

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 living in or visiting the high-hazard zone of Villarrica volcano. While the psychometric approach captures statistical variations in the multidimensional structure and relative positioning of key VRP factors, Cultural Theory helps characterize and interpret the cultural patterns influencing through which risk perception is socially differentiated. Together, these approaches provide a more comprehensive framework for understanding VRP in support of emergency management. In this study, VRP is interpreted as a relative measure of awareness of potential volcanic consequences and preparedness-related factors, rather than as an expression of alarmism or perceived likelihood. A key distinction is observed between residents and non-residents. Residents show lower risk-related knowledge scores but higher levels of internal trust, suggesting strong community ties yet alongside more limited understanding of volcanic hazards. Non-residents, in contrast, exhibit higher knowledge scores but lower internal trust, which may lead to overconfidence in their ability to respond to eruptions. However, both groups are associated with a potential overestimation of individual coping capacity during volcanic events. Despite these differences, both groups show similarly high levels of external trust, indicating confidence in authorities and experts, which is vital and suggesting favourable conditions for adherence to safety measures. Demographic and official emergency guidance. Socio-demographic factors also influence and further shape VRP configurations. Elderly individuals and those outside the workforce tend to occupy lower VRP positions, highlighting the need for targeted groups that may benefit from tailored risk communication strategies. Higher education levels correlate with educational attainment is generally associated with higher VRP, while economic activity (e.g., particularly in sectors such as tourism and agriculture) influences, is linked to pronounced variability in risk perception, with some groups exhibiting extreme variations. Further effort is needed on indigenous populations, as they show are slightly overrepresented in lower VRP, warranting better integration

35 ~~levels, underscoring the importance of indigenous integrating Indigenous knowledge systems more effectively into volcanic~~
risk assessments. ~~Similarly, In contrast, no clear patterns are observed for gender and identity or religion show no clear patterns,~~
although ~~they may still shape existing literature suggests these factors may influence risk perception in a more complex way.~~
Ultimately, ~~understanding the , context-dependent ways. Overall, the findings emphasize the importance of situating volcanic~~
40 ~~risk perception within its social, cultural and social dimensions of VRP is essential for designing, and economic context, and~~
~~demonstrate how integrating complementary theoretical frameworks can support the design of more effective, group-specific~~
risk communication strategies to ~~strengthen enhance~~ community resilience.

1 Introduction

Risk perception has been a crucial topic in disaster risk science, highlighted as a key component in the decision-making
~~processes~~ processes of individuals facing emergencies, with the outcomes of these decisions directly impacting human safety
(Siegrist & Arvai, 2020). Risk perception refers to ~~people's~~ people's judgments when characterizing and evaluating hazardous
45 activities and technologies (Slovic, 1987). These ~~sensitive~~ judgments are ~~primarily based on instinct and not purely rational~~
~~but are strongly influenced by intuition, affect, and experience~~ (Slovic & Peters, 2006), and involve ~~processes of~~ collecting,
selecting, ~~and interpreting, and communicating~~ signals about ~~the uncertain impacts of disaster and potentially harmful~~ events
(Wachinger, et al., 2013). ~~Consequently, risk perception is widely recognized as a contextual, socially embedded, and~~
50 ~~multifactorial process rather than a purely individual cognitive assessment (Gaillard, 2010).~~

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,~~
55 ~~2020). However, Volcanic Risk Perception (VRP) has been considered highly relevant and, floods, and tsunami-related~~
~~disasters, while comparatively less attention has been given to volcanic hazards (Siegrist & Arvai, 2020; Favereau et al., 2018).~~
~~However, this does not imply an absence of research on Volcanic Risk Perception (VRP). On the contrary, a growing body of~~
literature, especially since the 2000s, has documented how communities exposed to volcanic activity perceive, interpret, and
60 ~~respond to volcanic hazards across different geographical and cultural contexts, including Iceland (Bird et al., 2011; Kokorsch~~
~~& Gísladóttir, 2023), Mexico (López-Vázquez, 2009), Chile (Vergara-Pinto & Romero, 2023; Alegría & Vergara-Pinto, 2024),~~
~~and Colombia (Peña et al., 2020). Collectively, these studies show that VRP is shaped by local experience, social organization,~~
~~attachment to place, trust in institutions, and disaster memory. Nevertheless, compared to other geological hazards, VRP~~
~~studies remain relatively fragmented, strongly context-specific, and methodologically heterogeneous, limiting cross-case~~
65 ~~comparison and the systematic identification of relative levels of risk perception. VRP has therefore been identified as a key~~
gap in supporting volcanic emergency strategies and safety protocols more efficiently (Favereau et al., 2018). Volcanic
~~eruption is~~ eruptions are serious ~~hazard~~ hazards, having caused the deaths of approximately a quarter of a million people over
the past five centuries (Brown et al., 2017; Auker, et al., 2013). ~~Eruptions can last~~ Unlike many rapid-onset disasters, volcanic
70 ~~crises often unfold over extended periods, lasting~~ from days to years or even decades, with varying intensities and phases. ~~The~~

~~decisions~~Decisions made by ~~individuals~~exposed to ~~these hazards~~populations during ~~such periods~~these prolonged episodes are critical, as they ~~can significantly~~strongly influence ~~the resulting~~injuries or fatalities, and long-term social impacts. Notably, over 60% of fatal volcanic incidents occur more than a week after ~~the an~~ eruption begins, with ~~over~~more than 40% of these fatalities involving individuals who ~~returned~~return to the hazard ~~zone~~zones to recover assets, ~~ensure home safety, or for other~~ reasons~~secure livelihoods, or protect homes~~ (Barclay et al., 2019). Most victims ~~were~~are residents, although non-residents or temporary visitors, such as tourists, scientists, and media personnel, ~~were~~are also ~~commonly~~frequently affected (Brown et al., 2017). ~~These patterns highlight the central role of VRP in shaping observable behaviours rather than merely attitudes toward risk.~~

~~In the last decades, some efforts~~

75 ~~Approaches to study~~studying VRP include qualitative, quantitative, and mixed methodologies. Qualitative approaches such as interviews, ethnographic studies, and narrative analyses have been particularly effective in capturing meanings, beliefs, local knowledge, and cultural interpretations of volcanic hazards (Gaillard, 2008; Dove, 2008; Bird et al., 2011). Quantitative approaches, often grounded in psychometric traditions, allow for the operationalization and comparison of risk perception across individuals and groups through standardized survey instruments (Slovic, 1987; Marris et al., 1998; Favereau et al.

80 ~~2018). Mixed approaches attempt to integrate both perspectives (Gaillard, 2010). In this study, we adopt a quantitative approach focused on recognizing~~estimating relative levels of VRP, while explicitly acknowledging the limitations of quantifying certain cultural dimensions, such as belief systems or symbolic attachments, that are inherently complex and dynamic (Gaillard, 2008). Previous research on VRP has emphasized a set of recurring factors influencing individuals' ~~judgments~~show individuals interpret and decisions in the respond to volcanic environment~~hazards~~, Favereau et al. (2018)

85 identified fourteen key peer-reviewed scientific articles as recent main studies as major contributions on volcanic risk perception (i.e., to the field (e.g., 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~~Across these studies, the most studied frequently examined VRP factors ~~from those articles are, in order of relevance, include~~knowledge, trust (both internal and external), ~~experiences~~previous

90 ~~experience, proximity to the hazard, sense of community (including and attachment to the place and civic participation), demography, demographic characteristics, and vulnerability~~. Importantly, these studies consistently demonstrate that different communities, such as rural versus urban populations or residents versus non-residents, may perceive and respond to the same volcanic threat in markedly different ways (Bird et al., 2011; Gaillard, 2010).~~Favereau et al., 2018).~~

This research aims to explore some of those main identified volcanic risk perception focuses on four VRP factors, including ~~that have been repeatedly highlighted in literature: 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.~~place. In this context, knowledge is understood as the appropriation of Knowledge refers to understanding

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100 appropriate scientific information about volcanism and its associated risks, such as volcanic processes and hazards, combined
with experiential learning derived from previous eruptions, local memory, and social transmission (Carlino et al., 2008; Ricci
et al., 2013; Davis et al., 2005). According to the literature, several previous studies indicate that knowledge is influenced
by socioeconomic factors influence knowledge characteristics such as age and education level, where the young population
105 educated about natural hazards have more clarity about risks and share and access to information among peers (Carlino et al.,
2008), although higher levels of formal education do not necessarily translate into higher perceived risk (Haynes et al., 2008;
Sjöberg, 2003). Internal trust refers to people's realistic awareness about potential consequences when facing individuals'
confidence in their own understanding and ability to respond effectively to volcanic emergencies, which sense of trust and
often associated with self-efficacy might and preparedness. This dimension may be improved by involving exposed
populations enhanced through participation in emergency planning and public discussions for emergency plans (Barclay et al.,
110 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, the degree of confidence placed in external actors, particularly scientists are seen as the most valuable
source of information compared to the media and authorities' information for the civil population (, monitoring agencies, and
authorities. Previous research shows that lower trust in experts or institutions is often associated with heightened awareness of
risk, rather than a lower perception of hazard likelihood (Espluga et al., 2009; Njome et al., 2010), and also state this by
115 authorities (Haynes et al., 2008). In this study, perceiving risk is therefore interpreted as being more aware of potential
consequences, rather than as an expression of alarmism. Attachment to the place is an important has been widely identified as
a critical factor influencing evacuation decisions and long-term exposure to volcanic hazards. Strong emotional, symbolic, and
functional ties to place often reduce willingness to evacuate in case of a volcanic emergency; usually, higher attachments pull
people not to evacuate (, even when individuals are aware of the associated risks (Barberi et al., 2008; Favereau et al., 2018;
120 Barclay et al., 2019; Barberi et al., 2008). Analysis of evacuations from 2019). However, recent volcanic emergencies provides
insights about potential pull factors (e.g., protecting assets, economic resources, or studies emphasize that attachment to the
place) and push factors (e.g., poor shelter conditions) influencing whether people remain or place should not in shelters (Barclay
et al., 2019) be interpreted as irrational resistance to safety measures, but rather as a complex relationship between identity,
livelihood, comfort, and perceived normalcy (Kokorsch & Gísladóttir, 2023).

125 The primary data for this study were collected through risk perception surveys applied in areas historically impacted by lahars
surrounding Villarrica volcano, one of the most active volcanic systems in South America. Lahars have been selected as the
focal hazard because they represent the most frequent and socially experienced volcanic process affecting nearby communities
and have historically caused the most severe impacts in the region. While other hazards, such as tephra fallout, may occur, the
emphasis on lahars reflects a focus on locally experienced and socially internalized threats. Villarrica volcano is located in the
130 Southern Volcanic Zone of Chile and has produced approximately 160 eruptions over the past 2,000 years, with around 130
events recorded during the last five centuries (GVP, 2025). Most eruptions have been effusive, with a Volcanic Explosivity
Index (VEI) of 2, although the volcano has also produced VEI 3 and VEI 4 events (Petit-Breuilh, 2004; Van Daele, 2014). The
most severe impacts have been associated with lahars, which have repeatedly affected nearby urban and rural settlements,

135 including Pucón, Coñaripe, Villarrica, and surrounding rural valleys. Seasonal population increases due to tourism further
140 complicate exposure patterns and risk communication strategies. Risk perception levels are calculated using a statistical
clustering method based on survey responses, allowing for the identification of relative VRP profiles among residents and non-
residents. Demographic and socioeconomic variables are then analyzed to explore their influence on these profiles. This study
combines two complementary theoretical approaches: the psychometric paradigm, which supports the quantitative estimation
of relative VRP levels, and cultural theory, which facilitates the interpretation of social trends and contextual patterns within
145 different VRP groups. The following subsections describe these frameworks (Sections 1.1 and 1.2), followed by a description
of the study area and volcanic history (Section 1.3). The Methods section details the survey design and analytical procedures,
while the Results and Discussion sections present and interpret the findings in relation to volcanic risk management and
preparedness strategies.

1.1 General frameworks to study risk perception

145 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). These approaches are particularly useful
when the objective is to compare risk perception across individuals or social groups and to relate perception patterns to
150 decision-making and behavioural responses in emergency contexts. 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~~ within
different VRP groups based on ~~the~~ cultural theory ~~approach~~ perspective (Section 2.3). In this context, VRP levels are
understood as analytical and comparative constructs rather than absolute or fixed categories, allowing the identification of
155 gradients and profiles of perception within the studied population.

