produced changes in prices and land use, with the resulting process of the "unformalization of the formal" at an urban, as well as an economic, level. On the same note, Abramo [15] cites Alegría (2005), "the urban informality would be a series of irregularities-or regularities-in matters of rights: urban irregularity, constructive irregularity, and irregularity regarding the land rights."

From another perspective, Sabatini [32] states that it is possible to achieve real social development when concrete measures are taken to remove the barriers of spatial segregation and the discrimination of the poorest households. This will allow many people to have access to employment and urban services, as these are the key factors necessary to increase opportunities. A more inclusive city is a more productive city.

Changes in the pattern of urban segregation, where elite districts coexist with low socioeconomic sectors, has been promoted in cities such as Santiago de Chile, a social and economic integration. In terms of formality, the development processes for the Chilean cities are presented in different stages that involve the territory and the sector.

When centering the analysis on the territorial aspects, there are two main tools available for local planning: municipal and inter-municipal plans. Municipal plans are part of the local administration. They are circumscribed to the urban area and are approved by the Consejo Municipal (Municipal Council); they are valid for different time frames. The inter-municipal plans are directed at the central level by the MINVU. They include the peri-urban and rural areas, although they are necessarily negotiated with the local administrations [33].

3. Materials and methods

3.1. Research design and selection of the case studies

This study is a qualitative research (McFarlane [34]). The research is comprised of three domains: practical aspects, methodologies and typologies. This approach has been shown to be useful when working within the context of urban theory [35]. The

investigation will not only describe the social phenomenon, but care will be made in better understanding it, to achieve the goal of tactical learning [36].

The Chilean cities of Iquique, in the north, and Puerto Montt, in the south, represent two different geographical, social and economic environments. They are both booming urban centers, as a result of their closer connections to the global economy [36]. They share important challenges in terms of future planning, especially

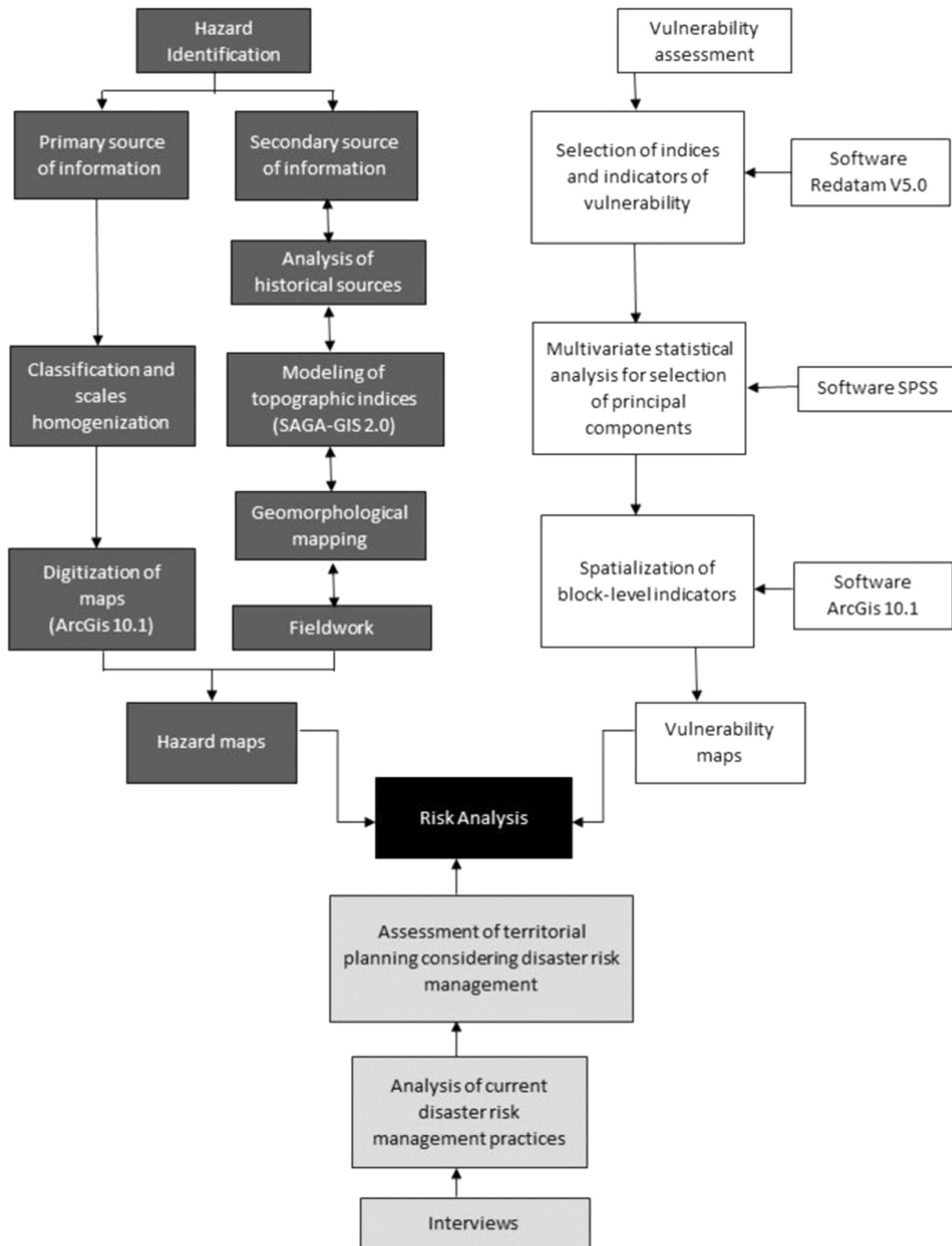


Fig. 1. Research process flowchart—the cities of Iquique and Puerto Montt, Chile.

because of the high exposure to natural hazards (e.g. earthquakes and tsunamis) and vulnerability that puts the sustainability of the attained socio-economic achievements in danger. The imperfect model of risk management and governance in these cities accounts for the dominance that the real estate and construction sectors have over urban planning [37]. That brings up for discussion the growing tendency of the formal and the informal in land use management—trends that, besides being dichotomous, coexist and are redefined mutually and constantly, it is a continue.

In recent years, extensive growth in the housing market has been observed in both cities. This growth has been produced by several economic processes (e.g., fast growth in the mining, fishing, trade and tourism industries). Hence, the morphology of the cities has evolved as structures associated with the models of urban concentration and dispersion. Socially, and for groups with the capacity to pay, a number of options have arisen in the peri-urban areas, frequently outside the limits of formal urban planning, which brings with it several benefits. These benefits include more land for a lower price, attractive surroundings, safety, and the absence of restrictive urban rules. For those who prefer the urban life, they benefit from an opposite trend, which goes from the city's periphery towards the center. This movement has recovered urban centers, creating a market with new attractions, mainly diminished trip times and costs, and easy access to entertainment and services.

On the other social extreme, for populations with less income, for whom there is not always a public sector option, access is represented by the overcrowded and sub-standard housing of poor structural quality and deficient utilities, either in depressed areas downtown or in city suburbs. These places are frequently located in areas of flooding or landslides, which corresponds to the extensive risk, characterized by events of low or medium intensity, but high frequency.

In summary, the consolidation of informal settlements within cities establishes the areas of maximum social fragility faced with special exposure to threats. Their characterization and assessment should be a priority task for risk management programs. Fig. 1 summarizes the research process used in this study.

3.2. Methods

For this study, the initial procedure comprised an extensive literature review on the topics of formality and informality in urban settings at the international levels, within the context of Latin America, particularly Chile. The analysis of institutional formality focuses on territorial aspects, including local planning processes (communal planning) and inter-communal planning.

Twelve unstructured interviews (i.e. six in each of the two cities, Iquique and Puerto Montt) were carried out with the authorities and public officers responsible for local planning. These interviews disclosed to us important information which contributed to the understanding of the context, the relationships between different stakeholders, and the history and construction of the risk in the cities studied. The interviews helped us to identify specific secondary sources of data and particular places where we focused our attention, through systematic field reconnaissance, assessing and geo-referencing the built environment, hazards, exposed elements, and vulnerability factors.

3.2.1. Mapping natural hazards

After an extensive review of the existing hazards and risks, we obtained hazard maps for the cities of Iquique and Puerto Montt. Table 1 describes, in detail, the sources and the methodological process followed for each type of threat.

The data from the two cities exhibited variations in the scales and formats used. Maps drawn from such sources had to be

Table 1
Summary table of the methodological processes by hazard type.

