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Psychometric and cultural characterization of relative volcanic risk perception levels of individuals highly exposed to proximal activity from Villarrica volcano, Chile

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Abstract. This study combines the Psychometric Paradigm and the Cultural Theory to analyze volcanic risk perception (VRP) of more than two hundred residents and a similar number of non-residents in the high-hazard zone of Villarrica volcano. While the psychometric approach captures statistical variations in VRP, Cultural Theory helps characterize cultural patterns influencing risk perception. Together, they provide a more comprehensive framework for emergency management. A key distinction is observed between residents and non-residents. Residents show lower knowledge scores but higher internal trust, suggesting strong community ties yet a limited understanding of volcanic hazards. Non-residents, in contrast, have higher knowledge but lower internal trust, which may lead to overconfidence in their ability to respond to eruptions. However, both groups share similar external trust, indicating confidence in authorities and experts, which is vital for adherence to safety measures. Demographic factors also influence VRP. Elderly individuals and those outside the workforce tend to have lower VRP, highlighting the need for targeted risk communication. Higher education levels correlate with higher VRP, while economic activity (e.g., tourism, agriculture) influences risk perception, with some groups exhibiting extreme variations. Further effort is needed on indigenous populations, as they show lower VRP, warranting better integration of indigenous knowledge into risk assessments. Similarly, gender and religion show no clear patterns, although they may still shape risk perception in a more complex way. Ultimately, understanding the cultural and social dimensions of VRP is essential for designing effective, group-specific risk communication strategies to strengthen community resilience.

1 Introduction

Risk perception has been a crucial topic in disaster risk science, highlighted as a key component in the decision-making process of individuals facing emergencies, with the outcomes of these decisions directly impacting human safety (Siegrist &

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Arvai, 2020). Risk perception refers to people's judgments when characterizing and evaluating hazardous activities and technologies (Slovic, 1987). These sensitive judgments are primarily based on instinct and intuition (Slovic & Peters, 2006) and involve collecting, selecting, and interpreting signals about the uncertain impacts of disaster events (Wachinger, 2013). In the context of natural hazards, significant scientific attention on risk perception has focused on earthquakes and tsunami-related disasters, while comparatively less attention has been given to volcanology (Favereau et al., 2018; Siegrist & Arvai, 2020). However, Volcanic Risk Perception (VRP) has been considered highly relevant and a key gap in supporting volcanic emergency strategies and safety protocols more efficiently (Favereau et al., 2018). Volcanic eruption is a serious hazard, having caused the deaths of approximately a quarter of a million people over the past five centuries (Brown et al., 2017; Auker, 2013). Eruptions can last from days to years or even decades, with varying intensities and phases. The decisions made by individuals exposed to these hazards during such periods are critical, as they can significantly influence the resulting injuries or fatalities. Notably, over 60% of fatal volcanic incidents occur more than a week after the eruption begins, with over 40% of these fatalities involving individuals who returned to the hazard zone to recover assets, ensure home safety, or for other reasons (Barclay et al., 2019). Most victims were residents, although non-residents or temporary visitors, such as tourists, scientists, and media personnel, were also commonly affected (Brown et al., 2017).

In the last decades, some efforts to study VRP have been focused on recognizing factors influencing individuals' judgments and decisions in the volcanic environment. Favereau et al. (2018) identified fourteen peer-reviewed scientific articles as recent main contributions on volcanic risk perception (i.e., Chester, 2005; Barberi et al., 2008; Carlino et al., 2008; Dove, 2008; Gaillard, 2008; Haynes et al., 2008; Patton et al., 2008; Perry and Lindell, 2008; Gavilanes-Ruiz et al., 2009, Njome et al., 2010; Tobin et al., 2011; Jones et al., 2013; Ricci et al., 2013; Eiser et al., 2015). The most studied VRP factors from those articles are, in order of relevance, knowledge, trust (internal and external), experiences, proximity, sense of community (including attachment to the place and civic participation), demography, and vulnerability (Favereau et al., 2018).

This research aims to explore some of those main identified volcanic risk perception factors, including knowledge, internal trust, external trust, and attachment to the place from risk perception surveys applied in areas surrounding Villarrica volcano, which is one of the most active volcanoes in South America. Risk perception levels are calculated through a statistical clustering method, and demographic data collected also from the surveys is used to analyze the potential socio-demographic influence on the results of those risk perception levels outcomes. Knowledge refers to understanding appropriate scientific information about volcanism and its associated risks, such as volcanic processes (Carlino et al., 2008; Ricci et al, 2013; Davis et al., 2005). According to the literature, several socioeconomic factors influence knowledge, such as age and education level, where the young population educated about natural hazards have more clarity about risks and share information among peers (Carlino et al., 2008; Haynes et al., 2008). Internal trust refers to people's realistic awareness about potential consequences when facing volcanic emergencies, which sense of trust and self-efficacy might be improved by involving exposed populations in public discussions for emergency plans (Barclay et al., 2019). External trust refers to feeling or perceiving a higher sense of risk if trust in experts is low or damaged (Espluga et al., 2019). In emergencies, scientists are seen as the most valuable source of information compared to the media and authorities' information for the civil

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population (Njome et al., 2010), and also state this by authorities (Haynes et al., 2008). Attachment to the place is an important factor influencing willingness to evacuate in case of a volcanic emergency; usually, higher attachments pull people not to evacuate (Favereau et al., 2018; Barclay et al., 2019; Barberi et al., 2008). Analysis of evacuations from recent volcanic emergencies provides insights about potential pull factors (e.g., protecting assets, economic resources, or attachment to the place) and push factors (e.g., poor shelter conditions) influencing whether people remain or not in shelters (Barclay et al., 2019).

1.1 General frameworks to study risk perception

Two general frameworks have been widely used to estimate and characterize risk perception levels in the context of human-made and natural hazards: the Psychometric Paradigm and Cultural Theory (described in the following sections). Both frameworks typically rely on data collection through questionnaires or workshops, using point-scale systems such as Likert scales or 5-point questions to quantify participant responses (Marris et al., 1998). This research proposes employing both approaches to achieve the specified objectives of calculating relative VRP levels of populations highly exposed to volcanic activity from Villarrica volcano (section 1.2) using a psychometric approach and the characterization of their social trends in different VRP groups based on the cultural theory approach (Section 2.3).

1.1.1 Psychometric Paradigm

The Psychometric Paradigm originated from psychology to gain insights into people's understanding of risk and enhance emergency communication strategies (Slovic, 1987). Grounded in foundational research on risk perception heuristics (Fischhoff et al., 1978; Slovic et al., 1979; Slovic, 1987), psychometric studies are commonly used to elicit quantitative judgments on perceived risk, acceptable risk levels, and the perceived benefits of various activities and technologies. In response to criticism of its reliance on heuristics, the paradigm later incorporated the concept of affect, emphasizing the role of emotions in risk perception and decision-making (Sjöberg, 1996; Slovic & Peters, 2006). Psychometric approaches have employed various statistical methods, including multiple regression analysis, Exploratory Factor Analysis, and Principal Components Analysis, to analyze risk perception survey data (Fischhoff et al., 1978; Jaspal et al., 2022; Mitsushita et al., 2023). Today, the psychometric approach is widely applied across multiple fields, particularly in health research, such as studies on perceived risks during the COVID-19 pandemic, and in disaster risk assessment (Jaspal et al., 2022; Mitsushita et al., 2023; Weber et al., 2002).

1.1.2 Cultural theory

The cultural Theory, developed by sociologists and anthropologists, seeks to identify cultural patterns that influence risk perception (Douglas & Wildavsky, 1982). It views risk as a social construct and classifies individuals into four archetypal groups, including isolates, hierarchists, individualists, and egalitarians, each reacting differently to risk (Douglas & Wildavsky, 1982; Tansey & O'Riordan, 1999; Edgar & Sedgwick, 1999). The cultural theory has been both supported and

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criticized. Miller (1996) argued that culture's complexity and dynamism make it difficult to fully explain through those proposed archetypes alone. Others have criticized its low explanatory power and methodological limitations (Tansey, 2004; Oltedal et al., 2004; Sjöberg, 1996). Despite these critiques, Cultural Theory remains widely used in disaster risk research, helping to identify cross-cultural patterns in risk perception. It has been particularly valuable in understanding how individuals across different countries and contexts perceive risks associated with natural hazards such as volcanism (Paton et al., 2011; Zeidler, 2015; Renn & Rohrmann, 2000; Jones et al., 2013).