1.1.1 Psychometric Paradigm

The Psychometric Paradigm originated from psychology to gain insights into people's understanding of risk and ~~enhance~~
~~emergency~~ to support the design of effective risk communication and emergency management strategies (Slovic, 1987).
Grounded in foundational research on risk perception heuristics (Fischhoff et al., 1978; Slovic et al., 1979; Slovic, 1987),
160 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 early criticism ~~of~~ regarding its reliance on cognitive
heuristics, the paradigm later incorporated the concept of affect, emphasizing the role of emotions and intuitive responses in
risk perception and decision-making (Sjöberg, 1996; Slovic & Peters, 2006). Psychometric approaches have employed
~~various~~ a wide range of statistical methods, including multiple regression analysis, Exploratory Factor Analysis, and Principal
165 Components Analysis, to analyze survey-based risk perception ~~survey~~ data (Fischhoff et al., 1978; Jaspal et al., 2022;

Mitsushita et al., 2023). When applied to non-aggregated data and combined with socio-demographic variables, psychometric analyses have demonstrated substantial explanatory power and have been shown to overcome some of the interpretability limitations raised in earlier critiques of the paradigm (Siegrist et al., 2005; Bronfman et al., 2008). In the context of volcanic hazards, psychometric approaches have been particularly useful for identifying differences in risk perception between residents and non-residents, for exploring normalization processes in areas affected by recurrent or persistent volcanic activity, and for comparing relative perception levels across exposed populations (Bird et al., 2011; López-Vázquez, 2009; Johnston et al., 1999). Today, the psychometric ~~approach~~paradigm is widely applied across multiple research fields, particularly in including health-research-related risk studies, such as studies on perceived risks during the COVID-19 pandemic, and in disaster risk assessment, where it supports the identification of perception profiles relevant for preparedness and communication strategies (Weber et al., 2002; Jaspal et al., 2022; Mitsushita et al., 2023; Weber et al., 2002).

1.1.2 Cultural theory

~~The cultural~~Cultural Theory, developed by sociologists and anthropologists, seeks to identify cultural patterns that influence how individuals and groups perceive and respond to risk perception (Douglas & Wildavsky, 1982). ~~It views~~Within this framework, risk is understood as a social construct, and classifies individuals into are often described through four archetypal groups, including orientations, namely isolates, hierarchists, individualists, and egalitarians, each reacting differently to risk associated with distinct attitudes toward authority, regulation, and uncertainty (Douglas & Wildavsky, 1982; Tansey & O'RiordanO'Riordan, 1999; Edgar & Sedgwick, 1999). ~~The cultural theory~~Cultural Theory has been both supported and criticized. Miller (1996) widely applied and critically debated. Some authors have argued that culture's complexity and dynamism make it culture is dynamic, context-dependent, and difficult to fully explainrepresent through those proposed a limited number of archetypes alone (Miller, 1996). Others have criticizedpointed to its relatively low explanatory power and methodological limitationsconstraints when used as a rigid classificatory tool (Tansey, 2004; Oltedal et al., 2004; Sjöberg, 1996). ~~Despite~~In response to these critiques, more recent applications have emphasized the use of Cultural Theory as an interpretative framework rather than a deterministic typology, focusing on identifying social tendencies, shared meanings, and contextual patterns rather than categorizing individuals into fixed groups (Tansey, 2004; Oltedal et al., 2004). Despite these limitations, Cultural Theory remains widely used a valuable perspective in disaster risk research, helping to identify cross-cultural patterns in risk perception. It has been particularly valuable infor understanding how individuals across different countries and contexts perceive risks associated with values, beliefs, traditions, and relationships with the environment shape perceptions of natural hazards such as volcanism (Paton et al., 2011; Zeidler, 2015; (Renn & Rohrmann, 2000; Paton et al., 2011). In volcanic contexts, this approach has contributed to explaining why populations exposed to similar hazards may develop markedly different interpretations of risk, responsibility, and acceptable levels of danger across cultural and geographical settings (Renn & Rohrmann, 2000; Paton et al., 2011; Jones et al., 2013; Zeidler, 2015). Within these settings, risk perception is often embedded in territorial identities, including rural livelihoods, tourism-based activities, and everyday

coexistence with the volcanic environment, which interact with belief systems and religious worldviews to shape interpretations of risk (Bird et al., 2011; Salazar & Jalabert, 2016; Gaillard, 2008).

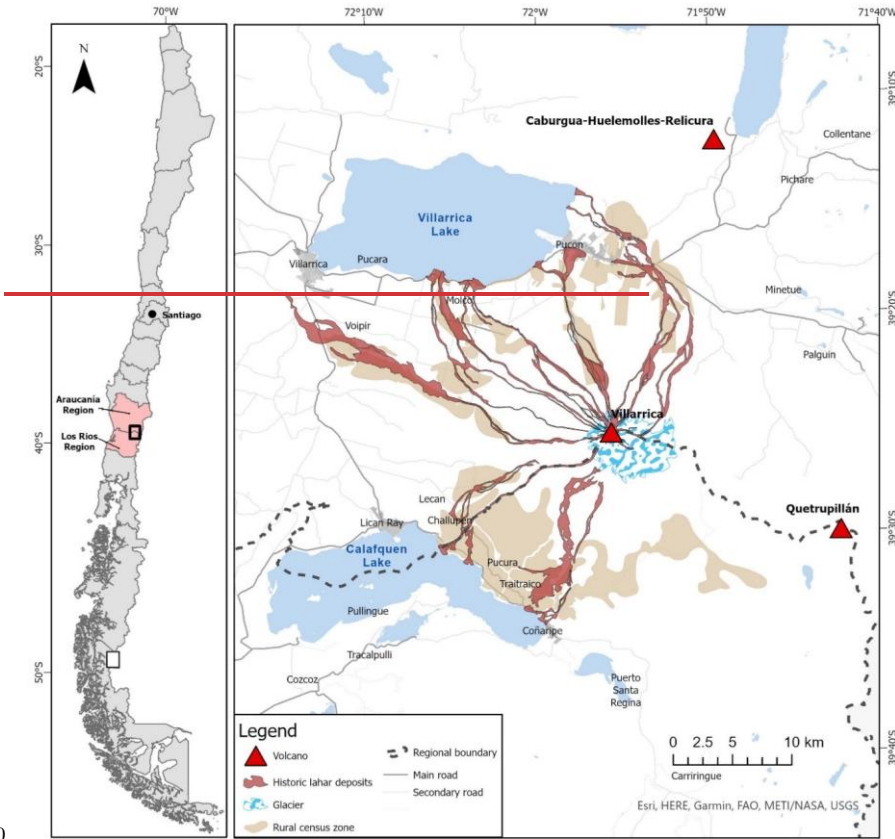
200 1.2 Study area: Villarrica volcano

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

205 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). In this study, the names Pucón and Villarrica refer both to urban localities and to their corresponding municipalities. When referring to rural areas, the analysis includes sparsely populated zones within the municipalities of Pucón, Villarrica, and Panguipulli. Pucón, with ~~about~~approximately 17 thousand population, 000 inhabitants, and Coñaripe, with about ~~one and half thousand~~1,500 inhabitants according to the 2017

210 Census 2017, are the closest urban ~~areas~~localities to the Villarrica summit and have been severely impacted by historic lahars from the volcano (Fig. 1) ~~Also, about ten thousand~~. In addition, around 10,000 people ~~lives~~live in ~~sparsely populated~~surrounding rural areas ~~surround the volcanic edifice~~, where ~~down valleys~~valley floors are ~~most~~particularly exposed ~~as due to the channelization of lahar impact tends to channelize in rivers~~flows along river networks. Urban ~~areas~~localities such as Pucón, Coñaripe, Villarrica, and Lican Ray ~~increased the experience significant seasonal population in~~increases during the

215 austral summer ~~times when transient populations visit the area, attracted, driven by tourism and recreational activities associated with the volcanic landscape and the ski centre close to center near the summit. This combination of permanent residents, rural populations, and transient visitors has led to increased land use pressure and expanding exposure in areas affected by volcanic hazards, particularly lahars, reinforcing the relevance of analyzing volcanic risk perception in this dynamic social and territorial context~~



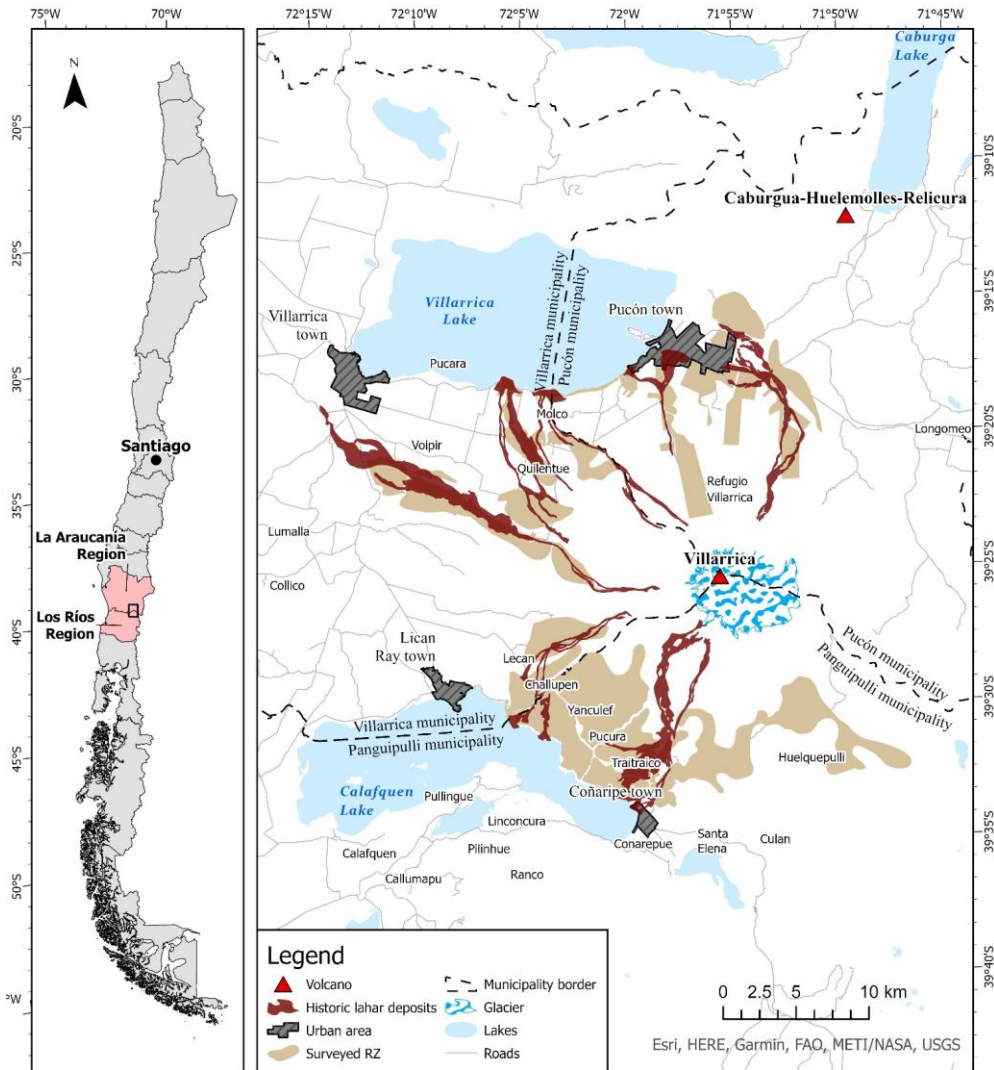
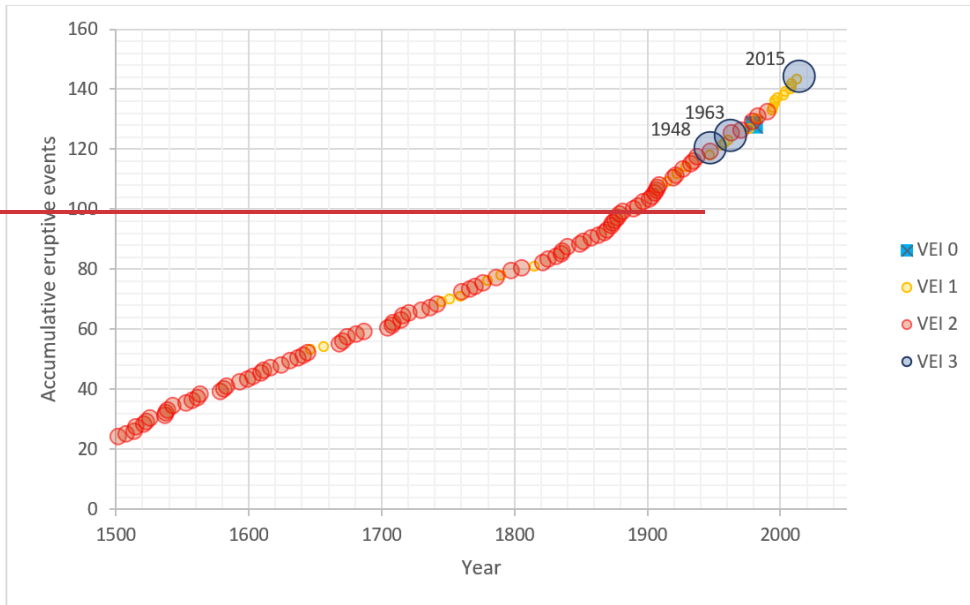


Figure 1: Villarrica volcano location and exposure of rural zones to historical lahar deposits.