City	Hazards	Sources	Materials	Processes	Results
Iquique	Tsunami	[38]	Tsunami flooding map (tiff)	Scanning, georeferencing, digitization (software ArcGis 10)	Susceptibility map
	Seismic amplification	[40]	Seismic intensity map (tiff)	Scanning, georeferencing, digitization (software ArcGis 10)	Susceptibility map
	Landslides	[45] and results prepared for this study using resources and materials available	Satellite images; Digital Elevation Models; Aerial photographs; Geological map [42]	Geomorphological mapping, fieldwork.	Map of Geomorphological units affected by slopes instability processes
Puerto Montt	Tsunami	[39]	Geohazards map (tiff)	Scanning, georeferencing, digitization (software ArcGis 10)	Susceptibility map
	Landslides	[39,48]	Geohazards map (tiff)	Scanning, georeferencing, digitization (software ArcGis 10)	Susceptibility map
	Historically flooded areas	[65,66]	Maps of Historically flooded areas (tiff)	Scanning, georeferencing, digitization (software ArcGis 10)	Map of Historical floods
	Local flooding by poor drainage	This research	Map of Historical floods; Satellite images; Digital Elevation Models; Aerial photographs; Soil map [69]; Geological map [39]	Geomorphological mapping, fieldwork	Map of local flooding areas

scanned, georeferenced, digitized and homogenized at a scale of 1:20,000 using GIS (geographic information systems). The hydrological and geomorphological hazards that were not covered by the previous studies were identified and plotted using the techniques of geomorphological mapping, fieldwork and historical information. Using GIS (Software ArcGis 10), the urban areas and surfaces representing the natural hazards were intersected, resulting in an estimate of the spatial exposure values per city.

- **Tsunami (Iquique):** The Hydrographic and Oceanographic Service of the Chilean Navy [63] defined the potential flooding areas in the event of a large tsunami using the COMCOT numerical simulation model. This model processes the topographic, bathymetric and urban information of the city, in addition to the highest probable tides. The seismic parameters used for modelling were estimated based on the 1877 earthquake ($M_s=8.5$), for which there are historical records of a destructive tsunami in Iquique.
- **Tsunami (Puerto Montt):** There were no computational models, numerical simulations, or historical records available about the tsunami hazard for the city. However, there was a geo-environmental map of the city of Puerto Montt, in which the areas highly susceptible to tsunami waves were preliminarily defined as under the elevation of 5 m above sea level [39].
- **Ground-motion amplification (Iquique):** Ramirez [40] estimated the seismic amplification for a probable earthquake in the city of Iquique, described by Roldán et al. [41]. To determine the amplification of the seismic movement in different geological units recognized in the city, according to Marquardt et al. [42], we followed the methodological procedures proposed by the National Earthquake Hazards Reduction Program (NEHRP). The NEHRP defines a standardized geological classification according to the site and specifies the factors of amplification for different types of soil. The Murphy et al. [43] approach was used to relate the maximum accelerations with seismic

intensity, magnitude, and distance to the hypocentre, as well as the specific parameters of the geographical site. We then integrated the maximum horizontal acceleration recorded during the Tarapacá (2005) and Tocopilla (2007) earthquakes. Finally, the attenuation formula of Frasar and Saragoni [44] was used to estimate the accelerations and the anticipated seismic intensities, using the magnitude ($M_w=8.2$) and the distance from the hypocentre ($r=112$ Km), as proposed by Roldán et al. [41].

- **Ground-motion amplification (Puerto Montt):** There were no studies of seismic amplification for this city.
- **Landslides (Iquique):** Opazo [45] mapped landslides covering the central area of the large marine escarpment that surrounds the city. In this study, the inventory of rocks that had fallen was integrated (using records of mass media and field reconnaissance). In total, 139 geomorphological units were defined. Each area was assessed using the weighting of the conditioning factors and the analysis of the geotechnical properties of the rocks and soils. Since Opazo's work does not cover all of the marine escarpments, this study identified the rest of the geomorphological unit's land instability processes. We applied geomorphological mapping techniques [46,47], such as the interpretation of air photographs, on a scale of 1:20,000 (provided by the Aerophotogrammetric Service of Chile). We also conducted an analysis of multitemporal Google Earth satellite images (2004 to 2014) and an analysis of the digital elevation models of the terrain (GDEM-ASTER). These techniques were complemented with field reconnaissance, with an emphasis on mapping slope systems. The constituent materials, the terrain features indicative of landslides (active, suspended and latent), and other eroded features of the slopes were described. Lastly, a map of the morphological units prone to mass removal was obtained, complementing the hazard areas described by Opazo.
- **Landslides (Puerto Montt):** The hazard map was developed by Antinao et al. [39], using the intersection in GIS of slope maps,

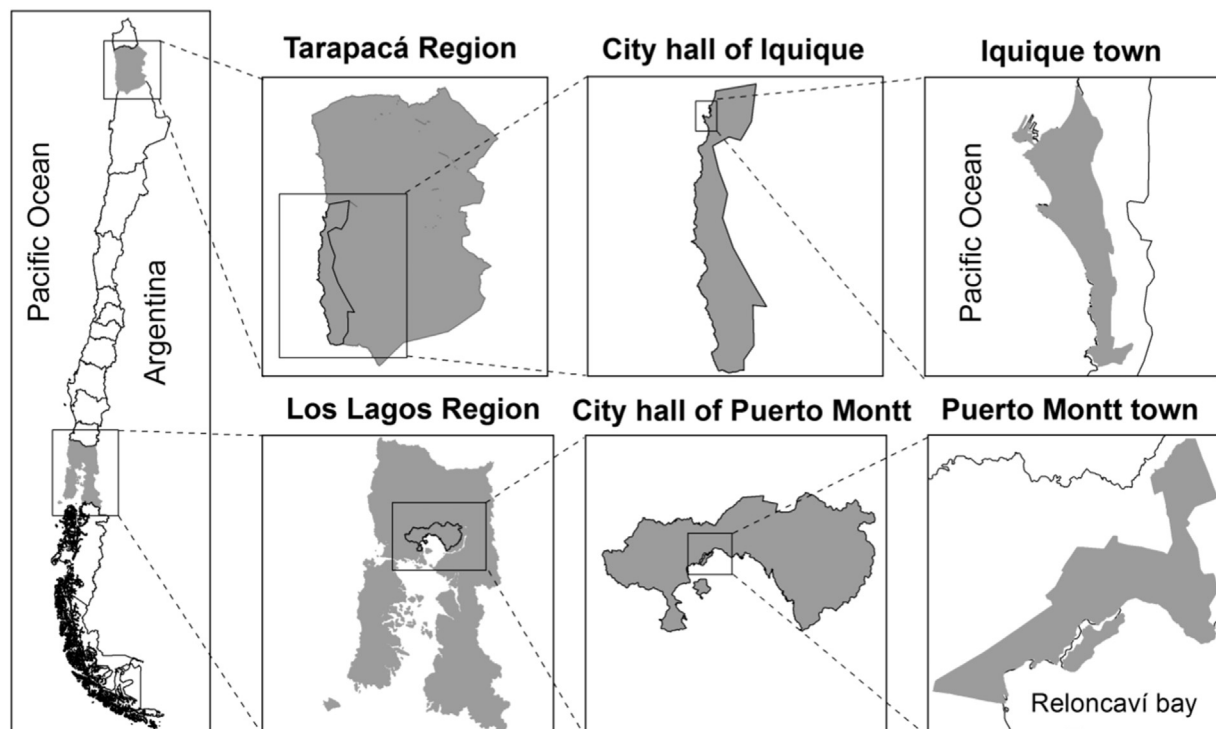


Fig. 2. Areas of the study: cities of Iquique and Puerto Montt, Chile.

Table 2
Characteristics of the *campamentos* in the city of Iquique.

<i>Campamento</i>	Number of families	Number of people	Year of formation	Land surface (m ²)	Land owner	Hazards	Zone division Municipal Regulatory Plan
Centerario	62	146	1980	2774	SERVIU	Earthquakes Mass movements Contamination	Habitable
Esperanza II	80	205	1992	5033	Mixed	Tsunami Earthquakes Mass movements Contamination	Habitable
Laguna Verde	285	755	1996	53,500	Mixed	Earthquakes Mass movements Contamination	Urban sprawl
Población Jorge Inostroza	1003	4031	1965	158,122	Private	Earthquakes Tsunami	Urban area

According to MINVU [12].

geological maps that account for the spatial distribution of the lithologic units, general geotechnical characteristics, and the land records of the historical landslides in the large to medium volume area (movement of material greater than 5,000 m³). At the same time, the inventory of landslides produced by Derch [48] was included, which comprises the land records and reports of newspapers between the years of 1973 and 2004.

