Universidad de Concepción
Dirección de Postgrado
Facultad de Ingeniería – Programa de Magister en Ciencias de la Ingeniería con Mención en Ingeniería Civil

PREPAREDNESS AGAINST FLOODS IN NEARLY PRISTINE SOCIO-HYDROLOGICAL SYSTEMS

(PREPARACIÓN ANTE INUNDACIONES EN SISTEMAS SOCIO-HIDROLÓGICOS CASI PRÍSTINOS)

POR

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Tesis presentada a la Facultad de Ingeniería Civil de la Universidad de Concepción para optar al grado académico de Magíster en Ciencias de la Ingeniería con mención en Ingeniera Civil

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enero 2021
Concepción, Chile

DEDICATION

Dadicated to participants from Arauco, Carampangue and Ramadillas, for their kindness and willingness to cooperate in the research.

ACKNOWLEDGEMENTS

Presented results are part of the project PREGA (Programa de Estudios Ecosistémicos del Golfo de Arauco) “Hidro-geomorfología del tramo inferior del río Carampangue) Nr. 4503152513.

I thank the Universidad de Concepción for the scholarship granted to the master’s degree.

Special thanks to Oscar Link and Juan Antonio Carrasco for the support during the last two years.

Finally, René Iribarren and Esteban Flores are greatly acknowledged for his engagement and support during the field campaigns.

ABSTRACT

The relations between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrological system were investigated, applying hydrological-hydraulic analysis of flood risk in combination with results from a survey, social cartography, semi-structured non-participant observation, and semi-structured interviews.

Results show that preparedness in nearly pristine systems is noticeable different to those reported for altered systems. People adopted innovative, simple, but efficient measures against floods, conditioned by (1) damage suffered during past floods, (2) perceived exposure to floods, and (3) the number of dependent people in the household.

The studied system resulted well adapted to floods but not resilient. Collecting preparedness explaining attributes as part of flood risk management plans would contribute towards uncertainty reduction in risk calculations and increase safety of goods and people against floods.

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CHAPTER 1: INTRODUCTION

1.1. Motivation

Increased frequency and magnitude of different extreme events, such as heat waves or rainfall, are one of the negatives effects of climate change that have contributed to the increase flood events. Of the total number of natural disasters events recorded globally over the past century, about 30% were floods being the most frequent, surpassing the number of earthquakes and windstorms that occurred during the same period.

Measures to face flood risk have been managed with a traditional hydrologic approach, generating robust infrastructure to avoid river overflows, like levees or dams. These solutions cost valuable and large amounts of financial, human and material resources. However, they are not always effective, either because an event for which the structure was not designed occurs, or because people do not react as expected. If people live in urban or rural communities, their responses could be different. The level of social development, economic restrictions or the condition of the river (free-flowing or regulated) could be also influential variables to consider in measures design and management.

During the last decades, a growing interest to include the social variable on flood risk management has been detected. A socio-hydrologic approach allows to better understand how aspects and actions of the society impact on flood risk and how flood events affect population.

1.2. Hypothesis

Psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system affect and explain their vulnerability, and thus, flood risk.

1.3. Objectives

1.3.1. General objective

The general objective is to analyze the relations between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system.

1.3.2. Specific objectives

- Identify, classify and contextualize psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system.

- Identify, classify and contextualize flood preparedness measures of people and communities exposed to river floods in a nearly pristine socio-hydrologic system.

- Explore the links between between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system.

1.4. Methodology

Preparedness measures and psycho-social attributes of people and communities were identified through tools of Social Sciences: survey, social cartography, semi-structured non-participant observation, and semi-structured interviews. A statistical method were used in data analysis.

1.5. Structure of the thesis

Chapter 1 presents the general problem to be investigated, hypothesis, objectives and methodology. Chapter 2 presents a review of researches related to preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system. Chapter 3 describes the materials and methods. Chapter 4 present the main results of the investigation and discussion. Finally, Chapter 5 concludes the obtained results and suggest future lines of research.

CHAPTER 2: STATE OF THE ART REVIEW

2.1. Introduction

This Chapter presents a review of vulnerability computation theories and flood risk management in nearly pristine socio-hydrological systems.

2.2. Preparedness

A possible way forward to achieve adaption and resilience against severe effects of climate change, such as floods associated with increased frequency and magnitude of rainfall events, relies on improved risk management, including prevention, protection, preparedness, emergency response, and recovery (European Commission 2004, Banwell *et al*. 2020). In particular, protection i.e.: physical and psychological preparedness (Scolobig *et al*. 2012) can be implemented at different scales, namely: individual, household, community, and institutional, affecting vulnerability, which relates to the characteristics of the people, the property, or the environment that are at risk (Blöschl *et al.* 2013).

2.3. Population attributes

In quantitative risk assessment research, risk is defined as a function of hazard, vulnerability, and exposure (Kron 2005, Koks *et al.* 2015). While methods for estimation of flood hazard and exposed values are well known (e.g.: BOE 2008), computation of vulnerability is not straight forward (Mechler *et al*. 2014, Mechler and Bouwer 2015, Visser *et al*. 2014, Koks *et al*. 2015). Vulnerability is often computed as a function of the distance of the people and property values to water, i.e. taking exposition as a proxy (e.g.: Botzen *et al*. 2009, Babcicky and Seebauer 2016, Link *et al*. 2019), and/or simple population attributes such as age, gender, and incomes (Cutter *et al* 2000, Wu *et al*. 2002, Koks *et al*. 2015, Rojas *et al*. 2017). In general, exposition to floods and risk perception are well correlated with the distance to water (Miceli *et al.* 2008, Wachinger *et al.* 2013, O'Neill *et al*. 2016, Mondino *et al.* 2020), however, preparedness does not depend on complex attributes (Bubeck *et al*. 2012, Wachinger *et al*. 2013). Important elements of vulnerability, such as social adaptive capacity, resilience, response capacity, level of preparedness or adoption of self-protection measures are still under investigation (Scolobig *et* al. 2012, Blöschl *et al*. 2013, Fuchs *et al*. 2017, Lopez *et al*. 2017), and a lack of quantitative methods for their assessment in the frame of flood risk computation is detected. Incorporating a social vulnerability component in risk computation could improve and make flood risk maps more effective (Koks *et al.* 2015, Di Baldassarre 2017).