1.3 Historical volcanic activity from Villarrica volcano

225 About 160 eruptions have been recorded at Villarrica Volcano over the past 2,000 years, with approximately 130 occurring
~~over~~during the ~~past~~last 500 years (Fig. 2; GVP, 2025). Most of these events were effusive eruptions, with a Volcanic
Explosivity Index (VEI) of 2 (Dzierma & ~~Whermann~~Wehrmann, 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 ~~inferred for~~ 670 CE and 1230 CE (GVP, 2025). Most ~~Villarrica~~ eruptions have
230 exhibited Hawaiian to 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~~of March 2015 involved powerful lava fountains,
pyroclastic density currents near the vent, and lahars, prompting preventive evacuations (Romero et al., 2023).
235 ~~Fortunately,~~Although no severe impacts were recorded, ~~although the~~subsequent studies highlighted mental health effects
~~among~~ emergency response volunteers ~~were later studied~~, emphasizing the need for psychosocial interventions during and
after ~~disasters~~volcanic crises (Espinoza et al., 2019). Following the 2015 eruption, Villarrica has remained intermittently active,
with periods of elevated unrest and a prolonged yellow alert status between 2022 and 2024, highlighting the persistence of
volcanic hazard in the area and reinforcing the relevance of ongoing preparedness and volcanic risk perception among exposed
240 populations (Romero et al., 2023; GVP, 2025).



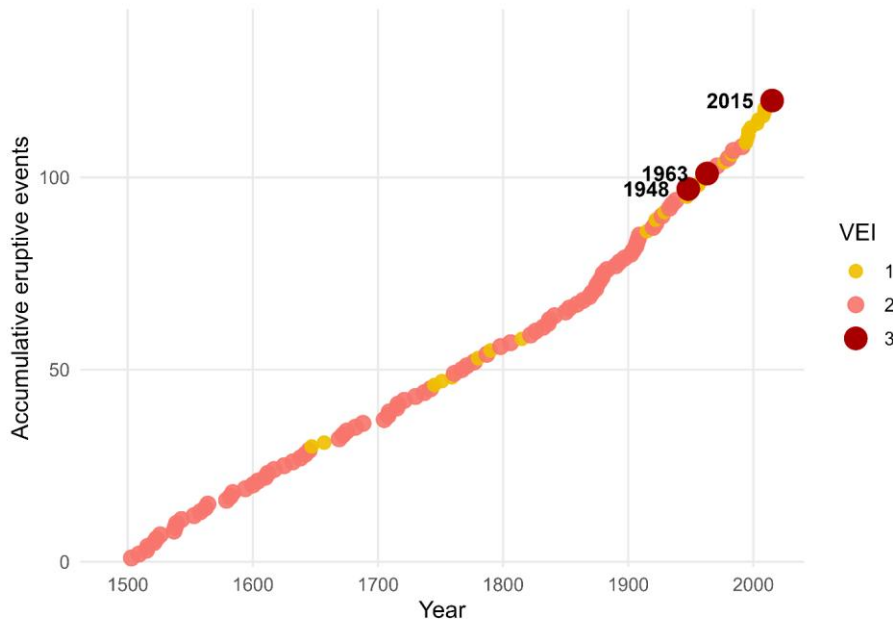


Figure 2: The eruptive record of Villarrica volcano over the past 500 years.

245 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). While psychometric approaches often rely on multi-point Likert-type scales, this study applies a simplified scoring strategy adapted to field-based surveys in highly exposed volcanic settings, as described below. 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). Furthermore, the cultural, social, and economic 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 these characteristics on risk perception (Section 2.3).

255 **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 questionnaire design follows the psychometric paradigm introduced in Section 1.1, operationalized through closed-ended questions suitable for rapid application during field campaigns. Instead of applying multi-point Likert scales, responses were collected using binary (yes/no) and multiple-choice formats. This approach was selected to reduce ambiguity, facilitate comprehension across diverse social and educational backgrounds, and ensure consistency during in situ data collection. For the VRP analysis, responses were recoded into dichotomous scores. A response consistent with a theoretically favourable VRP condition was assigned a value of one (1), while other responses were assigned a value of zero (0). The complete set of survey questions, their wording, associated VRP factors, and scoring criteria are presented in Table 1.

We considered the proximal volcanic hazard of lahars only. This is because lahar flows have been the most impactful volcanic process from Villarrica eruptions. we do not neglect the potential occurrence of ashfall impacts, we consider lahars more relevant for the application of VRP surveys among populations highly exposed to locally known and experienced volcanic hazards. 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 4~~). 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 Survey questions, associated desirable answers for VRP conditions according to current disaster risk science, factors, response options, and scoring criteria

Section	QID	VRP factor / Variable	Survey question	Response options	A positive sense of answers Scoring for appropriate VRP
A	D1	Demographic	Age	Open numeric	Not used
A	D2	Demographic	Gender	Male / Female	Not used
A	D3	Demographic	Nationality/Language	Open	Not used

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A	D4	Demographic	Educational level	Primary incomplete / Primary complete / Secondary incomplete / Secondary complete / Tertiary incomplete / Tertiary complete	Not used
A	D5	Demographic	Employment status	Employed (Tourism / Agriculture / Handcrafting / Other) / Unemployed / Student / Homemaker / Retired	Not used
A	D6	Demographic	Indigenous identity	Do you identify as belonging to an Indigenous or native people? Yes / No	Not used
A	D7	Demographic	Religion	Catholic / Evangelical / Jehovah's Witness / Jewish / Mormon / Muslim / Orthodox / Other / None	Not used
A	D8	Demographic	Residency status	Do you live in Pucón or Coñaripe? Yes / No	Not used
A	D9	Demographic	Tourist status	Are you currently in the area for vacation purposes? Yes / No	Not used
A	D10	Demographic	Visit frequency	How often do you visit this area? First time / A few times / Every year	Not used
B	K1	Knowledge	Do you think Villarrica volcano may erupt again in the future?	Yes / No	Yes = 1
B	K2	Knowledge	Do you know what a lahar is and their potential consequences?	Yes / No	Yes = 1
B	K3	Knowledge	Is there a districtan emergency plan for volcanic emergencies in Pucón and Coñaripe in case of an eruption of Villarrica volcano?	Yes / No / I don't know	Yes = 1
B	K4	Knowledge	In case of an eruption, do you know where a safe areas are in case of a volcanic emergency zone would be located?	Yes / No	Yes = 1
B	K5	Knowledge	Can volcanic activity cannot eruptions be forecasted in too much advance?	Yes / No / I don't know	No = 1
B	K6	Knowledge	Do you know the Villarrica volcanic hazard map elaborated produced by SERNAGEOMIN?	Yes / No	Yes = 1
B	K7	Knowledge	Are eruptions are highly frequent uncommon at Villarrica volcano?	Yes / No	Yes = 1
B	K8	Knowledge	In case of an eruption, is it better to approach rivers?	Yes / No / I don't know	No = 1

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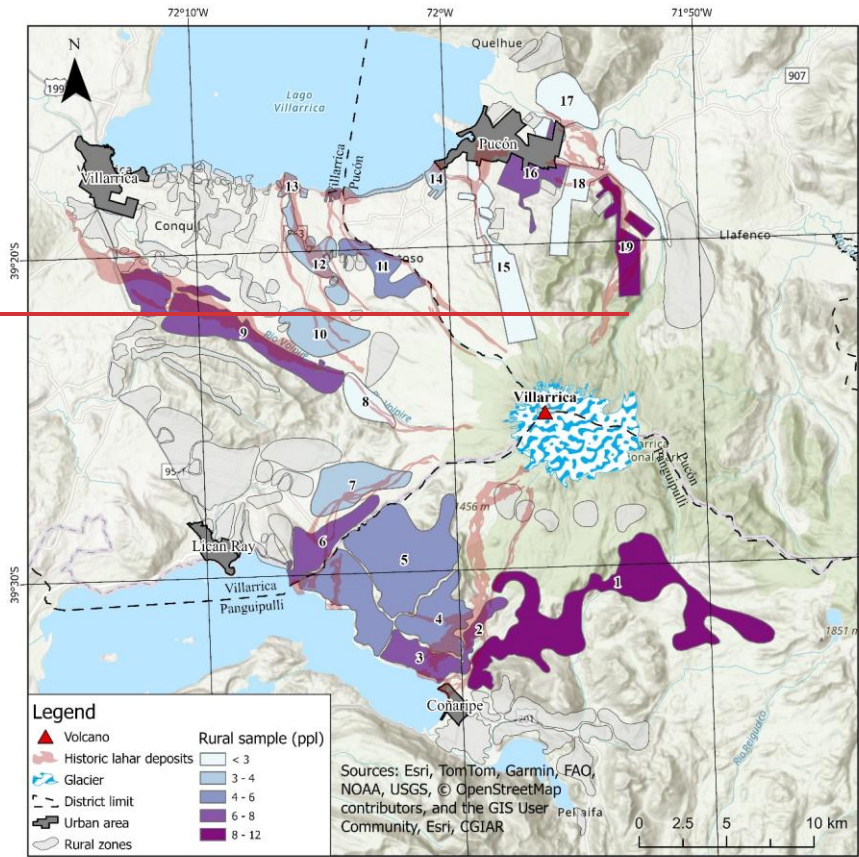
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E	A3	Attachment to place	They state to be aware of associated risks living in volcanic-exposed areas Does the place where you live have more benefits than risks?	Yes / No	No = 1
E	A4	Attachment to place	They would not build a new If your house in the same place in case its result were destroyed by a new volcanic eruption, would you rebuild it in the same place?	Yes / No	No = 1
E	A5	Attachment to place	They would move permanently to a different location Would you change your place of residence to avoid a potential future eruption?	Yes / No	Yes = 1
E	A6	Attachment to place	Do you have a family evacuation emergency plan in case of a new eruption?	Yes / No	Yes = 1
E	A7	Attachment to place	They think there is not adequate urban development in volcanic hazard zones Do you consider it appropriate for the city to continue expanding into areas exposed to volcanic hazards?	Yes / No	No = 1