- Areas of historical floods (Puerto Montt): Ayala et al. [49] identified the zones of the city with problems of flooding, locating streets, waterlogged intersections and points of the overflow of the natural channels. Other secondary sources were used. These included newspapers, local reports, field recognition carried out during rainy days, and information gathered from neighbors and people directly affected by the floods.
- Local flooding due to poor drainage (soils): for the mapping of these areas, we used historical floods as a reference, as was conducted in Ayala et al. [49], and analyzed the conditioning factors (e.g. topography and soil drainage capacity).

The initial recognition of the most depressed terrain was conducted using topographic indices through SAGA software modeling. We used an ASTER GDEM 30 m. resolution, which was corrected with the hydrological and topographical terrain analysis module, available in the same software.

We used the Topographic Wetness Index (TWI) to calculate the logarithm of the specific ratio of the catchment area and the slope. The result is information about the accumulation of the water, soil saturation and substrate saturation, thus being an indicator of the zones where surface runoff and flooding focusses (e.g. along the main talwegs and endorheic areas) (Soto et al.) [50]. The spatial distribution of the capacity of the soil drainage was obtained in a shapefile format, on the basis of the agrologic studies carried out by CIREN (2003), that determined six types of drainage, from excessive to very poor.

By applying the historical background, the TWI, and the drainage classes, a detailed morphological map was generated [51,52], with the objective of mapping the zones that were more prone to flooding. For this, we used a photo-aerial interpretation at the scale of 1:20,000 (provided by the Aerophotogrammetric service of Chile). We also used multitemporal satellite imagery (Google Earth 2003–2014). An analysis was performed where the textural features and reflectances were observed (e.g. wandering wetlands, aquatic vegetation, soil patterns, drainage patterns).

The units of the terrain were delineated through the mapping of the escarpments, based on a Digital Elevation Model (DEM) of 2 m in resolution, built on the basis of 3–5 m of equidistant level curves. Finally, using GIS, we intersected the soils where the drainage classes were imperfect, poor and very poor, with the different morphological units that were prone to flooding (e.g. depressions in terraces glacio-pluviales, flood plains).

3.2.2. Socio-residential vulnerability analysis

With regard to the vulnerability analysis, a multivariate analysis was conducted to identify the latent dimensions of the social vulnerability of both cities. Nine variables were extracted from the “2002 National Census of Population and VI of Housing” and spatially expressed at the block level: *Precarious Housing* (“rancho” and “mediagua” [substandard housings]); *Housing Occupation Type* (informal character settlement); and *No Access to Utilities* (e.g. water, electricity, sewage, and hygienic services). We then considered the variables related to the housing materials: *Precarious Roofing* (cardboard covered in tar, straw, and waste), *Precarious Walls* (adobe and waste), and *Precarious Floors* (cement aprons and soil).

The data was extracted from the 2011 Census for the studied areas. It is interesting to indicate that in recent decades, the MINVU has undertaken four cadastral surveys where data about informal settlements was gathered: (1) Cadastral survey of housing marginality 1984, (2) Cadastral survey of precarious settlements 1996; (3) Cadastral survey of *campamentos* 2007; and (4) Cadastral survey 2011: Social map of *campamentos* [22].

The levels of socio-residential vulnerability were established through a factor analysis. A cluster analysis² was applied to these factors, using the Ward method. The conglomerates of the homogeneous areas were typified as high, medium and low vulnerability [53].

The discrimination values between the groups are as follows:

- (1) High vulnerability, clustering with a load > 0.75.
- (2) Medium vulnerability, clustering with a load of –0.75 to 0.75.
- (3) Low vulnerability, clustering with a load < –0.75.

Afterwards, a descriptive analysis was conducted on the findings, according to the development patterns discussed in Bähr and Mertins [54] and the growth dynamics suggested by Abramo [55].

Finally, the resulting risk conditions were analyzed, placing emphasis on the zones that include informal settlements. To assess these settlements, criteria from the Chilean’s MINVU were used. This criteria defines the *campamentos* as preferably urban settlements, where more than eight families live in an irregular land possession, with lack of coverage of at least one of the three utilities (i.e. electricity, drinking water, and sewage system), and whose housings are grouped and contiguous [22].

For this study, the medium-sized cities of Iquique, located at the II Region of Tarapacá, and Puerto Montt, located at the X Region of Los Lagos, were selected (Fig. 2).

² Cluster analysis classifies spatial units into homogeneous groups to maximize the differences between the clusters.

Table 3
Characteristics of the campamentos in the city of Puerto Montt.

Campamento	Number of families	Number of people	Year of formation	Land surface (m ²)	Land owner	Hazards	Zone division Municipal Regulatory Plan
Estero Lobos Norte	132	400	W/I	24,887	SERVU	Earthquakes Mass movements	Restriction to pending issues
Estero Lobos Sur	41	129	1973	13,457	SERVU	Earthquakes Mass movements	Habitable
Ladera Angelimó	71	213	W/I	28,440	Private	Earthquakes Mass movements	Restriction to pending issues
Ladera Linzt	60	209	W/I	54,800	Private	Earthquakes Mass movements	Restriction due to pending issues
Ladera Mac-Iver	58	188	1980	15,337	Private	Earthquakes movements	Restriction due to pending issues
Las Camélias	319	1078	2000	57,382	Mixed	Earthquakes	Sanitary infrastructure Restriction due to pending issues
Villa Olímpica	23	68	1995	3531	Private	Earthquakes Mass movements	Residential Subcenter Restriction due to pending issues
Población Modelo	1323	4617	1921	315,590	Private	Earthquakes Mass movements	Urban area

According to MINVU [12]. W/I: Without information.

4. Results

4.1. Rapid urban growth in Iquique and Puerto Montt over the last two decades

Both cities illustrated moderate growth until the 1970s. From that moment on, they went on to become strengthened as a result of the expansion of the local and regional economies. A recent study showed that Iquique and Puerto Montt were among the cities with the highest growth figures projected for the next 20 years in the country [56].

4.1.1. Iquique case study

Iquique, a former support city for nitrate mining, was defined by scarce land demand and very low urbanization levels until the 1970s [57]. With the tax free zone established (ZOFRI) in 1975, and growing foreign investments in the mining sector, the city experienced an economic and demographic increase that made it one of the cities in Chile with the highest growth rates during the 1990s. Today, the city has a diversified economic base where tourism, trade, mining, industry and the real estate sector play important roles.

The strong population growth, in both cities, can be observed as a result of these new economic dynamics, as well as the endogenous growth and immigration from the neighboring countries, primarily Perú and Bolivia. In 1972, Iquique grew from 64,477 inhabitants to 179,000 in 2012 [58]. This represents close to 2.7% annual population growth over the last 40 years. In terms of the spatial characteristics, the city physically grew at a rate of 227 hectares per year between 2002 and 2012, according to the 2007 Plan Regulador Comunal (PRC) [Communal Regulatory Plan]. The urban sprawl occurred in south, where the medium and middle-high income groups are concentrated. The middle-low and low income groups are located in the downtown areas, such as Alto Hospicio [59].

The Alto Hospicio community is located on the upper coastal cliff, far from Iquique. This area used to be the crossing point between the nitrate mines and Iquique. However, it has now become an informal settlement that grew dramatically during the 1980s through a series of land occupations and housing construction projects. This uncontrolled growth forced the national government to invest in infrastructure and housing, leading to its formalization in 2004, when the settlement was declared a commune. The Alto Hospicio commune is estimated to have about 100 thousand inhabitants today.

As in many Chilean cities, the first neighborhoods arising from land occupations and self-construction, like the San Carlos settlement, Norte Hospital neighborhood, and Caupolicán settlement towards the South [60], appeared during the 1950s. This was the strategy of the poor to migrate from the neighboring areas into the city, searching for opportunities. In Iquique, this coincided with the definitive end of 'the saltpeter era', or nitrate mining exploitation, and the closing of the last mines, as well as the increase in fishing that the city experienced at that time.

Historically, the city grew by means of informal settlements (land occupations) and real estate projects for the middle and high income groups, all with very little planning and regulation (Podestá [57]). Instead of proactive planning, there has been reactive urban development, which follows a pattern of legalization after the informal or unregulated urbanization is experienced [60].