1.2 Study area: Villarrica volcano

Villarrica is a stratovolcano located in the Southern Volcanic Zone (SVZ) at 39.42°S, 71.93°W, active since the Late Pleistocene and situated between Villarrica and Calafquen lakes (Fig. 1). It is primarily a basaltic to basaltic-andesite volcano and ranks among the most active volcanic systems in South America (Lara & Clavero, 2004). The estimated proximal hazard zone includes potential impacts from lava flows, lahars, and minor pyroclastic flows, covering an area of approximately 1,500 km² (Lara et al., 2021; Lara et al., 2011). The volcanic edifice spans about 400 km², reaching an elevation of 2,847 meters above sea level and rising 2,450 meters above its base (Lara & Clavero, 2004). Pucón, with about 17 thousand population, and Coñaripe, with about one and half thousand according to the Census 2017, are the closest urban areas to the Villarrica summit and have been severely impacted by historic lahars from the volcano (Fig. 1) Also, about ten thousand people lives in sparsely populated rural areas surround the volcanic edifice where down valleys are most exposed as lahar impact tends to channelize in rivers. Urban areas such as Pucón, Coñaripe, Villarrica, and Lican Ray increased the population in summer times when transient populations visit the area, attracted by the volcanic landscape and the ski centre close to the summit.

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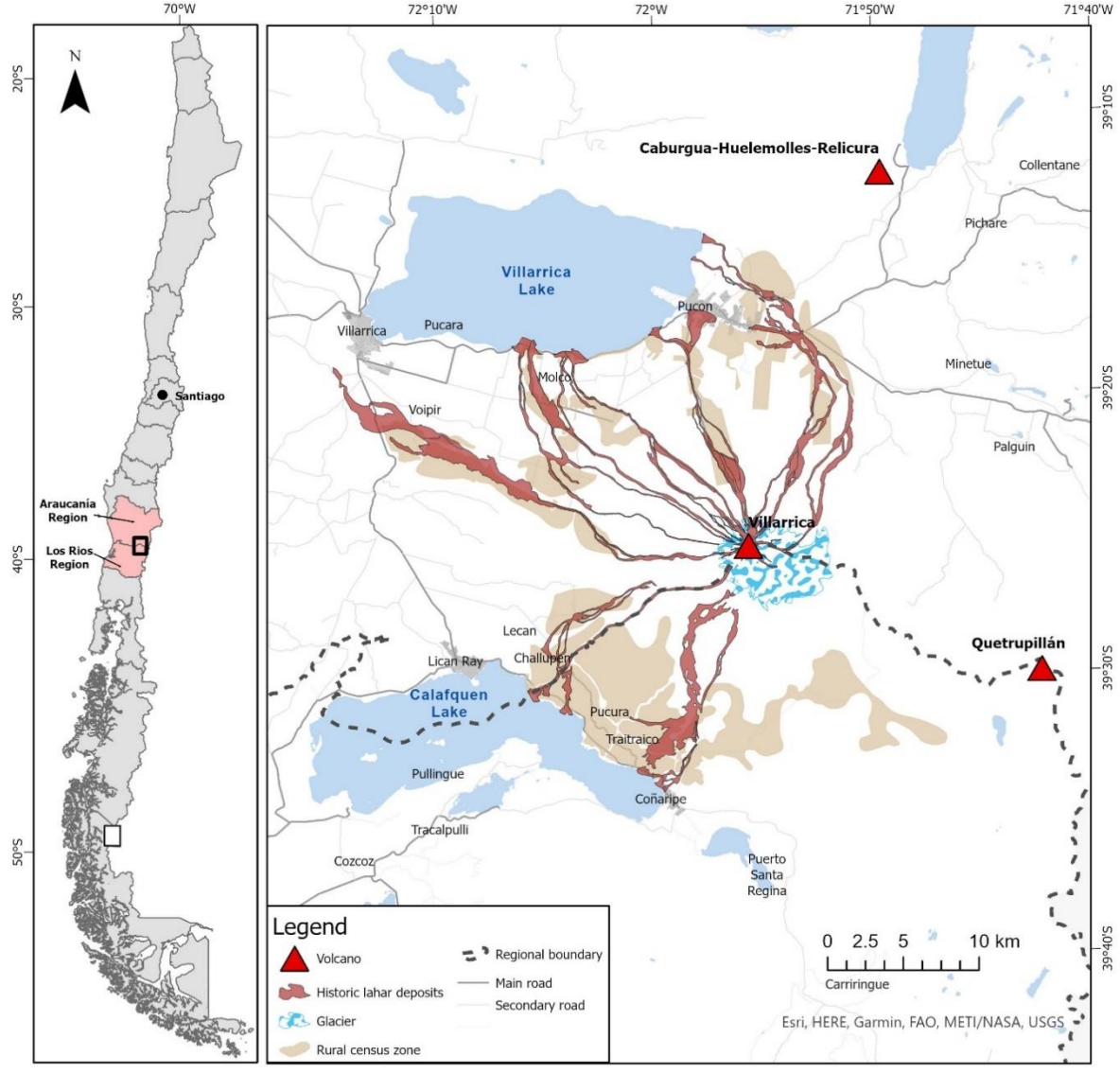

Figure 1: Villarrica volcano location and exposure of rural zones to historical lahar deposits.

1.3 Historical volcanic activity from Villarrica volcano

About 160 eruptions have been recorded at Villarrica Volcano over the past 2,000 years, with approximately 130 occurring over the past 500 years (Fig. 2; GVP, 2025). Most of these events were effusive eruptions, with a Volcanic Explosivity Index (VEI) of 2 (Dzierma & Whermann, 2010; Petit-Breuilh, 2004; GVP, 2025). At least one eruption with a VEI greater than 2 is estimated to occur approximately every 22 years for the volcano (Van Daele, 2014). However, Villarrica has also demonstrated the potential for VEI 3 eruptions, such as those in 1948, 1963, and 2015 (Fig. 2), and is also capable of VEI 4 eruptions, such as those in 670 CE and 1230 CE (GVP, 2025). Most Villarrica eruptions have exhibited Hawaiian to

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Strombolian eruptive styles, with associated hazards primarily including lahars, lava flows, tephra fallout, and small-volume pyroclastic flows (Petit-Breuilh, 2004; Moreno, 2006). The most significant eruptions resulting in casualties occurred in 1948, 1949, 1963, and 1971, with a cumulative death toll of approximately 60 people, all due to lahar impacts (Petit-Breuilh, 2004; Moreno, 2006). The VEI 3 eruption in March 2015 involved powerful lava fountains, pyroclastic density currents near the vent, and lahars, prompting evacuations (Romero et al., 2023). Fortunately, no severe impacts were recorded, although the mental health effects on emergency response volunteers were later studied, emphasizing the need for psychosocial interventions during and after disasters (Espinoza et al., 2019).

