

Proceedings

Study of Natural Hazards in the Upper Part of the Mapocho River Basin, Metropolitan Region of Chile, Using Satellite Imagery [†]

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Abstract: The upper section of the Mapocho river basin is in constant danger of landslides. This study had the objective of zoning the upper Mapocho river basin for the susceptibility of landslides using hydrological, geological, and geomorphological data. Areas with a high degree of landslide susceptibility are located on the lower part of the main valleys as well as at the headwaters of the basins. Landslide events in the mountainous region of Central Chile are caused by two main factors: intense precipitation and seismic activity.

Keywords: susceptibility; landslides; Mapocho river basin

1. Introduction

The Central Andes range of Chile is geologically characterized by the presence of stratified, sedimentary, volcanic, and volcanoclastic rocks that date from between the Eocene and middle Miocene [1]. Among the most essential structural traits are the North to South Olivares River Fault, to the west the Dominion of the Abanico basin and, to the East, the Dominion of the Faja Plegada and Corrida of Aconcagua [2,3]. Geomorphological dynamics of the central region of Chile are subject to tectonic (i.e., orogenesis), climatic (i.e., differential erosion), and volcanic processes. These processes are relief shaping agents characterized by their considerable dynamism due to their periglacial morphoclimatic position [4]. The geomorphological systems present in the upper part of the Mapocho river basin have been formed from endogenous and exogenous processes that are permanently active within and among the systems and in response to the combined action of meteorological and seismic variables [5]. The objective of this research study was gathering, systemizing, and analyzing raw data through the use of satellite images, aerial photographs, MDE and topographic maps of the geological, geomorphological, and hydrological components. This compilation of data made it possible to identify and zone the areas which are most susceptible to landslides in the upper Mapocho river basin.

2. Materials and Methods

2.1. Study Area

This study was carried out in the hydrographic sub-basins of the San Francisco, Molina and Olivares Rivers, which are located along the upper section of the Mapocho river basin in the Central Chilean Andes, 30 km northeast of the country's capital city, Santiago. This area lies between the

coordinates: latitude 33°03'–33°29' South and longitude 70°06'–70°23' West (Figure 1). Administratively, this zone covers the municipalities of Lo Barnechea and San José de Maipo, which are within the Santiago Province, Metropolitan Region, and has a total surface area of 1139 km².

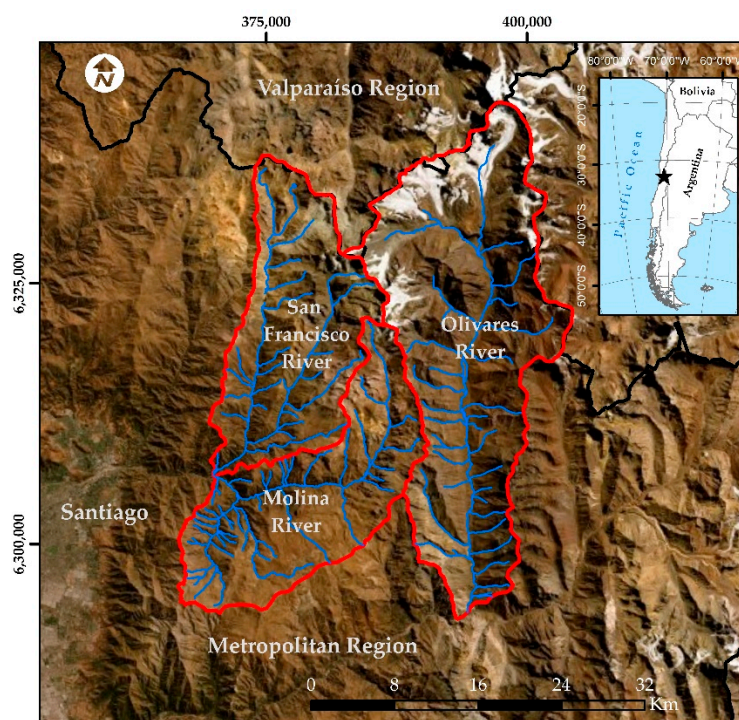


Figure 1. Location of the sub-basins of the San Francisco, Molina and Olivares rivers in the upper section of the Mapocho river basin.

2.2. Data Sources & Remote Sensing

A bibliographic review of components of hydrography, geology, and geomorphology was carried out. In visual interpretation was used: (a) mosaic of high resolution images of the Pleiades satellites at a resolution of 50 cm; (b) topographic maps of the Metropolitan Region, section E, digital cartography at a scale of 1:50,000; (c) analogous aerial photographs of the Hycon flight at a scale of 1:70,000 and (d) interferometric DEM ALOS PALSAR at a resolution of 12.5 m.

2.3. Visual Interpretation & Field Survey

The visual interpretation of the geological, geomorphological and hydrological attributes was made using the photo-interpretation of the mosaic of satellite images, which was supported by aerial photographs, topographic cartography and an interferometric digital elevation model (DEM). Also, nine field studies were conducted, with a total of 42 effective days of work, and these field studies were carried out in the sectors of Farellones-Valle Nevado, Yerba Loca, El Cepo, Olivares and San Francisco rivers.

2.4. Susceptibility Index

Susceptibility to landslides was evaluated using the susceptibility index (SI) proposed by Lara [6] and updated by Lara and Sepúlveda [7]. This index is calculated for each defined unit of land and is based on the sum of weighted scores for each of the conditioning factors of landslides (Equation (1)).

$$SI = \sum_{i=0}^6 f_i * map\ factor_i \tag{1}$$

where f_i corresponds to the sum of the weighted ratings (ranging from 1 to 5) assigned to base maps reclassified using GIS and $map\ factor_i$ corresponds to the percentage assigned (ranging from 5% to

40%) to each reclassified map according to its importance in generating landslides (Table 1). The software program ArcGis® was used to process the acquired data, create new data, reclassify base maps, and perform the calculation of the susceptibility index by using the tool Raster Calculator.