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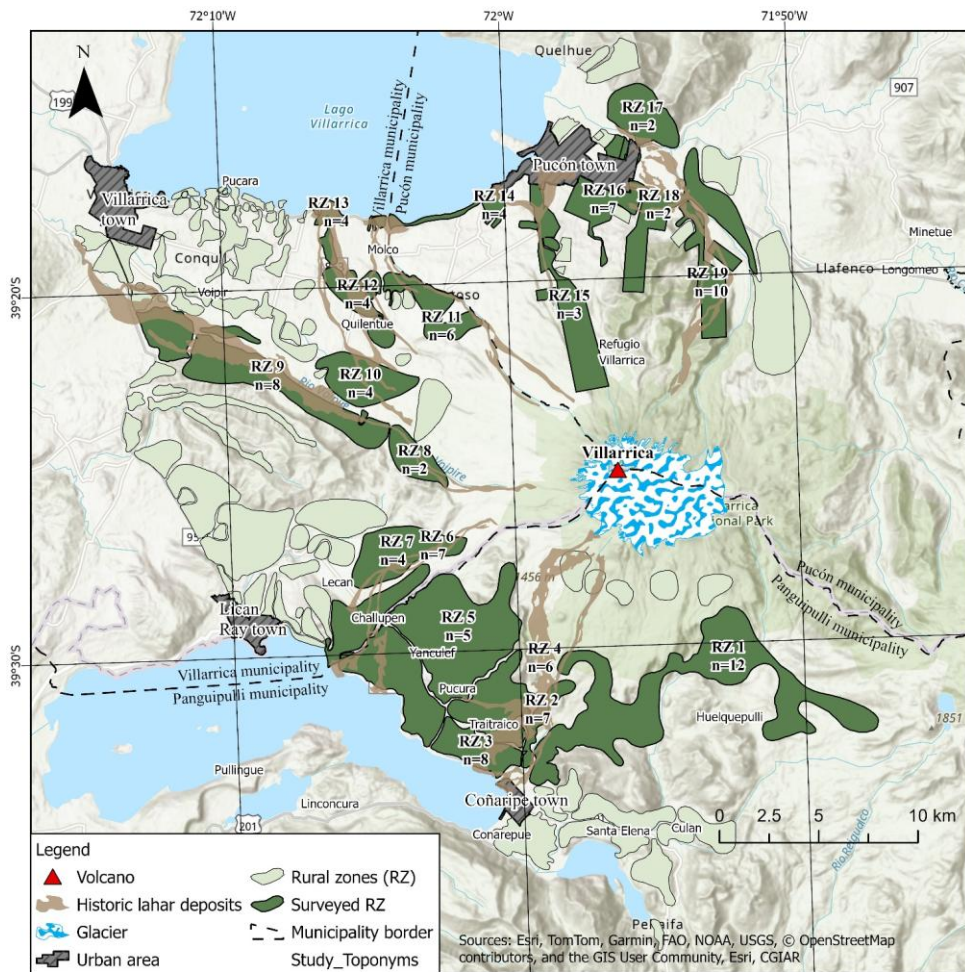


Figure 3: Rural areas zones for questionnaire application. **RZ** denotes rural zones defined for this study and identified with a unique numerical code.

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/localities, and responses related to attachment to the place were deemed considered methodologically irrelevant for non-resident respondents and therefore excluded from the results analysis. This created resulted in two distinct data 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 urban locality of Pucón urban area (229), with where more than half (150) representing the non-residential population. In the Coñaripe urban area, 78 questionnaires were collected, of which also more than half (57) were completed by the respondents (150) corresponded to non-resident transient respondents populations. In the urban locality of Coñaripe, 78 questionnaires were completed, with non-residents also representing the majority of respondents (57). In rural areas, only residents (105) were surveyed directly, through direct household interviews in their sparsely distributed households populated zones located within the municipalities of Pucón, Villarrica, and Panguipulli (Fig. 3). All samples were calculated with a 95% statistical confidence level and a standard error of less than or equal to 0.1, representing the total target population accounted for in based on the available census data used for each zone at the time of the survey application (Table 2).

Table 2. Sample calculation and size, residency status, and confidence levels of the surveyed population by zone

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 (Pucón, Villarrica, and Panguipulli municipalities)	4.750	Census 2002	105	105	0	0.95	0.1

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2.2 K-means Clustering analysis and social characterization

Each survey question was assigned a value of one (1) when the response aligns aligned with a theoretically optimal VRP condition (Table 1). Each aspect, including A total of 28 survey questions were used to compute the VRP scores, distributed across four factors: knowledge (10 questions), internal trust (5 questions), external trust (6 questions), and attachment to the place (receives an (7 questions). For the question addressing respondents' expected reaction in the event of an eruption, responses were dichotomized to capture risk awareness rather than emotional intensity: indifference was coded as 0, whereas all other responses indicating concern or affective engagement were coded as 1. Demographic and socio-cultural variables were excluded from the VRP score calculation and used exclusively for sample characterization and subgroup analyses. For non-resident respondents, attachment-to-place questions were omitted, and VRP scores were computed using the remaining

21 questions. Each factor score was calculated as the average score based on all of its associated questions. To ensure comparability across dimensions and avoid scale-related questions (Table 1). These scores are then categorized bias, factor scores were standardized using z-scores before clustering. The standardized scores were subsequently classified 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-1). The selection of five clusters was guided by the objective of producing an interpretable ordinal VRP scale (very high, high, moderate, low, and very low-translating into), consistent with classifications commonly used in risk perception and disaster risk studies. Raw factor scores, standardized z-scores, and final VRP level classifications for all respondents are provided in the Supplementary Material (Table S2).

Cluster centroids represent the relative position of respondents within the multidimensional factor space, defined as the mean standardized scores of all factors for each VRP level. Clusters were ordered according to their centroid scores, from higher to lower values, and interpreted as very high, high, moderate, low, and very low VRP levels. The clustering outcomes represent relative VRP based on their calculated clusters' centroids, where the highest sum scores represent better. The resulting classification reflects relative VRP conditions of VRP within the selected analyzed sample, where higher centroid scores indicate more favourable VRP conditions based on our current understanding of risks according to disaster risk science-understanding. Cluster centroids represent the mean position of each group in the multidimensional standardized factor space used in the k-means clustering procedure. Consequently, when projected onto a single factor, centroid values do not necessarily coincide with the median of the univariate score distributions shown in the boxplots. This difference reflects within-cluster heterogeneity, distributional asymmetry, and the fact that clustering is performed simultaneously across all factors rather than independently for each dimension. Therefore, centroid positions should be interpreted as reference values summarizing the relative contribution of each factor to the overall VRP classification, rather than as measures of central tendency within the individual score distributions. Cluster centroids for each VRP level are reported in the Supplementary Material (Table S1).

Equation 1

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

Where:

J = Objective function

k = Number of clusters

n = Number of cases

x_i = Case i

c_j = Centroid for cluster j

$$J = \sum_{j=1}^k \sum_{i \in C_j} \|z_i - c_j\|^2$$

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345 Where J is the sum of squared Euclidean distances minimized by the k-means algorithm, z_i is the vector of standardized (z-score) VRP factor scores for the case i , c_j is the centroid (mean vector) of cluster j in the standardized factor space, C_j is the set of cases assigned to cluster j , and k is the number of clusters.

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 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 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 (BridBird 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, including the resulting VRP levels, their geographical distribution of resulting relative VRP, the statistical distribution of the evaluated VRP factors, and the social-socio-cultural characterization of the sample based on their assigned VRP levels. The discussion section then highlights the main insights. All VRP levels discussed below represent relative configurations within each population sample, derived from these multivariate clustering, and should be interpreted comparatively rather than as absolute perception thresholds. The results are presented descriptively and the methodological approach combining the psychometric paradigm and cultural theory frameworks, followed are supported by future research recommendations. Finally, a conclusion section summarizes the contributions of this research: geographical evidence, without inferring statistical significance.

3.1 Results of VRP levels

K-means calculations show a result in a relatively balanced distribution of VRP groups/levels across the 205 resident and 207 non-resident questionnaires, averaging with each VRP category representing approximately 20% per group (of the sample, as expected given the clustering approach (Fig. 4). Among residents, the highest concentration is in corresponds to the high VRP with level (25.9% of the sample, compared to a maximum of 21.3% for non-residents in the same category. Residents make up 40%), whereas the lowest proportion is observed in the very high VRP level (17.1%). Low and very low VRP levels represent 20.0% and 19.5% of the low-and-resident sample, respectively. Among non-residents, VRP levels are more evenly distributed. Moderate VRP represents the largest group (20.8%), followed by very low VRP, respectively, (20.3%), while very high VRP shows the lowest proportion (18.8%). Overall, residents tend to display slightly greater variability across VRP levels than non-residents account for 20.8% in the moderate and 20.3% in the very low VRP. The lowest concentrations for, although 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 exhibit comparable distributions (Fig. 4).

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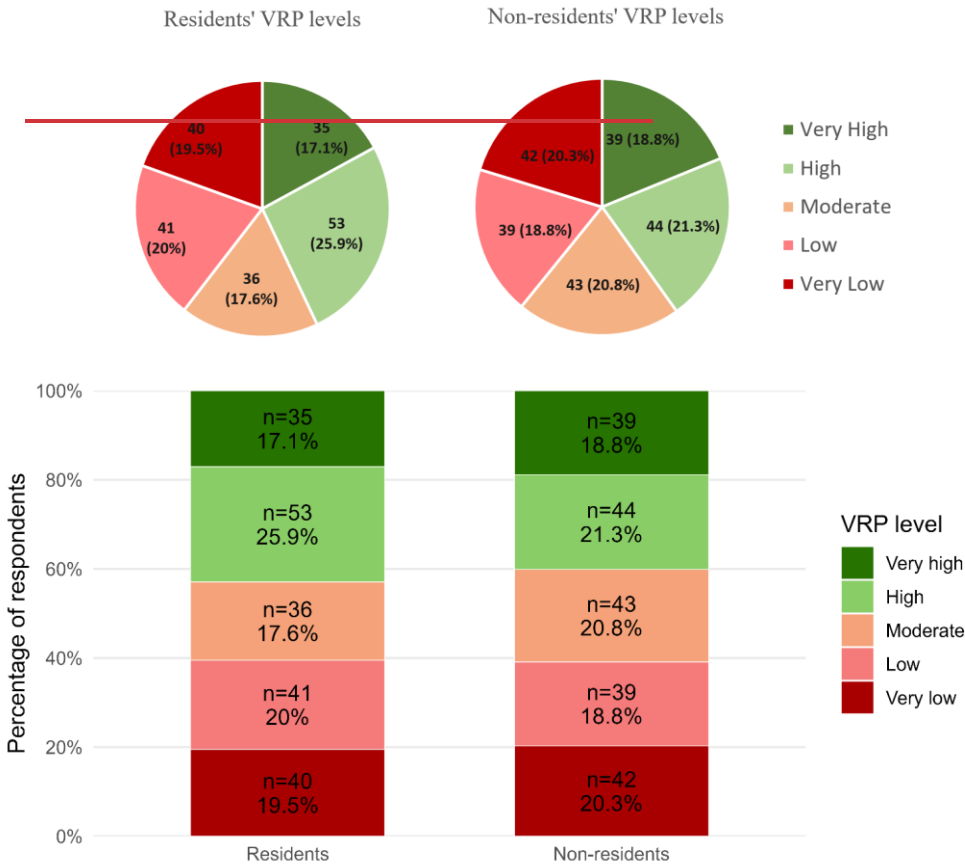


Figure 4: Total results, Percentage distribution of VRP levels and percentage by among residents and non-residents.

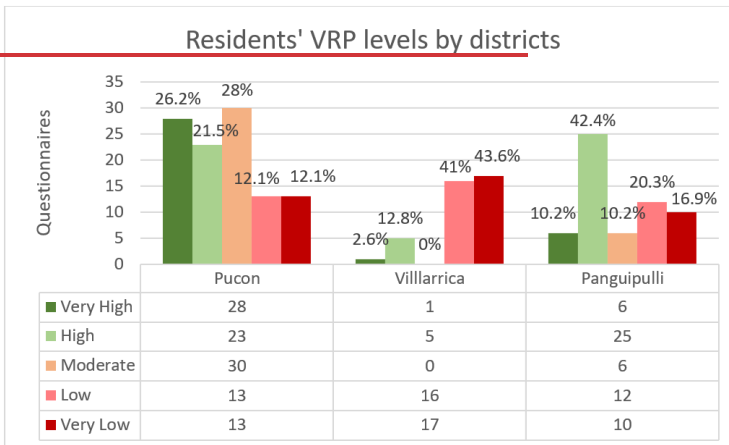
3.2 Geographical distribution of residents' VRP levels

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VRP varies significantly by district, VRP levels vary across districts within the study area. Given the high dynamics and mobility and transient nature of non-resident transient populations, their spatial patterns require a separate study and treatment-analytical approach. Therefore, we present the geographical distribution only for this section focuses exclusively on residents, who are relatively more spatially stable-exhibit greater spatial stability. In the Pucón district, residents show a higher proportion predominance of very high (26.2%), high (21.5%), and moderate (28.0%) VRP levels, while low and very low VRP

each account for only 12.1% (Fig. 5). In contrast, the Villarrica district has a higher concentration of the highest proportions of very low (41%) and low (43.6%) VRP of levels among all the studied districts. In contrast, high VRP accounts for 12.1% of the sample, very high for VRP 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%) and low (16.9%), and moderate VRP, while 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 of the sample. Spatially, higher VRP levels are more frequently observed in urban areas with a higher proportion of, particularly in Pucón town, where very high, high, and moderate VRP, such as in Pucón town levels are more prevalent (Fig. 6). In contrast, particularly in Villarrica's rural zones and all other studied, especially in Villarrica and surrounding districts, concentrate larger proportions of low and very low VRP (Fig. 6) levels. These patterns suggest that urban contexts are associated with higher VRP among residents, although this interpretation should be considered descriptive rather than causal.