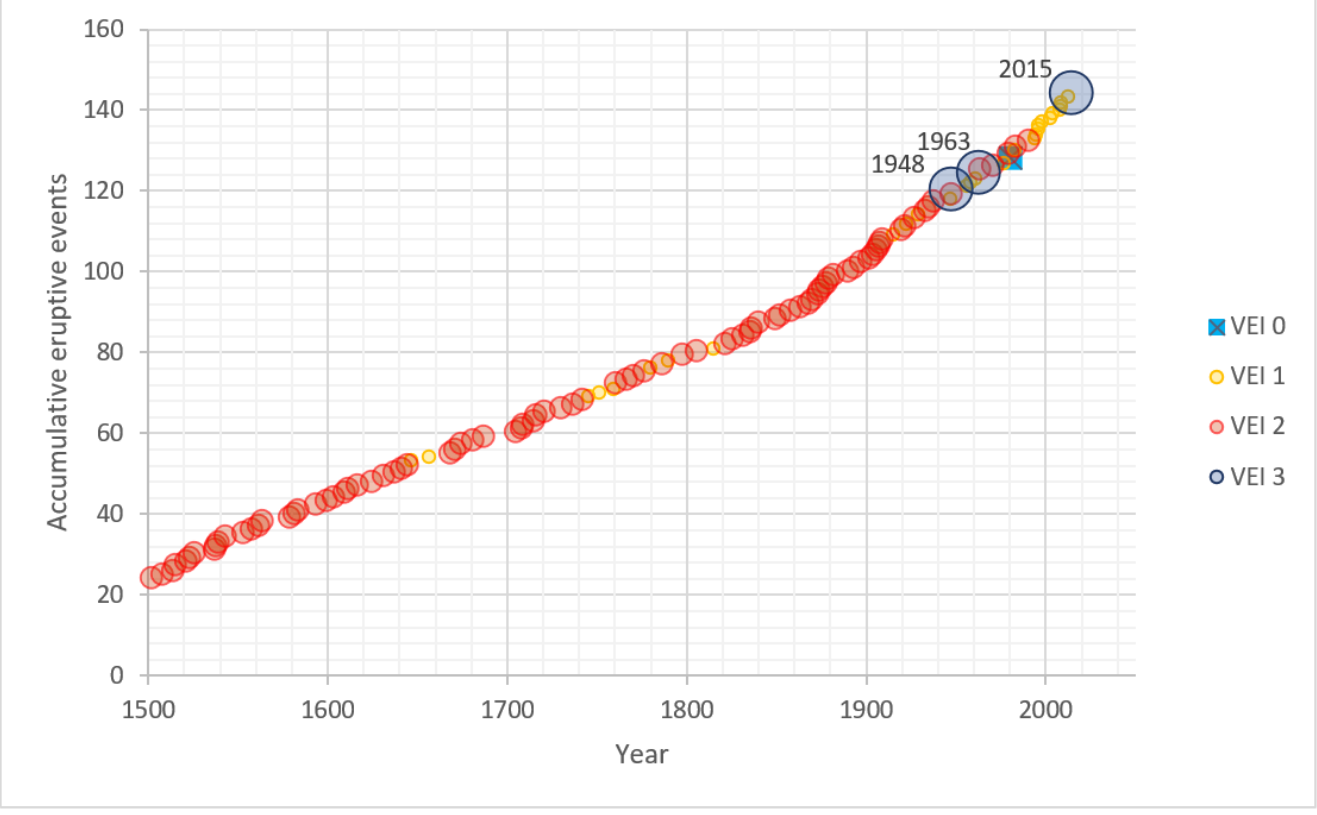

Figure 2: The eruptive record of Villarrica volcano over the past 500 years.

2 Methodology

The Psychometric Paradigm guides the development and implementation of a VRP questionnaire, structured into thematic groups of questions to estimate selected VRP factors (Section 2.1). In this case study, a k-means calculation is applied to surveyed answers from completed questionnaires to create a five-tier index scale based on their resulting k-means scores, representing relative volcanic risk perception levels. This approach allows for a detailed statistical analysis of the variance associated with selected risk perception factors by analyzing the k-means scores of calculated cluster centroids (Section 2.2).

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Furthermore, the cultural social characteristics of the sample are grouped and analyzed to assess how their relative VRP is distributed, providing insights into the influence of social and cultural characteristics on risk perception (Section 2.3).

2.1 Questionnaire design and application

We designed a survey consisting of twenty-eight questions addressing various aspects of risk perception and individuals' attitudes toward volcanic emergencies. The selected risk perception factors included knowledge, internal trust, external trust, and attachment to the place, which have been widely studied in volcanology (Section 1; Table 1). The survey questionnaire also included questions to determine cultural groups (Section 2.3). The survey was administered during two fieldwork campaigns conducted by the Chilean National Geological and Mining Service (SERNAGEOMIN) personnel. The first campaign, in 2016, targeted 19 census zones of rural areas, while the second, in 2017, focused on the two primary urban areas at risk: Pucón and Coñaripe. In this study, the summit of Villarrica Volcano marks the tripartite political-administrative boundary between the districts of Villarrica, Pucón, and Panguipulli in Chile (Fig. 3). The distinction between districts in the VRP results is crucial for supporting emergency management, as volcanic emergency plans in Chile, as in many other regions, are designed at the district level. Efforts were made to represent the sparsely populated rural areas of all exposed districts as accurately as possible. However, some higher valley areas near the volcano's summit were inaccessible due to road closures and poor weather conditions.

Table 1. Selected factors and associated desirable answers for VRP conditions according to current disaster risk science.

VRP factor	**A positive sense of answers for appropriate VRP**
Knowledge	They know the Villarrica volcano may erupt again
	They know what a lahar is and their potential consequences
	They know there is a district emergency plan for volcanic emergencies
	They know where safe areas are in case of a volcanic emergency
	They know volcanic activity cannot be forecasted in too much advance
	They have access to the Villarrica volcanic hazard map elaborated by SERNAGEOMIN
	They know eruptions are highly frequent in Villarrica volcano
	They have safety implements such as masks to protect themselves in case of volcanic ash
	They think it is essential to understand the available Villarrica volcanic hazard map
Internal trust	They are aware it is better not to be close to a river in case of a new eruption
	They are aware that an eruption may impact them directly
	They are aware eruption cannot be controlled by anybody
	They would actively follow authority instructions in case of a new eruption
	They think safety is not entirely in their control in case of an eruption

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	They would not get close to the volcano to check the eruption by themselves in case of eruption
External trust	They do not feel completely prepared by themselves in case of an eruption
	They would evacuate in case of an evacuation warning from authorities
	They do not rely on divinity to protect them in case of eruption
	They have an emergency contact in case they require evacuation
	They agree on promoting education about volcanic activity in volcanic' surrounding areas
	They trust in the Disaster Risk Management process implemented for volcanic emergencies by the government
Attachment to the place (not answered by non-residents)	They would evacuate in case of a new eruption
	They are aware their home is in a highly exposed zone in case of eruption
	They state to be aware of associated risks living in volcanic-exposed areas
	They would not build a new house in the same place in case its result destroyed by a new volcanic eruption
	They would move permanently to a different location to avoid a potential eruption
	They have a family evacuation emergency plan in case of a new eruption
	They think there is not adequate urban development in volcanic hazard zones