2.4. Nearly pristine socio-hydrological systems

Rural communities living along free-flowing rivers in the developing world present a very different situation than those pertaining to developed societies along regulated rivers (as e.g., the case of river Rhine in Germany, see: Kreibich *et al.* 2011, Becker *et al*. 2014, Kienzler *et al*. 2015). Although no rivers can be considered unequivocally “pristine” (e.g. Dufour and Piégay 2009, Bañales-Segel *et al*. 2020), a number of rivers in different regions of the globe present relatively minor and recent anthropogenic and environmental disturbances (see Grill *et al*. 2019). Nearly pristine socio-hydrological systems typically have poor people, and thus economically restricted in the way they can protect themselves against floods, and at the same time, floods follow the natural hydrologic regime of so-called free-flowing rivers, being more frequent and severe to exposed people and property goods. In such nearly pristine systems, standard practices include very low or no investment in precautionary measures against floods and lack river management. Trust in local authorities is depressed and local governments typically provide some minor help after emergencies (Banwell *et al*. 2020). Even having low income, people are forced to face the problems associated with floods on their own. In this particular context, following questions arise: What measures do they adopt? What attributes control the adoption of such measures? Are they adapted and resilient to climate change? In this research, the relations between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system are investigated to answer the aforementioned questions.

2.5. Conclusion

The literature review evidenced a lack of antecedents for vulnerability computation and flood risk management in nearly pristine socio-hydrological systems.

CHAPTER 3: MATERIALS AND METHODS

3.1. Introduction

This Chapter presents the materials and applied methods for the analysis of the relations between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrologic system.

3.2. Study area

The Carampangue River (84 km in length, Strahler number 4, mean annual discharge 61.5 $m^3 s^{-1}$) is a free-flowing river, which drains a coastal watershed (1262 km^2) located in Central Chile (37°06' - 37°42’ S, 72°57' - 73°27’W) (DGA 2014, CR^2 2020). **Figure 3.1** shows the location of the study area. The Carampangue Watershed corresponds with a climatic transition influenced by the Southeast Pacific Anticyclone SEPA and the westerlies (Valdés-Pineda *et al.* 2018). According to the modified Köppen’s climate classification (Beck *et al*. 2018), the predominant climate is the temperate dry and warm summer (Csb) presenting well-defined seasons. The ambient temperature ranges between 6 and 13°C. The average annual precipitation ranges between 1160 and 1823 mm, which occurs mostly during the winter months, from June to September (CR^2 2020). The Carampangue Watershed is in the Chilean Coastal Range. Its land use is mostly *Pinus radiata* and *Eucalyptus globulus* plantations (59%), followed by native forest (27%), meadows and shrubs (10%), agricultural (3%), and wetlands, urban and industrial areas (1%) (CONAF 2015). Along the river, there is a scarce presence of dispersing population until the lower reach, which comprises 15 km upstream the mouth into the Pacific Ocean. There, three localities, namely: Ramadillas, Carampangue and Arauco concentrate 1299, 3364, and 17597 inhabitants, respectively (INE 2017). 3875 people (17.4% of the local population) live in flood-prone areas for many generations. Floods occur on average every 2.23 years (Rojas *et al*. 2010).

The economic main activity is the non-metallic manufacturing industry (39%), followed by agriculture, livestock farming, hunting, and forestry (20%) (SII 2018). The monthly mean household income on the study site is about US$640, 16% of the population is considered poor, 19% of the houses lack basic services, and 14% of the people live in overcrowded conditions

(MDSF 2015). The study area is considered representative of a common situation in developing countries, such as those of Latin America, Asia, and Africa, where small groups of people with scarce resources live in flood-prone areas along an unregulated river.

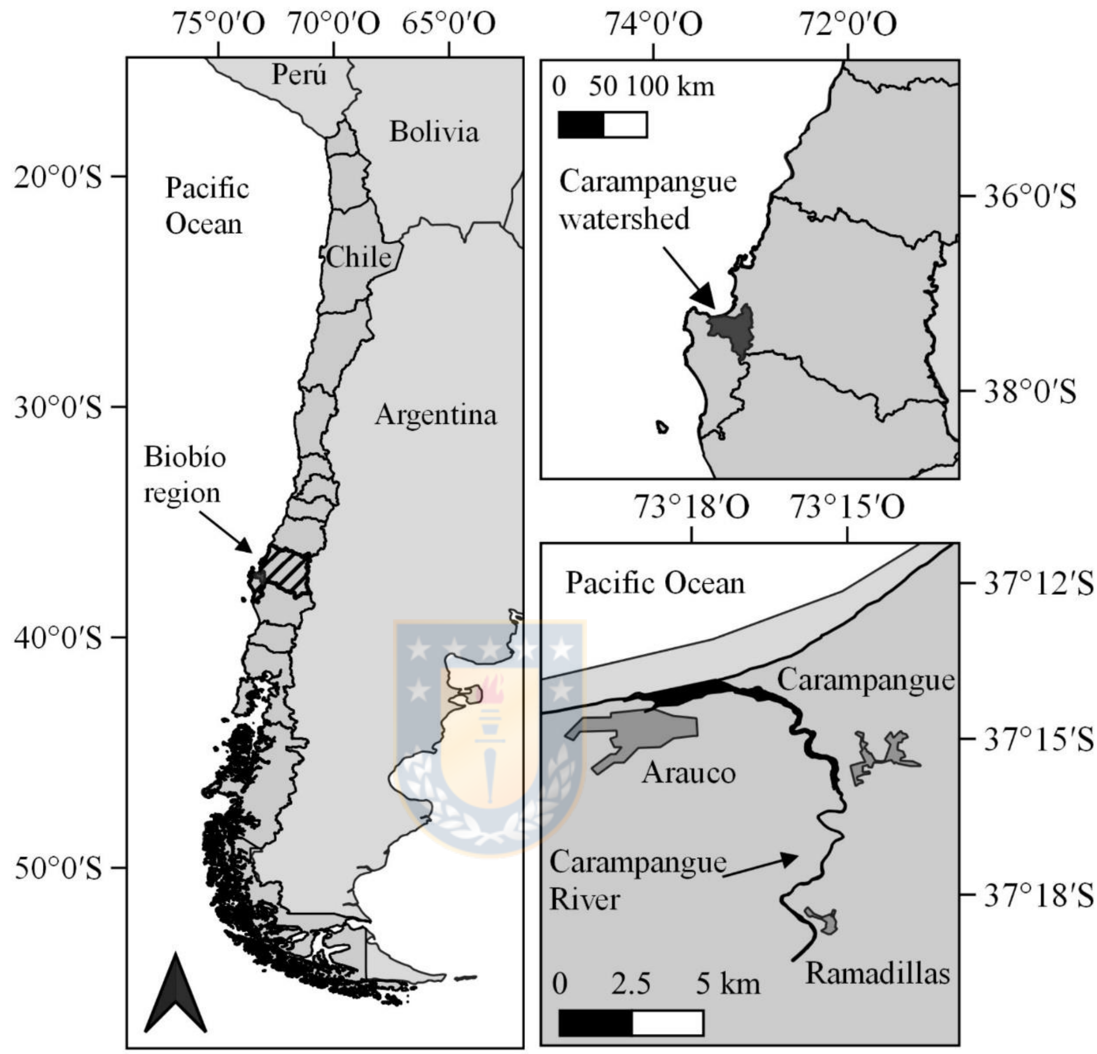

Figure 3.1 Study area.