Residents' VRP levels by districts



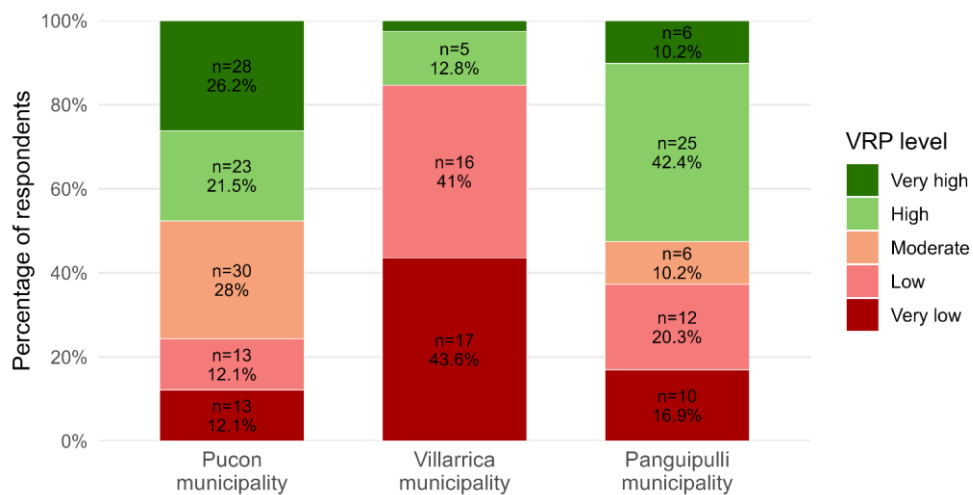
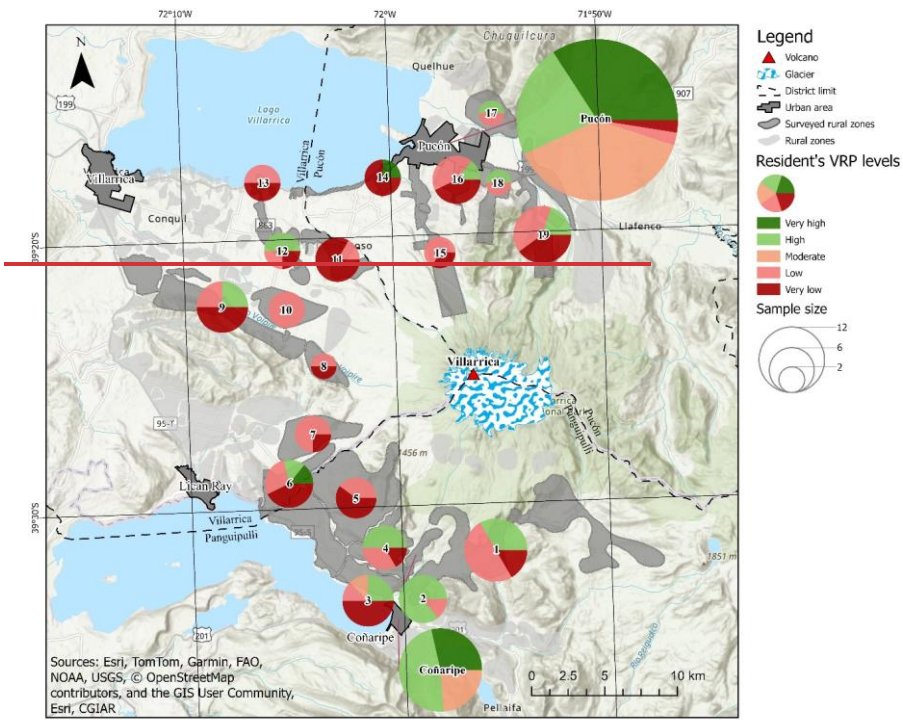
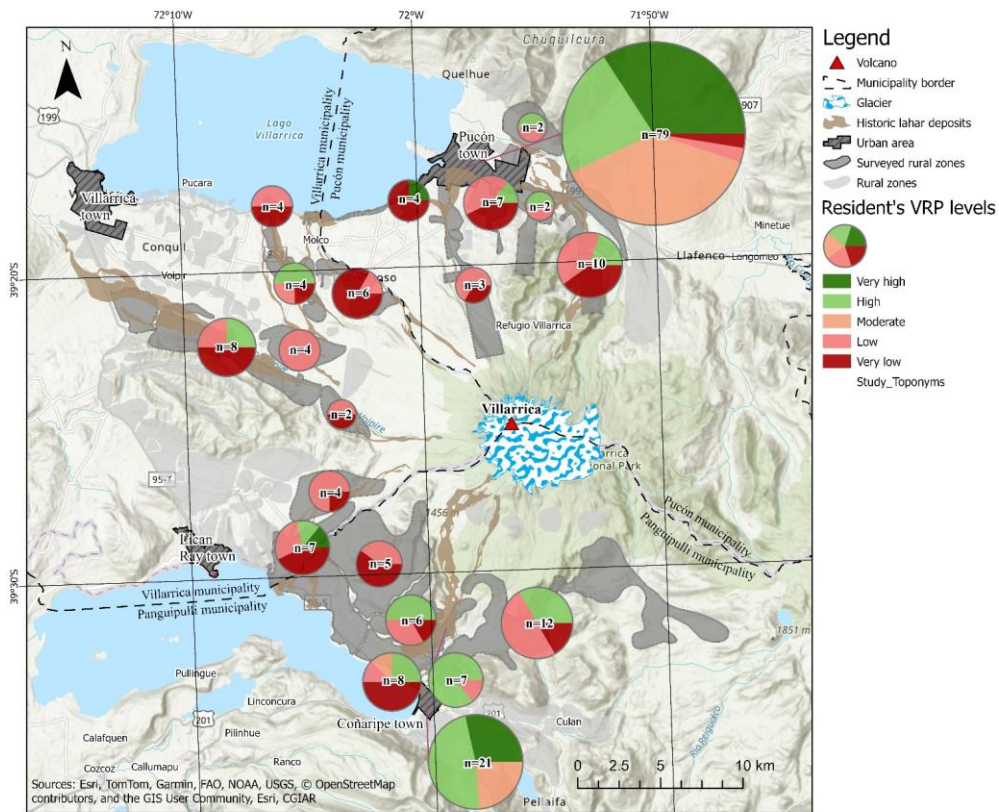


Figure 5: Total results, Percentage distribution of VRP levels and percentage among residents by districts municipality.





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Figure 6: Geographical distribution of VRP levels. Pie charts show the relative distribution of VRP levels by zone. Chart sizes provide a visual indication of sample size.

3.3 Statistical distribution of VRP factors

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This psychometric approach using k-means calculations offers valuable information on clustering provides insight into how each selected VRP factor statistically contributes to resulting the differentiation of VRP levels, enabling a more detailed characterization of their influence. The following paragraphs describe the distribution of standardized factor scores for residents and non-residents' distribution of VRP factor scores for each VRP level, residents, supported by boxplots and cluster centroid values.

3.3.1 VRP factors by residents

465 Four VRP factors were evaluated for residents: knowledge information, internal trust, external trust, and attachment to the
place. Among these, knowledge information exhibits the largest variation across VRP levels, as reflected by the separation of
cluster centroids (Fig. 7). The very low VRP level shows the greatest difference lowest centroid value (approximately -0.9 Std.
470 dev.), while the remaining VRP levels range between the calculated cluster centroids for each VRP level (Fig. 7). In this
factor, -0.5 and 0.2 Std. dev. This pattern indicates that residents classified within the very low VRP level has a
significantly tend to report lower score (-0.9 Std. dev.) compared to knowledge scores relative to other levels (ranging from
475 -0.5 to 0.2 Std. dev.), suggesting that residents in this category have a relatively weaker understanding of volcanic processes
and their potential impacts. The very low, low, groups. Notably, the relationship between knowledge, information, and VRP
is not strictly linear. The high VRP level exhibits knowledge scores comparable to those of the low VRP level, whereas
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 display higher centroid values. This non-linear
pattern suggests that increasing knowledge does not correspond directly to increasing VRP among residents. This pattern
reinforces that knowledge alone does not determine VRP levels but operates in interaction with trust-related and contextual
factors within broader perception configurations.

Internal trust shows relatively small differences across VRP levels, with substantial overlap in the distributions (Fig. 7).
480 Regarding internal trust, the low VRP level has exhibits the highest score (centroid value (approximately 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 shows
the lowest score (-0.2 Std. dev.). The higher However, given the limited separation between centroid values
and the dispersion observed in the boxplots, internal trust scores for the low appears to play a secondary role in differentiating
VRP level might reflect a greater awareness of vulnerability levels among residents living in a hazardous environment. In terms
485 of external. External trust, scores are divided into two main levels: very exhibits a clearer pattern. Very high, high, and
moderate VRP ($0.2-0.3$ Std. dev.), indicating a higher levels show positive centroid values (approximately $0.2-0.3$ Std. dev.),
whereas low and very low VRP levels cluster around neutral or slightly negative values. This pattern indicates that higher VRP
levels among residents are associated with higher external trust, particularly regarding willingness to evacuate in case of an
490 instructions. For Attachment to place shows consistently positive and closely clustered centroid values across all VRP levels
(approximately $0.1-0.2$ Std. dev.). The limited variation suggests that 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 place
functions as a relatively stable background factor rather than a primary driver of VRP differentiation among residents.

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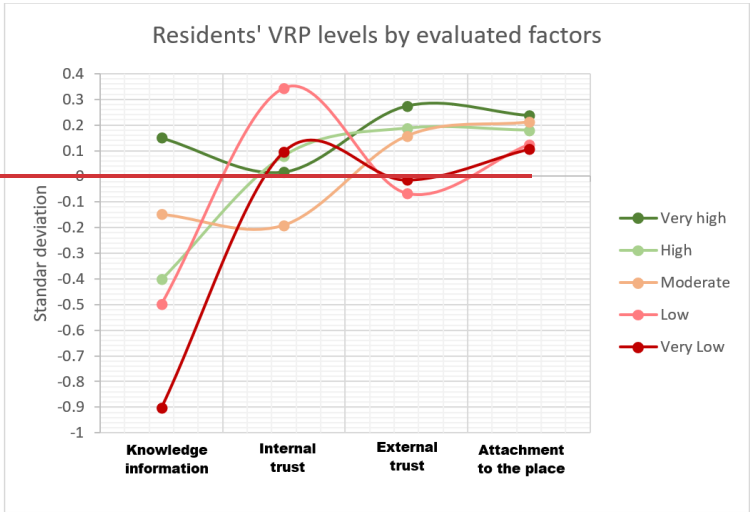
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3.3.2 VRP factors by non-residents

495 ~~Three~~For non-residents, three VRP factors were evaluated ~~for non-residents~~: knowledge information, internal trust, and
external trust. ~~In terms of knowledge~~Knowledge information ~~displays higher centroid values for~~ the very high and moderate
VRP levels ~~have the highest scores (approximately (approaching 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~~while very low, low, and
high VRP levels cluster around neutral values (Fig. 8). Although ~~internal trust scores are generally low, they show a wider~~these
500 differences indicate 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,~~the overall dispersion of knowledge scores is lower
than that observed among residents. Internal trust scores among non-residents are consistently low and show limited separation
505 between VRP levels, ranging from approximately -0.3 Std. dev. in the very low VRP level to values close to zero in the high
and very high VRP levels. Given the strong overlap among boxplots, internal trust does not appear to strongly differentiate
VRP levels in this group. External trust emerges as the most consistent differentiating factor among non-residents. Centroid
values increase progressively from lower to higher VRP levels, 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,
510 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 (approximately 0.3 Std. dev.). This
pattern indicates that VRP differentiation among non-residents is primarily structured by variations in external trust. Across
all factors, non-residents exhibit narrower boxplots and closer alignment between median and mean values compared to
residents, indicating lower within-group heterogeneity. This homogeneity supports the robustness of the VRP classification
515 among non-resident respondents. Overall, while residents' VRP reflects combined variations in knowledge, trust, and
attachment to place, non-residents' VRP is more narrowly differentiated, with external trust playing a dominant role.