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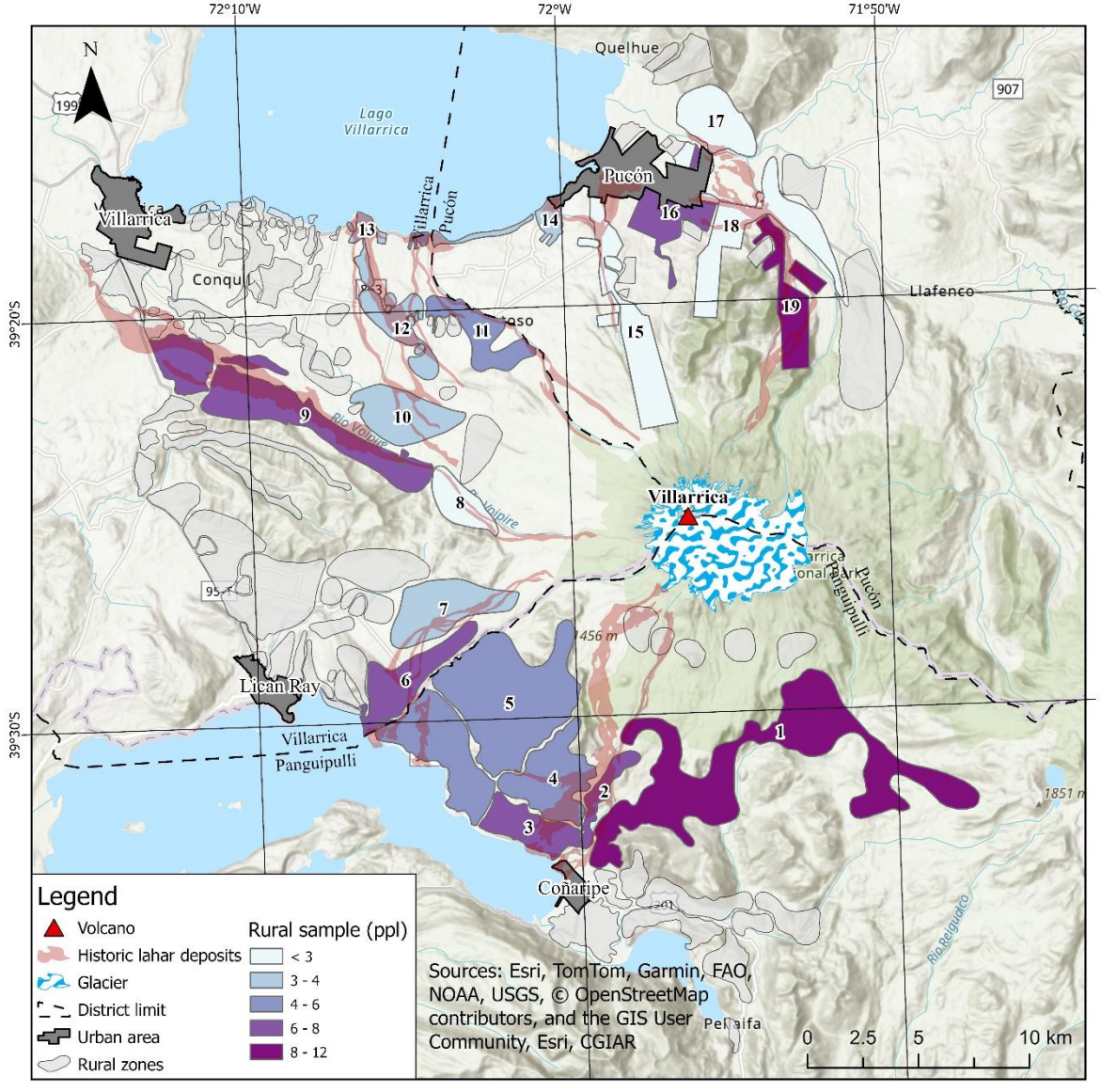

Figure 3: Rural areas zones for questionnaire application.

A total of 412 questionnaires were completed, with the sample geographically distributed in proportion to the population based on the available census data at the time (Table 2). Non-resident transient populations were also surveyed in urban areas, and responses related to attachment to the place were deemed irrelevant and excluded from the results. This created two groups of collected data: residents (n = 205), who responded to all four selected VRP factors, and non-residents (n = 207), for whom attachment to the place was not considered. VRP calculations were applied independently to each sample group. Most of the completed questionnaires were collected in the Pucón urban area (229), with more than half (150) representing the non-residential population. In the Coñaripe urban area, 78 questionnaires were collected, of which also more

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than half (57) were completed by non-resident transient respondents. In rural areas, only residents (105) were surveyed directly in their sparsely distributed households (Fig. 3). All samples were calculated with 95% statistical confidence and a standard error of less than 0.1, representing the total population accounted for in the available census data at the time of the survey application (Table 2).

Table 2. Sample calculation and residency of the surveyed population

Zones	Population	Source	Total surveyed sample	Residents	Non-residents	Confidence	Std. error
Pucón town	17.538	Census 2017	229	79	150	0.95	0.06
Coñaripe town	1.477	Census 2017	78	21	57	0.95	0.1
Rural areas	4.750	Census 2002	105	105	0	0.95	0.1

2.2 K-means Clustering analysis and social characterization

Each survey question is assigned a value of one (1) when the response aligns with a theoretically optimal VRP (Table 1). Each aspect, including knowledge, internal trust, external trust, and attachment to the place, receives an average score based on all related questions (Table 1). These scores are then categorized into five clusters using a k-means analysis (Eq. 1), which defines hypothetical centroids for each cluster based on Standard Variation, centroid scores are sorted ranging from high to low scores and then classified as very high, high, moderate, low, and very low translating into VRP levels. The clustering outcomes represent relative VRP based on their calculated clusters´ centroids, where the highest sum scores represent better conditions of VRP in the selected sample based on our current understanding of risks according to disaster risk science.

Equation 1

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2$$

Where:
J= Objective function
k= Number of clusters
n= Number of cases
x_i= Case i
c_j= Centroid for cluster j

2.3 Cultural groups analysis

In this research, the primary classification of cultural groups distinguishes between two main population samples: residents and non-residents. This distinction is important for understanding relative influences on VRP, as non-residents or transient visitors are generally believed to have lower awareness levels due to limited knowledge of local volcanic emergency plans, lack of preparedness, and a greater tendency to approach volcanic summits (Mei et al., 2020; Bird et al., 2010; Nomura et al., 2004). Unlike rural areas, where only permanent residents were surveyed, urban areas such as Pucón and Coñaripe included

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both residents and transient populations (Fig. 4 and Fig. 5). This classification also incorporates social variables commonly used in risk assessments of individuals and communities exposed to volcanic activity. The selected variables include age, educational level, gender, native identity, religion, language, occupation, and economic activity, with classifications and known vulnerable groups described below.

2.3.1 Age

Age groups are classified as young adults (18–40 years), adults (41–65 years), and the elderly (over 65 years). Children, a recognized vulnerable group during emergencies (Cutter, 2017), were excluded from this research due to ethical concerns regarding the sensitive nature of risk perception studies involving minors. In addition to children, the elderly population is considered more vulnerable during emergencies due to their relatively reduced mobility and reaction capacity. However, some studies have found little correlation between age and risk perception (e.g., Barberi et al., 2008).

2.3.2 Educational level

Educational level is categorized into three groups: primary, secondary, and tertiary education, regardless of whether respondents completed them. Some studies, such as Ricci et al. (2013) and Njome et al. (2010), have found a negative correlation between educational level and trust in authorities, suggesting that highly educated individuals may be more reluctant to follow official instructions during emergencies. Conversely, lower educational levels tend to be associated with reduced self-preparedness and lower engagement with official preparedness measures in the context of volcanic emergencies (Ricci et al., 2013).

2.3.3 Gender

Gender is classified as male and female. This study does not inquire about gender identity, including LGBTQ+ groups, as it remains a sensitive and evolving topic beyond the scope of this research. Women are recognized as a highly vulnerable group in the context of natural hazards due to persistent social inequalities, which in turn increase the vulnerability of children (Cutter, 2017). In the volcanic risk literature, women tend to be more aware of and concerned about volcanic hazards, whereas men are generally considered to exhibit higher levels of self-protection when facing the consequences of volcanic emergencies (Barberi et al., 2008; Eiser et al., 2015).

2.3.4 Native identity and professed religion

Native identity is classified into two categories: native and non-native. Professed religion is categorized based on the most prevalent religions in Chile: Catholic (59%), Evangelism (19%), and other (17%) (CPPUC, 2017). Cultural beliefs, including strong native identity and religious faith, can influence self-efficacy in responding to volcanic emergencies. For instance, some individuals may choose not to evacuate during an eruption, instead of waiting for a spiritual warning or divine communication (Wantim et al., 2024; Barclay et al., 2015; Njome et al., 2010). However, these beliefs and identities can also

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foster strong social networks and a sense of community, which may aid in effectively communicating volcanic risk information (Barclay et al., 2015; Chester et al., 2008). Additionally, they can contribute positively to socio-ecological system relationships (Salazar et al., 2016).

2.3.5 Nationality and language

The sample is classified by nationality and language into three groups: Chilean, Hispanic American, and non-Spanish speakers. Cultural and language barriers are widely recognized as major challenges in understanding local risks and emergency plans (Ogie et al., 2018; O'Brien et al., 2018; Teo et al., 2019). In the context of volcanic risk, temporary workers often have lower adaptive capacity due to weaker social networks, differing cultural beliefs, and reduced trust in local volcanic warning systems (Thouret et al., 2022).

2.3.6 Occupation

Occupation is classified into four categories: employed, unemployed, student, and stay-at-home or retired. Employment status can influence VRP, as employed individuals may receive emergency preparedness information through workplace programs, whereas unemployed individuals may face additional financial challenges that could impact their ability to respond to emergencies. Students and young educated individuals often have greater access to risk-related knowledge through educational programs and technology, such as the Internet, which can enhance their understanding of hazards and emergency plans (Chester et al., 2008). In contrast, stay-at-home and retired individuals may have limited access to such information, making them potentially more vulnerable during volcanic emergencies.