For a long time, the only instrument in force for Iquique's planning was the 1981 Plan Regulador Comunal PRC (the Commune Regulatory Plan). This plan was updated and modified in 1989 (sectional South), 1995 (coastline), and 2007 (Tres Islas and Playa Blanca sectionals).

In the last few years, one of the local authorities' main priority

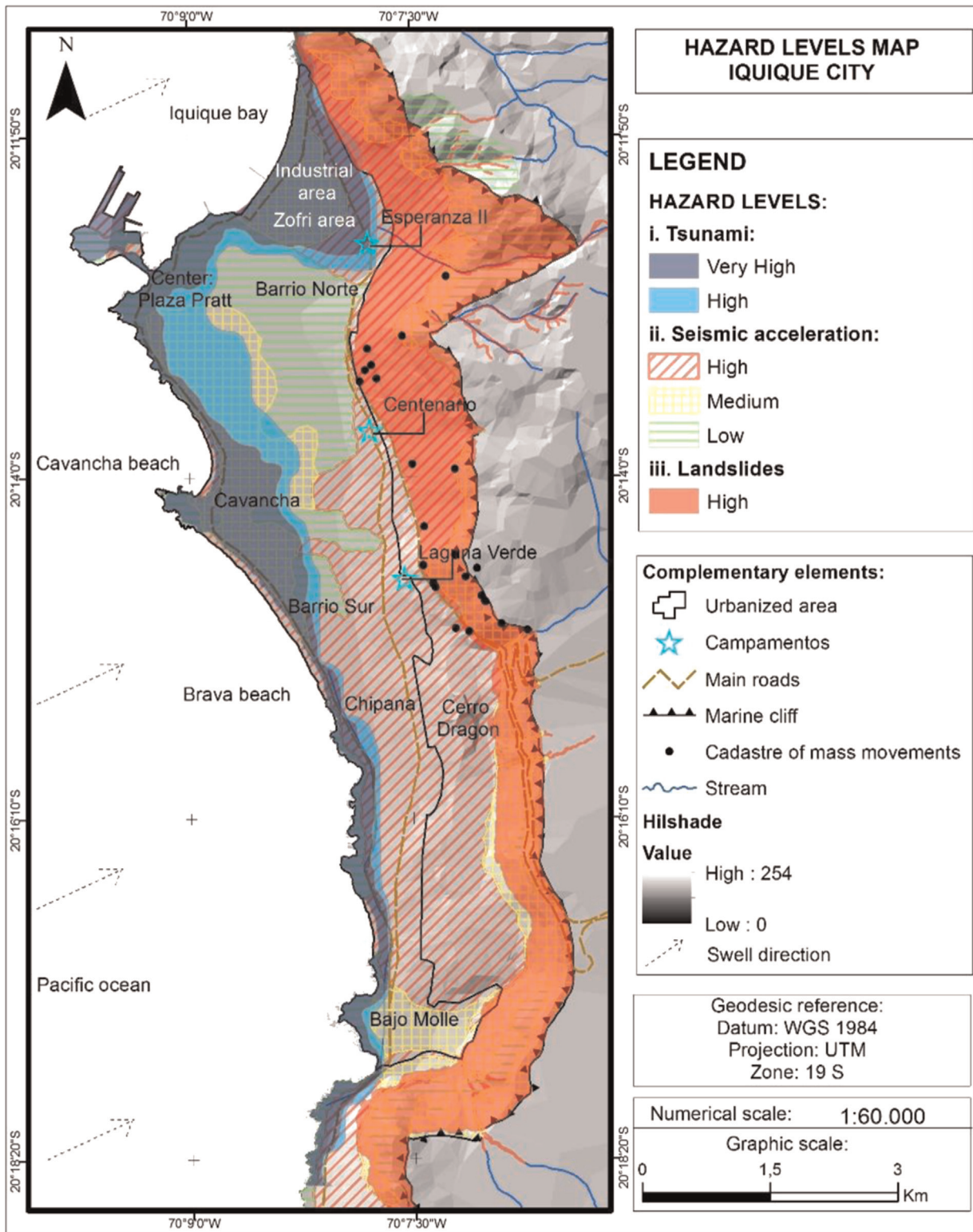


Fig. 3. Natural hazards for the city of Iquique.

has been to legalize the dynamic growth towards the southern area of the municipality, which has residential and industrial functions. As such, the current surface area of the city will double in size. At the same time, a second port and a new industrial zone in the northern area of the city are being planned as part of the implementation of the Southern Cone bi-oceanic corridor.

4.1.2. Puerto Montt case study

Similar to the case in Iquique, but in the south of the country, the city of Puerto Montt has experienced continuous demographic and economic growth since the 1950s. This growth has been associated with economic activities (e.g. traditional fishing, agriculture, and livestock). In the 1990s, these growth processes were

invigorated with the rise of the fishing industry, tourism, and transportation [60]. Since then, Puerto Montt, with its 228,118 inhabitants, according to the INE [62], has been transformed into one of the most dynamic and fastest growing cities in the country. Its population grew from 62,726 inhabitants in 1972 to 192,473 in 2012 [56], a population increment of 3% annually over the last 40 years.

In socio-spatial terms, Puerto Montt's economic development

“triggered a series of phenomena: people and companies made pressure over space in the city, with new expectations and business models that generated urban processes, which the regulatory instruments of the city had not taken into account in their formulation. Due to this, they were incapable to solve in a suitable manner the conflicts of localization, capacities, and uses that the development tendencies promoted within the metropolis” [61]. Nearby cities and conurbations, such as the Los Lagos region, are exerting an

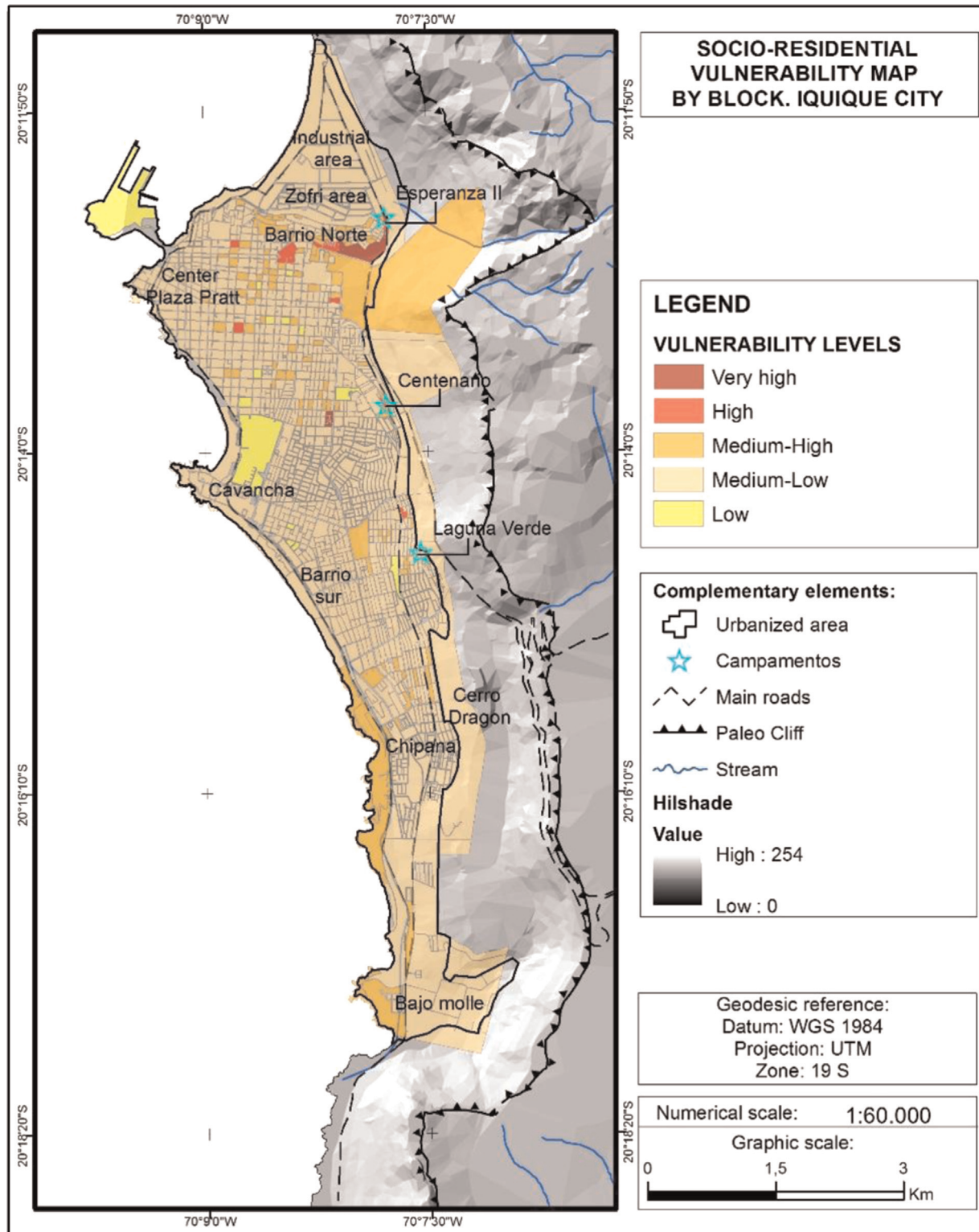


Fig. 4. Socio-residential vulnerability for the city of Iquique.

urbanizing influence on Puerto Montt, which has contributed to higher population growth rates.