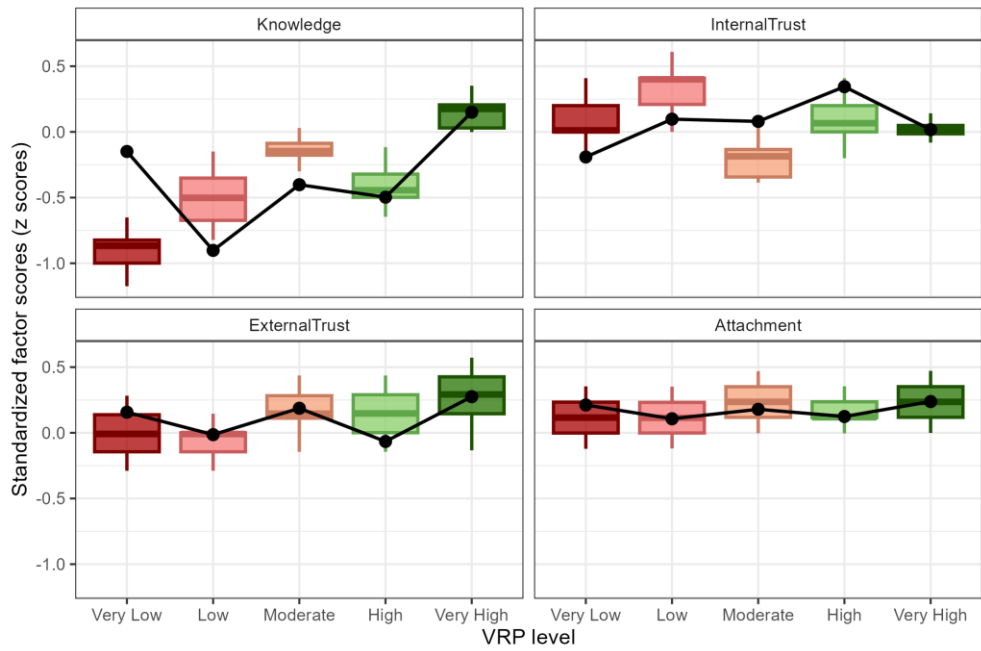
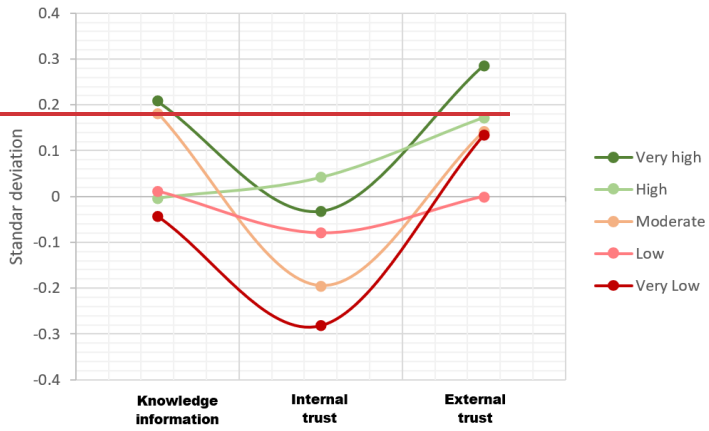


Figure 7: Statistical distribution of VRP factors for residents. Boxplots show the distribution of standardized factor scores for each VRP level. Colours indicate VRP levels, ranging from Very Low (dark red) to Very High (dark green). Black points and lines represent cluster centroids, corresponding to the average standardized scores within each VRP level.

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Non-residents' VRP levels by evaluated factors



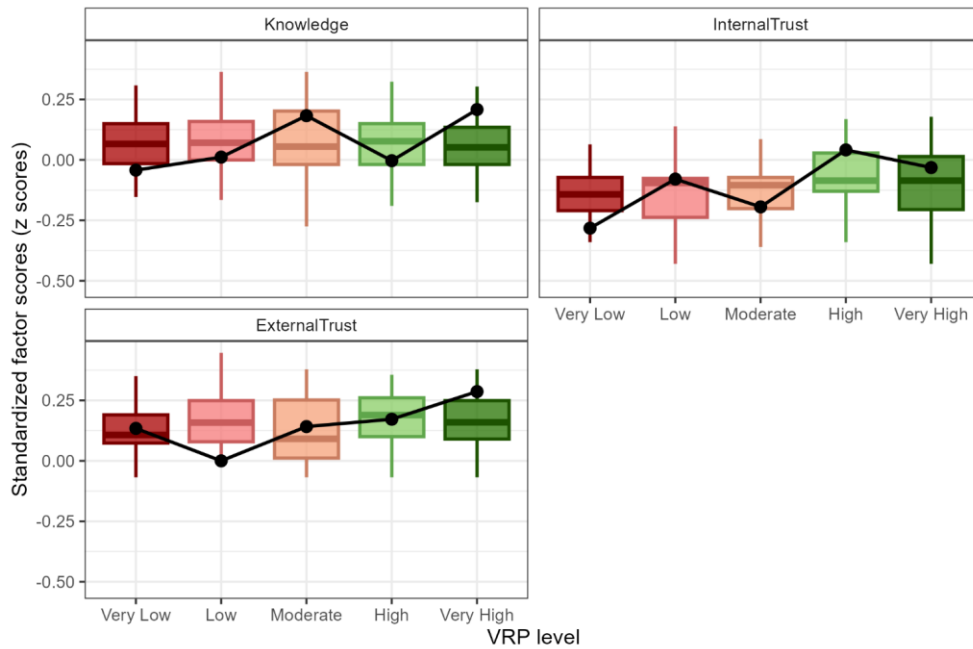


Figure 8: Statistical distribution of VRP factors for non-residents.

525 **3.4 Statistical- Boxplots show the distribution of VRP factors**

Among the evaluated cultural groups, the most variability across VRP levels standardized factor scores 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.

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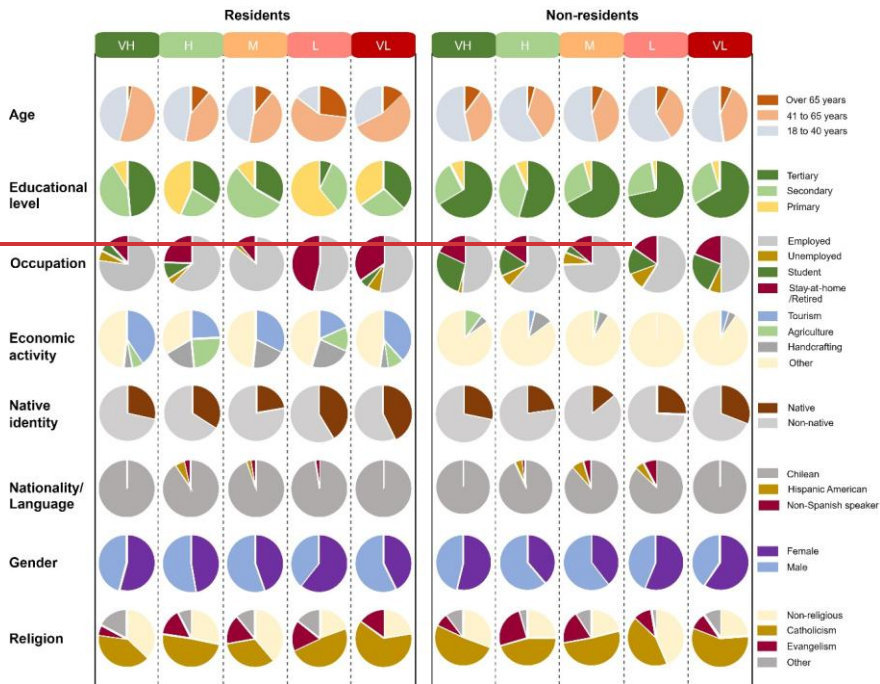


Figure 9: Distribution of cultural groups by VRP levels results for residents and non-residents.

535 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 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. Colours indicate VRP levels, ranging from Very Low (dark red) to Very High (dark green). Black points and lines represent cluster centroids, corresponding to the average standardized scores within each VRP level.

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3.4.2 Distribution of VRP Levels by Educational across socio-cultural groups

This section describes the distribution of volcanic risk perception (VRP) within socio-cultural groups, distinguishing between residents and non-residents. Figures 9a–9b and 10a–10b illustrate the relative distribution of VRP levels across demographic, socio-economic, and cultural variables. Greater variability in VRP distributions is observed across age, educational level, native identity, employment status, and economic activity, whereas gender and religious affiliation display more stable and comparatively balanced profiles across VRP levels. Differences related to nationality and language are also evident, although the interpretation of these patterns is constrained by smaller subgroup sizes. The following subsections detail these distributions, highlighting similarities and contrasts between residents and non-residents without inferring statistical significance.

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

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Residents

Demographic variables

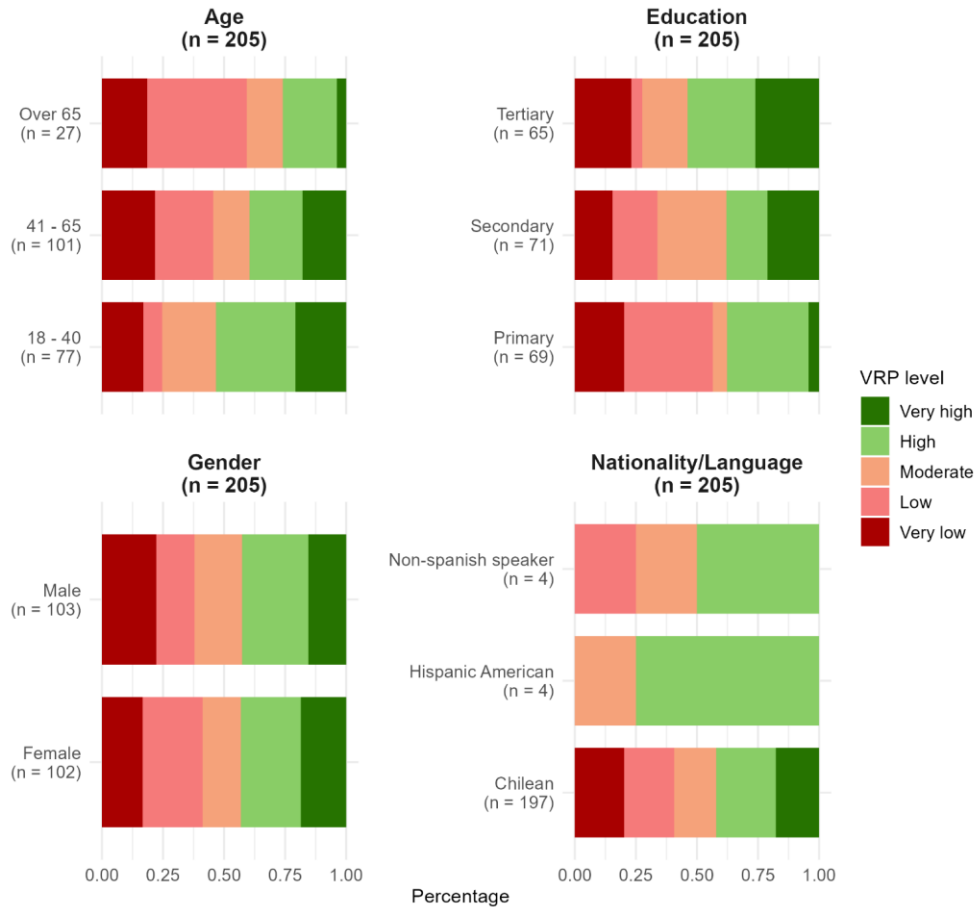


Figure 9a. Relative distribution of volcanic risk perception (VRP) levels across demographic variables for residents.