2.3.7 Economic activity

The surveyed employed population is categorized into four economic activities: tourism, agriculture, handcrafting, and others. Tourism is particularly sensitive in volcanic areas, as landscapes attract visitors who often lack hazard knowledge and preparedness. Similar trends have been observed among tourism employees, who may have a limited understanding of early warning systems (Brid et al., 2010). Agriculture is highly vulnerable to volcanic eruptions due to widespread ashfall, which can significantly impact farmers, crops, and livestock (Bonadonna et al., 2021). Handcrafting is also affected, as eruptions lead to a decline in tourism, reducing the number of potential customers.

3 Results

The following sections present the results of the K-means calculations for residents and non-residents exposed to proximal volcanic activity from Villarrica volcano and their geographical distribution of resulting relative VRP, the statistical distribution of the evaluated VRP factors, and the social characterization of the sample based on their assigned VRP levels. The discussion section then highlights the main insights from these results and the methodological approach combining the

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psychometric paradigm and cultural theory frameworks, followed by future research recommendations. Finally, a conclusion section summarizes the contributions of this research.

3.1 Results of VRP levels

K-means calculations show a balanced distribution of VRP groups across the 205 resident and 207 non-resident questionnaires, averaging approximately 20% per group (Fig. 4). Among residents, the highest concentration is in the high VRP with 25.9% of the sample, compared to a maximum of 21.3% for non-residents in the same category. Residents make up 20% and 19.5% of the low and very low VRP, respectively, while non-residents account for 20.8% in the moderate and 20.3% in the very low VRP. The lowest concentrations for both groups are in the very high VRP category, with 17.1% for residents and 18.8% for non-residents. Additionally, non-residents also comprise 18.8% of the very low VRP (Fig. 4).

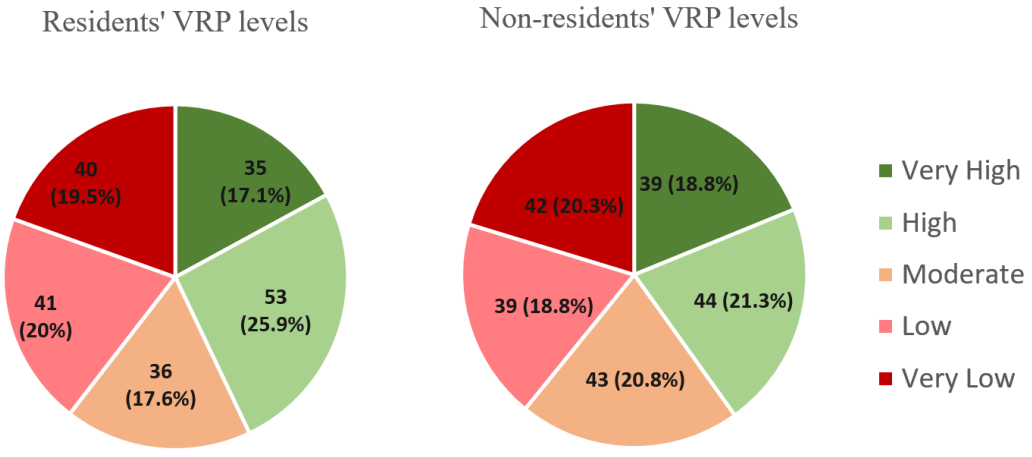

Figure 4: Total results of VRP levels and percentage by residents and non-residents.

3.2 Geographical distribution of residents' VRP levels

VRP varies significantly by district. Given the high dynamics and mobility of non-resident transient populations, they require separate study and treatment. Therefore, we present the geographical distribution only for residents, who are relatively more spatially stable. In the Pucón district, residents show a higher proportion of very high (26.2%), high (21.5%), and moderate (28%) VRP levels, while low and very low VRP each account for only 12.1% (Fig. 5). Villarrica district has a higher concentration of very low (41%) and low (43.6%) VRP of all the studied districts. In contrast, high VRP accounts for 12.1%, very high for only 2.6%, and no cases are recorded in the moderate VRP category (Fig. 5). In Panguipulli, high VRP dominates at 42.4%, followed by very low (20.3%), low (16.9%), and moderate and very high VRP, each representing 10.2% (Fig.5). In both the Pucón and Panguipulli districts, the trend is mostly influenced by answers collected in urban areas

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with a higher proportion of very high, high, and moderate VRP, such as in Pucón town (Fig. 6). In contrast, particularly in Villarica's rural zones and all other studied districts concentrate large proportions of low and very low VRP (Fig. 6).

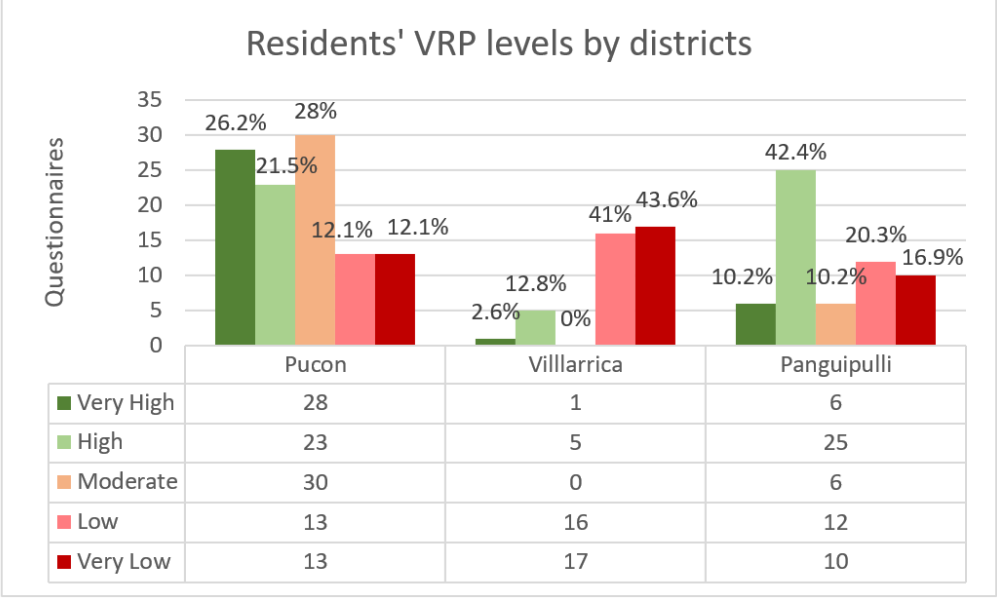

Figure 5: Total results of VRP levels and percentage by districts.