Another growth vector is the northeast of downtown Puerto Montt, around the international airport. A third area that illustrates high rates of growth as the result of public policy is the locality of Alerce. Unlike Alto Hospicio, Alerce is managed as a delegation that is dependent on the Puerto Montt commune. It has shifted from a formal process of planning to an informal one with

less structure, as the pressures of massive migration, housing growth, and the formation of neighborhoods at the peri-urban area and within the urban boundaries, have all led to an insufficient infrastructure and the inability of the road network to maintain suitable connectivity.

As a result of the old and more recent development patterns, nearly 10% of Puerto Montt’s population, primarily the informal settlements within the city, are not connected to drinking water

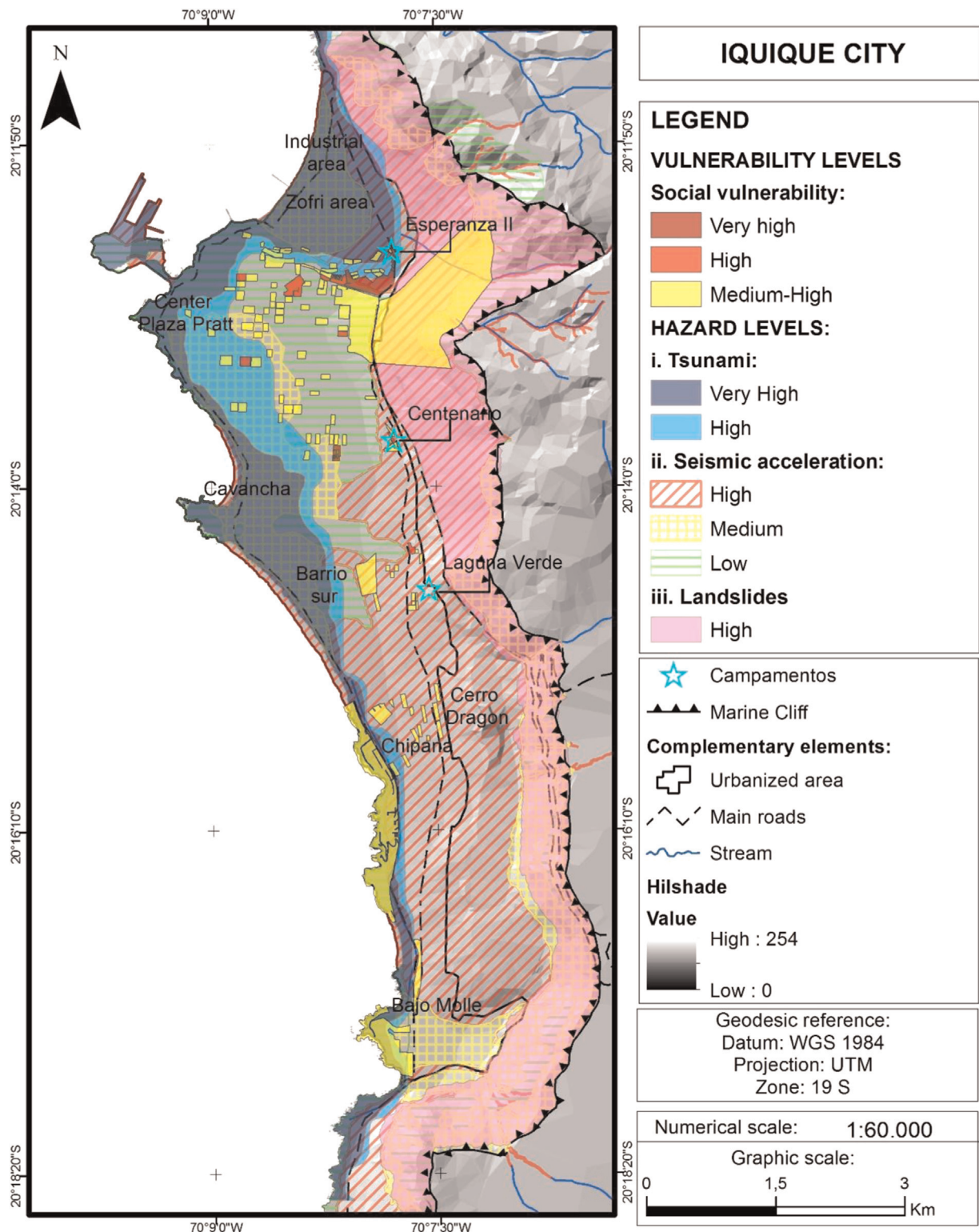


Fig. 5. Risks map for the city of Iquique.

and sewage systems [61]. Similar to the case of Iquique, Puerto Montt shows a lack of planning and legalization in its growth. “The modifications and sectional drawings, made by the public sector and the private have given the biggest number of new areas. These are organized without an apparent order, more as the result of tendencies and specific localizations, producing a constellation of different areas. This is a consequence of the addition of resulting areas to particular interests (Puerto Montt Municipality, 2008c)” [61].

In 2009, a new PRC was issued that seeks to arrange the territory based on a vision of decentralizing growth. Consequently, the “Plan Centro” (Center Plan) is currently being prepared. It seeks to renew and improve the urbanization of this area of the city.

4.2. Informal settlements in the cities of Iquique and Puerto Montt

In the Tarapacá Region, there are six *campamentos* that house 1156 families. 45% of these informal settlements are on state lands that belong to the Ministerio de Bienes Nacionales (Ministry of

National Properties). Approximately 1200 people represent 40% of the family groups concentrated in the regional capital of Iquique.

In the city of Puerto Montt, 53% of the *campamentos* are located on state lands that belong to the Servicio de Vivienda y Urbanización (Service of Housing and Urbanization) and to the township, where there are 780 families that represent a total of 2497 people [22].

The characteristics of the *campamentos* located in the cities of Iquique and Puerto Montt are illustrated in Tables 2 and 3.

4.3. Hazard analysis

The following are the typologies for the identified and mapped hazards:

Areas liable to be flooded by a tsunami: Fig. 3a illustrates the tsunami risk areas in Iquique that correspond to the numerical modeling for the 1877 event [63, 64]. The city of Puerto Montt (Fig. 5a) does not have numerical simulation models for a tsunami. However, the potential tsunami risk areas are located under the