3.3. Hydrologic-Hydraulic Analysis

3.3.1. Streamflow data

Measured mean daily streamflow data were obtained from the gauge station Carampangue, which is administrated by the Chilean General Water Directorate, DGA. The magnitude of the annual maximum discharge corresponding to different return periods was computed from a frequency analysis of the available records. **Table 3.1** shows the peak discharges (Q) with different return periods (T) determined by fitting a Gumbel distribution (σ=108.95, μ=446.18).

The duration and form of a typical flood hydrograph was determined from recorded hydrographs of past floods. These hydrographs were used as input in the numerical computation of the flooded areas.

Table 3.1 Peak discharge to different return periods.

T (years)	Q ($m^3 s^{-1}$)
2	487
100	947
1000	1217

3.3.2. Numerical simulations

Floods were simulated numerically by Faúndez (2017) using the unsteady, bidimensional hydraulic model IBER (Bladé *et al*. 2014). IBER solves the governing shallow water equations with source terms applying the finite volume method with the second order, explicit discretization scheme by Roe (1986). The wet-dry strategy assumes wet volumes when flow depth exceeded a threshold that was set to equal to 17 cm, which corresponds to the typical kerb height (Link *et al*. 2019).

A total of 426,149 triangular finite volumes with side lengths between 5 and 50 m were used for discretization of the domain.

A 2.5 × 2.5 m digital elevation model was developed from a Light Detection and Ranging (LiDAR) and recent bathymetries measured along the lower reaches of Carampangue River. The measured sea level at the maritime station Lebu was adjusted to GPS data by the Chilean Ministry of Public Work and then was imposed as an outlet boundary condition along the coast and river mouths. The hydrographs estimated at the Carampangue River were used as model input. The model was calibrated adjusting the Manning roughness coefficients following Chow (1994), Mignot *et al*. (2006) and IBER database to minimize the root mean square error.

Simulations of the flood passage for peak discharges with return periods of 2, 100, and 1000 years were conducted for the present analysis, and flooded area, flow depth and flow velocity were computed and integrated (**Figure 3.2**).

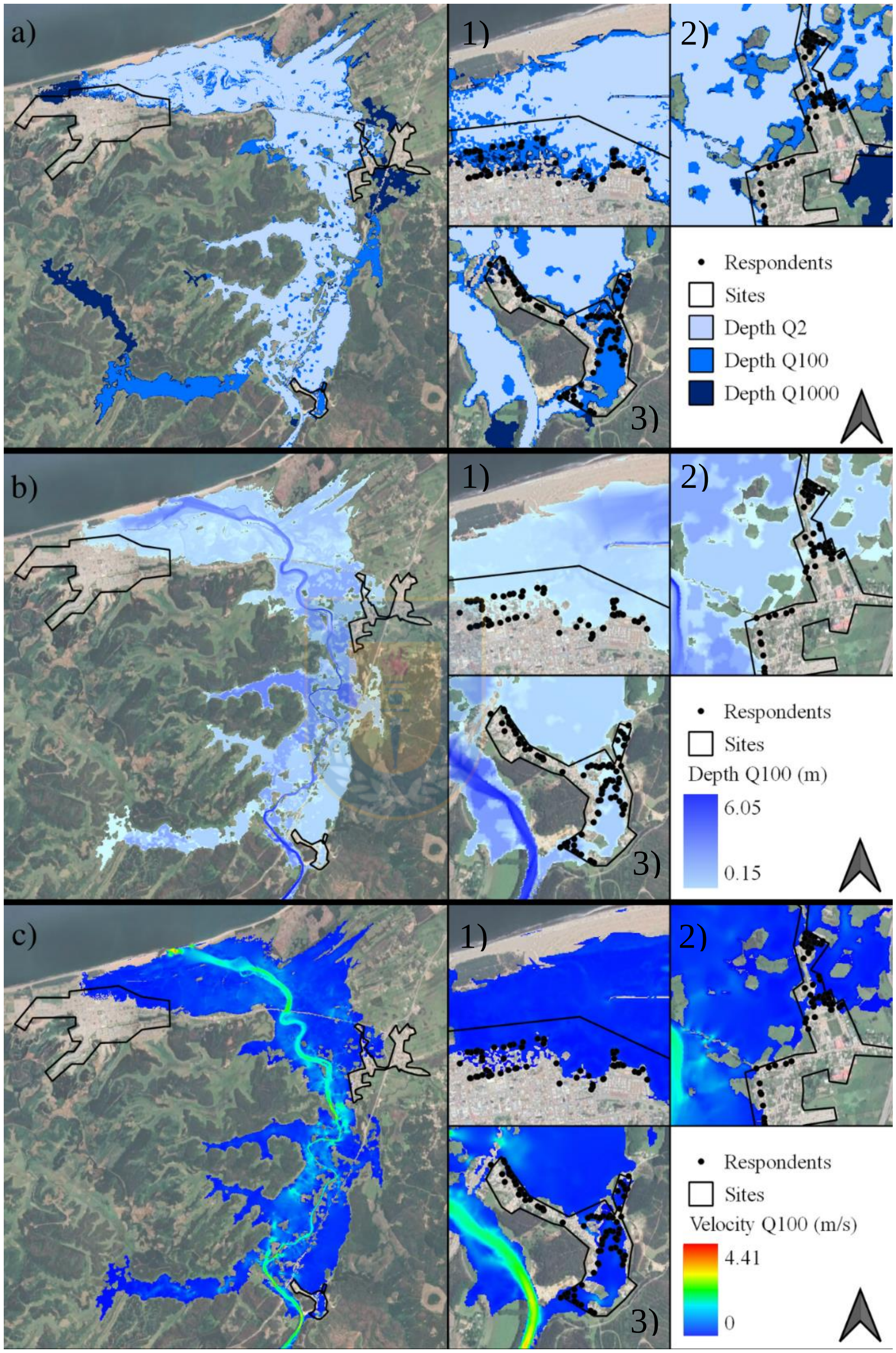

Figure 3.2 (a) Flood passage for peak discharges with return periods of 2, 100, and 1000 years, (b) Flood depth for peak discharges with return period of 100 years, and (c) Flood velocity for peak discharges with return period of 100 years in (1) Arauco, (2) Carampangue, and (3) Ramadillas.