Residents

Socio-economic and cultural variables

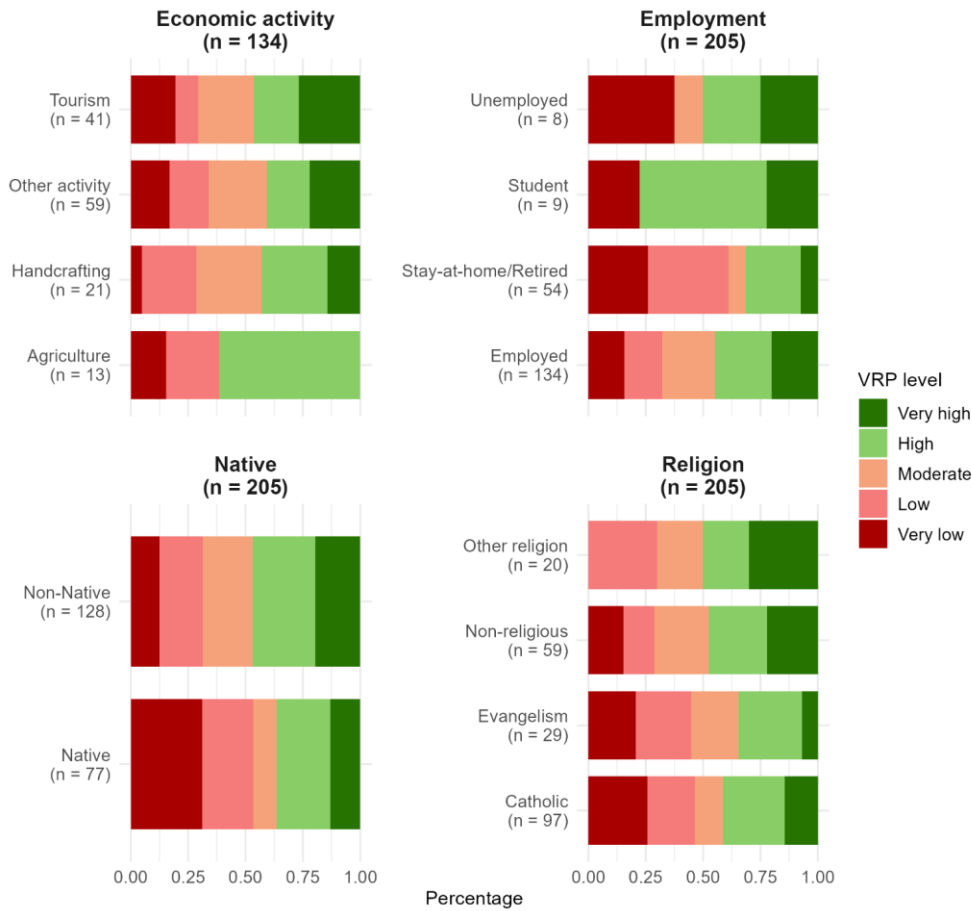


Figure 9b. Relative distribution of volcanic risk perception (VRP) levels across socio-economic and cultural variables for residents.

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Non-residents

Demographic variables

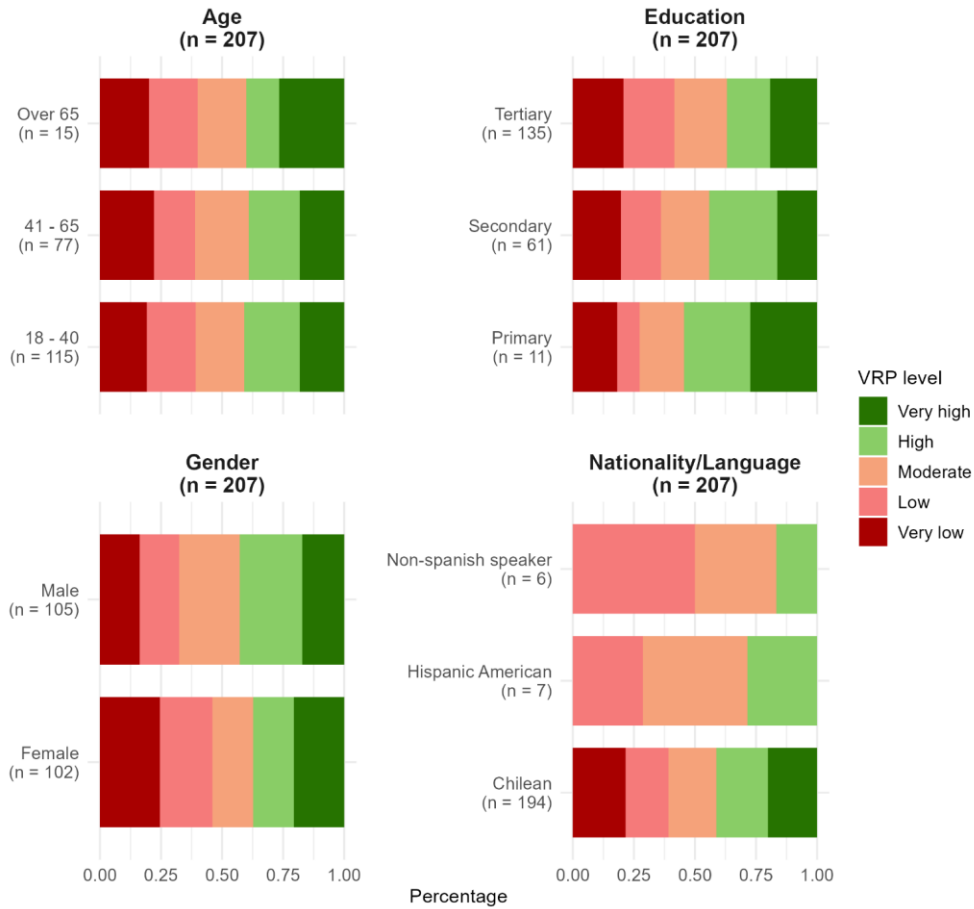


Figure 10a. Relative distribution of volcanic risk perception (VRP) levels across demographic variables for non-residents.

Non-residents

Socio-economic and cultural variables

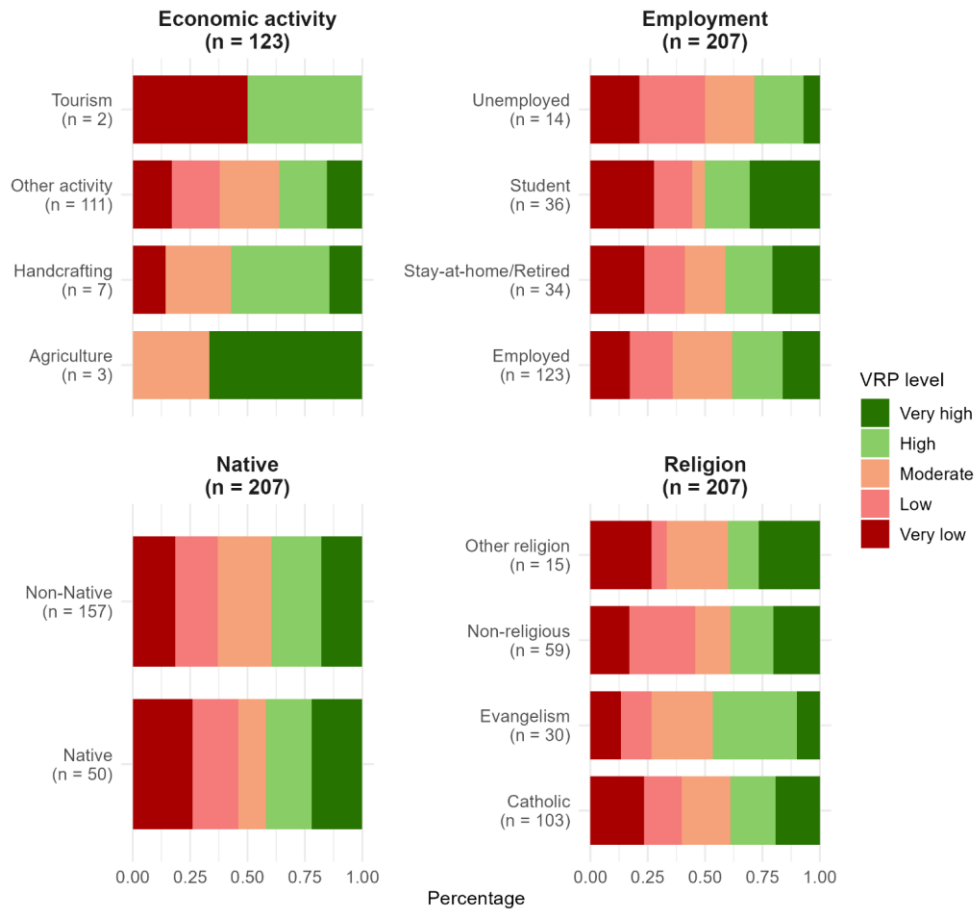


Figure 10b. Relative distribution of volcanic risk perception (VRP) levels across socio-economic and cultural variables for non-residents.

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3.4.1 Demographic profiles

Age.

Among residents, VRP distributions vary by age group (Fig. 9a). Young adults (18–40) show higher representation in high and very high VRP levels, whereas older residents (65+) exhibit a more evenly distributed profile across VRP categories, indicating greater heterogeneity rather than dominance of a single perception level. The intermediate age group (41–65) displays a transitional pattern with moderate and high VRP levels slightly more represented. Among non-residents (Fig. 10a), VRP distributions by age are generally more balanced, although elderly non-residents show greater variability, including higher representation in the very high VRP level.

Gender.

Across both residents and non-residents, VRP distributions by gender are largely comparable, with similar proportions across VRP levels and no systematic differences observed (Figs. 9a and 10a).

Education.

Among residents, primary education is more strongly represented in low and very low VRP levels, while secondary education exhibits a more evenly distributed profile. Residents with tertiary education show relatively higher proportions in high and very high VRP levels, although no single category dominates. Among non-residents, tertiary education predominates across the sample, and VRP levels remain broadly balanced, suggesting limited differentiation by educational level (Fig. 10a).

Nationality and language.

VRP distributions across nationality and language groups are generally stable among residents. Greater variability is observed among non-Chilean and non-Spanish-speaking subgroups; however, these patterns are based on small sample sizes and should be interpreted cautiously. Similar limitations apply to non-resident subgroups (Figs. 9a and 10a).

3.4.2 Socio-economic and cultural profiles

Employment status.

Employment status shows clearer differentiation in VRP distributions than demographic variables (Fig. 9b). Among residents, employed individuals are more frequently represented in moderate and high VRP levels, whereas unemployed and retired or stay-at-home residents concentrate more strongly in low and very low VRP levels. Resident students, although a small subgroup, display relatively higher representation in high VRP levels. Among non-residents (Fig. 10b), employed participants similarly show higher representation in moderate and high VRP levels. Students exhibit a more polarized distribution, with higher representation in both high and very high VRP levels.

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 distributions vary across economic activities. Among residents, tourism-related and agricultural activities exhibit more polarized profiles, with higher representation at the extremes of VRP levels. Other activities show more evenly distributed patterns. Among non-residents, some economic activities are also associated with higher VRP levels; however, interpretation is constrained by small subgroup sizes (Figs. 9b and 10b).

Native identity.

Among residents, individuals identifying as native are more strongly represented in low and very low VRP levels. In contrast, non-residents show more evenly distributed profiles across VRP levels. Overall, native identity does not emerge as a strong differentiating factor when residency status is considered (Figs. 9b and 10b).

Religion.

Religious affiliation does not show systematic differentiation across VRP levels for ~~both~~ residents ~~and~~ non-residents. However, among, with relatively balanced distributions observed across groups (Figs. 9b and 10b).

3.4.3 Summary of cross-cutting patterns

Overall, demographic variables are associated with relatively stable VRP distributions, whereas socio-economic and cultural variables exhibit greater variability. Residents display more differentiated VRP profiles than non-residents, they are more concentrated in the low (42%) and very low (43%) VRP levels, particularly with respect to age and economic activity. These patterns suggest that residency status is associated with differences in how VRP is structured across socio-cultural groups.