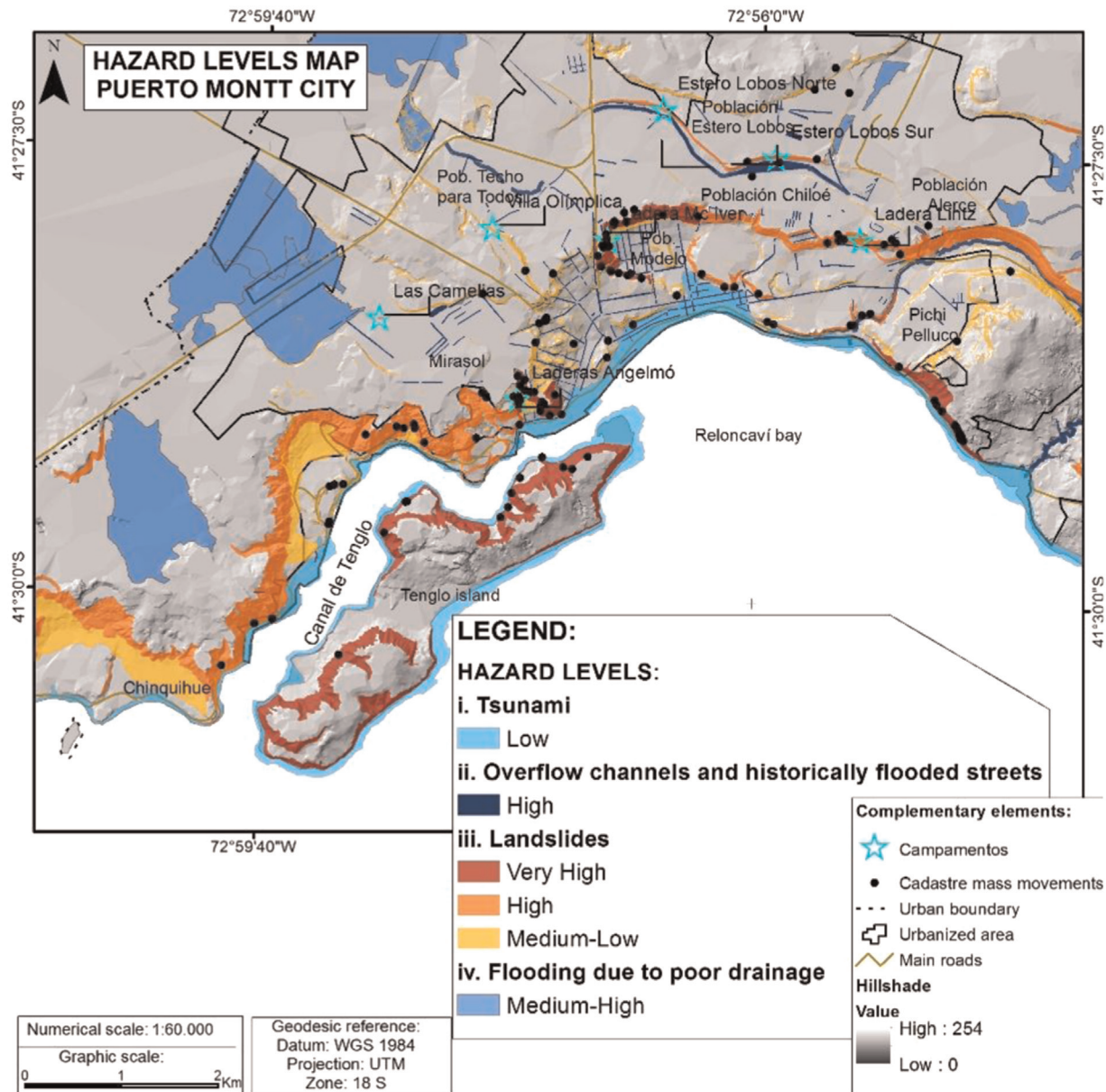


Fig. 6. Natural hazards for the city of Puerto Montt.

height of 5 m above sea level [39].

According to the recommendations of the U.S. *International Tsunami Information Center* (ITIC) and experiences from the events in Chile in 2010 and Japan in 2011, as a national policy, the safety zone for the coastal areas exposed to tsunami hazards should be considered at a height over 30 m above sea level [63].

Areas of flooding due to riverbed overflow: The city of Iquique is not subjected to riverbed overflow of a natural origin, while for the city of Puerto Montt (Fig. 6), this threat is relevant, and hence, was mapped by an analysis of historic records [65], compilations and the digitization of secondary information [39,66], as well as onsite mapping by establishing a restriction strip of 10m around the axis of the dangerous riverbeds [67].

Areas of landslides: The hillsides that are part of the rocky slope of the cliff were established as risk areas, that are unstable because of abrupt gradients (slopes higher than 50°), and where the rock is fractured and directly exposed. These hillsides experienced rock fall during the 8.1 Mw earthquake in April of 2014 [45]. In the case of the city of Puerto Montt (Figs. 7 and 8), landslide hazards are

highly relevant, due to their recurrence, magnitude and spatial scope, as is supported by the studies of Derch [48], Mella and Duhart [68], and the Geoenvironmental Map Synthesis of Puerto Montt Area and its urban surroundings [39].

Areas subject to local flooding due to poor drainage soils: These are spatially significant as observed in the city of Puerto Montt. The information provided by the Agrological Study of the Tenth Region (2003) and the soil coverage in the format *shapefile* of CIREN [69] was considered.

Areas with seismic amplification: The record for the city of Iquique was completed using the study by Ramírez [40]. Areas with great seismic acceleration can be observed in Figs. 9 and 10. It was not possible to include the record for Puerto Montt, since this city does not currently have seismic amplification studies.

4.4. Socio-residential vulnerability

The quality of the housing that embraces the population's life is very important, since inferior conditions do not allow for

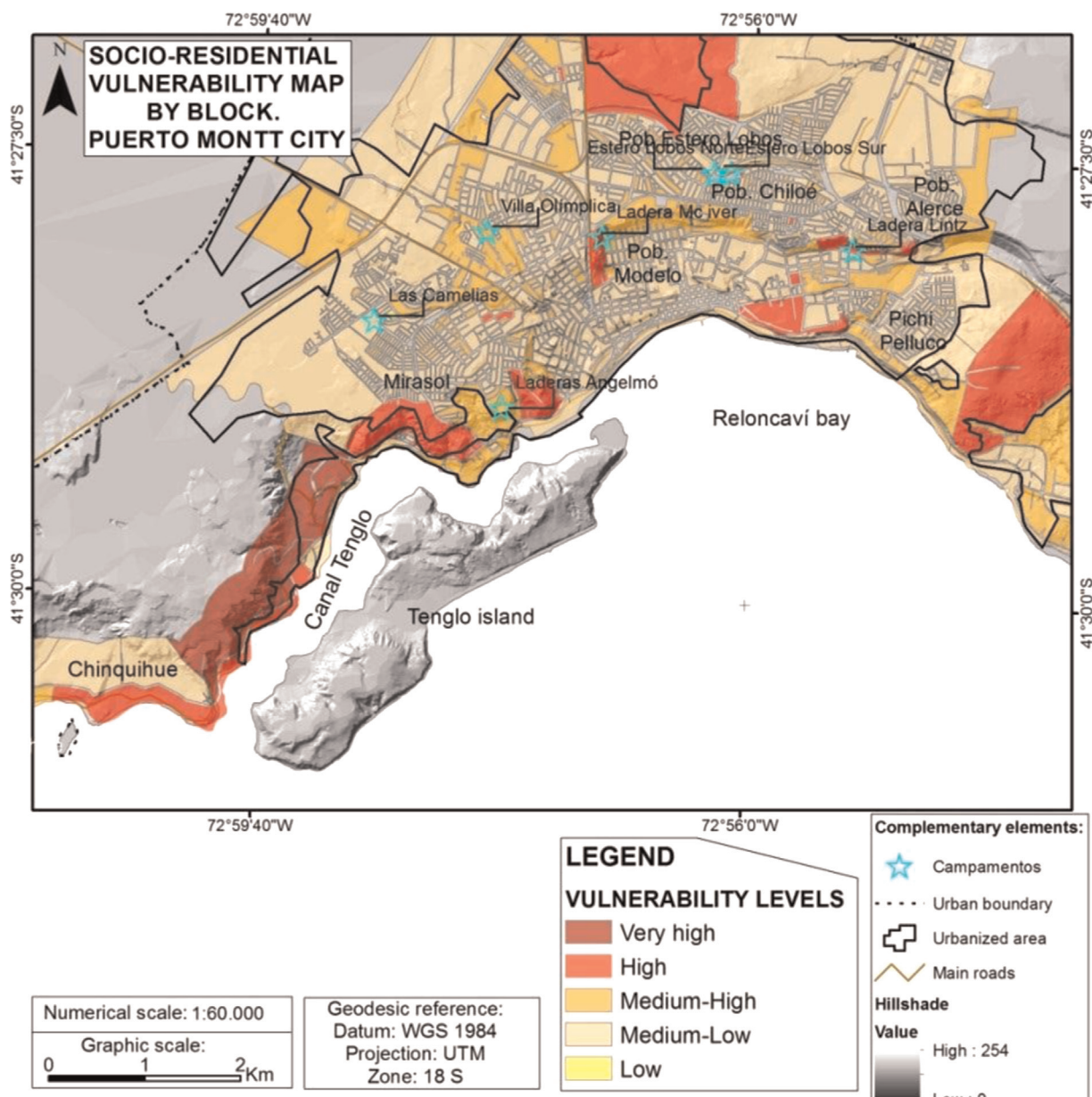


Fig. 7. Socio-residential vulnerability for the city of Puerto Montt.