3.4. Social Analysis

A face-to-face questionnaire (**Table 4.1**) survey was applied by Noguera (2017) to 223 residents, who provide a representative sample of the 3875 inhabitants exposed to floods (95% confidence interval and a 6.4% margin of error). The sample distribution was: 62 from Arauco, 77 from Carampangue and 84 from Ramadillas (**Figure 3.2**). They were surveyed to identify attributes of a population exposed to flood risk. The questionnaire survey included open- and closed-ended questions divided into three sets: residents' information, house information, and population risk perception. Residents' information included items about the number of members of the household, their age (considering people under 15 and over 65 years old as "age-dependent people"), and the presence of people with some form of disability. House's information included house location and house quality questions. Population risk perception included questions about risk perception, feelings of worry, perceived exposure, previous flood experiences, damage suffered in past floods, knowledge of the causes of flooding, and personal and institutional preparedness.

Three common tools of Social Sciences were designed and applied to identify residents' flood risk reaction, namely: social cartography, semi-structured non-participant observation, and semi-structured interview. Social cartography was based on the identification of flood-prone areas according to residents through maps that illustrated social knowledge, experiences, adaptation capacities, and psychological and physical preparedness at three different scales, namely: household, community, and institutional. Five participatory activities were carried out in the study area (2 in Arauco, 1 in Carampangue, 2 in Ramadillas) with a total participation of 57 adult residents distributed into 7 groups according to the location of their residence area. Three key players, one from each locality, who presented extensive knowledge about the territory, were selected to participate in semi-structured non-participant observations and semi-structured interviews. Both activities were conducted to further understand and contextualize the human-water interaction. This process was based on guided visits to each site, which allowed people to recognize interventions of flood-prone areas and different territory uses, as well as to identify measures to diminish flood risk at different scales, i.e.: household, community and institutional. The context was captured through a questionnaire that gathered information about influence of residents on the river and hydrological effects on society.

Precautionary measures were identified from the analysis of social cartography, semi-structured non-participant observation, and semi-structured interviews. These measures were classified into three classes, according to the International Commission for the Protection of the Rhine (2002): land-use control, flood proofing construction, and preparedness. Land-use control includes all measures that guide flood extent and development like keeping areas open and building codes and zoning ordinances, in terms of its effectiveness for the potential damage caused by these events. Flood proofing construction aims to mitigate damage either by avoiding water from entering the house (sealing buildings to protect its interior, shielding to keep water away, elevating the house level) or by generating interior measures in case of water penetration (appropriate spatial use in the building, appropriate equipment to repelling or avoid water). Preparedness is related to psychological processes and strategies, including preparation (information and education about flood risk at the individual, social, and institutional levels), forecasting and warning systems, and emergency measures.

3.5. Statistical Analysis

A binary logistic regression model was applied to explore the link between individual and social attributes and residents' flood risk reaction. Survey responses in **Table 4.1** were coded as binary answers (**Table 4.5**) to treat them with Statistical Package for the Social Sciences (SPSS) software to avoid misinterpretation due to non-linear marginalities of the variables. The dependent variable of the binary logistic regression is the answer to the question "Have you carried out household measures to face flood events?" which possible answer was "yes" or "no". 5 independent variables were used for binary logistic regression to assess the explanatory power of the residents' attributes. The variable "damage suffered in past floods" measured how households were affected due to past floods. "Dependent ≥ 3" corresponds to households with three or more people younger than 15 or older than 65 years and/or with a disability. Residents that believe they live in an area exposed to floods are represented by the variable "perceived exposure". The variables "risk perception" and "feelings of worry" represent the level of risk that households perceive and the level of worry that they feel, respectively.

The choice process for predictive variables was carried through a backward approach, where all candidate variables were entered at the first regression, testing the statistical significance of each variable on a multivariate analysis according to their p-value ($p \leq 0.1$). This process was repeated until all variables reached the required p-value. As result, the model calculated the probability that a resident adopts a cautionary measure against floods according to its psycho-social attributes.

3.6. Conclusion

Floods were simulated numerically using hydraulic model IBER. Psycho-social attributes of people were identified through a survey. Preparedness measures and psycho-social attributes of communities will be identified through social cartography, semi-structured non-participant observation, and semi-structured interviews. A statistical method will be used in data analysis.

CHAPTER 4: RESULTS

4.1. Introduction

This Chapter presents the main results of the hydrologic-hydraulic, social, and statistical analysis.

4.2. Hydrologic-Hydraulic Analysis

Computed flooded area with the 100 years discharge included 45.3, 6.2, and 12.6 ha of the localities Arauco, Carampangue, and Ramadillas, respectively (Figure 4.1). These localities presented 29 (46.8% of the surveyed houses), 33 (42.9% of the surveyed houses), and 52 (61.9% of the surveyed houses) exposed houses at a distances less than 2 m from the water, respectively. The total number of exposed households represented 51.1% of the surveyed houses. 78.5% of the total numbers of surveyed households live at distances less than 20 m from the water, and 91.9% at less than 40 m. Just 4.0% of the respondents live between 60 and 78.2 m from the water.