Table 1. Weighting of conditioning factors for landslides.

Factor	Weight ¹	Percent
Slope (f_1)	1, 2, 3, 4, 5	25%
Sun exposure (f_2)	1, 2, 3	5%
Geology (f_3)	1, 2, 3, 4, 5	40%
Distance to geologic fault (f_4)	0, 1, 2, 3, 4	10%
Distance to hydrographic network (f_5)	1, 2, 3, 4, 5	10%
Hydrographic density (f_6)	1, 3, 5	10%

¹ Weight 0 = Null; 1 = Very low; 2 = Low; 3 = Moderate; 4 = High; 5 = Very high.

The susceptibility index was evaluated and assigned according to each conditioning factor (f_i) and the class of each factor, which varied between 0 and 5 (Table 2).

Table 2. Index values and the degree of susceptibility to landslides.

Susceptibility Index	Degree of Susceptibility
>2	Low
2–3	Moderate
3 ^{1–5}	High

¹ Value that was established through the observations of landslides made in the field.

3. Results and Discussion

The 93 landslides events included in the inventory were concentrated in the rivers Yerba Loca, El Cepo and San Francisco. Five types of landslides deposits were recognized: debris flow, debris flood, rock fall, rock avalanche and slides. The susceptibility analysis indicated that more than 80% of the area under study were zones of low to moderate risk (Table 3). On the other hand, high risk areas (i.e., 16% of the surface area) were mainly concentrated in the bottoms of valleys and the unstable regions near valley headwaters. The sub-basin of the Molina river had the largest area of low risk zones and the sub-basins of the San Francisco and Olivares rivers contained the areas of greatest risk (Figure 2).

Table 3. Surface area and percentage by degree of susceptibility to landslides.

Range	Degree	Surface Area (Km ²)	Percent
0.9–2.25	Low	352.05	30.89%
2.25–3.51	Moderate	598.57	52.52%
3.51–4.6	High	189.01	16.59%

The upper sector of the Mapocho River basin, according to historical records from the past 100 years, is highly vulnerable to meteorological and climactic changes, which, if projections are maintained on a global scale, could increase the incidence of landslides events while also increasing their magnitude and their destructive power. In this sense, the impact of relief shaping agents on the sub-basins, which are currently in a stage of morphoclimatic transition and the active margin of two tectonic plates, will likely be greater in the present and near future.

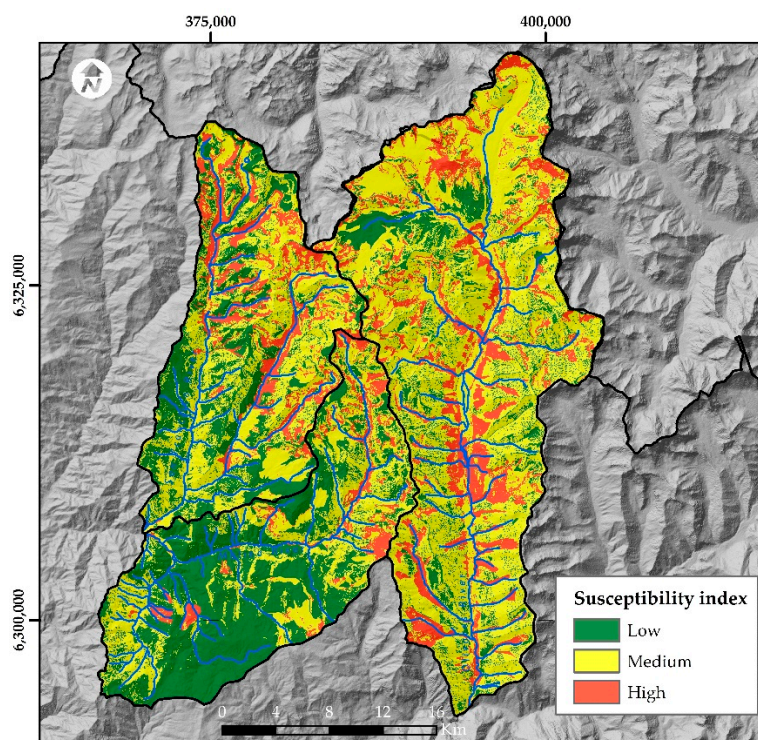


Figure 2. Susceptibility map to landslide in the upper sector of the Mapocho river basin.

4. Conclusions

The analysis established that tectogenesis and climatic changes following the Pleistocene era have triggered the development of various morphogenetic processes that have been identified and associated with systems glacial, gravitational, alluvial and fluvial. The changes in the morphology of the sub-basins are evolutionary in nature. From the post-glacial period to the present, they have undergone an accelerated transformation from glacial to fluvial basins. Through the creation of an inventory of landslides (93), at least five types of geologically active deposits were recognized in the area: debris flow, debris flood, rock avalanche, rock fall and slides. The two main and most common types of geologically active deposits were floods and debris flows. In the zoning of susceptibility to landslides, the zones of low, medium, and high susceptibility corresponded to 31%, 53% and 16% of the total surface of the area under study. Areas with a high degree of susceptibility to landslides were located in the upper parts of the main valleys, as well as in downstream areas. This is consistent with the main types of landslides deposits recognized on the ground. For the most part, these corresponded to water flows (with different concentrations of debris and water), meaning that their mobility is essentially conditioned by topography.

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