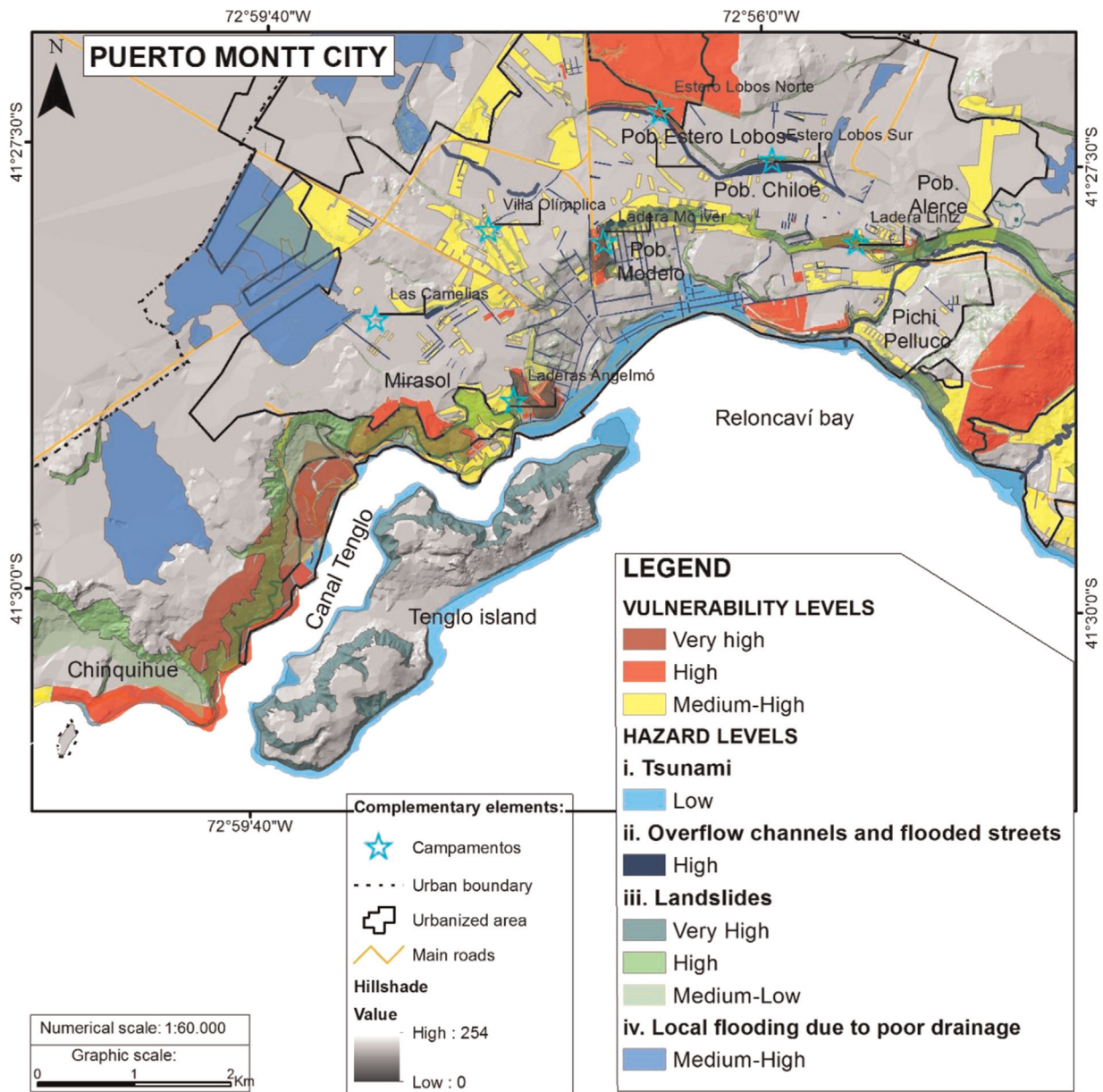


Fig. 8. Risks: city of Puerto Montt.

satisfactory development of daily life. We should highlight that this daily fragility associated with hazard exposure, exacerbates the condition of disaster risk. The substandard housing (scarcity), where inhabitants do not have worthy environmental conditions available in their immediate daily surroundings, would be the biggest socio-residential vulnerability. For this reason, a multivariate analysis was conducted to identify the latent dimensions of social vulnerability for both of the cities. The selected variables are related to the "shortage" or "scarcity" of the housing to cover the basic needs of the population for its normal development, but particularly to face extreme events. Comparing the areas of medium-high socio-residential vulnerability with other areas of the city with similar exposure to hazards, but lower vulnerability, one could see that the latter have lower levels of risk due to lesser social fragility, better interactions with the environment, and greater inclusion within the urban environment.

Based on the results obtained from the analysis of nine selected variables in Iquique, as described in the methodology, it can be clearly confirmed that there is a predominance of the medium-low

values of vulnerability, with the exception of the north, where there is an area typified as high social vulnerability, because of the precarious housing concentration in a few blocks around the tax free area (ZOFRI) (Fig. 4). Next to ZOFRI, there is an area of housing with medium-high values that includes part of the Esperanza II area. These precarious housing areas in the north of the city area are correlated, from the point of view of natural hazards, to sectors of important seismic acceleration and potential landslides, exposing the resident population to high levels of risk.

Fig. 5 shows the risk division, per zone, in the city of Iquique, as well as in the *campamentos*, taking into consideration the existing natural hazards of the city and the areas with the different levels of the socio-residential vulnerability present (Figs. 11, 13). It can be observed that the highest risk conditions are present in the northern area of the city, where the port is located, and in the ZOFRI and one of the *campamentos* with a higher social fragility, corresponding to Esperanza II.

Unlike the rest of the city, in the northern area, different hazards converge. Here, the area with possible flooding by tsunami is

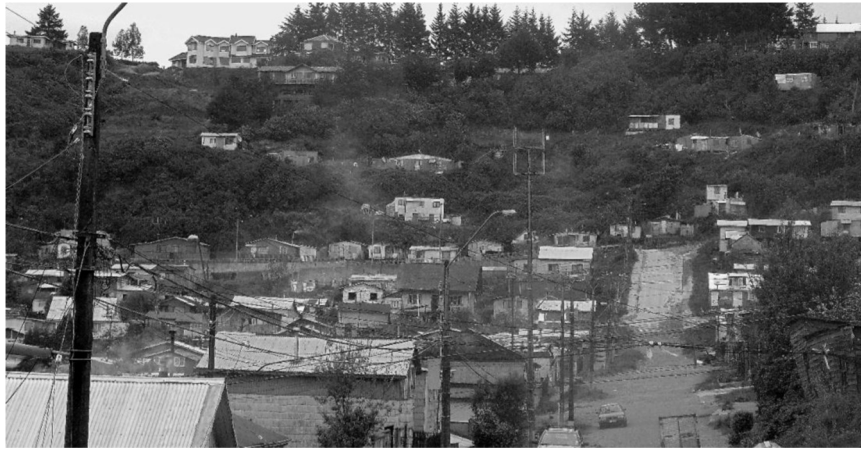


Fig. 9. Puerto Montt: Northern section of *Población Modelo* and *Campamento Ladera Mac-Iver*, located on very unstable slopes, where the 1960 earthquake caused two big landslides [39]. Currently, there is a man-made factor or intervention on the slopes, with illegally built houses in an area recommended as a restricted area for human activities. The housing at *Población Modelo* (which evolved from a *campamento*) can be observed in the lower area of the picture, where the streets experience a high frequency of flooding during intense rainfall events. Photo: Authors' personal collection, 2014.



Fig. 10. Puerto Montt: Panoramic view of *Campamento Ladera Lintz*, located on unstable scarps with high angle gradients. According to Derch [48], the *campamento* is located in an area that has had at least 8 landslides. Currently, it is recommended that the construction of housing near the scarps be forbidden [39]. Arrows indicate the informal settlements' localization. Photo: Authors' personal collection, 2014.

highlighted, and the high seismic acceleration of the land and the landslides are less relevant. The city sprawl is projected towards the south, with lower risk of flooding by a tsunami, but in a zone with a higher risk of seismic acceleration. All *campamentos* are located in areas with high seismic acceleration (Fig. 12).

In Puerto Montt, the patterns of socio-residential vulnerability are clearly seen in the eastern and western coastline area of the city, with a high number of substandard units being located in the area between Angelmó y Chiquihue, a territory subject to landslides. In the eastern side, in Pelluco, there is a pattern of scarcity of medium and high values, but from the point of view of natural hazards, it is a safer area, even though there are some localized landslide zones (Fig. 7).