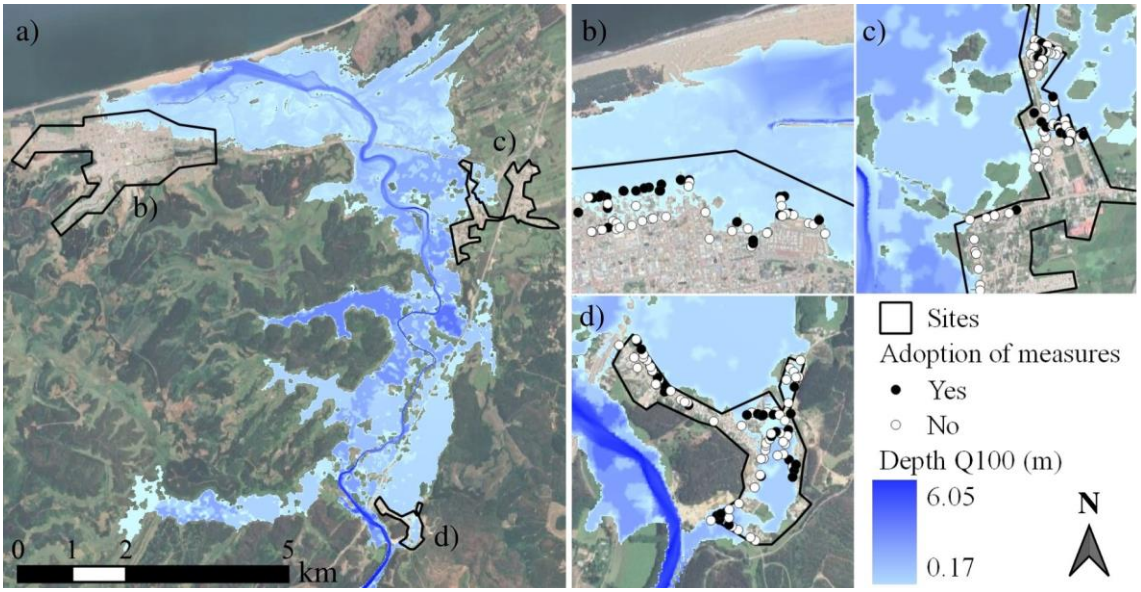

Figure 4.1 Flood depth for discharge with 100 years return period in (a) the study area: (b) Arauco, (c) Carampangue, and (d) Ramadillas. Black circles indicate households that declare to adopt cautionary measures; White circles indicate households that declare to not adopt cautionary measures.

4.3. Social Analysis

4.3.1. Attributes

Almost a third of the respondents (31.8 %) take measures to face floods, from which 63.4% lives in or at a distance less than 2 m of the flooded area according to the numerical simulation of the 100-yr flood (Figure 4.1). In 81.2% of the surveyed households live at least one dependent people, i.e. in a large part of the households there are children, elders, or disabled people, who need help to move or to know what to do before, during, or after a flood

(**Table 4.1**). This help can come from the members of the same household, from the community where they live, or from the institutions, i.e., in this case, from the local fire brigade or the municipality. 62.8% of the households presented precarious building conditions to face floods, which mostly correspond to low-income households. The percentage of residents that feel worried about flooding (77.1%) is higher than people who had experienced flood events in the past (45.7%), which may be related to community and generational transmission of experience and knowledge of the territory. The percentage of residents who would leave the area for a safer place if they could (59.6%) is lower than respondents who feel worried about flooding (77.1%), which might be explained by the sense of belonging, a community characteristic of older people identified in social cartography activities. 57.4% of the respondents think that they live in a flood-prone area, however, only a 56.7% of this percentage is really exposed, according to the numerical simulation of the 100-yr flood (

Figure 4.2). This flood simulation shows that only 56.8% of the whole sample perceive properly their flood exposure, which means: residents who think that they live in a flood-prone area really do, and residents who think that they do not live in a flood-prone area do not. According to the numerical simulation of the 2-yr flood (Figure 4.3), 87.4% of the residents who think that they live in a flood-prone area do not, which means that people tend to overestimate their exposure to flood risk.

Table 4.1 Survey questions and answers.

Residents' information		
	Yes	No
1) Presence of age-dependent people	78.0%	22.0%
2) Presence of people with disability	23.8%	76.2%
3) Presence of age-dependent people or people with disability	81.2%	18.8%
House quality		
	good	precarious
4) How is your house quality?	37.2%	62.8%
Population perception		
	Yes	No
5) Do you think your household is located in a flood-prone area?	57.4%	42.6%
6) Have you been affected by floods in the past?	45.7%	54.3%
7) Have you carried out household measures to face flood events?	31.8%	68.2%
8) Would you be willing to move to a safer area if you could?	59.6%	40.4%
9) Do you feel worried about flooding?	77.1%	22.9%
	Null/low	Medium/high
10) How do you rank damage suffered in past floods?	68.6%	31.4%
11) How do you rank your level of flood risk?	51.1%	48.9%
12) How do you rank your feeling of worry about flooding?	45.3%	54.7%

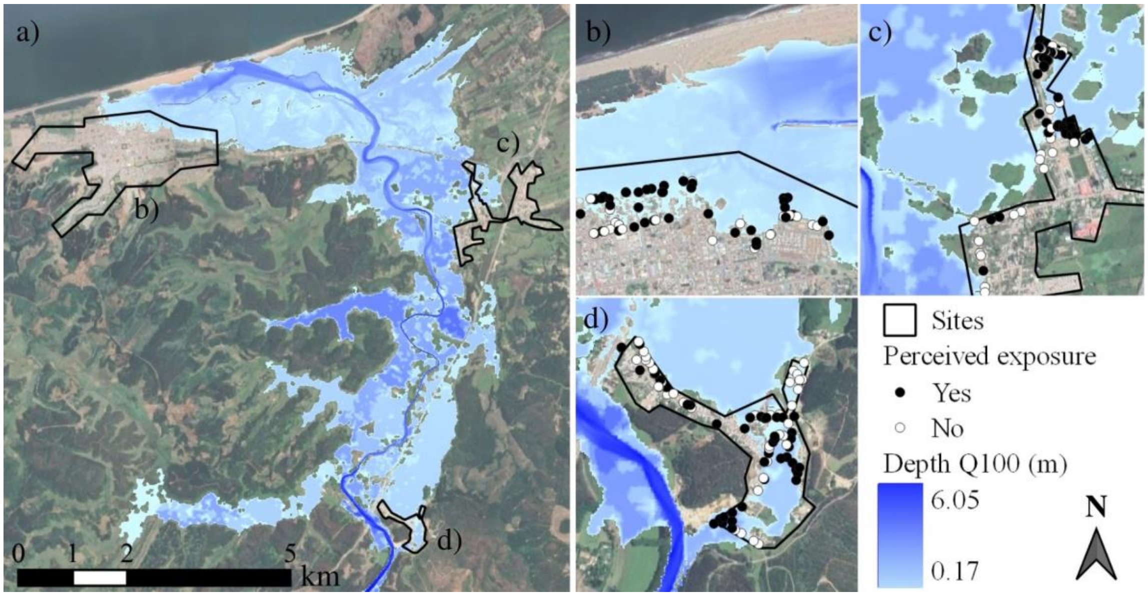

Figure 4.2 Flood depth for discharge with 100 years return period in (a) the study area: (b) Arauco, (c) Carampangue, and (d) Ramadillas. Black circles indicate households that declare to think that they live in a flood-prone area; White circles indicate households that declare to think that they do not live in a flood-prone area.