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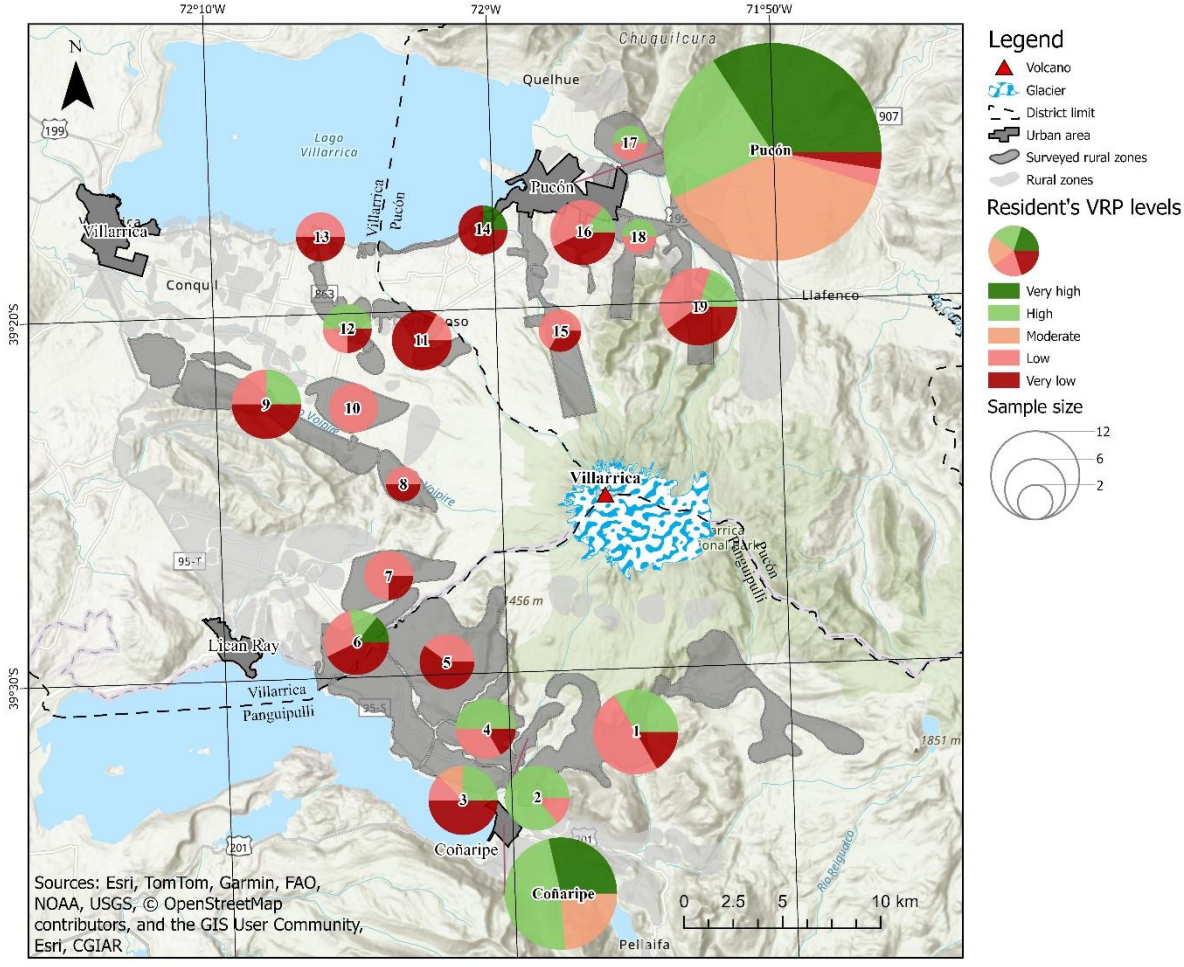

Figure 6: Geographical distribution of VRP levels.

3.3 Statistical distribution of VRP factors

This psychometric approach using k-means calculations offers valuable information on how each selected VRP factor statistically contributes to resulting VRP levels, enabling a more detailed characterization of their influence. The following paragraphs describe the residents and non-residents' distribution of VRP factor scores for each VRP level.

3.3.1 VRP factors by residents

Four VRP factors were evaluated for residents: knowledge information, internal trust, external trust, and attachment to the place. Among these, knowledge information shows the greatest difference between the calculated cluster centroids for each VRP level (Fig. 7). In this factor, the very low VRP level has a significantly lower score (-0.9 Std. dev.) compared to other levels (ranging from -0.5 to 0.2 Std. dev.), suggesting that residents in this category have a relatively weaker understanding

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of volcanic processes and their potential impacts. The very low, low, moderate, and very high VRP levels follow an increasing trend, whereas the high VRP level (-0.4 Std. dev.) is closer to the low VRP level (-0.5 Std. dev.), sharing similar knowledge information scores (Fig. 7). Regarding internal trust, the low VRP level has the highest score (0.3 Std. dev.), followed by very low, high, and very high VRP levels (between 0 and 0.1 Std. dev.), while the moderate VRP level has the lowest score (-0.2 Std. dev.). The higher internal trust scores for the low VRP level might reflect a greater awareness of vulnerability among residents living in a hazardous environment. In terms of external trust, scores are divided into two main levels: very high, high, and moderate VRP (0.2–0.3 Std. dev.), indicating a higher willingness to evacuate in case of an alarm, and low and very low VRP (-0.1–0 Std. dev.), suggesting a greater reticence to follow authorities' instructions. For attachment to the place, all VRP levels have similar positive scores (0.1–0.2 Std. dev.), indicating a residents' similar willingness to evacuate in a volcanic emergency.

3.3.2 VRP factors by non-residents

Three VRP factors were evaluated for non-residents: knowledge information, internal trust, and external trust. In terms of knowledge information, the very high and moderate VRP levels have the highest scores (approximately 2 Std. dev.), indicating a relatively better understanding of volcanic risks compared to the more moderate scores (around 0 Std. dev.) observed in the very low, low, and high VRP levels (Fig. 8). Although internal trust scores are generally low, they show a wider variation across VRP levels, ranging from very low (-0.3 Std. dev.), moderate (-0.2 Std. dev.), and low (-0.1 Std. dev.) to very high and high (both around 0 Std. dev.) (Fig. 8). These internal trust scores may suggest general overconfidence among non-resident visitors in facing volcanic emergencies, particularly within the very low, low, and moderate VRP levels. Regarding external trust, most scores are positive, with the very high VRP level reaching the highest score (0.3 Std. dev.), followed by a cluster of high, moderate, and very low VRP levels (ranging from 0.1 to 0.2 Std. dev.), and finally, the low VRP level (0 Std. dev.). These scores suggest that non-residents generally show a willingness to cooperate with authorities in the event of a volcanic alert, particularly those at the very high VRP level.

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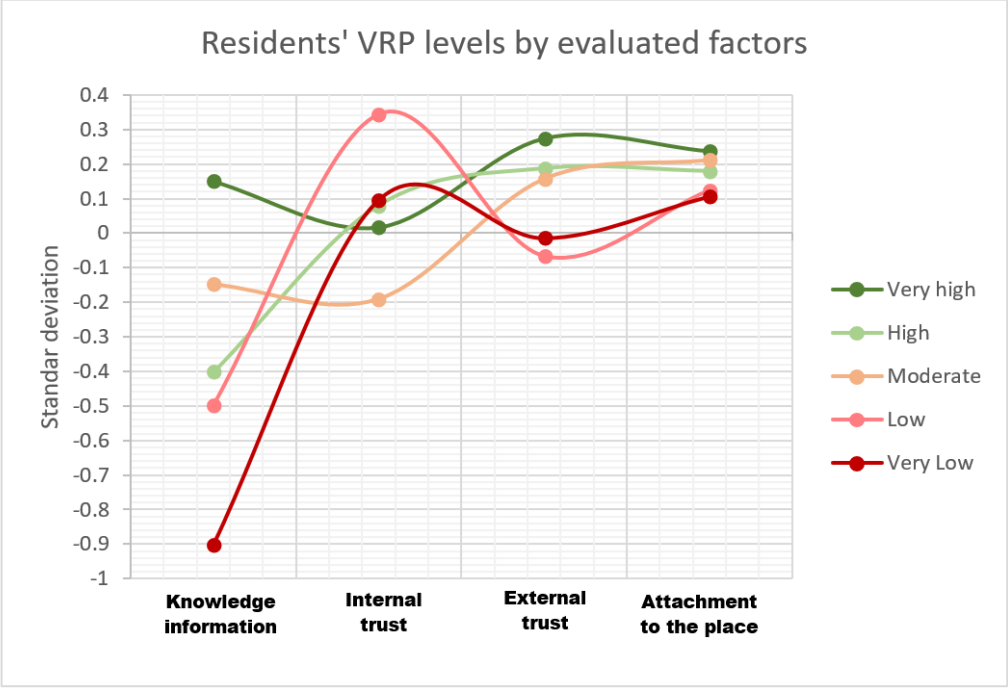

Figure 7: Statistical distribution of VRP factors for residents.