Fig. 8 illustrates the risk areas for the city of Puerto Montt, where the hydro-meteorological hazards are more important than earthquake or tsunami hazards. In general, all the *campamentos* are located in areas with a medium-high risk of landslides and high probability of flooding, the latter being a relevant issue for the populations of Estero Lobos Norte and Sur and the Chiloé settlement.

5. Discussion

The growth and transformation of Iquique and Puerto Montt has been fueled by an increment in their local economies that has resulted in a factor that attracts people to the territory, also known as a “pull” factor, transforming the urban dynamics generated by national and foreign migrants. In Iquique, population growth has

been fueled by the endogenous migration, in addition to the international migration from Perú and Bolivia, while in Puerto Montt, population growth has been stimulated more by intraregional migration. The impact derived from this demographic growth process can be seen in the increase in prices and land uses, together with the already described process of the “formalization of the informal” (i.e. the consolidation of illegal *campamentos* within the urban boundary, which have been legalized despite their irregularities, urban and constructive scarcities).

Among the different proportions of the patterns of land use suggested by Bähr and Mertins [54] regarding the model of functional and socio-spatial structure in Latin American cities, they describe the informal settlements (legal or semi-illegal) in different levels of consolidation. A topic for future research is the possible existence of risk or vulnerability hotspots in areas where high income populations live, but that may be in denial about the risks therein.

On the other hand, both cities expose the coexistence of the processes of consolidation/compaction and dispersion/diffusion, making evident the limitations of local governments to regulate the land market, which is strongly influenced by real estate developers [37].

In Iquique, residents at the *campamentos* represent 0.6% of the total city population, while in Puerto Montt, they represent 1%. Apart from the fact that these numbers could be subject to under-registration, they are definitely below the usually observed numbers of informal settlement residents in most of the secondary cities in Latin American and the Caribbean countries. Nevertheless, the risk for the people who live there underscores the importance



Fig. 11. Iquique: View of the *Población Jorge Inostroza*, located in a flooding risk area by tsunami, and on soil composed of aeolian deposits associated with a poor site response to seismic events—liquefaction susceptibility (Fig. 3). This sector corresponds to an area of high social vulnerability (Fig. 4) and it is characterized by a high density of dwellings built with precarious materials and a population in an overcrowding condition. Although this population had its origin as a *campamento*, today it is fully integrated into the city, forming the "Barrio Norte" of the communal regulatory plan. Photo: Google Street View, 2015.



Fig. 12. Iquique: View towards the interior of *Campamento Laguna Verde*, located in an area that is not exposed to flooding by tsunami, but is located on the sandy mantles associated with soils with poor resistance, next to the northern side of the El Dragón dune. The dwellings have been built with precarious materials in an area with high construction density. Photo: Google Street View, 2014.



Fig. 13. Iquique. Southern sector of the Cavancha neighborhood. This is a luxury residential area linked to tourism, located a few meters off the coastline within the tsunami risk zone (Fig. 3), with flood heights ranging between 4 and 6 m [63]. It represents the case of an urban area with low socio-residential vulnerability (Fig. 4), but with high exposure to the tsunami impact. Photo: Google Street View, 2015.

of these informal settlements. In the case of Iquique, our study showed that 100% of the population that inhabits the informal settlements is exposed, to at least one or more of the following threats: flooding, landslides, and seismic acceleration. In Puerto Montt, more than 48% of the population in the informal settlements is exposed to landslides, while 8.5% is exposed to flooding.

With regard to seismic risk for the city of Iquique, important

seismic acceleration areas are observed in the densely populated sectors. These values constantly increase due to the important and permanent urban sprawl that usually favors the occupation of attractive landscapes by high and middle income populations, while people with fewer resources are located in areas where the land has less value, and in many cases, is more risk-prone.

These numbers are consistent with the official records that

illustrate that 70% of the families (19,198 families) that live in the *campamentos* in the country reside in risk-prone areas associated with floods or land movement [22].

Even though our attention has focused on the fragility and exposure to hazards of informal settlements, it is important to acknowledge that, according to the urban exposure estimated in this study, the areas of existing formal urban development exposed to tsunamis in Iquique and Puerto Montt, are 46% and 3.2%, respectively.

We want to acknowledge an important limitation of this study. This limitation is the focus on the effect of the socio-ecological dynamics on the vulnerability, exposure, and disaster risk of informal urban settlements. This topic has historically been understudied in the international development, disaster risk reduction, and urban planning literature. This investigation did not intend to seek or deepen the causal relationships, the root causes of the relationship between poverty and disasters, nor the informality observed in the formality in the two cities, pushed by the construction and real estate industries, reshaping the local and regional development.

6. Conclusions

The expansion of local and regional economies encourages intense processes of endogenous and exogenous migration. These movements produce deep transformations in the urban centers, frequently exceeding the regulatory capacities of the involved governments.

This study illustrates the need to continue the development of a model that allows for an explanation of the different facets of formality and informality within the context of urban development. It is essential to better understand formality and informality as dynamic processes that interact, coexist and are permanently renewed.

The strong association between informal settlements with high hazard exposure, and the consequent high level of disaster risk level, motivates future research on causal relationships between informality, vulnerability and disaster risk within different cultural and geographic contexts and an in-depth study of risk governance in informal contexts to better understand the aspects of risk perception and risk behavior. The specific case of tsunami risk deserves an equally thorough investigation that includes the processes of formal and informal occupations exposed to this hazard.

Although the informal settlements have been absorbed and consolidated in both cities for several decades now, they still illustrate high levels of scarcity. Mitigating hazard exposures and reducing vulnerabilities in these informal settlements would dramatically reduce their disaster risk levels. The underlying problem is what we call “vulnerability due to neglect,” which is the outcome of the institutional disregard of, or “obliviousness” to, community risks and ways to address them. The problem is compounded by the fact that this institutional obliviousness is not confined to a single institution, but rather encompasses all governmental, non-governmental, civil society, and private sector organizations.

These results confirm the importance of the comparative studies in urban areas described by McFarlane and Robinson [70], as well as the need to move forward with new methodologies and approaches.

The knowledge of the patterns of urban growth that are inside this formality/informality interaction must be integrated with the secondary and small cities’ development planning processes in the countries of the region. In particular, comprehensive disaster risk management should include a prospective approach (avoiding risk construction), a corrective approach (dealing with existing risk),

and a compensatory approach (risk transfer and strengthening resilience) [71], as a contribution to the sustainability of the expected development achievements. In addition, there is the need to adapt the emergency and civil protection plans to the specific vulnerability characteristics described in this paper.

7. Epilogue

On Wednesday, April 22, 2015, the Calbuco volcano erupted in southern Chile (located at the border between the municipalities of Puerto Varas and Puerto Montt) for the first time in more than four decades, after just two hours of intense micro-seismic activity. According to SERNAGEOMIN, Calbuco was ranked third in dangerousness of the 90 active volcanoes in Chile [72]. There are four urban centers in the surrounding area of the Calbuco volcano: Ensenada, Alerce, Colonia Río Sur, and Correntoso. There is also an international road between Puerto Varas (Chile) and San Carlos de Bariloche (Argentina).

The National Emergency Office (ONEMI) ordered an immediate preventive evacuation of the population living within a radius of 20 km from the volcano, due to the presence of an extensive pyroclastic column and ash that reached the surrounding villages and the city of Bariloche (Argentina). The most affected areas included the cities of Alerce, Puerto Varas and Puerto Montt.

This event shows the need to include the volcanic eruption hazard in future studies to better determine the possible risk scenarios for the city of Puerto Montt. Even though ashfall was the main issue experienced in the current emergency, the proximity to the Calbuco volcano and the wind factor leave this town in a serious health risk for the pollution generated. Moreover, the expansion of the city to the northeast of Alerce (on the slopes of the volcano) and the high density of poor people in this area could result in the higher exposure of vulnerable communities to lahar flows in the coming years.

Contributors

All the authors devised the study design, reviewed the scientific literature, and participated in the field work. CPC, ML and JPS wrote the summary; introduction; urban growth, informal settlements and socio-natural risks pieces; material and methods sections; and parts of the results, discussion, and conclusion sections. JO contributed with the social geography analysis; ML provided the risk governance perspective; JPS contributed with the disaster risk and informal urban development viewpoint; and CPC and II did the geomorphology analysis and the disaster risk assessment. All authors approved the final draft of the report.

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Conflicts of interest

We declare that we have no conflicts of interest.

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