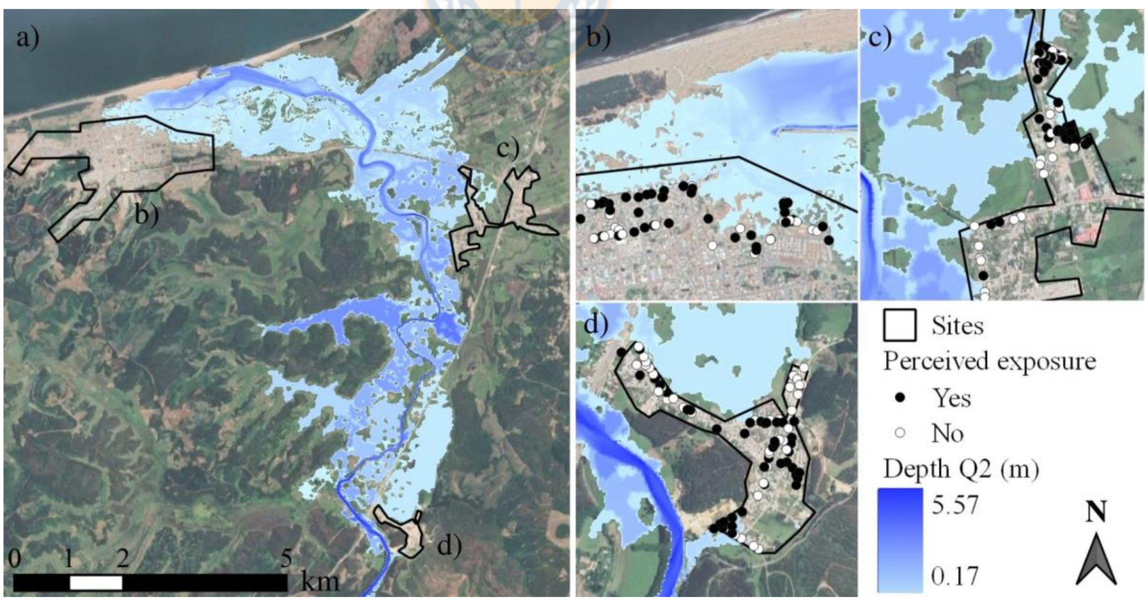

Figure 4.3 Flood depth for discharge with 2 years return period in (a) the study area: (b) Arauco, (c) Carampangue, and (d) Ramadillas. Black circles indicate households that declare to think that they live in a flood-prone area; White circles indicate households that declare to think that they do not live in a flood-prone area.

4.3.2. Measures

Table 4.2 shows adopted measures to mitigate the impact of flood events at the household, community, and institutional levels. At the household level, motivated by their flood risk awareness, residents identify areas where people and animals could be placed in safety during floods, as well as evacuation corridors, being the only psychological preparedness measure at this level. As physical preparedness, due to the occurrence of the frequent flood, there are households with an emergency power circuit physically installed above the observed water depth during floods (**Figure 4.4**). Moreover, changing the floor to a water-resistant material is a frequent measure; in most cases, from wood to ceramic. Many houses show handmade small platforms to elevate furniture or to cross through them to get out of the house during floods (**Figure 4.4**). Installing eyebolts with ropes in the ceiling of the house is another equipment measure to elevate furniture. Empty paint cans are used to store belongings. In addition to the commonly observed sandbag barriers, tires to seal buildings are often used in the study area (**Figure 4.5**). Front walls construction, raising floor slab level, stilt construction and soil fill are common flood-proof construction measures adopted by residents (**Figure**

4.5). However, soil fill can trigger a water level increase in neighbor’s sites, so it should not be called a real solution to deal with floods without land planning. **Figure 4.5** shows this issue. In the study area, residents adopted not only commonly observed preparation measures such as trimming trees, cleaning gutters, repairing rood leaks, and wearing appropriate clothing, but also transferring older people, animals (cattle, sheep, horses), and vehicles to a safer area. Ditches are dug by residents in gardens to keep water away from the houses; however, this measure is not always enough and the whole gardens can get completely covered by water. Due to waterlogging, people adopt preventive measures to be stocked and not need to go out, like gathering food, firewood, and emergency supplies (batteries, lantern, hygiene and sanitation items, and medicine). The use of boats or a network of pedestrian bridges built by themselves is a common measure to go out when they need to work or buy (**Figure 4.4** and **Figure** 4.5**)**. In extreme cases, evacuating people or animals with boats is a common emergency measure.

Table 4.2 Measures to mitigate the impact of flood events at household level.

Measures	Classification		Temporality
identifying a safe area	building codes and zoning ordinances	land use control	before
power circuit above flood depth	equipment	flood-proofing construction	before
changing floor material			before
handmade platforms			before
installing eyebolts with ropes in the ceiling			before
storing belongings			during
tire barriers construction	sealing		before
sandbags barriers construction			before
building a front wall	shielding		before
ditch construction			before
raising floor slab level	elevation		before
stilt construction			before
soil fill			before
trimming trees	preparation	preparedness	before
keeping rain gutters and downspouts clear			before
repairing roof leaks			before
transferring people, animals, and vehicles			before
gathering supplies			before
wearing appropriate clothing			during
evacuating people and animals	emergency measures		during
disinfecting inside the houses			after
drying inside the houses			after

Figure 4.4 Measures to mitigate the impact of flood events: (a) handmade platforms to cross through them to get out of the house during floods, (b) transferring animals, (c) power circuit above flood depth, and (d) handmade platforms to elevate furniture