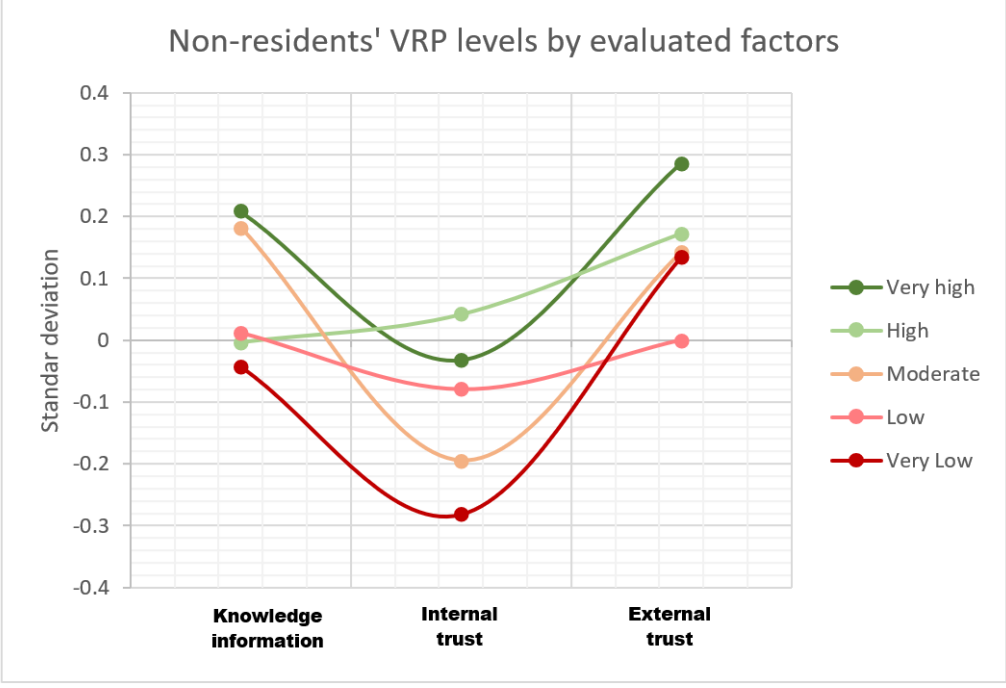

Figure 8: Statistical distribution of VRP factors for non-residents.

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3.4 Statistical distribution of VRP factors

Among the evaluated cultural groups, the most variability across VRP levels for both residents and non-residents is observed in age, education level, native identity, occupation, and economic activity (Fig. 9), which differences are described in the following paragraphs. In contrast, gender (roughly 50% male and 50% female, and slightly more concentrated) and religion (roughly average 50% catholic, 25% non-religious, and 25% Evangelical or other) exhibit less variability or a more balanced distribution (Fig. 9). Regarding nationality and language, foreign residents are predominantly represented in high and moderate VRP levels, while foreign non-residents are mostly concentrated in moderate and low VRP levels.

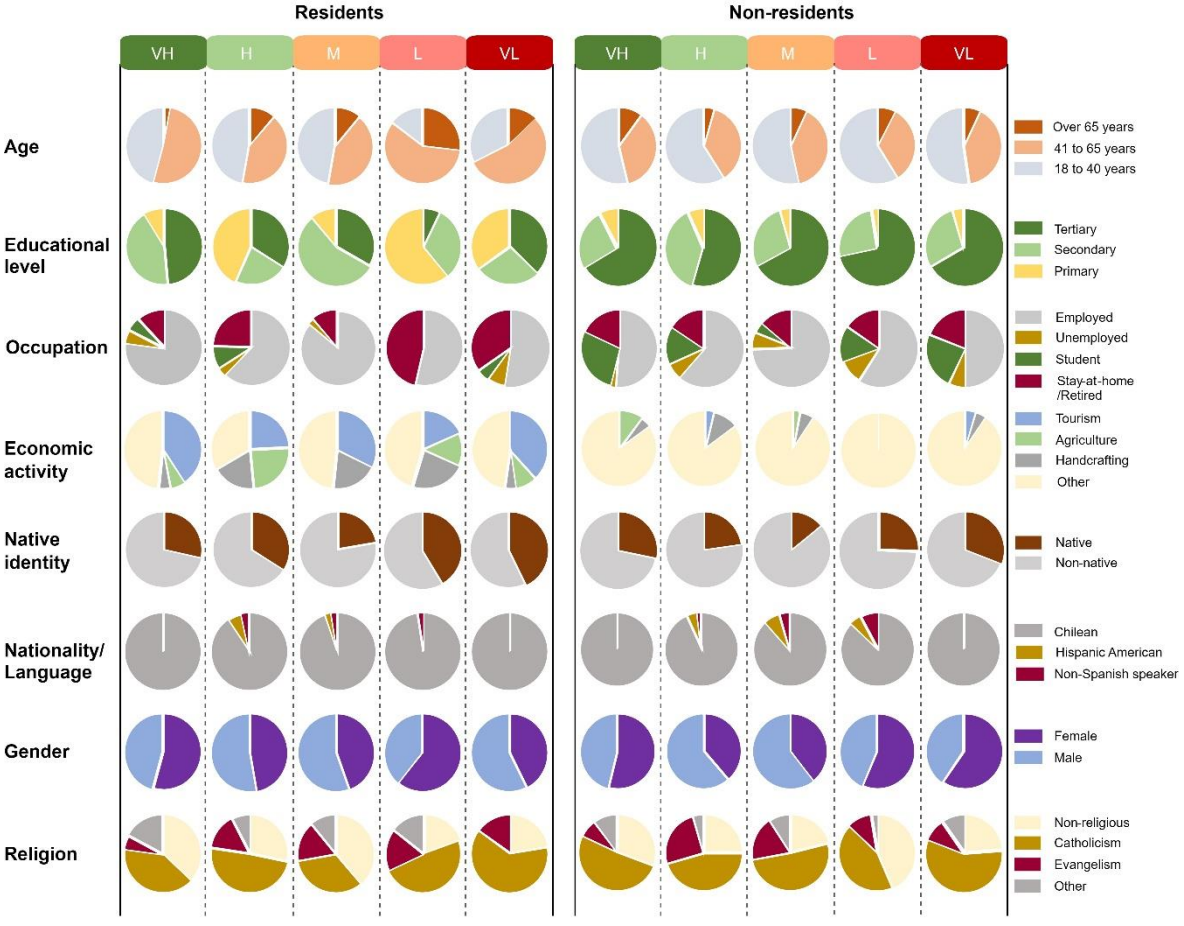

Figure 9: Distribution of cultural groups by VRP levels results for residents and non-residents.

3.4.1 VRP Levels by Age

In the sample, elderly residents are distributed relatively evenly across VRP levels, comprising about 12% in each category, except that the very low VRP level represents 27% of the total. Elderly non-residents show a consistent presence of approximately 7.5% across all categories. Adults make up 40–60% of residents and 30–40% of non-residents across VRP

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categories, with a higher concentration among residents of about 59% and 55% in the low and very low VRP levels, respectively. Young adults display similar proportions, comprising about 50% in most categories, except for a reduced presence of approximately 15% among residents with low VRP levels and about 30% with very low VRP levels.

3.4.2 VRP Levels by Educational level

The primary education group is highly represented among residents, accounting for 61% of the low and 35% of the very low VRP levels. Secondary education is most prominent in the moderate VRP level (57%) and the very high VRP level (43%). In contrast, individuals with tertiary education are predominantly non-residents, comprising 55–70% across all VRP categories, with a peak of 72% in the very low VRP level.

3.4.3 VRP Levels by Occupation

Employment dominates across all VRP categories, averaging 66% for residents and 59% for non-residents, with the highest concentrations in the moderate VRP level (86% for residents and 75% for non-residents). The second most dominant group, stay-at-home or retired individuals, averages 25% among residents and 16% among non-residents. This group is primarily concentrated in the low (46%) and very low (35%) VRP levels among residents. Students are mostly non-residents, with major concentrations in extreme VRP levels 28% high and 23% very low. They account for an average of 15% in both high and low VRP levels, while only about 5% are in the moderate category. Among residents, students average 4% across all VRP levels, peaking at 9% in the high category, with no representation in the moderate or low levels.

3.4.4 VRP Levels by Economic Activity

Most of the evaluated economic activities are concentrated in the resident category. Tourism-related employment among residents is distributed mainly to the extreme VRP levels, with 40% in the very high category, 38% in the very low category, and 32% in the moderate category. Agriculture is also primarily represented among residents, with 24% in the high VRP level, 14% in the low level, and 10% in the very low level. In contrast, non-residents working in agriculture tend to concentrate on the very high VRP level (10%). Handcrafting is most prevalent in the high (18%), moderate (19%), and low (23%) VRP levels. Among non-residents, those engaged in handcrafting are most represented in the high VRP level (11%).