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635 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~~ et al. (1998) tested these approaches and found several cultural biases, although the psychometric approach explains about 32% of the ~~variations~~variation 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 ~~&and~~ 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.

645 ~~We~~Rather than treating these frameworks as competing explanations, 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 strategiesinsights into volcanic risk perception. The psychometric paradigm is effective in capturing the multidimensional structure and relative positioning of key VRP factors, while Cultural Theory contributes to interpreting how groups commonly addressed in volcanic risk contexts are socially composed and differentiated. This combined approach allows the identification of distinct configurations of risk perception that would not be evident through the application of a single framework alone. Importantly, this integration facilitates a shift from interpreting risk perception solely in terms of individual factor scores toward understanding how combinations of knowledge, trust, and territorial attachment jointly shape differentiated risk perception profiles. Such an approach is particularly relevant for applied contexts, as both VRP levels and associated cultural patterns can inform civil protection agencies in designing more targeted and context-sensitive emergency management and communication strategies. In this study, Cultural Theory is not applied as a classificatory or predictive model, but rather as an interpretative lens to contextualize social and cultural patterns emerging from the VRP results. This approach follows recent applications that emphasize interpretation over typological assignment in disaster risk research.

4.2 Methodological approach

4.2 Residents and non-residents as contrasting risk perception contexts

Residents and non-residents represent a fundamental distinction in this research, as both groups were ~~targeted with~~surveyed using the same VRP questions, except for those related to place attachment. Although VRP levels were calculated independently for residents and non-residents, comparative interpretations focus on structural patterns and relative factor

670 ~~contributions rather than direct metric equivalence.~~ This distinction is justified because transient visitors (~~non-residents~~) typically lack a local sense of community, including emotional attachment to ~~the~~ place and ~~sustained~~ civic participation in emergency planning ~~processes~~ (Paton et al., 2008; ~~BarbieriBarberi~~ et al., 2008; Ricci et al., 2013). For residents, the results indicate consistently positive ~~behaviorscores~~ across all VRP levels, which may reflect a strong sense of community ~~cohesion~~ 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 ~~showedexhibited~~ the greatest variation between the two groups, ~~which-residents.~~ Residents scored lower, ~~whilewhereas~~ non-residents ~~exhibitedshowed~~ more moderate scores (Section 3.3). This discrepancy may ~~suggestindicate~~ that ~~populations living in~~ exposed residents ~~might lack an adequate understandingareas do not necessarily possess higher levels~~ of volcanic ~~hazards and their consequences~~ risk knowledge, a ~~trendpattern~~ widely ~~observeddocumented~~ in volcanic risk ~~literature~~ perception studies (e.g., Carlino et al., 2008; Ricci et al., 2013; Davis ~~et al., 2005~~) & Ricci, 2004). ~~This finding suggests that long-term exposure and familiarity with volcanic environments may contribute to the normalization of risk, where everyday coexistence with volcanic activity reduces perceived threat and the motivation to seek or retain detailed hazard-related information.~~ Regarding internal trust, non-residents displayed 680 lower and predominantly negative VRP scores compared to residents (Section 3.3), suggesting ~~that non-residents may have~~ lower ~~risk-awarenessreliance on local social networks~~ and a ~~possible~~ tendency to overestimate their ~~abilityindividual capacity~~ to ~~handlecope with~~ volcanic ~~eruptions~~ hazards (Barberi et al., 2008). In contrast, external trust ~~waslevels were~~ similar across both groups, with ~~mostlypredominantly~~ positive scores ~~atacross~~ all VRP levels (Section 3.3). This ~~finding suggestsresult indicates~~ that both residents and non-residents ~~place comparable~~ trust ~~in scientific~~ experts and authorities, ~~making them more~~ 685 ~~likely to follow~~ increasing the likelihood of compliance with official ~~guidelinesrecommendations~~ and emergency protocols (Espuga et al., ~~2016~~2009; Njome et al., 2010; Haynes et al., 2008).

4.3 Cultural patterns of VRP levels

Some ~~distinct~~ cultural patterns ~~in the resulting associated with~~ VRP levels ~~can be were~~ identified ~~primarily~~ among residents, ~~primarily based on age and educational level,~~ whereas non-residents ~~are were~~ more evenly distributed across ~~all~~ VRP 690 ~~levels~~ categories (Section 3.4). ~~In the sample, Among~~ residents ~~tend to be slightly older than non-residents, with adults, age and educational level emerged as the most relevant differentiating factors.~~ Adults and elderly individuals ~~were~~ more ~~frequently~~ concentrated in low ~~and very low~~ VRP levels. ~~Notably, consistent with previous findings that identify elderly individuals, a known populations as potentially vulnerable group within this research that tends to lower VRP scores, could benefit from tailored risk management strategies groups in disaster contexts.~~ However, as ~~observed~~ in similar studies, no ~~clear pattern of influence consistent or linear relationship~~ between age and ~~VRP level has been~~ risk perception can be ~~firmly~~ established (e.g., ~~BarbieriBarberi~~ et al., 2008). ~~In contrast, educational level exhibits~~ Educational levels ~~exhibited~~ a stronger ~~correlation~~ association with VRP ~~levels~~ (Section 3.4). Among residents, ~~those individuals~~ with primary education ~~are were~~ 695 predominantly concentrated in ~~the~~ low (61%) and very low (35%) VRP categories, ~~though although~~ a notable proportion (43%) ~~was~~ also ~~falls into~~ found in the high VRP category. ~~A clearer pattern emerges~~ In contrast, residents with secondary

700 education, where more than 50% of individuals are found in the very high and frequently represented in moderate and very high VRP levels, suggesting a potential relationship between higher that formal 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, may play a role in enhancing risk awareness and interpretation. This pattern may reflect greater exposure to scientific information, risk communication materials, or institutional narratives related to volcanic hazards.

705 Regarding occupation, individuals residents outside the workforce, such as stay-at-home or retired residents, are retired individuals or those engaged in unpaid domestic activities, were predominantly concentrated in the low (46%) and very-low (35%) and very low VRP categories (Section 3.4). This group could be considered vulnerable and may require targeted risk communication and face increased vulnerability due to limited access to information channels or reduced engagement strategies. In contrast with institutional preparedness initiatives. Conversely, students are, primarily represented in the among

710 non-resident sample, with their residents, displayed VRP levels distributed concentrated at the both extremes, notably very high (28%) and very low, suggesting heterogeneous perceptions potentially influenced by unequal access to reliable information 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 digital media environments (e.g., Chester et al., 2008; Njome et al., 2010). Among those economically active in the workforce, both employed and unemployed individuals are relatively

715 evenly distributed across all VRP categories. However, for residents, VRP levels vary significantly varied substantially depending on their economic activity sector (Section 3.4). Some occupations in the study area Occupations closely linked to local livelihoods, such as agriculture, handcrafting, agriculture, and particularly especially tourism are highly sensitive to volcanic eruptions and exhibit extreme variations, showed pronounced variability in VRP levels. Given that individuals in these sectors face the direct economic consequences from that volcanic activity, efforts to enhance their risk awareness and preparedness could be crucial for improving overall resilience can impose on these sectors, such variability may reflect tensions between economic dependency, perceived threat, and risk acceptance. These findings highlight the importance of developing sector-specific risk communication strategies that acknowledge both economic vulnerability and perceptual diversity.

720 ——— Despite the results showing a slightly higher concentration of Although self-identified native populations were slightly overrepresented in the low (42%) and very low (43%) VRP categories (Section 3.4), a deeper this result should be interpreted with caution. Similar patterns have been reported in other Indigenous contexts, where lower scores in standardized risk perception measures coexist with strong place-based knowledge, experiential understanding of indigenous knowledge is hazards, and culturally embedded interpretations of risk that are not fully captured by survey-based instruments (Roder et al., 2016). Indigenous relationships with volcanic landscapes are often shaped by culturally embedded knowledge systems, cosmologies, and historical experience, which may not be fully captured through standardized survey instruments. Greater

725 integration of Indigenous knowledge frameworks is therefore 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 understand how volcanic risk is perceived and responded to within these communities (e.g., Hastangka & Suprpto, 2023; Niroa & Nakamura, 2022; Order et al., 2016) and future development should incorporate these findings.

735 ~~A similar gap exists regarding 2016). No clear patterns were identified concerning 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 or~~
~~religion. While existing literature suggests that these factors may influence volcanic risk perception through worldview~~
~~formation and belief systems (e.g., Cutter, 2017; Barberi et al., 2008; Eiser et al., 2015). Likewise, no distinct pattern was~~
740 ~~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); Clarke, 2005; Breskaya and Zrinščak, 2024). their effects may be highly context-dependent and require more~~
~~targeted qualitative or mixed-method approaches to be adequately captured.~~

5 Conclusion

This research integrates the Psychometric Paradigm and Cultural Theory to examine ~~VRP~~volcanic risk perception, demonstrating that both approaches are complementary and ~~jointly provide to some extent~~ valuable insights for risk
745 management. While the psychometric approach captures the ~~statistical dynamics multidimensional structure and relative~~
~~positioning of multiple~~key VRP factors, Cultural Theory ~~helps identify patterns in facilitates the interpretation of~~ how social
~~and cultural groups perceive risk groupings relate to these perception patterns.~~ Together, these frameworks ~~offersupport~~ a more
~~comprehensiveness nuanced~~ understanding of risk perception that ~~can support the development of more targeted emergency~~
~~management strategies. A key extends beyond isolated variables. Importantly, the identified VRP levels reflect relative~~
750 ~~awareness-based profiles shaped by interacting social and contextual factors, rather than fixed or absolute measures of~~
~~perceived danger. A central finding of this research is the difference indifferentiated~~ VRP between residents and non-residents.
Residents, who tend to ~~haveexhibit~~ stronger community ties, ~~exhibit and territorial attachment, show~~ lower levels of risk-
~~related~~ knowledge but higher ~~levels of~~internal trust, whereas non-residents display higher knowledge scores ~~butcoupled with~~
lower internal trust, ~~possiblypotentially~~ leading to an overestimation of ~~their ability to handle volcanic hazards.~~
755 ~~Howeverpersonal coping capacity. Despite these differences, both groups shareexhibit~~ similar levels of external trust,
~~suggesting that trust in experts and authorities plays a criticalunderscoring the central role of institutional credibility in their~~
~~willingness to followshaping compliance with~~ emergency protocols. ~~Additionally, socio~~guidance.
~~Socio-~~demographic factors such as age, education, and occupation ~~further influence VRP configurations.~~ Elderly individuals
and those outside the workforce ~~are more likely to have lower VRP, making them particularlyemerge as potentially~~ vulnerable
760 groups ~~that may require~~requiring tailored risk communication strategies. Education appears to play a ~~significantrelevant~~ role,
~~with higher educational attainment correlating with increased VRP in shaping risk perception among residents. Similarly,~~
~~while~~ individuals employed in economically sensitive sectors ~~such as tourism and agriculture display extreme variations in~~
~~VRP, highlightinghighly variable VRP levels, emphasizing~~ the need for ~~sectorcontext-specific risk awareness initiatives. The~~
~~engagement approaches. Finally, the study also identifies several areas that require further exploration requiring further~~
765 ~~investigation. The slightly lower VRP observed among~~ Indigenous populations ~~are slightly overrepresented in lower VRP~~

770 ~~categories, suggesting a need for greater integration of Indigenous knowledge highlights the importance of incorporating culturally grounded knowledge systems into volcanic risk assessments. Likewise, no research. Similarly, the absence of clear patterns were observed concerning related to gender identity and religion, yet existing literature suggests these factors could influence risk perception in that these dimensions may operate through complex ways, context-dependent mechanisms that are not easily captured by standardized instruments. Future research should investigate how therefore explore integrative methodological approaches capable of addressing these sociocultural influences shape VRP and explore more nuanced factors that may impact public responses to volcanic hazards dynamics in greater depth.~~ Overall, this research reinforces the importance of ~~consideringsituating volcanic risk perception within its broader social, cultural, social, and economic contexts in volcanic risk perception studies context.~~ By ~~incorporating diverse perspectivesadvancing typological and improving targeted communication efforts,context-sensitive understandings of VRP, this study contributes to the development of more effective, inclusive, and adaptive~~ emergency management agencies can enhance community resilience and preparednessstrategies in volcanic regions.

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