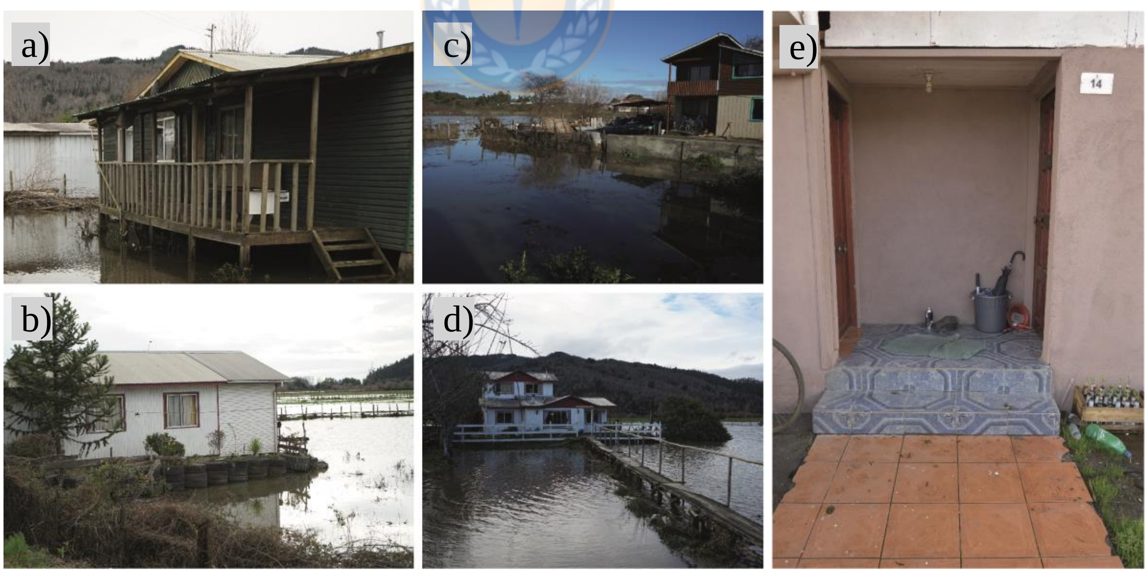

Figure 4.5 Measures to mitigate the impact of flood events: (a) stilt construction, (b) tire barriers construction, (c) soil fill, (d) network of pedestrian bridges, and (e) raising floor slab level.

At the community level (**Table 4.3**), identifying safe areas and sandbag construction barriers are measures also applied by households. However, in this latter case, these measures are organized and carried out by community member groups. Also, they clean public spaces in green areas and parks, and look out the area to identify potential sources that could negatively alter water-course, such as leaves and branches accumulation, debris, and garbage. Due to the lack of institutional measures, drains are built by groups of community members to channel water. Residents of the study area do not always have internet or television access, and therefore, a common practice is to share the weather forecast among them. Fire brigades play an important role at the community level. They are formed by members of the communities who act on their initiative, without being organized by a municipal or government plan. When water is approaching the communities, the fire alarm is activated by firefighters to warn the people. They also evacuate people when community help is not enough. Emergency shelters in community centers are managed by local neighborhood associations who also, along with community members groups, organize clothing and food drives and money collection to help the most in need families who are affected by floods. Physical preparedness measures at this level are predominant being only identified two psychological preparedness measures, which were identifying the safe area and sharing weather forecast.

Table 4.3 Measures to mitigate the impact of flood events at community level.

Measures	Classification		Temporality
identifying a safe area	building codes and zoning ordinances	land use control	before
sandbags barriers construction	sealing	Flood-proofing construction	before
drain construction	shielding		before
cleaning public spaces	preparation	preparedness	before
touring the area			before
sharing weather forecast	forecasting and warning		before
activating fire alarm			during
evacuating people (fire brigade)	emergency measures		during
shelters in community centers			during
money collection			after
clothing and food drive			after

Only physical preparedness was identified at the institutional level (**Table 4.4**). Once a year, Municipality manage streets, walksides, channels, and illegal garbage areas cleaning, which are rated insufficient measures by residents. River canalization through gabion construction in small reaches of the Carampangue River is considered an effective measure to control riverbank overflow. However, this is not a comprehensive solution and could affect environmental systems likewise drain construction. Finally, when there are many evacuated residents, Municipality manages emergency shelters in schools.

Table 4.4 Measures to mitigate the impact of flood events at institutional level.

<table>
<tr><th>Measures</th><th colspan="2">Classification</th><th>Temporality</th></tr>
<tr><td>river canalization</td><td rowspan="2">shielding</td><td rowspan="2">flood-proofing construction</td><td>before</td></tr>
<tr><td>drain construction</td><td>before</td></tr>
<tr><td>cleaning streets, walksides and channels, illegal garbage areas</td><td>preparation</td><td rowspan="4">preparedness</td><td>before</td></tr>
<tr><td>shelters in schools</td><td rowspan="3">emergency measures</td><td>during</td></tr>
<tr><td>disinfecting streets</td><td>after</td></tr>
<tr><td>giving chlorine, coal and money</td><td>after</td></tr>
</table>

4.4. Statistical Analysis

Binary logistic regression models were estimated until each variable was statistically significant ($p \leq 0.1$). The dependent variable is the adoption of measures, the initial independent variables of the binary logistic regression model and the selected for the final model are shown in **Table 4.5** and Table 4.6, respectively.

Table 4.5 Variables in the initial model.

Variables	Survey question	Type of variable
dependent ≥ 3	Presence of at least three dependent people in the household	nominal dichotomous, (0) no; (1) yes

risk perception	How do you rank your level of flood risk?	nominal dichotomous, (0) null/low; (1) medium/high
feelings of worry	How do you rank your feeling of worry about flooding?	ordinal dichotomous, (0) null/low; (1) medium/high
perceive exposure	Do you think your household is located in a flood-prone area?	nominal dichotomous, (0) no; (1) yes
damage suffered in past floods	Have you carried out household measures to face flood events?	ordinal dichotomous, (0) null/low; (1) medium/high

Table 4.6 Parameters and statistics of selected independent variables for the regression model.

Variable	β	E.T.	P-value	Exp(β)	I.C. 95 % Exp(β)	
					Inf.	Sup.
constant	-1.910	0.303	0.000	-	-	-
damage suffered in past floods	1.025	0.341	0.003	2.786	1.429	5.434
perceived exposure	0.934	0.361	0.01	2.546	1.255	5.162
dependent ≥ 3	0.769	0.358	0.032	2.157	1.070	4.351

The probability that a household adopt measures against flooding (P_m) is calculated using the following equation:

$$P_m = \frac{e^{[1.025X_1+0.934X_2+0.769X_3-1.910]}}{1+e^{[1.025X_1+0.934X_2+0.769X_3-1.910]}} \quad (1)$$

where X_1 represents the level of damage suffered in past floods, X_2 denotes perceived exposure, and X_3 indicates the presence of at least three dependent people in the household.

According to β coefficients (**Table 4.6**), the probability that a household adopt measures against flooding increases if: (1) residents have suffered damage in past floods, (2) residents think that their households are located in a flood exposed area, or (3) three or more dependent people live in the household. Suffered damage in past floods is the variable that most influences the probability that a household adopt measures against flooding. Odds that a household has suffered damage in a past flood increases 3 times, compared to a household that have not experienced it, keeping the other attributes equal, and understanding odds as the ratio between the probability that a household with certain attributes adopt measures against floods compared to households that don’t.