3.4.5 VRP Levels by Native Identity

People who self-identify as natives make up approximately 25% of all VRP levels for both residents and non-residents. However, among residents, they are more concentrated in the low (42%) and very low (43%) VRP levels.

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4 Discussion

4.1 Methodological approach

The Psychometric Paradigm and Cultural Theory approaches were combined in this research, where responses from a questionnaire allowed not only the assessment of relative risk perception levels but also an analysis of how selected factors influence them and how different cultural groups are characterized by these levels. Both approaches have been criticized for their low statistical explanatory power (e.g., Sjöberg, 1996; Marris et al., 1998). Marris and others (1998) tested these approaches and found several cultural biases, although the psychometric approach explains about 32% of the variations in risk perception for only one out of four specifically analyzed cultural groups. However, as suggested by other studies (e.g., Paton et al., 2011; Zeidler, 2015; Renn & Rohrmann, 2000; Jones et al., 2013), we do not disregard the complementary usefulness of Cultural Theory, particularly in characterizing the cultural patterns of the surveyed population. We argue that both approaches are complementary and, when used together, provide broader and more practical risk perception insights to support emergency management strategies. The results of this study illustrate that the Psychometric Paradigm is useful for capturing the statistical dynamics of multiple risk perception factors, while Cultural Theory offers insights into how groups usually studied in volcanic with similar risk perception levels are composed. Both risk perception levels and cultural patterns could help civil defense agencies, for example, in better targeting population groups with tailored emergency management strategies.

4.2 Methodological approach

Residents and non-residents represent a fundamental distinction in this research, as both groups were targeted with the same VRP questions, except for those related to place attachment. This distinction is justified because transient visitors (non-residents) typically lack a local sense of community, including emotional attachment to the place and civic participation in emergency planning (Paton et al., 2008; Barbieri et al., 2008; Ricci et al., 2013). For residents, the results indicate consistently positive behavior across all VRP levels, which may reflect a strong sense of community when facing volcanic emergencies (Section 3.3.1). Only three VRP factors were evaluated for both residents and non-residents: knowledge, internal trust, and external trust. Among these, knowledge showed the greatest variation between the two groups, which residents scored lower, while non-residents exhibited more moderate scores (Section 3.3). This discrepancy may suggest that exposed residents might lack an adequate understanding of volcanic hazards and their consequences, a trend widely observed in volcanic risk literature (e.g., Carlino et al., 2008; Ricci et al., 2013; Davis et al., 2005). Regarding internal trust, non-residents displayed lower and predominantly negative VRP scores compared to residents (Section 3.3), suggesting that non-residents may have lower risk awareness and a tendency to overestimate their ability to handle volcanic eruptions (Barberi et al., 2008). In contrast, external trust was similar across both groups, with mostly positive scores at all VRP levels (Section 3.3). This finding suggests that both residents and non-residents trust experts and authorities, making them more likely to follow official guidelines and emergency protocols (Espluga et al., 2016; Njome et al., 2010; Haynes et al., 2008).

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4.3 Cultural patterns of VRP levels

Some cultural patterns in the resulting VRP levels can be identified among residents, primarily based on age and educational level, whereas non-residents are more evenly distributed across all VRP levels (Section 3.4). In the sample, residents tend to be slightly older than non-residents, with adults and elderly individuals more concentrated in low VRP levels. Notably, elderly individuals, a known vulnerable group within this research that tends to lower VRP scores, could benefit from tailored risk management strategies. However, as in similar studies, no clear pattern of influence between age and VRP level has been established (e.g., Barbieri et al., 2008). In contrast, educational level exhibits a stronger correlation with VRP (Section 3.4). Among residents, those with primary education are predominantly concentrated in the low (61%) and very low (35%) VRP categories, though a notable proportion (43%) also falls into the high VRP category. A clearer pattern emerges with secondary education, where more than 50% of individuals are found in the very high and moderate VRP levels, suggesting a potential relationship between higher education and increased risk perception. Among non-residents, tertiary education is highly prevalent across all VRP levels, but no clear differences in VRP levels are observed within this group.

Regarding occupation, individuals outside the workforce, such as stay-at-home or retired residents, are predominantly concentrated in the low (46%) and very low (35%) VRP categories (Section 3.4). This group could be considered vulnerable and may require targeted risk communication and engagement strategies. In contrast, students are primarily represented in the non-resident sample, with their VRP levels distributed at the extremes, notably very high (28%) and very low (24%). This distribution suggests no clear pattern influencing VRP, despite students' greater access to technology and information (or misinformation), as observed in other studies (e.g., Chester et al., 2008; Njome et al., 2010). Among those active in the workforce, both employed and unemployed individuals are relatively evenly distributed across all VRP categories. However, for residents, VRP levels vary significantly depending on their economic activity (Section 3.4). Some occupations in the study area such as handcrafting, agriculture, and particularly tourism are highly sensitive to volcanic eruptions and exhibit extreme variations in VRP levels. Given that individuals in these sectors face direct consequences from volcanic activity, efforts to enhance their risk awareness and preparedness could be crucial for improving overall resilience.

Despite the results showing a slightly higher concentration of self-identified native populations in the low (42%) and very low (43%) VRP categories (Section 3.4), a deeper understanding of indigenous knowledge is needed to better assess their relationship with the volcanic threat and the subsequent response to eruptive activity. Some efforts have been made to integrate indigenous knowledge when interpreting VRP (e.g., Hastangka & Suprapto, 2023; Niroa & Nakamura, 2022; Order et al., 2016) and future development should incorporate these findings. A similar gap exists regarding gender identity, as no clear pattern was found across VRP levels. Further research is necessary to evaluate whether, and to what extent, different gender identities influence volcanic risk perception (e.g., Cutter, 2017; Barberi et al., 2008; Eiser et al., 2015). Likewise, no distinct pattern was identified concerning religion. However, literature suggests that shifts in religious beliefs, including the radicalization of some ideologies, may shape individuals' worldviews and, consequently, their risk perception (e.g., Clarke, 2005; Breskaya & Zrinščak, 2024).

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5 Conclusion

This research integrates the Psychometric Paradigm and Cultural Theory to examine VRP, demonstrating that both approaches are complementary and provide to some extent valuable insights for risk management. While the psychometric approach captures the statistical dynamics of multiple VRP factors, Cultural Theory helps identify patterns in how cultural groups perceive risk. Together, these frameworks offer a more comprehensive understanding of risk perception that can support the development of more targeted emergency management strategies. A key finding of this research is the difference in VRP between residents and non-residents. Residents, who tend to have stronger community ties, exhibit lower levels of risk knowledge but higher levels of internal trust, whereas non-residents display higher knowledge scores but lower internal trust, possibly leading to an overestimation of their ability to handle volcanic hazards. However, both groups share similar levels of external trust, suggesting that trust in experts and authorities plays a critical role in their willingness to follow emergency protocols. Additionally, socio-demographic factors such as age, education, and occupation influence VRP. Elderly individuals and those outside the workforce are more likely to have lower VRP, making them particularly vulnerable groups that may require tailored risk communication strategies. Education appears to play a significant role, with higher educational attainment correlating with increased VRP among residents. Similarly, individuals employed in economically sensitive sectors such as tourism and agriculture display extreme variations in VRP, highlighting the need for sector-specific risk awareness initiatives. The study also identifies areas that require further exploration. Indigenous populations are slightly overrepresented in lower VRP categories, suggesting a need for greater integration of Indigenous knowledge into volcanic risk assessments. Likewise, no clear patterns were observed concerning gender identity or religion, yet existing literature suggests these factors could influence risk perception in complex ways. Future research should investigate how sociocultural influences shape VRP and explore more nuanced factors that may impact public responses to volcanic hazards. Overall, this research reinforces the importance of considering cultural, social, and economic contexts in volcanic risk perception studies. By incorporating diverse perspectives and improving targeted communication efforts, emergency management agencies can enhance community resilience and preparedness in volcanic regions.

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