Although risk perception seemed to be significant in social cartography, statistical analysis did not show this variable to be statistically significant, being deleted with a 0.672 p-value at the second regression. This discrepancy could be explained because the risk perception is partly captured through perceived exposure. Similarly, the feelings of worry were not significantly correlated with the adoption of cautionary measures against floods ($p = 0.139$). This is explained because most of the people (77%) was worried about flooding.

4.5. Discussion

The term nearly pristine socio-hydrological system is used to distinguish situations that are different from altered socio-hydrological systems, such as developed societies along regulated rivers. In this sense, nearly pristine systems include situations having poor people living in flood-prone areas along free-flowing rivers. Thus, the system behaviour is expected to be forced by severe economic restrictions in the way people can protect themselves against floods, and at the same time, by frequent and severe floods that follow the natural hydrologic regime of rivers, affecting exposed people and property values. In such nearly pristine systems, standard practices include very low or no investment in precautionary measures against floods and lack river management. Trust in local authorities is depressed and local governments typically provide some minor help after emergencies (Banwell *et al*. 2020). Even low-income people are forced to face the problems associated with floods on their own. In the study area, a flood occurs every 2.23 years, which evidences the natural flow regime, and confirm that land-use changes from native forest to forest plantations have a minor impact on floods (Stehr *et al*. 2010), even when currently almost 59% of the watershed is covered by forest plantations.

This study reveals that almost a third of the respondents (33.4%) undertake measures to face flood events, as financial insurance is out of the possibilities of the people, and the interest of insurance companies due to the low value of the houses. These findings contrast with the situation in Central Europe along rivers Elbe and Danube reported by Thieken *et al.* (2007), where almost 70% of the people undertake precautionary actions and depending on the study site, and 18% to 50% had insurance. These results agree with the conclusion by Fothergill and Peek (2004), who argue that poor people are less likely to prepare for disasters or buy insurance, but have proportionally higher material losses and face more obstacles during the phases of response, recovery, and reconstruction. However, Scolobig *et al*. (2012) found even lower percentages in the Italian Central Alps: both before and after the events, only a small percentage of inhabitants (3.5 and 2.5 %, respectively) took some measures to protect their households. These measures include water canalization, strengthening of cellars and basements, shields with water barriers and walls to protect their houses. The low percentages were attributed that respondents judge that their communities are more ready to face an event than themselves as individuals, a characteristic of evolved socio-hydrological systems. People in this study area adopted innovative, simple, but efficient measures (**Table 4.2**), such as installing a second power circuit above flood depth, building handmade platforms to connect houses with streets, installing eyebolts with ropes in the ceiling, having small boats for transferring people and domestic animals to safer places during floods, at the household level; sharing weather forecast, activating a fire alarm, money collection, at the community level; and providing chlorine for disinfection after floods, coal to heat and dry values, and money, at the institutional level. These simple measures contrast with those observed in altered socio-hydrological systems from the developed world, such as those observed along rivers Danube and Elbe in Central Europe by Thieken *et al.* (2007).

Miceli *et al*. (2007) found a positive correlation between risk perception and preparedness along the Lys River in Aosta Valley, Italy, while Becker *et al*. (2014) found that a high-risk perception in communities along the Rhine doesn't imply a high preparedness. Moreover, preparedness along the Rhine was much better explained by previous experience (Kreibich *et al.* 2011, Kienzler *et al.* 2015). In this case, the adoption of cautionary measures against floods, i.e. preparedness, correlated with the damage suffered during past floods, i.e. previous experience, the number of dependent people in the household, and the perceived exposure to floods, which could be understood as a proxy of risk perception. Perceived exposure is the only variable of the three mentioned which can be managed at institutional level, either informing the population, or generating risk management plans in those areas where the risk is underestimated.

Results provide evidence of different adaptions to frequent floods depending on the household, community, and institutional levels. Even when the severity of flood disasters in the study area does not have triggered involuntary migrations yet, results show gaps in the objective of achieving a resilient system. Especially, when people are asked if they would leave the area for a “safer” place if they could, 59.6% of the respondents gave a positive answer. In Chile, economic constraints force people to stay in the flood-prone areas (Aránguiz *et al*. 2020). However, this percentage is lower than that of the respondents who feel worried about flooding (77%), which might be explained by the sense of belonging, a community characteristic especially by older people identified in social cartography activities.

Because of its position and very limited human disturbances, the Carampangue basin could represent a suitable site to study socio-hydrological processes and dynamics in nearly reference conditions. Also, because of the very recent increase of urban development, the area is likely to be impacted by direct and indirect disturbances and represent a privileged site for studying the interactions of humans and water in a nearly-pristine system, where more sustainable ways of development could be tested and assessed. This study highlights the importance of studying socio-hydrological systems in reference basins with relatively low direct anthropogenic disturbances at the basin scale, in terms of interactions between people and the river system and processes. Future studies in this and similar systems should also focus on changes in risk perception, effects of climate change on floods, and interactions between the socio-hydrological system and the river ecosystem in a broader context of river science.

4.6. Conclusion

Flood simulations were compared with psycho-social attributes of people. Preparedness measures and psycho-social attributes of communities, identified through social cartography, semi-structured non-participant observation, and semi-structured interviews, were classified and contextualized. A statistical model was applied to explore the link between individual and social attributes and residents' flood risk reaction.

CHAPTER 5: CONCLUSIONS

The relations between preparedness and psycho-social attributes of people and communities exposed to river floods in a nearly pristine socio-hydrological system were investigated, integrating hydrological-hydraulic analysis of flood hazard and results from a survey, social cartography, semi-structured non-participant observation, and semi-structured interviews.

Preparedness was noticeable different to those reported for altered systems in the developed worlds: people adopted innovative, simple, but efficient measures against floods, conditioned by the damage suffered during past floods, the perceived exposure to floods, and the number of dependent people in the household.

The study system resulted well adapted to floods but gaps to achieve resilience were detected. This study highlights the importance of studying socio-hydrological systems in reference basins with relatively low direct anthropogenic disturbances at the basin scale, in terms of interactions between people and the river system and processes.

Future studies in this and similar systems should also focus on changes in risk perception, effects of climate change on floods, and interactions between the socio-hydrological system and the river ecosystem in a broader context of river science.

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